2004

Lawrence Livermore National Laboratory

Environmental Report

UCRL-50027-04

Cover

LLNL's Site 300 is located in the Corral Hollow watershed, an area known for its diversity in native wildlife. Located between the arid central valley and the more mesic coastal hills, the Corral Hollow watershed contains plant and wildlife species common to both regions. The area is particularly rich in reptile and amphibian species. Generations of herpetologists have been drawn to the Corral Hollow area to observe the many species that inhabit this area including the coast horned lizard (upper left). Many species of mammals are also found at Site 300. One of the most common is the black-tailed jackrabbit (lower left). Site 300 is also known for its native plants and plant communities. Approximately 500 acres of native perennial grassland dominated by one-sided bluegrass (right) occur at Site 300. Native perennial grasslands, once a dominant vegetation type throughout California, have become rare because of competition from exotic grasses and other forces. The many native plant and wildlife species found at Site 300 continue to be one of the many things that make Site 300 a unique place to work.

Cover photos: LLNL Wildlife Biologists Michael van Hattem and Lisa Paterson.
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Composition assistance
Beverly L. Chamberlain

Art
Brett S. Clark

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

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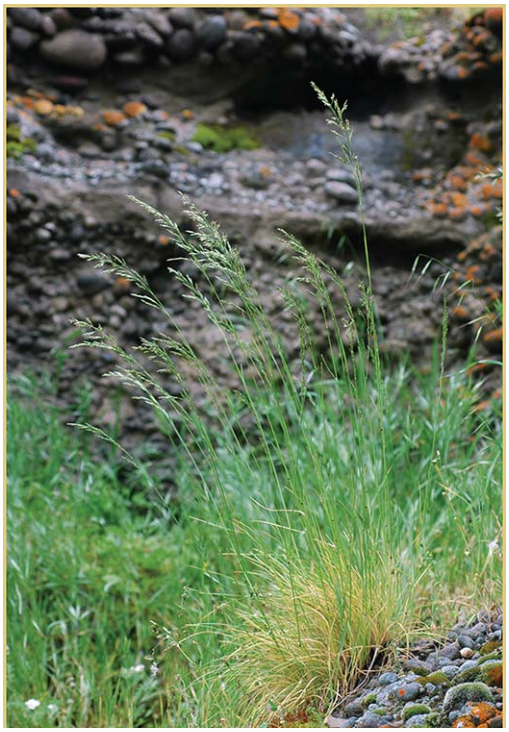
Authors

S. Ring Peterson

Paris E. Althouse
Nicholas A. Bertoldo
Richard A. Brown
Christopher B. Campbell
Lucinda M. Clark
Gretchen M. Gallegos
Allen R. Grayson
Robert J. Harrach
Henry E. Jones
Donald H. MacQueen
Sandra Mathews
Barbara A. Nisbet
Charles D. Noyes
Lisa Paterson
S. Ring Peterson
Michael A. Revelli
Duane Rueppel
Lily Sanchez
Michael J. Taffet
Paula J. Tate
Kent Wilson

Editor

Nancy J. Woods



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Livermore Site Office
PO Box 808, L-293
7000 East Avenue
Livermore, California 94551-0808

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Subject: 2004 Annual Site Environmental Report for the Lawrence Livermore National Laboratory

This report, prepared by the Lawrence Livermore National Laboratory (LLNL) for the Department of Energy, National Nuclear Security Administration (DOE/NNSA) Livermore Site Office, provides a comprehensive summary of the environmental program activities at LLNL for Calendar Year 2004. The Annual Site Environmental Report (ASER) is prepared annually and is distributed to relevant regulatory agencies and other interested organizations and 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 environmental protection and compliance programs at LLNL are implemented to ensure the health and safety of employees and residents of neighboring communities, in addition to the preservation of the environment. Remediation activities continue to reduce contaminants on-site and off-site.

LLNL has committed to achieve continuous improvement in environmental performance through pollution prevention, energy efficiency, and other measures. LLNL is currently making progress towards implementing an environmental management system that meets the requirements of ISO 14001 by the end of Calendar Year 2005.

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 2004* is prepared for the U.S. Department of Energy (DOE) by the Environmental Protection Department at Lawrence Livermore National Laboratory (LLNL). The submittal of the Environmental Report 2004 satisfies requirements under DOE Order 231.1A, *Environmental Safety and Health Reporting* and DOE Order 5400.5, *Radiation Protection of the Public and Environment*. The purpose of the *Environmental Report 2004* is to present summary environmental data, confirm compliance with environmental standards and requirements, and highlight facility programs and efforts.

The *Environmental Report 2004* will by distributed in electronic form on compact disc (CD), and will also be accessible on the Internet at the LLNL Site Annual Environmental Report homepage: http://www.llnl.gov/saer/. Both the report and data tables can be viewed in their most up-to-date form on the website. Environmental reports covering calendar years 1994 through 2003, and corrections to them, are also found at http://www.llnl.gov/saer/.

The report contains an executive summary, an introduction with an overview of the meteorology and hydrogeology of the two LLNL sites (Chapter 1), and a summary of LLNL's compliance with environmental regulations and environmental programs, with emphasis on pollution prevention (Chapter 2). The majority of the report features LLNL's environmental monitoring programs: effluent and ambient air (Chapter 3); waters, including wastewater, storm water runoff, surface water, rain, and groundwater (Chapter 4); and terrestrial, including soil and sediment, vegetation and foodstuff, ambient radiation, and special status wildlife and plants (Chapter 5). All environmental monitoring data summarized in this report are provided in files on the CD. The radiological impact on the public is discussed in Chapter 6, and Chapter 7 provides an overview of LLNL's groundwater remediation program. Information on both the Livermore site and Site 300 is included in each chapter. The report concludes with a discussion of quality assurance activities associated with these monitoring programs (Chapter 8).

The *Environmental Report 2004* continues the practice of using *Système International* units. This is consistent with federal law stated in the Metric Conversion Action of 1975 and Presidential Order 12770, Metric Usage in Federal Government Programs (July 25, 1991). For ease of comparison to environmental reports issued prior to 1991, dose values and many radiological measurements are presented in both metric and U.S. customary units. A conversion table is also provided in the Glossary under the heading of "metric units."

The document is the responsibility of LLNL's Operation and Regulatory Affairs Division of the Environmental Protection Department. Monitoring data were obtained through the combined efforts of the Operation and Regulatory Affairs Division, Environmental Restoration Division, Chemistry and Materials Science Environmental Services' Environmental Monitoring Radiation Laboratory, and the Hazards Control Department. Special recognition is deserved for the dedication and professionalism of the technicians

who gathered the data—Gary A. Bear, Karl Brunckhorst, David J. Castro, Crystal Foster, Steven Hall, Renee Needens, Terrance W. Poole, Donald G. Ramsey, Sterling Sawyer, and Robert Williams—of the data management personnel—Hildy Kiefer, Kimberley A. Swanson, Beth Schad, Suzanne Chamberlain, Della Burruss, and Susan Lambaren—and of the secretarial staff who prepared and distributed the drafts—Carol Moser and Stephanie Flores. Special thanks go to Richard Blake and Charlene Grandfield for their strong support of the project and reviews of the drafts.

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EX

Executive Summary

Purpose of this Report

The Lawrence Livermore National Laboratory (LLNL) annual *Environmental Report,* prepared for the Department of Energy (DOE) and made available to the public, presents summary environmental data that characterizes site environmental management performance, summarizes environmental occurrences and responses reported during the calendar year, confirms compliance with environmental standards and requirements, and highlights significant programs and efforts. By explaining the results of effluent and environmental monitoring, mentioning environmental performance indicators and performance measure programs, and assessing the impact of Laboratory operations on the environment and the public, the report also demonstrates LLNL's continuing commitment to minimize any potentially adverse impact of its operations.

Major LLNL Programs

LLNL is managed by the University of California for the National Nuclear Security Administration (NNSA) within the Department of Energy. LLNL was established in 1952 in Livermore to ensure national security through the design, development, and stewardship of nuclear weapons; its research programs address national security and national needs; in 1955, operations began at Site 300, LLNL's experimental test site.

LLNL plays a prominent role in NNSA's Stockpile Stewardship Program, in which laboratory scientists and engineers ensure the safety and reliability of the nation's nuclear weapons and certify weapon performance without nuclear testing. Nuclear weapons expertise and extensive capabilities in physical and life sciences are applied to Nonproliferation and Homeland Security, meeting the challenge of protecting the nation from terrorism. LLNL also provides the Department of Defense, the intelligence community, and other agencies with analytical support and advanced technologies to meet national security needs.

LLNL also pursues research and development in other areas of importance to the nation. LLNL carries out long-term research to help provide the United States with abundant, secure, reliable, and sustainable energy coupled with a clean environment. Bioscience research at LLNL is directed at understanding the causes and mechanisms of ill health, developing biodefense capabilities, improving disease prevention and lowering health-care costs. In addition, often in collaboration with universities, industry, and/or other laboratories, scientists and engineers pursue projects in fundamental science and applied technology that build on the Laboratory's strengths and take advantage of LLNL's unique research capabilities and facilities.

Laboratory Policy

Safe, secure, and efficient operations that provide a safe, clean environment for employees and neighboring communities are an essential part of the Laboratory's research and development programs and underpin their success. Experts in environment, safety and health (ES&H) within the Safety and Environmental Protection Directorate support all Laboratory activities. Using the Integrated Safety Management System, work is performed in a manner that protects the health and safety of employees and the public, preserves the quality of the environment, and prevents property damage. LLNL complies with applicable ES&H laws, regulations, and requirements identified in approved Work Smart Standards. A high-quality radiological control program at LLNL assures that radiological exposures and releases are reduced to as low as reasonably achievable to protect the health and safety of all its employees, contractors, the general public, and the environment.

Over the last two decades, LLNL has made great strides in improving its environmental stewardship and has actively taken steps to reduce any potential impacts the Laboratory's operations might have on the environment and the community. For example, the new Decontamination and Waste Treatment Facility has increased LLNL's ability to provide safer, cost-effective waste operations and to reduce legacy wastes. To further these efforts, LLNL is committed to the implementation of a strong Environmental Management System through its Integrated Safety Management System. The Laboratory encourages participation by the public on matters related to its environmental impact on the community and provides access to information on its ES&H activities.

All monitoring and analysis of samples and data, including the preparation of this report, are conducted under the Environmental Protection Department's Quality Assurance Management Plan. This plan is included under LLNL's Quality Assurance Policy, with its commitment to effectiveness, excellence, innovation, and continuous quality improvement.

Monitoring

Air Monitoring

In 2004, radioactivity released to the atmosphere was monitored at 67 sampling locations at six facilities on the Livermore site and one at Site 300. Because filtering systems in exhaust stacks trap essentially all particulates, the only radioactive contaminant released to the environment through monitored stacks was tritium. Stack releases of

tritium from the Tritium Facility and the Decontamination and Waste Treatment Facility contributed 90% of the estimated of 1.5 TBq (40.4 Ci) released from the Livermore site in 2004. This 1.5 TBq release is a third of the tritium released in 2003 but is about 60% higher than releases in 2001 and 2002.

The magnitude of nonradiological releases (e.g., criteria pollutants such as organics/volatile organics, nitrogen oxides, carbon monoxide, particulates, sulfur oxides) is estimated based on specifications of equipment and hours of operation. All criteria pollutant emissions were far below limits prescribed by the air districts.

In addition to effluent monitoring, numerous ambient air monitors sample for tritium, radioactive particles, and beryllium. Some samplers are situated specifically to monitor areas of known contamination, some monitor potential exposure to the public, and others, distant from the sites, monitor natural background. In 2004, ambient air monitoring confirmed estimated releases from monitored stacks and helped to determine source terms for resuspended plutonium (Livermore site) and uranium (Site 300); no unexplained radioactivity was detected.

Water (Except Groundwater) and Wastewater Monitoring

At the Livermore site, waters monitored for potential radiological and nonradiological contaminants related to LLNL operations include sewer water, storm water runoff, rainwater, drinking water, and surface waters; at Site 300, sewage ponds, surface impoundments, rainwater, and storm water runoff are monitored for radiological and nonradiological contaminants. Water monitoring is carried out to determine if any contaminants have the potential to reach drinking water wells or surface waters to which the public is exposed; water monitoring also helps determine the impact of Laboratory operations on groundwater. LLNL monitors wastewater to demonstrate compliance with permit requirements.

In 2004, no wastewater discharges from LLNL to the Livermore Water Reclamation Plant (LWRP) exceeded any discharge limits for release of radioactive materials to the sanitary sewer; data were comparable to the lowest historical values. LLNL's continuous sanitary sewer monitoring system detected only one release of nonradiological constituents outside permissible limits: in March, there was a minor discharge (250–300 gallons) of pH 4.6 effluent, slightly below the 5.0 pH limit. Overall sanitary sewer monitoring data for 2004 demonstrated that LLNL's wastewater discharge control program effectively ensured that sanitary sewer effluent posed no threat to the LWRP or the environment.

Storm water is sampled both upstream and downstream from both sites to determine the impact of each site. It is sampled for oxygen content and contaminants such as radioactivity, metals, dioxins, polychlorinated biphenyls (PCBs), and nitrate. At the Livermore site, tritium was higher in downstream than in upstream samples; for 2004, the

maximum concentration measured was 0.55% of the drinking water standard. Exposure of fathead minnows to runoff collected from the first major storm of the season showed neither acute nor chronic toxicity.

Concentrations of tritium in rain samples may be highly variable depending upon operations taking place during the rain. In 2004, the maximum concentration of tritium in rain collected on the Livermore site was 2.6% of the drinking water standard; at Site 300, all rain collected was below the lower limit of detection.

All off-site surface waters and all drinking waters had no gross alpha or tritium measurements above the detection limit; median gross beta measurements were below detection limits. The on-site surface water in the Drainage Retention Basin (DRB) exhibited very low levels of gross alpha, gross beta, and tritium; toxicity tests on fathead minnows showed no ill effects. At Site 300, maintenance on the drinking and cooling water systems resulted in discharges to ground without adverse effect on surrounding waters.

Terrestrial Monitoring

Except for plutonium concentrations at the Livermore site that continue to be slightly elevated due to historic operations, concentrations of radionuclides in soils and sediments were within global background levels in 2004. Plutonium concentrations at the LWRP continue to be about a factor of 30 higher than concentrations at any other sampled location, but even this concentration is only 2% of the screening level for cleanup recommended by the National Council on Radiation Protection. Uranium-238 was found in the soils at Site 300, but it was below screening levels except near Building 812, which is currently undergoing remedial investigation under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA).

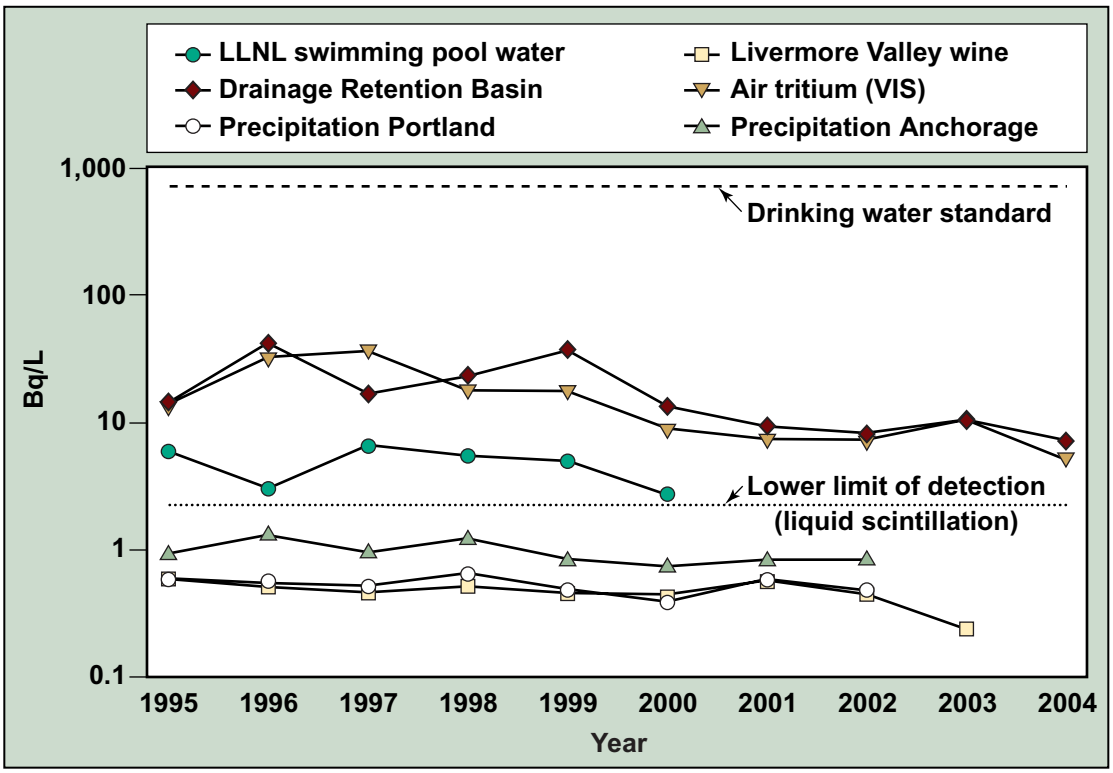
Vegetation and wine are sampled for tritium. The median concentrations of all off-site vegetation samples except one were below the lower limit of detection of the analytical method. Concentrations in Livermore Valley wines, although about 2.5 times higher than other California wines, were a factor of four times lower than concentrations in wines from the Rhone Valley in France.

LLNL uses thermoluminescent dosimeters (TLDs) to monitor potential releases of gamma radioactivity from Laboratory operations. TLDs also measure naturally-occurring cosmic and terrestrial radioactivity. As in other years, any effect of LLNL operations was indistinguishable from normal background.

Multimedia Comparison

In **Figure EX-1**, annual median concentrations of tritium in various environmental media sampled by LLNL over the last ten years are compared with background levels of tritium in rain (measured at Portland, Oregon and Anchorage, Alaska), the Environ-

mental Protection Agency's (EPA's) drinking water standard, and the lower limit of detection for liquid scintillation counting. A reasonable correlation may be seen between the media measured by LLNL—air moisture, water from the DRB, water from the LLNL swimming pool, and Livermore Valley wine. Differences are due to distance from the tritium sources to the location of the sampled medium, the fraction of time the wind blows towards the location, and how well the sample medium reflects tritium concentrations throughout the year.



Source: Concentrations in precipitation in Portland and Anchorage: Data from IAEA/WMO (2004). Global Network of Isotopes in Precipitation. The GNIP Database. Accessible at: http://isohis.iaea.org.

Figure EX-1. Annual median concentrations of tritium in various LLNL media compared with background levels in precipitation and the drinking water standard

Background tritium levels seen in rain samples from Portland and Anchorage include cosmogenic tritium and residual tritium from bomb tests. Background tritium levels show large variability because of latitude-effects and distance from large bodies of water. Livermore Valley wines and rain in Portland exhibit similar tritium concentrations. In 2004, the highest tritium concentrations measured at LLNL were 120 times lower than the drinking water standard.

Radiological Dose

Dose calculated to the site-wide maximally exposed individual (SW-MEI) for 2004 was 0.079 µSv (0.0079 mrem) for the Livermore site and 0.26 µSv (0.026 mrem) at Site 300. Three sources of tritium at LLNL contributed 94% of the dose received by the SW-MEI. At Site 300, the Building 851 firing table contributed 95% of the dose to the SW-MEI. There were no unplanned releases to the environment. The dose for 2004 is less than 20% the 2003 dose for the Livermore site and less than half of the previous lowest dose (in 2001) since dose reporting began. The dose to the SW-MEI at Site 300 was 50% higher in 2004 than in 2003 but was comparable to releases over the last 10 years.

In **Figure EX-2**, calculated radiological doses to the maximally exposed member of the public from operations at each site in 2004 are compared with regulatory limits and doses potentially received from the environment or from common activities (e.g., medical x-rays). The contribution of LLNL operations to unavoidable dose was inconsequential.

The 2004 dose calculated for biota at the Livermore site or at Site 300 was far below screening limits set by DOE, even when extremely unlikely assumptions were made that maximized the effect of LLNL releases on biota.

Groundwater Remediation and Monitoring

Groundwater at both the Livermore site and Site 300 is contaminated from historical operations; both are undergoing CERCLA (or Superfund) cleanup. At the Livermore site, contaminants include volatile organic compounds (VOCs), fuel hydrocarbons, metals, and tritium, but only the VOCs in groundwater, and saturated and unsaturated soils need remediation. Cleanup began in 1989. In 2004, concentrations continued to decrease in most Livermore site VOC plumes due to active remediation. VOC concentrations on the western edge of the site either declined or remained the same.

Site 300 cleanup began in 1981. VOCs are the main contaminant found at the eight Site 300 operable units (OUs). As well, nitrate, perchlorate, tritium, high explosives, depleted uranium, organosilicate oil, and metals are found at one or more of the OUs. In addition to VOCs, in 2004, perchlorate, nitrate, the high explosive RDX, and organosilicate oil were removed from groundwater. No off-site wells contain any VOCs in excess of cleanup levels, and considerable reduction in on-site concentrations has been

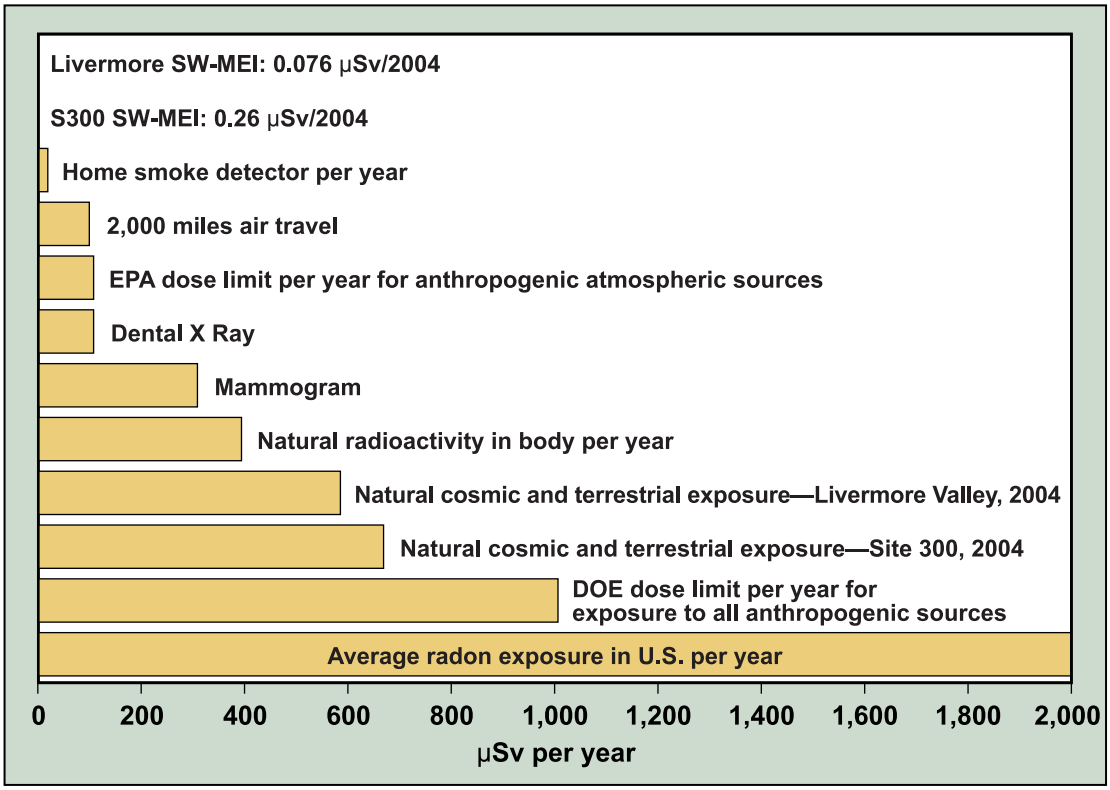


Figure EX-2. Comparison of doses to the SW-MEI at the Livermore site and Site 300 with doses received from natural background and other everyday exposures

made (most contamination is well contained within the site). Tritium above drinking water standards will have decayed to below the standard by the time the groundwater leaves the site, and depleted uranium is already below the drinking water standard. In addition to the eight operable units under remediation, four areas are under investigation to determine remediation options.

In the last ten years, the Livermore site has processed about nine times the volume of groundwater than has Site 300, but Site 300 has processed 2.5 times more soil vapor than the Livermore site. Long-term VOC concentrations in groundwater and soil vapor for Site 300 are lower by factors of two and seven, respectively, than concentrations at the Livermore site. Cumulative kilograms of VOCs removed over the last ten years from each site are shown in **Figure EX-3**.

As well as groundwater remediation activities, extensive monitoring of groundwater occurs at and near the Livermore site and Site 300 to determine potential impact on the environment and the public. Groundwater from wells down gradient from the Livermore site is analyzed for pesticides, herbicides, radioactivity, nitrate, and hexavalent chromium; the maximum off-site concentration of tritium measured was 0.73% of the drinking water standard. At Site 300, groundwater is analyzed for radioactivity, a wide

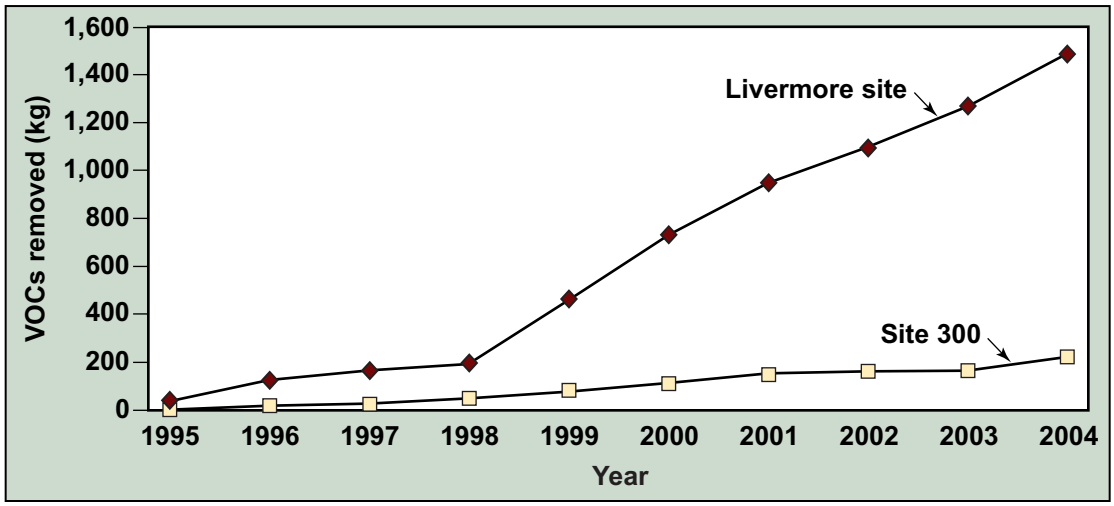


Figure EX-3. Cumulative kilograms of VOCs removed from groundwater and soil vapor at the Livermore site and Site 300 over the last ten years

range of organic compounds, metals, explosive compounds, and VOCs. No new release of constituents of concern (COC) to groundwater from any of the Site 300 sampling areas was found in 2004, and no COC that could be related to LLNL operations was found in off-site Site 300 wells.

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 Clear 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 and the California Environmental Quality Act; the Endangered Species Act; the National Historic Preservation Act; the Antiquities Act; and CERCLA.

In 2004 and early 2005, the Agency for Toxic Substances and Disease Registry (ATSDR) completed public health assessments (PHAs) for the Livermore site and Site 300 that were several years in preparation. ATSDR is required by law to conduct a PHA at each site on the EPA National Priorities List to determine if people are being exposed to hazardous substances and if the exposure is harmful and should be reduced. At the Livermore site, ATSDR determined that the only COCs were off-site boron (found naturally in groundwater and storm water runoff), nitrate (in groundwater, but unrelated to LLNL releases), tritium (in air), plutonium-239 (in resuspended soil and sewage

sludge), and tetrachlorethyelene (in groundwater); at Site 300 the COCs were VOCs in the groundwater in the General Services Area. The Livermore site PHA concluded "no apparent public health hazard" from past and present releases, while the Site 300 PHA concluded "no public health hazard", because there have been no exposures in the past and exposures in the future are unlikely.

LLNL continued to perform all activities necessary to comply with clean air and clean water requirements. In 2004, LLNL held 178 permits from the Bay Area Air Quality Management District and 40 from the San Joaquin Valley Air Pollution Control District. In addition, for the Livermore site, LLNL had permits for operation of hazardous waste facilities, generation and treatment of medical waste, discharges of treated groundwater to the recharge basin, discharges of storm water associated with industrial activities and construction, discharges of waste water and CERCLA restoration activities to the sanitary sewer, and use of aboveground and belowground storage tanks. Site 300 held many similar permits; in addition, it held permits for operation of a domestic sewage lagoon and percolation pits and large discharges from the drinking water system. Both sites have a Federal Facility Agreement for groundwater investigation/remediation. The Laboratory complies with all requirements for self-monitoring and inspections associated with these permits.

Special Status Wildlife and Plants

In 2004, a bridge over the Arroyo Mocho was permitted and constructed. It replaced an eroded, low flow crossing that obstructed the movement of threatened steelhead trout to historic spawning grounds and was impassible to vehicles throughout much of the winter. Wildlife biologists worked closely with the design and construction teams to ensure minimal disturbance of flora and fauna. When disturbance was anticipated, amphibians, reptiles, and fish were moved temporarily out of harm's way; at construction's end, plants raised elsewhere were transplanted to the bridge site.

LLNL studies, guards, and tries to improve the habitat of five species at Site 300 that are covered by the federal or California endangered species act (California tiger salamander, California red-legged frog, Alameda whipsnake, valley elderberry longhorn beetle, and large-flowered fiddleneck) as well as rare species or those otherwise of special interest. At Site 300, LLNL also counts nests, birds, and rare species of plants. The red-legged frog is found also on the Livermore site, where egg masses are counted annually and bullfrogs (a predator) are eradicated. In 2004, masses of bullfrog eggs were removed weekly throughout the spring and summer. Adult bullfrogs were also removed.

Pollution Prevention

LLNL has an active program of pollution prevention, energy efficiency, waste minimization, sustainable design, and other activities to protect the environment. In June 2004, LLNL submitted its estimate to NNSA that, due to the use of nonlead frangible ammu-

nition at the Site 300 firing range, lead releases to the environment had been reduced by 72% since 2002. In 2005, this program received an NNSA Environmental Stewardship Award.

In early 2005, LLNL received a DOE Best-in-Class award for its tilt-pour furnace process. Traditional processing uses ceramic crucibles that are disposed of as radioactive waste after a single use. In the tilt-pour furnace process, crucibles can be used for hundreds of runs before replacement is needed.

Use of a flow-through radionuclide detector that detects multiple radionuclides in a waste stream has resulted in recharacterization of 44% of the surveyed waste from mixed to low-level. In 2005, this program received a DOE Best-in-Class Award and a DOE P2 Star Award.

Other promising projects in 2004 included a pilot program to use biodiesel in ten of LLNL's medium duty fleet of vehicles and an accelerated solvent extraction system that will remove soluble VOCs and PCBs from solid samples, which will result in reductions of 230 kg mixed low-level waste and 1 kg transuranic waste each year.

Conclusion

The combination of environmental and effluent monitoring, source characterization, and dose assessment showed that radiological doses to the public caused by LLNL operations in 2004 were less than 0.26% of regulatory standards and more than 11,000 times smaller than dose from natural background. Analytical results and evaluations generally showed continuing low levels of most contaminants; remediation efforts further reduced the concentrations of contaminants of concern in groundwater and soil vapor. In addition, LLNL's extensive environmental compliance activities related to water, air, endangered species, waste, wastewater, and waste reduction controlled or reduced LLNL's effects on the environment. LLNL's environmental program clearly demonstrates a commitment to protecting the environment from operational impacts.

1 Introduction

Lawrence Livermore National Laboratory (LLNL) is a premier research and development institution for science and technology applied to national security. The Laboratory is managed and operated by the University of California for the U.S. Department of Energy. LLNL's primary mission is to ensure that the nation's nuclear weapons remain safe, secure, and reliable. The Laboratory's special capabilities are also applied to the prevention of the spread and use of weapons of mass destruction and to strengthen homeland security. With broadly based capabilities and leadership in mission-focused areas of science and technology, the Laboratory meets other national needs with major advances in research programs in energy and environment, bioscience and biotechnology, and basic science and applied technology. The Laboratory serves as a resource to the U.S. government and is 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 environmental protection, security, fire, health and safety, and medical departments—necessary to support its operations and more than 8000 personnel.

Location

LLNL consists of two sites—the urban Livermore site located in Livermore, California in Alameda County, and the rural Experimental Test Site (Site 300) located near Tracy, California, in San Joaquin and Alameda counties (**Figure 1-1**).

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. Since then, Livermore has evolved from a small town of fewer than 7000 people to a city of about 80,000. Today the city borders the LLNL site on the west and north. The economy, which had been primarily agricultural, has diversified to include light industry and business parks.

The Livermore site occupies an area of 3.3 km^2 (1.3 mi^2), including the land that serves as a buffer zone around the site. Adjoining the site border 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 operating management and environmental management systems.

To the south of the LLNL and Sandia/California sites, there are mostly low-density residential areas and agricultural areas devoted to grazing, orchards, and vineyards. Farther south, property is primarily open space and ranchettes with some agricultural use. Within the last few years, residential developments, both houses and apartments, have filled the

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

formerly vacant fields immediately to the west of the Livermore site. A small business park lies to the southwest. 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. An extensive 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.

Within an 80-km (50-mi) radius of the Livermore site lie nearby communities, such as Tracy and Pleasanton, and the distant population centers of Oakland, San Jose, and San Francisco. Although over seven million people reside within 80 km of the Laboratory, just 10% of them live within 32 km (20 miles).

Site 300, LLNL's Experimental Test Site, which dates from 1955, 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 the town of Tracy, population 76,500, located 10 km[1] (6 mi) to the northeast. About 6.2 million people live within 80 km (50 mi) of Site 300. 95% live more than 32 km (20 mi) from Site 300 in such distant metropolitan areas as Oakland, San Jose, and Stockton.

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. An understanding of LLNL's meteorological and geographic setting is needed to better monitor Laboratory operations effectively and efficiently.

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 2004 were 22.0 °C (71.7 °F), 8.1 °C (46.6 °F), and 15.0 °C (59.1 °F), respectively. The mean daily maximum, minimum, and average temperatures for Site 300 in 2004 were 20.8 °C (69.4 °F), 12.1 °C (53.8 °F), and 16.5 °C (61.6 °F), respectively. Nighttime temperatures are typically higher (and diurnal temperature range smaller) at Site 300 compared to the Livermore site; stronger winds at the higher elevation prevent formation of strong nighttime 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

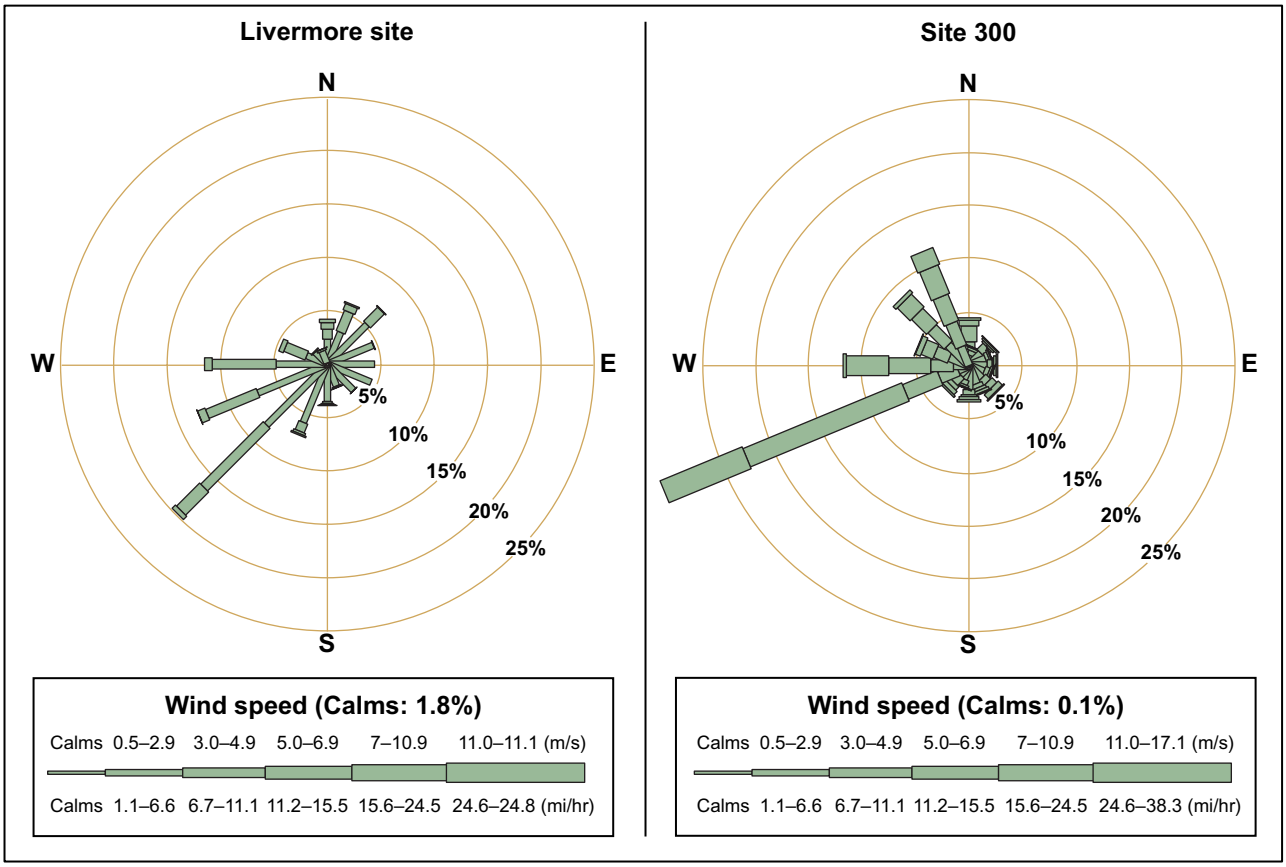
1. This distance is from the northeast border of Site 300 to Sutter Tracy Community Hospital.

at the Livermore site. While the mean annual temperature was near-normal during 2004, several individual months experienced large departures from normal. A persistent warm high pressure system and offshore winds caused March to be the warmest at the Livermore site since at least 1989 and also caused record heat in April. High temperatures reached 29 °C (84 °F) on March 18, the highest ever recorded for so early in the season. The high temperature reached 31.0 °C (88 °F) on April 25 and 33.5 °C (92 °F) on the following two days, a record for April and for so early in the year. The arrival of Arctic air caused record cold in late November and early December. Freezing temperatures occurred on three mornings in late November, including –1.8 °C (29 °F) and –3.9 °C (25 °F) on November 29 and 30, respectively. Morning low temperatures continued to dip below freezing during the first five days of December, including –5 °C (23 °F) on December 4, the lowest temperature recorded in 2004. The lowest temperature at Site 300 was –0.4 °C (31 °F) on the morning of December 20. The warmest day of the year was August 11 when the temperature reached 40 °C (104 °F) at the Livermore site and 36.8 °C (98 °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 included in **Figure 1-2**. These data show that about 52% of the wind comes from the south-southwest through west directions. This prevailing pattern occurs primarily during the summer. During the winter, winds from the northeast are more common. The peak wind gust at the Livermore site of 25 m/s (56 mph) from the south occurred on February 25 in advance of a storm. Based on a 47-year record, the highest and lowest annual rainfalls were 85.2 and 16.7 cm (33.57 and 6.57 in.), and the normal annual rainfall is 34.6 cm (13.62 in.). In 2004, the Livermore site received 27.8 cm (10.96 in.) of rain, or only 80% of normal. The spring (March–May) total rainfall of 1.5 cm (0.58 in.) was the third driest ever recorded at the Livermore site since 1958. An early storm dropped 1.3 cm (0.52 in.) of rain on September 19. The maximum daily rainfall of 3.1 cm (1.21 in.) fell on December 30.

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 occurred 43% of the time during 2004. The peak wind speed at Site 300 reached 29 m/s (65 mph) on January 1 and December 29 from the south and south-southeast, respectively. As is the case for the Livermore site, precipitation at Site 300 is seasonal, with most rainfall occurring between October and April. Because Site 300 is situated downwind (north) of more significant terrain (i.e., winds are typically southerly during storms) than at the Livermore site, rainfall amounts are typically 20 to 25% lower. Based on a 45-year record, the highest and lowest annual rainfalls were 59.9 and 14.2 cm (23.58 and 5.61 in.), and the normal annual rainfall is 26.8 cm



Note: 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 2004 at the Livermore site was 2.5 m/s (5.6 mph); at Site 300 it was 6.1 m/s (13.7 mph).

Figure 1-2. Wind rose showing wind direction and speed frequency at the Livermore site and Site 300 during 2004

(10.55 in.). In 2004, Site 300 received 20.2 cm (7.96 in.) of rain, or only 75% of normal. The spring (March–May) total rainfall of 0.8 cm (0.30 in.) was the least ever recorded since at least 1960. An early storm dropped 0.9 cm (0.34 in.) of rain on September 19. The maximum daily rainfall of 2.1 cm (0.81 in.) fell on December 30.

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. The Livermore Valley, the most prominent valley in the Diablo Range, 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 the Arroyo del Valle and the 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 4-8**.

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 of Site 300 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; Thorpe et al. 1990; Blake et al. 1995). This section is a summary of the reports of these investigations and the 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 and is considered 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 groundwater elevation contour map of the Livermore site area's shallowest, laterally extensive water-bearing unit (hydrostratigraphic unit or HSU), HSU-2. Although groundwater elevations vary due to seasonal and year-to-year differences in both recharge and groundwater withdrawal from the basin, 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.

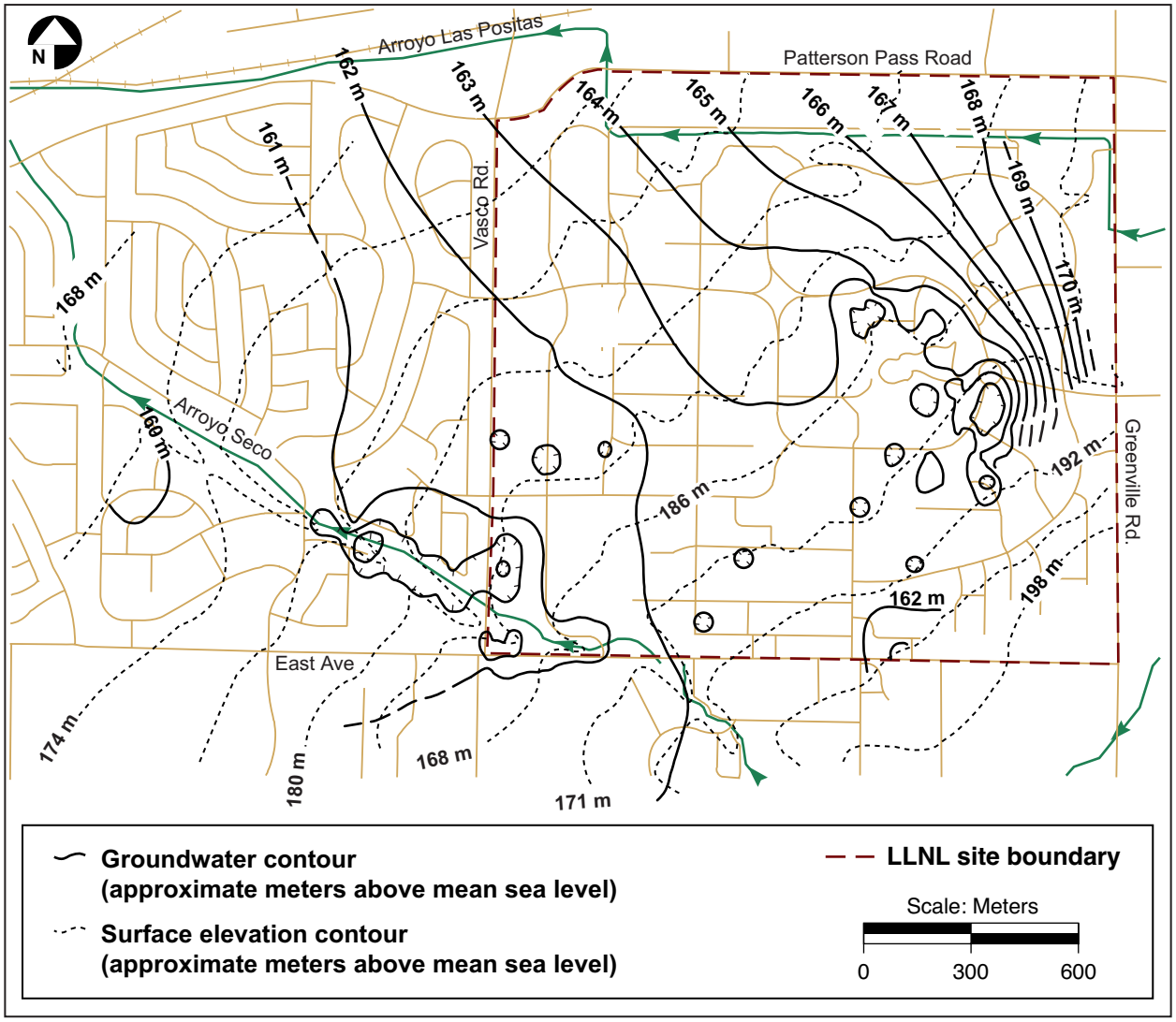


Figure 1-3. Groundwater elevation contours of hydrostratigraphic unit 2 (HSU-2), the shallowest laterally extensive water-bearing unit beneath the Livermore site, November 2004

While groundwater flow beneath the site is generally westward, similar to the regional flow direction, in places it becomes southwesterly, and even easterly, due to extensive groundwater extraction associated with the remedial activities at the site. Groundwater recharge and agricultural pumping have also affected the direction of groundwater flow at the site. Aquifer tests on monitoring wells in the vicinity of the Livermore site indicate that the hydraulic conductivity (a measure of the ability of geologic media to transmit water) of the permeable sediments ranges from 1 to about 16 m/day (3.3 to 52 ft/day) (Isherwood et al. 1991). The range in these values reflects the heterogeneity typical of the more permeable alluvial sediments that underlie the area. This range, in combination with the observed water table gradients, yields an estimated average groundwater velocity of about 20 m/y (66 ft/y) (Thorpe et al. 1990).

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.

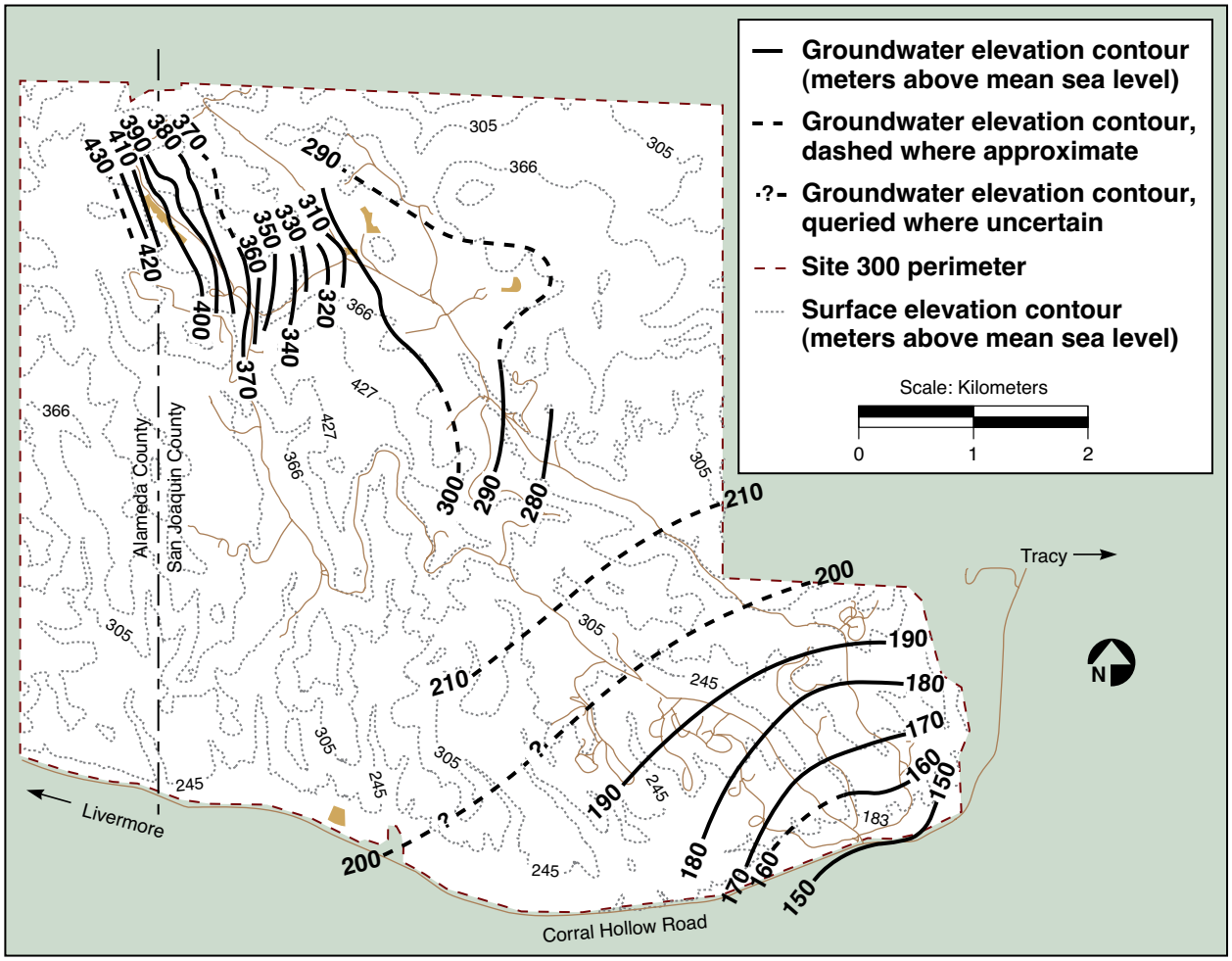


Figure 1-4. Approximate groundwater elevations for the principal continuous water-bearing zone at Site 300

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 7.

Summary

LLNL recognizes the importance of geology, hydrogeology, climate, and geographical relationships with its neighbors in assessing potential impacts of operations at the Livermore site and Site 300. Each year LLNL gains additional information to better predict, interpret, and avoid potential impacts. Each environmental medium that is discussed in this document—air, water, terrestrial, and wildlife—may be affected differently. LLNL takes 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

We acknowledge the work of Brent Bowen, Bert Heffner, Donald MacQueen, Charles Noyes, Ring Peterson, and Michael Taffet in preparing this chapter.

2

Environmental Compliance and Program Summaries

Lawrence Livermore National Laboratory, as stated in LLNL's Environmental Policy signed by LLNL's Director in July 2004, is committed to providing responsible stewardship of environmental resources. Environmental stewardship is integrated into Laboratory strategic planning and decision-making processes and into the management of all work activities through the Integrated Safety Management System.

In support of this policy, LLNL commits to:

- Work to continuously improve the efficient and effective performance of the environmental management system
- Comply with applicable environmental laws and regulations
- Incorporate pollution prevention, waste minimization, and resource conservation into planning and decision-making processes
- Ensure that interactions with regulators, DOE, and the community are based upon integrity, openness, and adherence to national security requirements
- Establish appropriate environmental objectives and performance indicators to guide these efforts and measure our progress

This chapter provides a brief summary of LLNL's compliance with environmental regulations and LLNL's environmental management programs.

Compliance Summary

Lawrence Livermore National Laboratory participates 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. The following describes regulations and guidance applicable to LLNL during 2004, including a summary of permits active in 2004, and inspections of the Livermore site and Site 300 by external agencies. The following summaries also provide references for more information where available.

Environmental Restoration and Waste Management

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. CERCLA compliance activities are summarized in the following sections; program activities and findings are further described in Chapter 7.

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 soil and groundwater. The primary soil and groundwater contaminants (constituents of concern) are volatile organic compounds (VOCs), primarily trichloroethylene (TCE) and perchloroethylene (PCE).

Significant 2004 Livermore site GWP restoration activities include installing 4 groundwater extraction wells, 2 dual (groundwater and soil vapor) extraction wells, 7 soil vapor extraction wells, and abandoning 1 anode well; conducting 1 hydraulic test; and conducting 24 soil vapor extraction tests. LLNL met all regulatory milestones by activating the Soil Vapor Treatment Facility TFD Helipad (VTFD-HPD) and Soil Vapor Treatment Facility B518 Perched Zone (VTF 518-PZ) on schedule.

Treatment Facilities: In 2004, LLNL operated groundwater treatment facilities in the following treatment facility (TF) areas: A, B, C, D, E, G, 406, 518, and 5475 (see Figure 7-1). A total of 80 groundwater extraction wells and 16 dual extraction wells supplied water to 26 treatment facilities at a combined average flow rate of about 2236 liters per minute. In 2004, these facilities treated more than 1.2 billion liters of groundwater and removed about 86 kilograms of VOCs compared to 90 kilograms in 2003. The smaller quantity of mass removed in 2004 is partially due to decreasing concentrations in the TFD and TFE areas and declining groundwater extraction well flow rates due to remediation-induced dewatering at the site. Since remediation began in 1989, approximately 9.7 billion liters of groundwater have been treated, resulting in a

mass removal of about 1097 kilograms of VOCs. In addition, LLNL operated four soil vapor treatment facilities (VTFs): VTF5475, VTFE-ELM, VTFD-HPD, and VTF518-PZ. In 2004, these facilities treated about 1.2 million cubic meters of vapor and removed an estimated 133 kilograms of VOCs compared to about 84 kilograms in 2003. The significantly larger quantity of mass removed in 2004 is due to start up of VTFD-HPD and VTF518-PZ, as well as continued operation of VTFE-ELM and VTF5475. Since initial operation, more than 2.6 million cubic meters of vapor have been treated by the VTFs, resulting in a mass removal of more than 681 kilograms of VOCs. The groundwater and soil vapor treatment systems removed 219 kilograms of VOC in 2004, and have removed about 1778 kilograms of VOCs from the subsurface since remediation began in 1989. See Chapter 7 for further information.

Community Relations: Livermore site community relations activities in 2004 included communicating and meeting with neighbors and 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 site environmental activities; and responding to public and news media inquiries. In addition, DOE and LLNL met with members of Tri-Valley Communities Against a Radioactive Environment (Tri-Valley CAREs) and their scientific advisor as part of the activities funded by an EPA Technical Assistance Grant (TAG). Community questions were also addressed via electronic mail, and project documents, letters, and public notices were posted on a public website at www-envirinfo.llnl.gov.

Documentation: In 2004, DOE/LLNL submitted the *LLNL Ground Water Project 2003 Annual Report* (Karachewski et al. 2004) and quarterly self-monitoring reports on schedule. In addition, DOE/LLNL completed all 2004 Remedial Action Implementation Plan (Dresen et al. 1993) milestones ahead of schedule.

Site Evaluations Prior to Construction: LLNL was placed on the National Priorities List in 1987 based on historical contamination of soil and groundwater. The *CERCLA Record of Decision for the Lawrence Livermore National Laboratory Livermore Site* (LLNL 1992) identifies selected remedial actions agreed upon by the EPA, SFBRWQCB, and DTSC. The Record of Decision requires that before any construction begins, the project site must 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 potential for radioactive contamination, rubble may be either surveyed or analyzed for radioactivity. During 2004, soil and/or rubble were evaluated at 70 construction sites. Based on the evaluation, the soil and/or rubble were either reused on site or disposed of according to established procedures.

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), DTSC, and the authority of an FFA for the site. (There are separate FFAs for Site 300 and the Livermore site.) The groundwater contaminants (constituents of concern) for Site 300 vary within the

different environmental restoration operable units at the site. 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. 1999).

Treatment Facilities and Field Investigations: 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. Sixteen treatment facilities operated during 2004. Twenty-five wells that extract groundwater only, 7 wells that extract soil vapor only, and 24 wells that extract both groundwater and soil vapor operated during 2004, treating about 17.6 million liters of groundwater. The 24 wells that extract both vapor and groundwater and the 7 wells that extract only vapor together removed 212,106 m^3 of vapor. In 2004, the Site 300 treatment facilities removed approximately 58 kilograms of VOCs, 0.072 kilograms of perchlorate, 705 kilograms of nitrate, 1 kilogram of RDX high explosive compound, and 0.58 grams of organic silicate oil. Since remediation efforts began in 1990, more than 994 million liters of groundwater and approximately 4.5 million m^3 of vapor have been treated, to yield about 292 kilograms of removed VOCs. See Chapter 7 for further information.

Due to budgetary constraints, LLNL delayed 2004 FFA milestones for construction of additional treatment facilities and completion of field work at several programmatic areas until 2005. The Site 300 Remedial Project Managers (U.S. EPA Region IV, DTSC, and the RWQCB) agreed to this delay.

Community Relations: The Site 300 CERCLA project maintains continuing communications with the community of Tracy and nearby neighbors. Community relations activities in 2004 included maintenance of information repositories and administrative records; participation in community meetings; off-site, private well-sampling activities; mailings to stakeholders; and interviews with the news media. LLNL hosted TAG meetings with Tri-Valley CAREs. TAG 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 and comment on Site 300 CERCLA activities.

Documentation: In 2004, LLNL submitted all required documentation to oversight agencies by agreed upon regulatory submission dates. The *Final Remedial Design for the Building 850 Operable Unit* (Taffet et al. 2004a), *Second Draft Final Remedial Investigation/Feasibility Study (RI/FS) for the Pit 7 Complex Operable Unit* (Taffet et al. 2004b), *Annual 2003 Compliance Report for Lawrence Livermore National Laboratory Site 300* (Dibley et al. 2004a), *First Semester 2004 Compliance Report for Lawrence Livermore National Laboratory Site 300* (Dibley et al. 2004b), quarterly reports, and work plans were among the documents submitted.

Agency for Toxic Substances and Disease Registry Assessment

The Agency for Toxic Substances and Disease Registry (ATSDR), part of the Centers for Disease Control of the U.S. Department of Health and Human Services, is responsible for assessing public health impacts at U.S. DOE sites undergoing environmental restoration. In 2004, the ATSDR completed a public health assessment (PHA) of the Livermore site that incorporates the findings of all the PHAs and health consultations conducted over the past ten years by the ATSDR and the California Department of Health Services Environmental Health Investigation Branch. The 2004 PHA found "No Apparent Public Health Hazard" from past and ongoing operations of the laboratory.

According to the PHA, the findings mean

> "...that although community exposures of site-related contaminants may have occurred or may be occurring, the resulting doses are unlikely to result in any adverse health effects and are consequently below levels of health concern....The current environmental monitoring program conducted by LLNL is adequate to ensure that future releases of hazardous substances will not present a future public health hazard." (ATSDR 2004)

The PHA, which was published in June 2004, can be read as a printed copy at the Livermore Public Library or the LLNL Environmental Repository, or viewed at http://www-envirinfo.llnl.gov/. On August 11, 2004, the ATSDR held its final public meeting in Livermore to discuss its findings and answer questions.

The 2004 PHA is the latest in a long series of activities to assure that LLNL presents no potential environmental or public health impacts to the community. See **Table 2-1** for examples of the many historic studies on the potential for impacts due to plutonium releases to the city sewer plant in 1967. None of the studies has found a potential for public health impact or harm.

In January 2005, the ATSDR also completed a PHA of Site 300, which concludes:

> "... that the environmental contamination related to Site 300 presents No Public Health Hazard based on the fact that exposure to contaminants from Site 300 is not occurring now, has not occurred in the past and is not expected to occur in the future.... Currently off-site residents are not being exposed to contaminated groundwater originating from Site 300....There are no completed past exposure pathways for contaminated groundwater. No contamination from Site 300 has ever been detected in off-site water supply wells." (ATSDR 2005)

Table 2-1. History of off-site plutonium sampling in soil and sludge

Time	Location(s)[a]	Sample Design[a,b]	Sample Collection[a]	Sample Analysis[a]	Regulatory Oversight[a]	Sample Type: Sample Range[a]	Finding/Reference[a]
Surveillance Monitoring 1959–1970	LWRP	LRL	LRL	LRL	USAEC, CDPH-BRH, USDHEW (later USEPA)	**soil:** 1.5–22 pCi gross alpha/g[c] **digester sludge:** ≤60 pCi gross alpha/g[c]	No action required; nothing over guidelines (LRL 1959-1970)
Surveillance Monitoring 1960–1969	LWRP	CDPH-BRH	LWRP	CDPH-BRH	CDPH-BRH	**digester sludge:** ≤297 pCi gross alpha/g[c]	No action required; nothing over guidelines (CDPH-BRH 1960-1969)
Inadvertent plutonium release 5/25–6/15/67	LWRP	LRL, City of Livermore, USAEC, CDPH-BRH	LWRP/LRL	LRL	City of Livermore, USAEC, CDPH-BRH	**sewage:** ~2 pCi gross alpha/mL[c] **digester sludge:** ≤1205 pCi gross alpha/g[c]	Nothing over guidelines; sludge below levels of health concern. No health basis for additional sampling; recommendation of sampling would be irresponsible (ATSDR 2003)[d]
Expanded Surveillance Soil Sampling 1971–1972	Valley-wide	LLL	LLL	LLL	USAEC, CDPH-BRH	**soil:** 27–162 mCi/km^2	Below regulatory levels (Gudiksen et al. 1972; Gudiksen et al. 1973)
1973	3 homes in Livermore with sludge	LLL	LLL	LLL	USAEC, CDPH-BRH	**soil:** 0.00797–1.84 pCi/g	Below regulatory levels (ATSDR 2000)[d]
1973	LWRP lagoon	LLL	LWRP/LLL	LLL	USAEC, CDPH-BRH, City of Livermore	**dried sludge:** ~2.6 pCi/g	Below regulatory levels (Silver et al. 1974)
1974–1975	LLNL sludge uptake study	LLL	LLL	LLL	USAEC	**sludge:** 2.2–4.4 pCi/g	No hazard from food grown using sludge; 50 year integrated dose less than 0.002 rem for inhalation and 0.00004 rem for ingestion compared to approximately 15 rem from natural background radiation over same time period. (Myers et al. 1976)
Surveillance Sampling 1973–ongoing	Valley-wide	LLL (later LLNL)	LLL (later LLNL)	LLL (later LLNL)	USAEC/DOE, CDPH-BRH, USEPA	**soil:** ≤0.106 pCi/g	Below residential USEPA Region 9 Preliminary Remediation Goal of 2.5 pCi/g (Sanchez et al. 2004; Table 5-5)

Table 2-1 History of off-site plutonium sampling in soil and sludge (continued)

Time	Location(s)[a]	Sample Design[a,b]	Sample Collection[a]	Sample Analysis[a]	Regulatory Oversight[a]	Sample Type: Sample Range[a]	Finding/Reference[a]
Surveillance Sampling 1973–ongoing	LWRP	LLL (later LLNL)	LLL (later LLNL)	LLL (later LLNL)	USAEC/DOE, CDPH-BRH, USEPA	**Highest values: soil (1992)** ≤2.96 pCi/g **sludge (1987):** ≤10.18 pCi/g	Below industrial USEPA Region 9 Preliminary Remediation Goal; then 13 pCi/g, now 10 pCi/g (Sanchez et al. 2004; Table 5-5)
1980	Downwind locations	CDHS	CDHS	CDHS	CDHS, LLNL	**soil:** 0.0025–0.0312 pCi/g	No significant elevations beyond vicinity of LLNL facility (Toy et al. 1981; Tamplin 1980)
1993	Big Trees Park	USEPA, NAREL	NAREL	NAREL	USEPA	**soil:** ≤0.164 pCi/g	No health hazard; recommend further sampling only in Big Trees Park (NAREL 1994; Gallegos et al. 1994)
1995	Big Trees Park additional sampling	USEPA, NAREL, LLNL, CDHS-RHB, LWRP, LARPD, Arroyo Seco School, Public input	LLNL	LLNL, USEPA, CDHS-RHB, Lockheed Analytical Services	USEPA, CDHS-RHB	**soil:** ≤1.02 pCi/g	No unacceptable risk to human health (MacQueen 1995) No further action needed, not a health concern (USEPA 1995)
1998	Big Trees Park	USEPA, CDHS, ATSDR, LLNL, CDHS-RHB, LWRP, LARPD, Public input	LLNL	USEPA, CDHS, ATSDR, General Engineering Laboratory, Georgia Institute of Technology Environmental Resources Center, LLNL	USEPA, CDHS-RHB	**soil:** ≤0.774 pCi/g	Below levels of health concern set by EPA; no further action required. (ATSDR 2000)[d] No health basis for additional sampling; recommendation of soil sampling would be irresponsible. (ATSDR 2003)[d]

Note: Through the years covered by this summary table, the names of many of the institutions involved have changed. Lawrence Radiation Laboratory (LRL) became Lawrence Livermore Laboratory (LLL) and then became Lawrence Livermore National Laboratory (LLNL). The United States Atomic Energy Commission (USAEC) became the Energy Research and Development Administration (ERDA), and then became the Department of Energy (DOE). The California Department of Public Health, Bureau of Radiological Health (CDPH-BRH) became the California Department of Health Services, Radiation Health Branch (CDHS-RHB). The radiological oversight function of the United States Department of Health, Education, and Welfare (USDHEW) transferred to the United States Environmental Protection Agency (USEPA) when the USEPA was established in 1970.

a See Acronyms and Abbreviations for list of acronyms.

b Based on Federal standards and guidelines.

c "Gross alpha" represents total detected alpha radiation from all alpha-emitting nuclides; LLNL upgraded monitoring in 1971 to analyze for plutonium-239+240.

d The 2000 and 2003 ATSDR reports are part of its LLNL public health assessment. ATSDR performs health assessments at all DOE sites conducting environmental restoration under CERCLA. The ATSDR, LLNL's annual, and other environmental reports may be viewed at http://www-envirinfo.llnl.gov/ or by contacting Bert Heffner at 925/424-4026.

The ATSDR recommended continuing environmental remediation and environmental monitoring. It determined earlier in the PHA process that

> "The current environmental monitoring program conducted by LLNL is adequate to ensure that future releases of hazardous substances will not present a future public health hazard." (ATSDR 2005)

The Site 300 PHA can be viewed at http://www-envirinfo.llnl.gov/ or read as a printed copy at the Tracy City Library or the LLNL Environmental Repository. The ATSDR held a public meeting on February 24, 2005, in Tracy to discuss its findings and answer questions.

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

Title III of 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."

On June 28, 2004, LLNL submitted to the National Nuclear Security Administration (NNSA)/DOE the TRI Form R for lead detailing environmental release estimates for Site 300. (Form R is used for reporting TRI chemical releases including waste management and waste minimization activities.) A 72% reduction in lead releases was achieved as a result of a continuing effort to substitute nontoxic, nonlead (frangible), and reduced lead containing ammunition where feasible.

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

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 requirements for managing hazardous wastes in California. RCRA and HWCA also regulate hazardous waste treatment, storage, and disposal facilities, including permit requirements. Because RCRA program authorization was delegated to the State of California in 1992, LLNL works with DTSC on compliance with federal and state issues and in obtaining hazardous waste permits.

Table 2-2. Compliance with EPCRA

EPCRA requirement[a]	Brief description of requirement[a]	LLNL action
302 Planning Notification	Notify SERC of presence of extremely hazardous substances.	Originally submitted May 1987.
303 Planning Notification	Designate a facility representative to serve as emergency response coordinator.	Update submitted April 27, 2004.
304 Release Notification	Report releases of certain hazardous substances to SERC and LEPC.	No EPCRA-listed extremely hazardous substances were released above reportable quantities in 2004.
311 MSDS/Chemical Inventory	Submit MSDSs or chemical list to SERC, LEPC, and Fire Department.	Update submitted April 27, 2004.
312 MSDS/Chemical Inventory	Submit hazardous chemical inventory to local administering agency (county).	Business plans and chemical inventory submitted to San Joaquin County (January 13, 2004) and Alameda County (April 1, 2004).
313 Toxics Release Inventory	Submit Form R to U.S. EPA and California EPA for toxic chemicals released above threshold levels.	Form R for lead (Site 300 only) was submitted to DOE June 28, 2004; DOE forwarded it to U.S. EPA and California EPA June 28, 2004.

a See Acronyms and Abbreviations for list of acronyms.

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]). The units that were operated under interim status (Area 514 Facility and the Building 233 Container Storage Facility) have been relocated to permitted facilities. Building 233 and Area 514 are currently undergoing RCRA closure. Permitted waste management units include container storage, tank storage, and various treatment processes (e.g., wastewater filtration, blending, and size reduction). During 2003/2004, LLNL also submitted several Class 1 and Class 2 permit modification requests to DTSC; all the requested Class 1 and some Class 2 permit modifications have been approved and implemented. Many of these modification requests are related to as-built changes and consolidation of storage and treatment of hazardous waste at the DWTF complex. On December 29, 2004, DTSC updated LLNL's Hazardous Waste Facility Permit (HWFP).

A final closure plan for the Building 419 Interim Status Facility was submitted to DTSC February 2001. DTSC is continuing its review of this closure plan. LLNL has provided additional information requested by DTSC, including responding to Building 419 Notices of Deficiency (NODs) that DTSC issued in November 2004.

See **Table 2-3** for a summary of permits active in 2004. See **Table 2-4** for a summary of inspections and **Table 2-7** for a description of a Summary of Violations (SOVs) received as a result of a DTSC's Compliance Evaluation Inspection (CEI) conducted during

Table 2-3. Permits active in 2004

Type of permit	Livermore site[a][b]	Site 300 [a][b]
Hazardous waste	EPA ID No. CA2890012584. Hazardous Waste Facility Permit Number 99-NC-006 (RCRA Part B permit)—to operate hazardous waste management facilities including Buildings 693 and 695, and Area 612. Activities authorized in these areas include treatment and storage of hazardous and mixed wastes subject to the conditions specified in the Part B permit. LLNL is also a Registered Hazardous Waste Hauler and is authorized to transport wastes from Site 300 to the Livermore site. Authorization to mix resin in Unit CE231-1 under a Conditionally Exempt Specified Wastestream permit.	EPA ID No. CA2890090002. Part B Permit—Container Storage Area (Building 883) and Explosives Waste Storage Facility. Part B Permit—Explosives Waste Treatment Facility. Part B Permit—RCRA-Closed Building 829 High Explosives Open Burn Facility, Post-Closure Permit.
Medical waste	Two permits for large quantity medical waste generation and treatment: one covering the Biosciences Directorate, Health Services Department, Forensic Science Center, Medical Photonics Lab, Tissue Culture Lab, and Chemistry and Materials Science Department; the second covering medical waste generation and treatment activities planned for the Biosafety Level 3 (BSL-3) laboratory.	Limited Quantity Hauling Exemption for small quantity medical waste generator.
Air	BAAQMD issued 178 permits for operation of various types of equipment, including boilers, emergency generators, cold 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, optic coating operations, storage tanks containing VOCs in excess of 1.0%, drum crusher, semiconductor operations, diesel air-compressor engines, groundwater air strippers, soil vapor extraction units, material-handling equipment, sewer diversion system, oil and water separator, fire-test cells, gasoline-dispensing operation, paper-pulverizer system, and firing tanks.	SJVAPCD issued 40 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, drying ovens, and the Contained Firing Facility.
Storage tanks	Seven operating permits covering 10 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; 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[c]; 875-D1U2 Permit No. 006549[c]; 879-D1U1 Permit No. 006785; 879-G3U1 Permit No. 007967; and 882-D1U1 Permit No. 006530

Table 2-3. Permits active in 2004 (continued)

Type of permit	Livermore site[a][b]	Site 300 [a][b]
Sanitary sewer	Discharge Permit 1250[d] (2003/2004 and 2004/2005[e]) for discharges of wastewater to the sanitary sewer. Permit 1510G (2002/2004[f]) for discharges of groundwater from CERCLA restoration activities to the sanitary sewer.	
Water	WDR Order No. 88-075 for discharges of treated groundwater from Treatment Facility A to recharge basin.[g] 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. 201C317827; Sensitive Compartmented Information Facility, Site ID No. 201C317621; Soil Reuse Project, Site ID No. 201C305529; National Ignition Facility, Site ID No. 201C306762; East Avenue Security Upgrade Project, Site ID No. 201C320036; 5th Street Project, Site ID No. 201C321420; and Central Cafeteria, Site ID No. 201C320518, for discharges of storm water associated with construction activities affecting 0.4 hectares (1 acre) or more. FFA for groundwater investigation/remediation. Regional General Permit 1 for the Arroyo Mocho Fish Passage/Sediment Reduction Project[h]	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. Nationwide Permit 27 for enhancing red-legged frog breeding ponds. Water Quality Certification for red-legged frog breeding ponds, WDID # 5B39CR00047. FFA for groundwater investigation/remediation. 34 registered Class V injection wells

a Numbers of permits are based on actual permitted units or activities maintained and renewed by LLNL during 2004.

b See Acronyms and Abbreviations for list of acronyms.

c These tanks were closed and removed on September 22, 2004.

d Permit 1250 includes wastewater generated at Site 300 and discharged at the Livermore site.

e The Discharge Permit 1250 period is from May 15 to May 14; therefore, two permits were active during the 2004 calendar year.

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

g Recharge basins referenced in WDR Order No. 88-075 are located south of East Avenue within Sandia National Laboratories/California boundaries.

h Project location is at the Arroyo Mocho Pump Station. See section on Water Quality and Protection for discussion.

Table 2-4. Inspections and tours of Livermore site and Site 300 by external agencies in 2004

Medium	Description[a]	Agency[a]	Date	Finding[a]
Livermore Site				
Waste	Hazardous waste facilities CEI	DTSC	5/27, 5/28, 6/1, 6/2, 6/3	Received inspection reports and SOVs 7/19/04 and 12/7/04. See **Table 2-7** for description and resolution.
	Visit of RCRA closure project Building 233 Container Storage Area. This was a tour, not an inspection	DTSC	3/19	Site visit to see the unit undergoing closure
	Medical waste	ACDEH	9/21	No violations
Air	Emission sources	BAAQMD	2/25, 3/16, 7/29, 8/5, 11/30	Received one NOV 3/16/04. See **Table 2-7** for description and resolution.
Sanitary sewer	Annual compliance sampling Categorical sampling Process evaluation at DWTF	LWRP	9/7–9/8 9/7 9/8	No violations No violations No violations
Storage tanks	Compliance with underground storage tank requirements and operating permits	ACDEH	10/20 10/27	No violations
Site 300				
Waste	Permitted hazardous waste operational facilities (EWTF, EWSF, Building 883 CSA), RCRA-closed, post-closure permitted facility Building 829 HE Open Burn Facility, Building 883 WAA, Building 802 Space Action Team WAA, Building 814 Space Action Team WAA, Satellite Accumulation Areas, waste generating areas, and a review of hazardous waste-related documentation.	DTSC	10/28/2003-10/29/2003	Received an inspection report 1/20/04 with a violation. See **Table 2-7** for description and resolution.
	Compliance with hazardous waste generator regulations.	San Joaquin County—CUPA	8/2	Received three violations. See **Table 2-7** for description and resolution.
Air	Emission sources	SJVAPCD	7/8	No violations
Water	Eastern General Services Area Ground Water Treatment System Permitted operations	CVRWQCB	2/9, 2/11 10/25	No violations No violations
Storage tanks	Compliance with underground storage tank requirements and operating permits	SJCEHD	1/27, 9/22 10/20, 10/26	No violations

a See Acronyms and Abbreviations for list of acronyms.

May, June, and July 2004. LLNL has responded to all seven summary of violations (SOVs) issued on July 19 and December 7, 2004, as part of the 2004 CEI.

Site 300: The hazardous waste management facilities at Site 300 consist of three operational RCRA-permitted facilities. The Explosives Waste Storage Facility and Explosives Waste Treatment Facility are permitted to store and treat explosives waste only. The Building 883 Container Storage Area is permitted to store routine facility-generated waste such as spent acids, bases, contaminated oil, and spent solvents. See **Tables 2-3** and **2-4** respectively for a summary of active permits and inspections at Site 300 in 2004. As a follow up to the October 28, 2003, DTSC CEI, DTSC issued a violation to Site 300 on January 20, 2004, for not having a training plan for personnel inspecting the Building 829 post-closure facility. LLNL has contested the violation and is awaiting a response from DTSC. See **Table 2-7** for details.

DTSC did not inspect Site 300 during calendar year 2004. However, annual facility inspections are based on the state fiscal year, which starts on July 1 and ends on June 30. Therefore, it is anticipated that DTSC will conduct the annual CEI on or before June 30, 2005, in order to comply with the requirement for an annual inspection based on the state fiscal year.

The San Joaquin County Environmental Health Department, acting as the Certified, Unified Program Agency (CUPA), found three violations during a hazardous waste generator compliance inspection on August 2, 2004 (see **Table 2-7** for details). LLNL corrected the violations and submitted the Certification of Return to Compliance on September 9, 2004.

Hazardous Waste Reports

LLNL completed two annual hazardous waste reports, one for the Livermore site and the other for Site 300, that addressed the 2004 transportation, storage, disposal, and recycling of hazardous wastes at the respective sites. The 2004 Hazardous Waste Report-Mainsite and 2004 Hazardous Waste Report-Site 300 were submitted to the DTSC by April 1, 2005.

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 2004.

Waste Accumulation Areas

LLNL Programs maintain waste accumulation areas (WAAs) in compliance with waste generator requirements specified in 40 Code of Federal Regulations (CFR) part 262, and Title 22 California Code of Regulations (CCR) part 66262.34, for the temporary storage (less than 90 days) of hazardous waste prior to transfer to a treatment, storage, and disposal facility. In January 2004, there were 20 WAAs at the Livermore site. During 2004, four temporary WAAs were put into service, while 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 require-

ments. Approximately 1086 prescribed WAA inspections were conducted at the Livermore site. At Site 300 during 2004, one permanent WAA was in operation; two temporary WAAs were put into service, while one temporary WAA was taken out of service. Program representatives conducted approximately 114 prescribed WAA inspections at Site 300.

California Medical Waste Management Act

All LLNL medical waste management operations comply with the California Medical Waste Management Act, which 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 California Department of Health Services and is enforced by the Alameda County Department of Environmental Health (ACDEH).

LLNL is registered with the ACDEH as a generator of medical waste and has a treatment permit. No violations were issued as a result of the September 2004 ACDEH inspection of buildings at LLNL Health Services, the Biosciences Directorate, and the Medical Photonics Laboratory. (See **Tables 2-3** and **2-4**.)

Radioactive Waste and Mixed Waste Management

LLNL manages radioactive waste and mixed waste in compliance with applicable sections of DOE Order 435.1, as described in LLNL's *ES&H Manual,* Document 36.1, "Hazardous, Radioactive, and Biological Waste Management Requirements." LLNL has also written the *Radioactive Waste Management Basis* (LLNL 2001), which summarizes radioactive waste management controls relating to waste generators and treatment and storage facilities.

Federal Facility Compliance Act

LLNL is continuing to work with DOE to maintain compliance with the Federal Facilities Compliance Act Site Treatment Plan (STP) for LLNL that was signed in February 1997. During 2004, LLNL requested extensions for six of the eleven STP milestones that were due in 2004. DTSC granted the milestone extensions because LLNL had made significant progress towards completion of the milestones and had reduced the overall inventory of mixed waste stored at LLNL. The remaining five milestones for 2004 were completed on time. LLNL also completed seven milestones well in advance of their due dates, which ranged from 2005 to 2010.

In 2004 LLNL reduced the inventory of mixed low-level waste by over 120 cubic meters. LLNL also completed the characterization of the mixed transuranic (TRU) drums that were in inventory and initiated shipments of TRU waste to the Waste Isolation Pilot Plant (WIPP). 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) and implementing regulations found in 40 CFR Part 700-789 govern the uses of newly developed chemical substances and TSCA-governed waste by establishing the following partial list of requirements: record-keeping, reporting, disposal standards, employee protection, compliance and enforcement, and clean up standards.

In 2004, LLNL generated TSCA-regulated polychlorinated biphenyl (PCB) waste from electrical equipment contaminated with PCBs, liquid PCBs used to calibrate analytical equipment, and asbestos from building demolition or renovation projects.

All TSCA-regulated waste was disposed 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 an approved facility accepts this waste for final disposal.

Air Quality and Protection

Clean Air Act

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 Air Pollution Control District (SJVAPCD) and/or BAAQMD for Site 300.

LLNL operated 178 permitted air emission sources at the Livermore site in 2004. During an inspection in March 2004, the BAAQMD issued a notice of violation (NOV) for non-compliance with a sampling requirement in the time period of July 28-30, 2003. (see **Table 2-4**). LLNL was subsequently assessed a $650 penalty (see **Table 2-7**).

The BAAQMD revised Regulation 2 Rule 2 and Regulation 2 Rule 4 in December 2004, which impacted the site-wide emission limits of LLNL's Synthetic Minor Operating Permit. The revised regulation redefined a "small facility" as well as the accessibility to the Small Facility Bank that provides emission credits for new and modified sources. As a result, LLNL was required to agree to reduce the annual permitted threshold values by 15 tons per regulated pollutant type. As such, our new emission limit for oxides of nitrogen from combustion sources is 35 tons per year rather than the previous 50 tons per year. The same reduction to 35 tons per year from 50 tons per year also applies to emissions of precursor organic compounds from solvent evaporation which occurs in many institutional operations, such as wipe cleaning and painting. As long as the

reduction to 35 tons per year is maintained, LLNL is ensured the opportunity to borrow credits from the Small Facility Bank rather than buy such credits on the open market; buying such credits on the open market is an expensive and time-consuming process. In accordance with permit conditions, on June 29, 2004, LLNL submitted to the BAAQMD an annual report summarizing emissions from July 1, 2003, through June 30, 2004.

In 2004, the SJVUAPCD issued or renewed air permits for 40 air emission sources for Site 300 (see **Table 2-3**). There were no violations issued from the 2004 air inspection of Site 300 facilities (see **Table 2-4**).

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 2004 Annual Report* (Harrach et al. 2005), submitted to DOE and EPA, reported that the estimated maximum radiological doses to the public were 0.079 µSv (0.0079 mrem) for the Livermore site and 0.26 µSv (0.026 mrem) for Site 300 in 2004. 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 defned by the NESHAPs regulations. Additional information on the data are described in Chapter 6.

In 2004, LLNL continuously monitored radionuclide emissions from Building 331 (the Tritium Facility), Building 332 (the Plutonium Building), and portions of five other facilities (see Chapter 3). There were no unplanned atmospheric releases at the Livermore site or at Site 300 in 2004. Monitoring activities and results related to air are described further in Chapter 3.

Water Quality and Protection

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. These permits, as well as water quality certifications for discharges authorized under Section 401 of the CWA, are issued by local Regional Water Quality Control Boards

(RWQCBs) and the State Water Resources Control Board. RWQCBs enforce both the regional and state issued permits. Section 401 state certifications are required when the Army Corps of Engineers issues permits under Section 404 of the CWA. Several other agencies issue other water-related permits. The Livermore Water Reclamation Plant (LWRP) requires permits for discharges to the city's sanitary sewer system. The California Department of Fish and Game (CDFG), under the Fish and Game Code, requires streambed alteration agreements (SAAs) for any work that may disturb or impact rivers, streams, or lakes. The Safe Drinking Water Act requires registration with the EPA and management of injection wells to protect underground sources of drinking water.

Water-related permits and inspections from outside agencies are summarized in **Tables 2-3** and **2-4**, respectively. LLNL received one NOV in 2004 for the Terascale Simulation Facility for the failure to pay an NPDES permit annual fee, but the NOV was later withdrawn (see **Table 2-5**). LLNL identified an administrative nonconformance with permit conditions for failure to document formal storm water inspections at the Sensitive Compartmented Information Facility, which is permitted by NPDES permit number CAS000002. This instance is discussed in the required annual compliance certification.

Table 2-5. Water-related permit nonconformance

Permit No[a]	Nonconformance[a]	Date(s) of nonconformance	Description–solution[a]
1250, LWRP sanitary sewer permit	Excursion below pH permit limit of 5; approximately 250 gallons of effluent discharged to the LWRP with a pH of 4.63.	3/7/04	Remainder of effluent captured and contained on site by Sewer Diversion Facility. LLNL received no enforcement action from the LWRP.
CAS000002 WDID No. 201C317827	NOV issued for failure to pay permit fee for the Terascale Simulation Facility	8/19/04	NOV was withdrawn after the fee was paid and because the agency sent the invoices to the wrong address.
CAS000002, WDID No. 201C317621 ALP	Sensitive Compartmented Information Facility—Failure to document required storm water inspections.	12/24/03–6/30/04[b]	Incidents were identified to project management and noted in the annual compliance certification dated 6/29/04.

a See Acronyms and Abbreviations for list of acronyms.

b These dates reflect the construction reporting period of June 2003 through May 2004.

In 2004, LLNL obtained coverage under Regional General Permit 1 for Fish Passage/Sediment Reduction Projects at Water Crossings from the Army Corps of Engineers. This permit authorized LLNL to remove an existing, at-grade creek crossing in the upper reaches of the Arroyo Mocho, which prevented steelhead and resident trout migration, and replace the creek crossing with a clear-span bridge. The bridge is used regularly by LLNL staff to access the Arroyo Mocho Pump Station. See the Arroyo Mocho Road Improvement and Anadromous Fish Passage Project section of Chapter 5 for details.

LLNL received no enforcement action from the LWRP during 2004. See **Table 2-5** for a summary of nonconformance with water-related permits. Monitoring activities and results related to water permits are described in Chapter 4.

Tank Management

The CWA and California Aboveground Petroleum Storage Act require facilities meeting specific storage requirements to have and implement Spill Prevention Control and Countermeasure plans for aboveground, oil-containing containers, including equipment and tanks. ACDEH and San Joaquin County Environmental Health Department (SJCEHD) also issue permits for operating underground storage tanks containing hazardous materials or hazardous waste as required under the California Health and Safety Code.

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 fuel, insulating oil, and process wastewater. Some non-permitted wastewater tank systems are a combination of underground storage tanks and aboveground storage tanks. **Table 2-6** shows the status of in-service tanks at the Livermore site and Site 300 as of December 31, 2004. All permitted underground storage tanks were inspected by the regulating agencies in 2004. No violations were noted during the inspections. See **Table 2-4** for summary of inspections.

Other Environmental Statutes

National Environmental Policy Act

The National Environmental Policy Act (NEPA) is our country's basic environmental charter. NEPA requires the federal government to do two things when they consider a proposed project or action: 1) consider how the action will affect the human environment, and 2) inform the public and involve them in the decision making process. LLNL is not a federal agency, but LLNL activities are generally funded by the federal government; therefore, the activities must comply with the requirements of NEPA.

Federal agencies meet the first NEPA requirement by studying the impact a project would have on the human environment. The agency studies the components of the human environment that may be affected by the project, which may or may not include: air, water, soil, biological resources, socioeconomics, aesthetics, noise, or cultural resources. The results of their studies are written in a "NEPA document." Federal agencies meet the second requirement (inform the public) by distributing the NEPA documents. NEPA documents are made available in public reading rooms, on the

Table 2-6. In-service tanks in 2004

Tank type	Livermore site		Site 300	
	Permitted	Permits not required	Permitted	Permits not required
Underground storage tanks				
Diesel fuel	7	0	2	0
Gasoline	2	0	1	0
Used oil	1	0	0	0
Process wastewater	0	45	0	11
Subtotal	10	45	3	11
Aboveground storage tanks				
Diesel fuel	0	24	0	7
Insulating oil	0	1	0	3
Process wastewater	9[a]	58	0	16
Miscellaneous non-waste tanks	0	11	0	2
Subtotal	9	94	0	28
Total	19	139	3	39

a Nine tanks are located at Building 695, the Decontamination and Waste Treatment Facility.

internet, and sometimes are directly mailed to interested parties. Federal agencies often involve the public in their decisions about proposed projects by holding public meetings and asking for comments on their NEPA documents.

There are two types of NEPA documents: environmental impact statements and environmental assessments (EAs). Environmental impact statements are prepared for major federal actions that significantly affect the quality of the human environment. In contrast, EAs are prepared for federal actions that will not have a significant impact on the environment. The federal agency decides which type of document to prepare after studying the impact to the environment.

Some projects do not require the preparation of either an environmental impact statement or an environmental assessment. These projects fit into categories of activities that are well understood and known to have no impact on the human environment. After an agency studies the environmental impacts of a project and determines that the project fits into one of these categories, no further documentation is required. Nonetheless, some federal agencies, including DOE at LLNL, choose to write a memorandum that describes the project and explains why it meets the criteria for being categorically excluded. These memoranda are referred to as CXs, Cat Xs, and Categorical Exclusions —technically, they are not actual NEPA documents.

The paragraphs that follow provide details about the NEPA documents and Categorical Exclusions that have been prepared for LLNL projects this year.

There were no LLNL projects in 2004 that required DOE EAs. Sixteen categorical exclusion recommendations were approved by DOE, and there were no proposed actions at LLNL that required separate DOE floodplain or wetlands assessments under DOE regulations in 10 CFR 1022.

In 2004, DOE published the draft *Site-wide Environmental Impact Statement for the Continued Operation of Lawrence Livermore National Laboratory and Supplemental Stockpile Stewardship and Management Programmatic Environmental Impact Statement (LLNL SW/SPEIS)*. The draft *LLNL SW/SPEIS* was issued for a 90-day public comment period (February 27 to May 27, 2004). Three public hearings were held in 2004: April 27 in Livermore, April 28 in Tracy, and April 30 in Washington, D.C.

The final *LLNL SW/SPEIS* is scheduled to be complete, and a Record of Decision filed, in summer 2005. The final *LLNL SW/SPEIS* 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.

Since November 1992, the University of California (UC) and LLNL have implemented mitigation measures identified by the *1992 EIS/EIR*. An addendum to the *1992 EIS/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 2000 mitigation monitoring report was published in 2003. The 2001, 2002, and 2003 mitigation monitoring reports will be published in 2005.

National Historic Preservation Act

The National Historic Preservation Act (NHPA) applies to historically important places and to the preservation of prehistoric and historic resources of the United States. LLNL resources subject to NHPA consideration 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 support DOE NHPA responsibilities. LLNL does so 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 undertakings may have on historic properties. The agencies must allow and consider comments of the federal Advisory Council on Historic Preservation. The Section 106 regulations outline a five-step review process that is conducted for individual federal actions. 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 has taken two approaches to streamline historic preservation efforts and focus on important historic properties under its management. First, DOE, UC, and the State Historic Preservation Officer (SHPO) reached an agreement in July 2003 that governs historic preservation program activities until resource inventory and assessment activities specified in the agreement are complete. The goal is to reduce the amount of paperwork necessary to ensure protection of important historic properties by reaching a consensus on where and how to effectively focus LLNL's efforts. Second, as is specified in the agreement, is to complete within a reasonable timeframe an inventory of places (prehistoric and historic, archeological, and architectural) that meets a statutory threshold of historic importance. LLNL is on schedule with this inventory and assessment effort. During 2004, LLNL completed significance assessments for all known archeological sites as well as prepared an historic context statement. LLNL also completed all work necessary to support future National Register of Historic Places determinations for buildings, structures, and objects at the Livermore site and Site 300. Formal National Register determinations will be made by DOE in consultation with the SHPO in 2005.

Antiquities Act

Provisions of the Antiquities Act provide for recovery of paleontological remains. After 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 2004.

Endangered Species Act and Sensitive Natural Resources

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 are met 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, DOE consults with the U.S. Fish and Wildlife Service (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 biological opinions. A biological assessment (BA) for the implementation of the Arroyo Seco Management Plan was prepared and submitted to USFWS on August 14, 2003, and the USFWS issued a biological opinion for this project on June 10, 2005. USFWS is currently reviewing the BA. A BA for the implementation of the Arroyo Mocho road improvement and anadromous fish passage project was prepared and submitted to USFWS on November 6, 2003. USFWS responded with their biological opinion for the Arroyo Mocho project on February 10, 2004. In 2004, two BAs were submitted to the USFWS for LLNL activities. A BA for the Livermore site and Site 300 regarding the *Site-wide Environmental Impact Statement for the Continued Operation of Lawrence Livermore National Laboratory* and *Supplemental Stockpile Stewardship and Management Programmatic Environmental Impact Statement* was prepared and submitted to USFWS on April 9, 2004. On December 13, 2004, a BA was submitted to the USFWS for closure of the Site 300 Class II High Explosives Impoundments. The USFWS is currently reviewing both BAs. Biological surveys for special-status species and monitoring results are described in Chapter 5.

Environmental Occurrences

In 2004, notification of environmental occurrences was required under a number of environmental laws and regulations as well as DOE Order 231.1A and DOE Manual 231.1-2. The orders and manual provide guidelines to contractor facilities regarding categorization and reporting of environmental occurrences to DOE and divides occurrences into categories.

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 2004, four environmental incidents, summarized in **Table 2-7**, were reportable under DOE Order 232.1A and were categorized as Significance Category 4 reportable occurrences under Group 9, Noncompliance Notifications according to DOE Order 232.1A. DOE was notified of these incidents. Other regulatory agencies involved are described in **Table 2-7** for each of the incidents. No occurrences were reportable under Group 5, Environmental.

Program Summary

Integrated Safety Management System

LLNL implements an Integrated Safety Management System (ISMS) designed to ensure the systematic integration of environment, safety, and health (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. LLNL regards protection of the environment as an essential component in its overall safety management system.

The core requirements of ISMS are based on DOE's Seven Guiding Principles 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. How LLNL manages and performs work can be described by the Five Core

Table 2-7. Environmental Occurrences reported under the Occurence Reporting System in 2004

Date[a]	Occurrence category/group	Description[b]
January 20	Significance Category SC4 Occurrence under Group 9(2)	DTSC issued a class II minor violation to Site 300 for failing to have a training plan as part of the post-closure permit application for the Building 829 RCRA-closed facility. LLNL contested the violation in a letter dated March 17, 2004, and has requested that DTSC rescind the violation. As of April 2005, DTSC has not responded to the request. OR-2004-0001
March 16	Significance Category SC4 Occurrence under Group 9(2)	LLNL received an NOV from BAAQMD for a single violation of a sampling requirement for Source #3646 (MTU #2), a groundwater stripping system. BAAQMD Regulations 8-47-501.1 and 8-47-601 require three consecutive days of influent water analysis when a groundwater stripping system is started up. The logbook for Source #3646 shows that a sample was taken on 7/28/03 and 7/30/03, but there was no record of a sample taken on 7/29/03. LLNL paid a civil penalty of $650. OR 2004-0015
July 19	Significance Category SC4 Occurrence under Group 9(2)	LLNL received SOVs from DTSC for two alleged violations observed during the 2004 CEI of permitted hazardous waste handling operations. • Treatment of hazardous waste in an unauthorized unit (using steel metal pan/sorting table with the Debris Washer unit). Although LLNL contends the violation was invalid, LLNL prepared and DTSC approved a Class 1 permit modification authorizing the use of sorting tables. • Commingling incompatible wastes in the same container. An LLNL researcher placed hazardous waste solvents (methanol, ethanol, acetone, and water) and 70% nitric acid in a 5-gallon poly container, causing the incompatible wastes to react and generate nitrous oxide gases. LLNL has made sure that wastes are compatible with each other and containers and personnel have been trained. On December 17, LLNL received amended SOVs from DTSC for five alleged violations observed during the same CEI. • Certifying and shipping prohibited waste for land disposal without meeting treatment standards. LLNL submitted proof of proper management and disposal of this waste by an off-site TSDF in March 2005. Waste treatment and disposal occurred on January 31, 2005. • Storage more than one year. LLNL stored mixed waste for more than one year in Area 612-1A, without authorization. LLNL will submit to DTSC all requests for continued storage of mixed wastes meeting LDR standards at least 30 days prior to reaching the one year allowable limit in the HWFP. • Failure to comply with labeling requirements. LLNL failed to comply with the following container labeling requirements: a. On or about May 27,2004 at Area 612-5, two boxes containing mixed wastes were labeled as hazardous wastes. The waste was shipped as hazardous waste to Envirocare of Utah on June 9, 2004. b. On or about May 28, 2004, at Area 612-2, the date of acceptance at the hazardous waste management unit was not marked on the label of a 5-gallon container of mixed waste aqueous acid solution, corrosive. This violation was corrected during the inspection.

Table 2-7. Environmental Occurrences reported under the Occurence Reporting System in 2004

July 19 (continued)	Significance Category SC4 Occurrence under Group 9(2)	c. On or about May 27, 2004, at Building 695's Reactive (Room 1023), mixed waste bottles and bags contaminated with beryllium had a label marked 5/25/04, which was the date the waste was removed from its container. The date on the label should have been 9/27/98, which was the original TSDF acceptance date on the container. This waste has been treated and DTSC requires no further action. • Failure to follow the Waste Analysis Plan. In Area 612-2, two containers (one 5-gal and one 30-gal) of hazardous mixed waste aqueous acid solution, toxic, corrosive wastes were accompanied by the incorrect WDRs. DTSC requires no further action. • Failure to accurately record observations in an inspection log. LLNL failed to accurately record observations noted during an inspection. DTSC requires no further action. OR 2004-0028.
August 2	Significance Category SC4 Occurrence under Group 9(2)	LLNL received an NOV from the San Joaquin County Environmental Health Department—CUPA for improper handling of hazardous waste at two Site 300 facilities and deficient hazardous waste training for one employee. • A container (bucket) filled with crushed oil filters was found in Building 875 without a lid. The bucket is used to move the filters from the crusher to the hazardous waste drum. In this case, workers used the bucket as interim storage instead of emptying the contents into the drum at the end of their shift. Management will re-educate workers and re-emphasize hazardous waste handling procedures. • A worker in Building 879 stated that used fuel filters were disposed of as municipal solid waste; however, used fuel filters are to be disposed as hazardous waste. EPD will characterize the hazard constituents and fuel filters will be disposed as hazardous waste. • A paint shop employee in Building 872 signed a waste generation requisition and was not current in the hazardous waste generator refresher class (EP0006-HZRW). The employee completed the on-line course and documentation was provided to the inspector at the close-out inspection the same day. OR 2004-0034.

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.

Functions: (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. LLNL's ISMS in 2004 is detailed in *Integrated Safety Management System Description* (LLNL 2003a) which can be found at the following website: http://www.llnl.gov/es_and_h/ism/ism-descriptionv6.pdf.

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. They are LLNL's ES&H requirements (i.e., applicable laws, regulations, DOE orders, etc.). The necessary and sufficient process was utilized to develop WSS requirements. This was accomplished through review and recommendation by the LLNL subject matter experts and their DOE counterparts. 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 Board (CCB), with representatives from DOE, UC, and LLNL, manages the change control process. In addition, LLNL undertakes periodic review of all the requirements to ensure that the WSS set is current and complete.

The WSS set currently identified to satisfy the ES&H needs of the LLNL work environment is in Appendix G of the UC contract, and can be viewed at: http://labs.ucop.edu/internet/wss/wss.html.

Environmental Management System

In July 2004, LLNL adopted the International Organization for Standardization (ISO) 14001 standard as a WSS. LLNL's approach is to build on its existing ISMS to develop an Environmental Management System (EMS) that meets the requirements of ISO 14001. The EMS

- Promotes responsible environmental stewardship practices that are protective of the air, water, land, and other natural and cultural resources
- Complies with applicable environmental regulations in a cost-effective manner
- Focuses on continuous improvement of LLNL environmental performance

LLNL has committed to achieve continuous improvement in operational and environmental performance through Pollution Prevention (P2) and other sustainable business tools.

The ISO 14001 standard uses the identification, determination of significance, and mitigation of "environmental aspects" to drive and measure environmental protection improvements within work activities, facilities, and the institution. An environmental aspect is an element of an organization's activities, products, or services that can interact with the environment. Significant environmental aspects are those that are both feasible to address, and when acted upon, result in marked environmental performance improvement. In 2004, LLNL identified the environmental aspects listed in **Table 2-8**.

Table 2-8. LLNL environmental aspects

Category	Aspects	Aspect identified in 2005 as significant
Biological materials/waste	Biological material use	
	Medical/biological waste generation	
Regulated air emissions	Criteria pollutant emissions	
	Radioactive air emissions	
	Greenhouse gas emissions	
	Hazardous air pollutants emissions	
Ecological resources	Ecological resources disturbance	X
Land use/land management	Land use/land management	
Discharges to ground, storm, and surface waters	Discharges to ground	
	Discharges to storm drain system	
	Discharges to the arroyo/surface waters	
Sanitary sewers	Discharges to the sanitary sewer system	
Energy emissions	Energy emissions	
Energy use	Electrical energy use	X
	Renewable energy use	X
	Fossil fuel consumption	X
Hazardous materials/waste	Hazardous materials use	X
	Hazardous waste generation	
Municipal, industrial, and nonhazardous materials/waste	Municipal waste generation	X
	Industrial waste generation	
	Nonhazardous materials use	X
Radioactive material/waste	Radioactive material use	X
	Low-level radioactive waste generation	
	Transuranic waste generation	X
	Mixed waste generation	X
Other air emissions (odors, etc.)	Other air emissions (odors, etc.)	
Water use	Water use	
Cultural resources disturbance	Cultural resources disturbance	
Environmental noise	Environmental noise	

Table 2-8 also indicates the aspects that LLNL identified during the beginning of 2005 as significant using criteria based on the following environmental and business factors:

- Existing laws, regulations, or standards to address the impacts of the environmental aspect
- Perceptions of interested parties (either positive or negative)
- Ability of engineered or administrative controls to mitigate the impacts of the environmental aspect
- Scale of the impacts of the environmental aspect is localized or can be contained within LLNL
- Severity and duration of the impact of the environmental aspect
- Frequency and probability of the environmental aspect to occur
- Reuse and recycling opportunities available for the environmental aspect
- Operational and technical information to manage the impacts of the environmental aspect is readily available
- Ability and cost to change the impacts of the environmental aspect

For each of these significant aspects, LLNL has developed objectives to meet LLNL's environmental policy with respect to that particular environmental aspect. LLNL has also identified environmental targets to achieve these objectives. Where appropriate, LLNL's approach is to utilize activities and programs that are already in place. For significant environmental aspects without existing programs, LLNL is proposing studies to first better understand how the impacts of the significant environmental aspect can be most efficiently and effectively affected. As part of the continuous improvement integral to ISO 14001, LLNL will review annually its significant environmental aspects, and their respective objectives and targets.

Environmental Protection Department

As the lead organization at LLNL for providing environmental expertise and guidance on operations at LLNL, the Environmental Protection Department (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. EPD has also taken the leadership role in the decommissioning and decontamination (D&D) of facilities at LLNL to adapt to changes in programs resulting from the end of

the Cold War. EPD's Space Action Team tactically implements LLNL's institutional D&D activities. Since 1994, 155 real property facilities encompassing 408,000 gross square feet have been removed from LLNL.

EPD monitors air, sewerable water, groundwater, surface water, rain, 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. These monitoring activities in 2004 are presented in the remaining chapters of this report.

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. These functions are organized into three divisions within the department: Operations and Regulatory Affairs (ORAD), Radioactive and Hazardous Waste Management (RHWM), and Environmental Restoration (ERD).

Operations and Regulatory Affairs Division

The Operations and Regulatory Affairs Division (ORAD) consists of six 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 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 interacts with the community on these issues through Environmental Community Relations. 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 other first responders and environmental specialists.

Radioactive and Hazardous Waste Management Division

The Radioactive and Hazardous Waste Management (RHWM) Division manages all hazardous, radioactive, and mixed wastes generated at LLNL facilities 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 California and U.S. 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 of LLNL's mixed waste in accordance with the requirements of the Federal Facilities 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 also 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 program to identify all components of the waste and a certification effort that provides appropriate documentation for the disposal site.

Environmental Restoration Division

The Environmental Restoration Division (ERD) was established to evaluate and remediate soil and groundwater contaminated by past hazardous materials handling and disposal practices 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 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. These CERCLA activities

in 2004 are summarized in the "Environmental Restoration and Waste Management" section earlier in this chapter. ERD's groundwater remediation activities in 2004 are further described in Chapter 7 of this report.

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 any environmental incidents to an EOG environmental analyst assigned to support their program area. The EOG environmental analyst then notifies the on-duty EDO of the incident, and together with other ORAD staff, the team determines 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.

Pollution Prevention

LLNL has a Pollution Prevention (P2) team whose role it is to help facilitate LLNL's P2 program within the framework of the ISMS and in accordance with applicable laws, regulations and DOE orders as required within the UC Contract. Responsibilities include P2 program stewardship and maintenance, P2 analysis and reporting of waste generation, P2 opportunity assessment and high return-on-investment follow through, implementation of recycling, reuse and waste minimization programs for hazardous as

well as nonhazardous waste, and coordination of P2 programs and activities with other energy efficiency and resource conservation efforts at LLNL. The P2 team supports P2 efforts and activities through environmental teams. In addition, the P2 team undertakes coordination of the affirmative procurement program and provides awareness presentations, articles, events, and other materials.

DOE Pollution Prevention Goals

In 1999, DOE developed pollution prevention and energy efficiency leadership goals for DOE facilities in response to presidential executive orders for the Greening of the Federal Government. These goals are compared in **Table 2-9** with LLNL's quantities of routine waste generated in 1993 (i.e., LLNL's baseline), its 2005 target, the actual amount of waste generated in 2004, and the percent reduction in 2004 compared with the baseline. Routine waste described in **Table 2-9** includes waste from ongoing operations produced by any type of production, analysis, and/or research and development taking place at the Laboratory. Periodic laboratory or facility clean-outs and spill cleanups that occur as a result of these processes are also considered normal operations.

The following five energy efficiency goals were included in the leadership goals. The bottom section of **Table 2-9** lists the goals, baseline quantities, the 2005 targets when applicable and provides a verbal description of the status for each goal.

- Reduce energy consumption per gross square foot by 20% by 2005 and 25% by 2010 relative to 1990.
- Increase the use of clean energy sources (renewable and low greenhouse gas energy.
- Retrofit or replacement of 100% of chillers with capacity greater than 150 tons that use class I refrigerants by 2005.
- Eliminate the use of Class I ozone-depleting substances.
- Reduce greenhouse gas emissions attributed to facility energy use through life-cycle cost-effective measures by 4% by 2005 and 30% by 2010, using 1990 as a baseline.

In 2004, because so many of the original goals will be met by 2005, DOE and NNSA began to develop a revised set of P2 goals that will be approved in 2005.

In 2001, LLNL revised the method by which it calculates waste to better identify future P2 opportunities and to eliminate categories of wastes that would otherwise be counted twice under the RHWM Division's Total Waste Management System (TWMS) database, which was replaced in FY 2004 with a new database called HazTrack. The quantities for hazardous waste, low-level radioactive waste, and mixed low-level waste reported in HazTrack now include all wastes generated under requisition.

Table 2-9. Pollution prevention and energy efficiency leadership goals at LLNL

Goal	Item	1993 baseline quantity	2005 target based on DOE leadership goal[)]	2005 LLNL target commitment	2004 actuals	Percent reduction since 1993	Percent of 2005 target
Pollution Prevention Goals							
1	Hazardous Wastes Generated (90% of 1993 baseline)	1054 MT[(a)]	105.4 MT	105.4 MT	141.3 MT	87	97
1	Mixed Waste Generated (80% of 1993 Baseline)	26 m^3	5.2 m^3	5.2 m^3	18.8 m^3	28	35
1	Low-level Waste Generated (80% of 1993 baseline)	346 m^3	69.2 m^3	69.2 m^3	151.3 m^3	56	70
1	TRU/Mixed TRU Waste Generated (80 % of 1993 baseline)	12.0 m^3	2.4 m^3	2.4 m^3	1.2 m^3	90	1.13
3	Sanitary Waste Generated (75% of 1993 baseline)	5873 MT	1468 MT	1468 MT	4596 MT	22	29
4	Sanitary Wastes Recycled (45% of waste generated)	N/A	45%	45%	2921 MT	64	142
6	Purchases of EPA-designated items with Recycled Content (100% by cost of recycled versus nonrecycled)	N/A	100%	—[(b)]	$1.147M/ $2.136M	53	53
2	TRI Chemical Releases (90% of 1993 Baseline)	3983.3 lb[(c)]	398.3 lb	398.3 lb	605.2lb	85	94
10	Eliminate use of Class 1 ozone-depleting substances by 2010	NA	0	The current schedule based on life-cycle cost-effective use of existing chillers and one halon fire-supression unit shows five chillers and up to three fire-suppression units being replace after 2010.			
Energy Efficiency Goals							
7	Unit Energy Consumption (20% of 1990 baseline for lab and industrial facilities)	289,600 BTU/gross ft^2	231,700 BTU/gross ft^2	As of FY 2000, LLNL has met the goal. The current schedule based on life-cycle cost-effective use of existing equipment shows eight chillers and one fire-suppression unit being replaced by 2015.			
8	Request for bid packages for energy supply with clean energy provisions (100% of requests with provisions versus those without)	N/A	100%	Because NNSA purchases LLNL's electricity, LLNL cannot commit to meeting this goal.			
8	Purchase of electricity from less greenhouse gas-intensive sources (% of electricity from less green-house gas sources to total consumption)	N/A	100% of all future DOE competitive solicitations for electricity	Because NNSA purchases LLNL's electricity, LLNL cannot commit to meeting this goal.			

Table 2-9. Pollution prevention and energy efficiency leadership goals at LLNL (continued)

Goal	Item	1993 baseline quantity	2005 target based on DOE leadership goal[]	2005 LLNL target commitment	2004 actuals	Percent reduction since 1993	Percent of 2005 target
9	Replacement of chillers (100% of total 150 ton [or larger] pre-1984 units with class I refrigerants replaced)	7 (number of units in use in 1999)	0	The current schedule based on life-cycle cost-effective use of existing equipment shows three chillers being replaced by 2007.			
11	Greenhouse gas emission from energy use (25% of greenhouse gas emission reduced relative to 1990 baseline)	117,414.49 tons	112,717.9 tons	Because NNSA purchases LLNL's electricity, LLNL cannot commit to meeting this goal.			

a MT = metric ton

b LLNL cannot meet this goal by 2005.

c In 2004, lead was the only toxic chemical that had exceeded the TRI reporting threshold at LLNL. In just three years, from 2001 to 2004, Site 300 reduced the amount of TRI-reportable lead from 3983 lbs to 605.2 lbs, a reduction of 84.8%.

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, 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 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 team tracks waste generation using the HazTrack database. By reviewing the information in this database, program managers and P2 staff can monitor and analyze waste streams to determine cost effective improvements to LLNL operations.

Diverted Waste

Together, the Livermore site and Site 300 generated 4596 metric tons of routine nonhazardous solid waste in 2004. This volume includes diverted waste (for example, material diverted through recycling and reuse programs) and landfill wastes. LLNL generated 13,827 metric tons of nonroutine nonhazardous solid waste in FY 2004. This includes waste that is reused as cover soil at Class II landfills or is recycled through the nonroutine metals recycling programs. Nonroutine nonhazardous solid wastes include wastes from construction, and decontamination and demolition activities. In FY 2004, the portion of nonhazardous waste (routine and nonroutine) sent to landfill was 2850 metric tons. The routine portion was 1675 metric tons and the nonroutine portion was 1175 metric tons. The breakdown for routine and nonroutine nonhazardous waste that was sent to landfills in FY 2004 is shown in **Table 2-10**.

Table 2-10. Total nonhazardous waste sent to landfills in FY 2004

Nonhazardous waste	2004 total (metric tons)
Routine	
Compacted (landfill)	1675
Nonroutine	
Construction demolition (noncompacted landfill)	1083
Industrial (TWMS and HazTrack[a])	92
Nonroutine subtotal	1175
LLNL total	2850

a RHWM Waste Management Systems

Together the Livermore Site and Site 300 diverted 2922 metric tons of routine nonhazardous waste in 2004. This represents a diversion rate of 64%. 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 through LLNL's comprehensive waste diversion program was 16,748 metric tons in FY 2004 (**Table 2-11**).

Source Reduction and Pollution Prevention

A water conservation pilot project was implemented at the EPD T5475 facility in 2003. During 2004, based on the success of the pilot project, waterless urinals were retrofitted in several LSO Directorate buildings and the Discovery Center (visitor's center). Several new buildings were also equipped with the waterless urinals. Water savings is estimated to be up to 20,000 gallons per urinal per year.

Since October 2003, beginning with a pilot program that ended in March 2004, EPD has been participating in the Federal Electronics Challenge (FEC). The FEC is a voluntary partnership program that encourages federal facilities and agencies to purchase greener electronic products, reduce impacts of electronic products during use, and manage obsolete electronics in an environmentally safe way. EPD's participation in the FEC complemented efforts already underway to assess LLNL's management practices for electronic waste (e-waste), including preparation for reporting of the recycle/disposal of cathode ray tubes under SB 20 (Electronic Waste Recycling Act). The FEC recognizes the efforts and achievements of FEC Partners through an optional national awards and recognition program. In 2004, EPD applied for and received a Bronze Award for meeting FEC's mandatory requirements for end-of-life management of electronic equipment as well as meeting several optional activities pertaining to the two other life-cycle phases (acquisition and procurement; operation and maintenance). Winners are posted

Table 2-11. Diverted waste in FY 2004

Waste description	Cumulative 2004 total (metric tons)
Routine	
Batteries (small)	4
Batteries (lead-acid)	35
Beverage containers	5
Cardboard	147
Compost	388
Cooking grease	3
Magazines, newspapers, and phone books	35
Metals	1,461
Paper	329
Pipette box recycling	1
Street sweepings	146
Tires and scrap	17
Toner cartridges	17
Wood pallets	351
Total routine waste diverted	2,939
Nonroutine	
Asphalt/concrete	12,207
Class II Cover	1,233
Miscellaneous	11
Nonroutine metals	235
Offsite daily cover/onsite reuse	140
SAT Freon	0
Total nonroutine waste diverted	13,826
LLNL diversion total	16,765

on the website http://www.federalelectronicschallenge.net/winners.htm. Bronze level partners are recognized as "demonstrating significant commitment and achievements in one life-cycle phase."

In December 2004, DOE NNSA selected two projects at LLNL to receive the DOE Best-in-Class Awards. The first of these was for LLNL's tilt-pour furnace process, which is used for the pyrochemical processing of plutonium. It is an example of a research project that has pollution prevention value and is important to both LLNL and DOE missions. Traditionally, processing was performed with stationary furnaces and ceramic crucibles that could not be reused and would have to be disposed of as TRU waste after each run. The tilt-pour furnace uses crucibles that can be used for hundreds of runs before replacement is required, substantially decreasing the TRU waste stream generated.

The second project that received a DOE Best-in-Class Award also received a DOE P2 Star Award. For this project, the on-site environmental analytical laboratory instituted a rigorous "up-front" waste characterization program that effectively changed the waste stream generated from hazardous mixed-waste to an approved, certified low-level waste stream. In the 8 months of operating history, 44% of the waste (by mass) has been diverted from mixed to low-level. This will result in significant cost savings and reduction in waste re-handling/personnel exposure.

Both Best-in-Class Awards were presented in 2005.

Return-on-investment Projects

DOE funded three P2 projects in 2004 with DOE High-Return-on-Investment (ROI) funds carried over from 2002. Other ongoing ROI projects are listed in **Table 2-12**.

Table 2-12. Ongoing High ROI projects in FY 2004

Operation	Project
Mercury Thermometer Exchange	The goal of a pilot project (2003–2004) within the Chemistry & Chemical Engineering Division of the Chemistry & Material Science Directorate was to reduce environmental, health, and safety risk by removing mercury-containing thermometers from use in specified LLNL laboratories. An associated goal was to evaluate how the alternative non-mercury thermometers are received by chemists having specialized temperature measurement needs. Final procurements of the non-mercury thermometers were completed in FY 2004. Chemists have responded positively to the new thermometers, which have met the temperature measurement requirements for their intended uses.
Global Electric Motor-cars (GEM)	A pilot project carried out in 2003 evaluated the integration of electric vehicles (Daimler-Chrysler GEMs) into the LLNL fleet. With the study deemed a success, several Directorates have worked with Fleet Management to purchase the GEM cars for on-site use. Twenty-three new electric vehicles entered service in FY 2004.

- **Biodiesel Project for Medium Service Vehicles**

  This project will bring B20, a blend of 20% biodiesel[1] and 80% petroleum diesel, onsite for use in a 6-month pilot project for LLNL's medium duty fleet. Use of B20 significantly reduces vehicle emissions of carbon monoxide (–13%), unburned hydrocarbons (–11%), particulates (–18%), and the greenhouse gas, carbon dioxide (–16%) as compared to petroleum diesel (World Energy; Howell 2003). The pilot is intended to test B20 in a variety of LLNL medium duty vehicles, to evaluate use and maintenance issues, and to build user and management confidence in this alternative fuel.

  This project will install a clean 500-gallon tank in the fueling area. A new pump and flowmeter will be installed to dispense the B20 from the 500-gallon tank. LLNL will purchase B20 from their current supplier of diesel fuel. The B20 will arrive at the site pre-blended and ready for dispensing.

  Ten medium-duty vehicles (approximately 10% of LLNL's medium duty fleet) have been chosen for the pilot. They represent different models, different manufactures (Chevrolet, Ford, International), and different age vehicles. Each vehicle in the pilot will have preventative maintenance performed twice during the pilot to monitor for problems, specifically with the fuel system. Vehicle users will complete a questionnaire at the end of the pilot to monitor satisfaction with vehicle performance while using B20.

  Under the Energy Policy Act of 1992, use of biodiesel is an option for applicable federal fleets to meet a portion of their annual alternative fuel vehicle (AFV) acquisition requirements. LLNL Fleet Management is committed to making progress in FY05 toward the Vehicle Fleet Efficiency Goals by reducing the use of petroleum-based fuels, acquiring alternative fuel vehicles, and using alternative fuels.

- **Accelerated Solvent Extraction System for Preparation of Semivolatile Organic Compound/Polychlorinated Biphenyl Samples**

  LLNL's Chemistry and Materials Science Environmental Services (CES) routinely analyzes radioactive waste samples for semivolatile organic compounds (SVOCs) and polychlorinated biphenyl (PCB) compounds; in the process, mixed, radioactive and hazardous solvent wastes are generated. This ROI project involved the purchase and application of an accelerated solvent extraction (ASE) system that uses high temperature and pressures to allow the extraction of SVOCs and PCBs from solid samples in less time and with less volume of solvent. The project will have a payback period of 1.6 years and will result in the diversion of 230 kg of mixed low-level waste and one kg of TRU waste each year.

- **Purchase and Application of a Flow-through Radionuclide Detector**

  This project funded the Chemical Biology and Nuclear Science Division's Environmental Radiochemistry Group's purchase of a flow-through radionuclide detector system and accessories to make the equipment fully operational. This

1. Biodiesel is a renewable, domestically produced, and non-toxic diesel fuel substitute. It is a methyl ester most commonly derived from either soy or rapeseed oil.

detector system will be used to detect multiple radionuclide contaminants in a waste stream. This project reduces the generation of mixed waste by 200 kg each year and will have a payback period of a little less than one year. The flow-through radionuclide detector also minimizes personnel exposure to hazardous and radioactive materials.

Review of New Processes, Programs, or Experiments

As part of this effort, the Pollution Prevention Team was tasked to revise LLNL's P2 Plan by incorporating it into the Environmental Management System (EMS) Plan. As previously described, LLNL incorporated ISO 14001 as a WSS and is bringing its ISMS into conformance with this standard.

Pollution Prevention Employee Training and Awareness Programs

In 2004, LLNL conducted a number of activities to promote employee awareness of Pollution Prevention. A key event, the annual Earth Expo, was held in April to coincide with Earth Day. It featured representatives from EPD, businesses with environmentally friendly products, environmental conservation organizations, utilities, environmental agencies, and other organizations with environmental charters and interests. During the course of the year, Pollution Prevention articles appeared in the LLNL newspaper, *Newsline*, and electronic newsletter, *NewsOnLine*. The P2 team conducted training for purchasing staff on EPA requirements for affirmative procurement. The P2 team also placed banners at entry gates for America Recycles Day and National Pollution Prevention Week.

In spring 2003 the P2 team brought a new P2 web site (http://www-p2.llnl.gov/) online for LLNL employees. The web site, which was updated in 2004, is a resource for employees regarding pollution prevention, energy efficiency, the reuse and recycling of materials, green building, and other environmental topics. Employees can also use the site to suggest P2 ideas, ask questions about P2 planning and implementation, and find out about P2 "current events." The P2 team also operates the Earth Hotline for employees to call with questions, suggestions, or ideas regarding LLNL's pollution prevention and waste diversion endeavors.

Contributing Authors

Many authors significantly contributed to this large and diverse chapter. We acknowledge here the work of Shari Brigdon, Bruce Campbell, Bob Fischer, Gretchen Gallegos, Allen Grayson, Bert Heffner, Rod Hollister, Susi Jackson, Carol Kielusiak, Albert Lamarre, Sandra Mathews, Bill McConnachie, Katie Myers, Jennifer Nelson-Lee, Barbara Nisbet, Charles Noyes, Lisa Paterson, Lily Sanchez, Michael Taffet, Stan Terusaki, Earl Thomas, Joseph Woods, and Peter Yimbo.

3

Air Monitoring Programs

Paris E. Althouse
Barbara A. Nisbet
S. Ring Peterson
Paula J. Tate
Kent Wilson

Lawrence Livermore National Laboratory performs continuous air sampling to evaluate its compliance with local, state, and federal laws and regulations and to ensure that human health and the environment are protected. 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 Order 5400.5, Radiation Protection of the Public and the Environment, and American National Standards Institute (ANSI) standards. The *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. DOE 1991) provides the guidance for implementing DOE Order 5400.5.

The U.S. Environmental Protection Agency (EPA) Region IX has enforcement authority for LLNL compliance with radiological air emissions regulations. Enforcement authority for the Clean Air Act regulations pertaining to nonradiological air emissions belongs to two local air districts, the Bay Area Air Quality Management District (BAAQMD) and the San Joaquin Valley Air Pollution Control District (SJVAPCD).

Air effluent monitoring of atmospheric discharge points is conducted to measure the quantities of radionuclides released from individual facilities during routine and nonroutine operations; ambient air monitoring at LLNL-site and off-site locations determines if airborne radionuclides or beryllium are being released in measurable quantities to its environs by these and other LLNL operations. Ambient air monitoring also serves to verify the air concentrations predicted by air dispersion modeling and to determine compliance with the NESHAPs regulation. (See *LLNL NESHAPs 2004 Annual Report* [Harrach et al. 2005].)

Air Effluent Monitoring

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 section apply to stationary point source discharges.

Air effluent monitoring of atmospheric discharge points is used to determine the actual radionuclide releases from individual facilities during routine and non-routine 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.) It involves the extraction of a measured volume of air from the exhaust of a facility 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. 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 SJVAPCD, and monitoring of the effluent is not required. Based on air toxics emissions inventory and risk assessment required by the California Air Toxics "Hot Spots" legislation, BAAQMD and SJVAPCD have ranked LLNL as a low-risk facility for nonradiological air emissions.

Methods

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. 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. 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 2004, LLNL operated 67 sampling systems for radioactivity from air exhausts at 6 facilities at the Livermore site (see **Figure 3-1**) and 1 sampling system at Site 300 (see **Figure 3-2**). From NESHAPs assessments of operations during 2004, one additional discharge point, a new operation in the Building 695 yard, the TRU Mover, was found to require continuous sampling. These systems are listed in **Table 3-1** along with the analytes of interest, the type of sampler, and the number of samplers. LLNL periodically reassesses the need for continuous monitoring and assesses new operations or changes in operations.

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

In addition to sample collection for environmental reporting, some facilities used real-time alarm monitors (listed in **Table 3-1**) 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

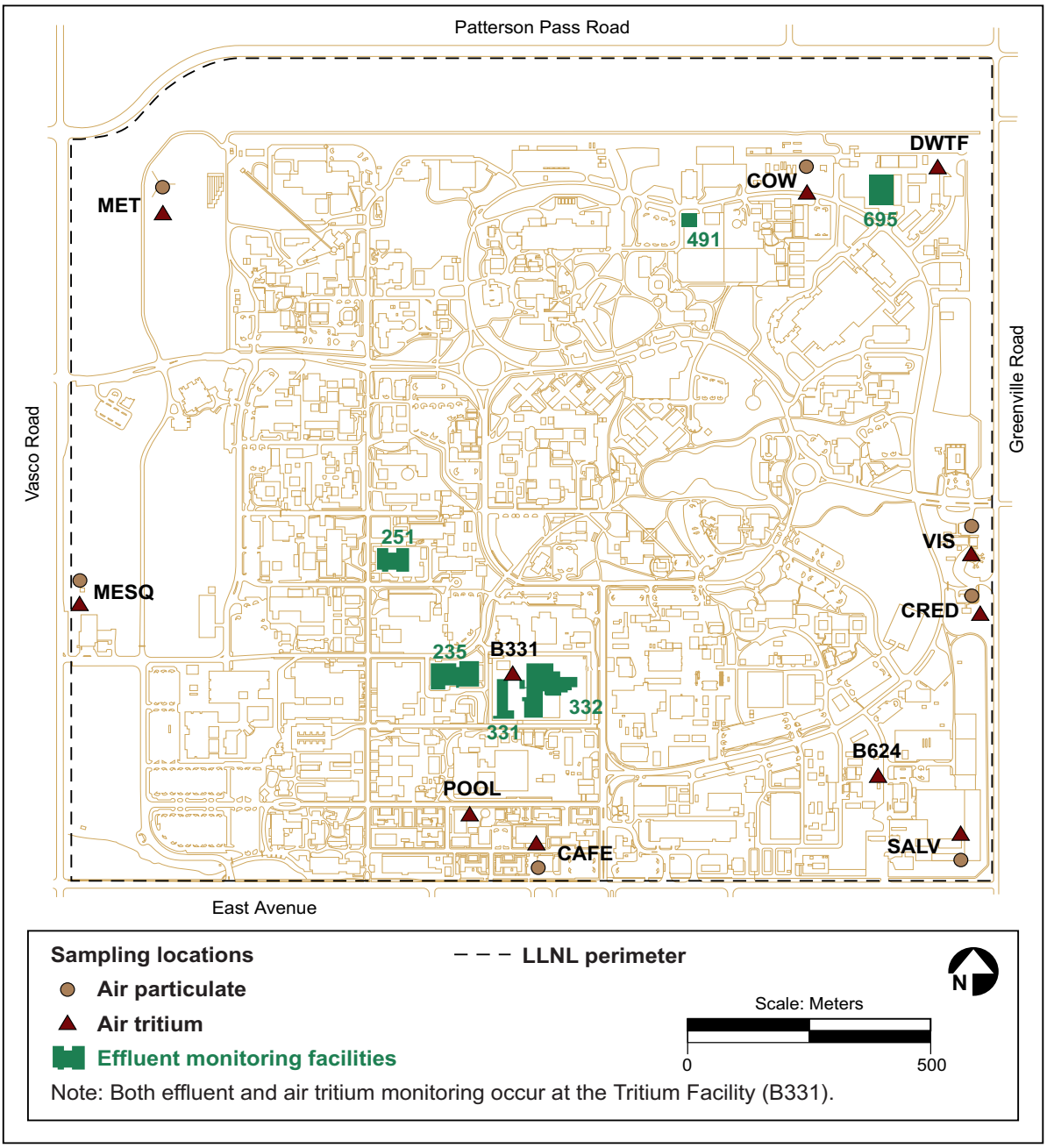


Figure 3-1. Livermore site air monitoring locations, 2004

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. Air effluent samples were obtained in accordance with written standardized procedures summarized in the *Environmental Monitoring Plan* (Woods 2005).

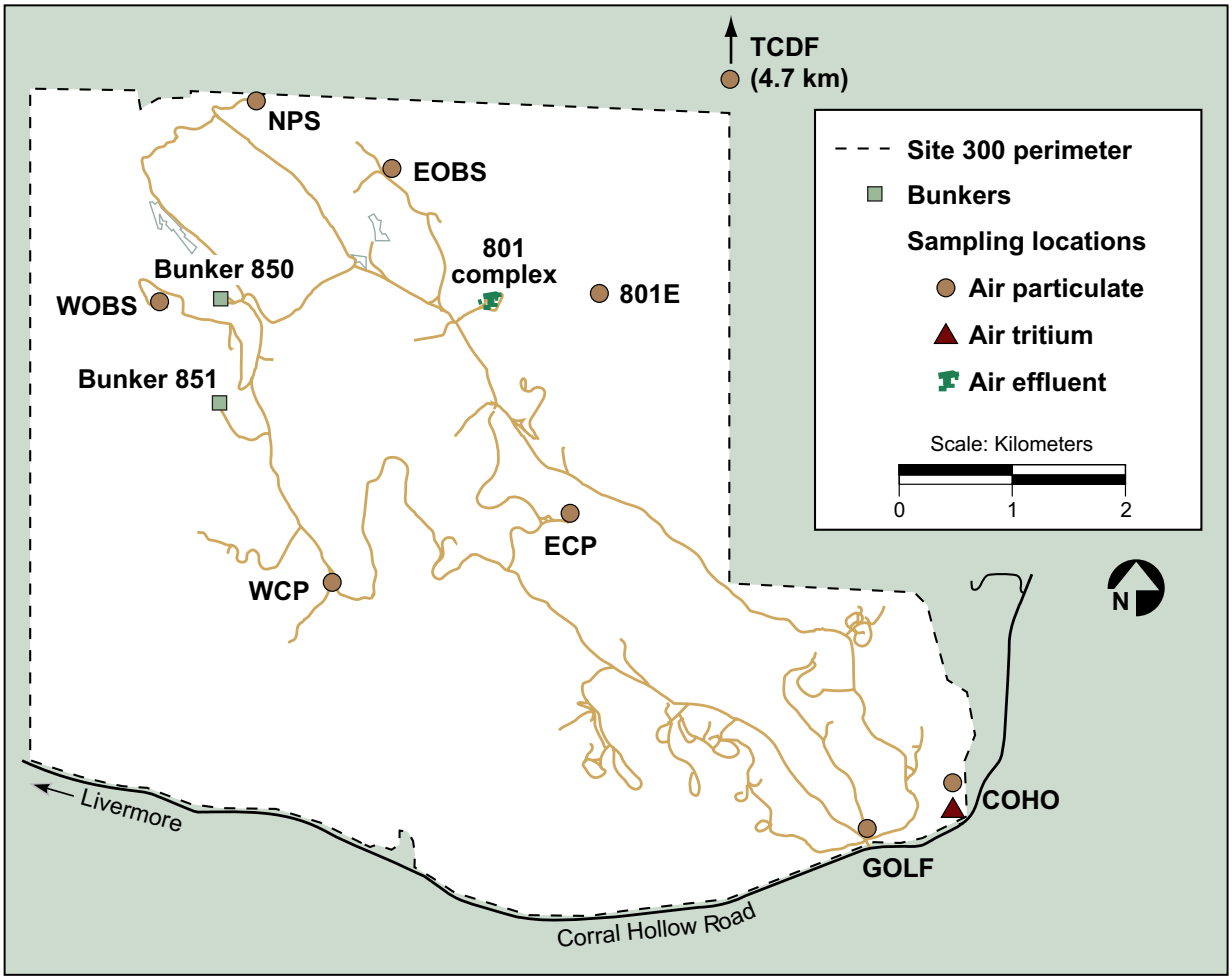


Figure 3-2. Site 300 air monitoring locations, 2004

To establish the background levels of gross alpha and beta activity that are used to determine if a release has occurred from monitored stacks, LLNL operates three low-volume radiological air particulate samplers at locations HOSP and FCC in the Livermore Valley and NPS at Site 300. These samplers collect particulate on membrane filters at a continuous rate of 0.03 m^3/min. The low-volume samplers are not part of the ambient air network.

The following sections discuss the radiological air emissions from facilities that have continuously monitored discharge points. All effluent air analytical results are summarized in the file "Ch3 Air Effluent" included on the report CD.

Table 3-1. Air effluent sampling locations and sampling systems

Building	Facility	Analytes	Sampler type	Number of samplers
235	Chemistry and Materials Science	Gross α, β on particles	Filter	1
251	Heavy Element	Gross α, β on particles	Filter	27
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	15
491	Laser isotope separation[c]	Gross α, β on particles	Filter	1
695	Decontamination and Waste Treatment Facility	Gross α, β on particles	Filter	1
695 Yard	TRU Mover	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

c Operations discontinued; however, the air effluent sampling system at this building continues to operate as part of the maintenance and surveillance shutdown plan for the Advanced Vapor Laser Isotope Separation (AVLIS) program.

Air Effluent Radiological Monitoring Results

In 2004, a total of 0.61 TBq (16 Ci) of tritium was released from the Tritium Facility (Building 331). Of this, approximately 0.45 TBq (12 Ci) were released as tritiated water vapor (HTO). The remaining tritium released, 0.16 TBq (4.0 Ci), was elemental tritium gas (HT). The median emissions from the facility were 1.9×10^3 Bq/m^3 (5.1×10^{-8} Ci/m^3) for HTO, and 1.3×10^2 Bq/m^3 (3.5×10^{-9} Ci/m^3) for HT. The highest single weekly stack emission from the facility was 9.6×10^{-2} TBq (2.6 Ci), of which 8.5×10^{-2} TBq (2.3 Ci) was HT. Emissions from Building 331 for 2004 continued to remain considerably lower than those during the 1980s. **Figure 3-3** illustrates the combined 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. Some sampling systems may exhibit as few as one to four values (out of 26 to 52 samples per year) greater than the MDC. Generally, these samples are only marginally above the MDC. In addition, due to the way some of the exhaust systems are configured, the monitoring systems sometimes sample air from the atmosphere in addition to HEPA-

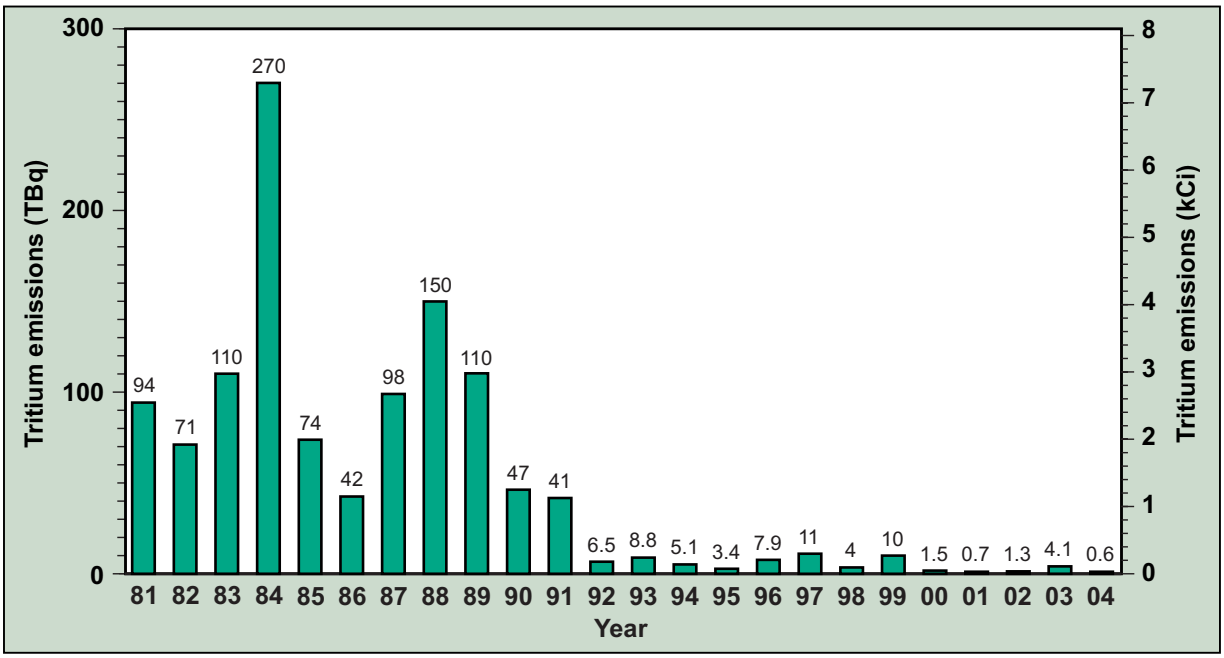


Figure 3-3. Tritium Facility combined HTO and HT emissions from 1981 through 2004

filtered air from facility operations, thereby collecting background atmospheric radioactivity. LLNL uses zero values for these results based on knowledge of the facility, the use of HEPA filters in all significant release pathways, and alpha-spectroscopy-based isotopic analyses of selected air sampling filters. These analyses demonstrate the presence of naturally occurring radionuclides, such as radon daughters like polonium. Even if LLNL used the MDC values to calculate the emission estimates for these facilities (which would be an extremely conservative approach) the total dose to a member of the public attributable to LLNL activities would not be significantly affected.

In 2004, a significant number of samples collected throughout the year from two release emission points at Building 251 (the unhardened area) yielded gross alpha results greater than the MDC. Gross alpha is used as the primary indicator of potential emissions for operations, such as those at Building 251 that involve the use of uranium and transuranic materials. The gross alpha and gross beta activity emissions for Building 251 were 1.9×10^2 Bq/y (5.0×10^{-9} Ci/y) and 1.6×10^3 Bq/y (4.3×10^{-8} Ci/y). Because of the number of samples with values above the MDC, gross alpha and gross beta measurements are being reported as actual emissions.

Table 3-2 summarizes total radiological emissions as determined from the continuous sampling of facility exhausts for 2004.

Table 3-2. Measured radiological air effluent emissions above the detection limit for Livermore site, 2004

Building (Facility)	HT (Bq)	HTO (Bq)	Gross alpha (Bq)	Gross beta (Bq)
331 (Tritium Facility)	1.6×10^{11}	4.5×10^{11}	—	—
251 (Heavy Element Facility)	—	—	1.9×10^{2}	1.6×10^{3}

Nonradiological Results

The Livermore site currently emits approximately 153 kg/day of regulated air pollutants as defined by the Clean Air Act, including nitrogen oxides, sulfur oxides, particulate matter [PM-10], and carbon monoxide (see **Table 3-3**). Carbon monoxide emissions appear to have increased in 2004 because a higher emission factor, required by the Synthetic Minor Operating Permit, was used in estimations for small boilers on site. The emission sources that release the greatest amount of regulated pollutants at the Livermore site are surface-coating, internal combustion engines, solvent wiping, and, natural gas fired boilers. **Table 3-3** lists estimated airborne releases for regulated pollutants from the Livermore site.

Table 3-3. Nonradioactive air emissions, Livermore site and Site 300, 2004

Pollutant	Estimated releases (kg/day)	
	Livermore site	Site 300
Organics/volatile organics	16.0	0.47
Nitrogen oxides	75.1	1.84
Carbon monoxide	54.7	0.40
Particulates (PM-10)	5.7	0.41
Sulfur oxides	1.5	0.53

LLNL air pollutant emissions are very low compared with daily releases of air pollutants for the entire Bay Area. For example, the total emissions of nitrogen oxides released in the Bay Area for 2004 were approximately 6.9×10^4 kg/day, compared with the estimated release from the Livermore site of 75.1 kg/day, which is 0.11% of total Bay Area emissions from stationary sources. The 2004 BAAQMD estimate for reactive organic emissions was 9.1×10^4 kg/day, while the estimated releases for 2004 from the Livemore site were 16.0 kg/day, or 0.02% of the total Bay Area emissions from stationary sources.

Certain operations at Site 300 require permits from SJVAPCD. The total estimated air pollutant emissions during 2004 from operations (permitted and exempt sources) at Site 300 are given in **Table 3-3**. The emission sources that release the greatest amounts

of criteria pollutants at Site 300 include internal combustion engines, boilers, a gasoline-dispensing facility, prescribed burns, paint spray booths, drying ovens, and soil vapor extraction equipment.

Impact of Air Effluent on the Environment

The dose to the hypothetical maximally exposed member of the public caused by the measured air emissions from the Tritium Facility (modeling HT emissions as HTO as required by EPA) is 1.4×10^{-2} µSv/y (1.4×10^{-3} mrem/y) and the dose from Building 251 is 6.8×10^{-6} µSv/y (6.8×10^{-7} mrem/y). Thus, the estimated radiological dose caused by measured air emissions from LLNL operations is minimal. See Chapter 6 for a discussion 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.

Ambient Air Monitoring

LLNL monitors ambient air to determine if airborne radionuclides or beryllium are being released by Laboratory operations, what the concentrations are, and what the trends are in the LLNL environs. In the ambient air monitoring program, LLNL collects particles on filters and physically 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 area sources, are monitored to fill NESHAPs requirements. In 2003, the EPA approved use of the air surveillance monitoring data from the location of the site-wide maximally exposed individual (SW-MEI) to demonstrate compliance with NESHAPs for minor emission point sources (Harrach et al. 2004). In addition, the Derived Concentration Guides (DCGs) found in DOE Order 5400.5 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. Data tables in this chapter present the DCG and the percent of the DCG for the given isotope. For beryllium metals, an ambient air concentration limit of 10,000 pgm/m^3 is established by the BAAQMD under Regulation 11 for the Hazardous Air Pollutants.

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 at a background location near the city of Tracy. All monitoring networks use continuously operating samplers.

The sampling locations for each monitoring network are listed in **Table 3-4** and shown on **Figures 3-1**, **3-2** and **3-4**. Several locations target specific areas of known contamination while other locations monitor concentrations at the perimeters of the sites or at distant background locations. Throughout the year at selected locations, additional samplers are placed next to permanent samplers. Duplicate samples thus obtained provide quality control of the data. Trip blanks are also taken on the air particulate sampling routes to help identify any contaminate introduced during the sampling process.

An LLNL state-certified analytical laboratory performed all sample analyses. Samples were analyzed for gross alpha and beta activity, gamma-emitting radionuclides, plutonium, uranium, tritium and beryllium metals. **Table 3-4** provides the requested analysis for each ambient air sampling station. Ambient air samples were obtained in accordance with written standardized procedures summarized in the *Environmental Monitoring Plan* (Woods 2005).

Sample Collection

The air particulate networks use high-volume air sampling units, which collect airborne particulate weekly at a continuous rate of 0.42 m^3/min using Whatman 41 cellulose filters. The tritium samplers, operating at a flow rate of 500 cm^3/min, draw air through sampling flasks containing silica gel that traps the air moisture. These flasks are changed every two weeks.

Sampling Locations

Based on historical meteorological data, all ambient air samplers have been positioned to detect any significant concentration of radioactive or beryllium effluents from LLNL operations with reasonable probability. Before startup of a new operation, the need for a new sampling location is assessed using air dispersion modeling.

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 near the city of Tracy. There are 7 air particulate samplers on the Livermore site, 9 in the Livermore Valley, and 8 at Site 300. There are 11 air tritium samplers at the Livermore site, 6 in the Livermore Valley, and 1 at Site 300. In December 2003, the air particulate location TFIR was removed and replaced (in March 2004) by a more suitable background location for Site 300. This station is called TCDF and is approximately 4.7 kilometers north of Site 300.

Table 3-4. Sampling locations and type and frequency of analyses for ambient air

		Livermore site				
	Target location	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	Cellulose					Silica gel
SALV, MET, MESQ, COW, CAFE, VIS[b]	Onsite	X	X	X	X	X
DWTF, POOL	Onsite					X
B331, B624	Diffuse/onsite					X
CRED[b]	SW-MEI[c]	X	X			X
ZON7, PATT, AMON	Downwind	X	X			X
CHUR, FCC[d], TANK	Upwind	X	X			
FIRE, HOSP[d]	Upwind	X	X			X
VET	Upwind					X
LWRP	Special Interest	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, GOLF, WOBS	Onsite[b]	X	X	X	X	
ECP, WCP, NPS[d], 801E	Onsite[b]	X	X	X		
COHO	Onsite[b]	X		X		X
TCDF[e]	Offsite[b]	X		X	X	

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

b On the Livermore site, samplers VIS and CRED represent the location of the site-wide maximally exposed individual (SW-MEI), and concentrations obtained from them are averaged for compliance with minor sources; at Site 300, the average of all locations is applied.

c SW-MEI for NESHAPs compliance based on air dispersion modeling.

d Low-volume sampler also operated at this location; particles are collected on millipore filters. These samplers are operated to provide background values for the air effluent monitoring program.

e Location TFIR was removed at the end of 2003 and replaced by TCDF, which began in March 2004.

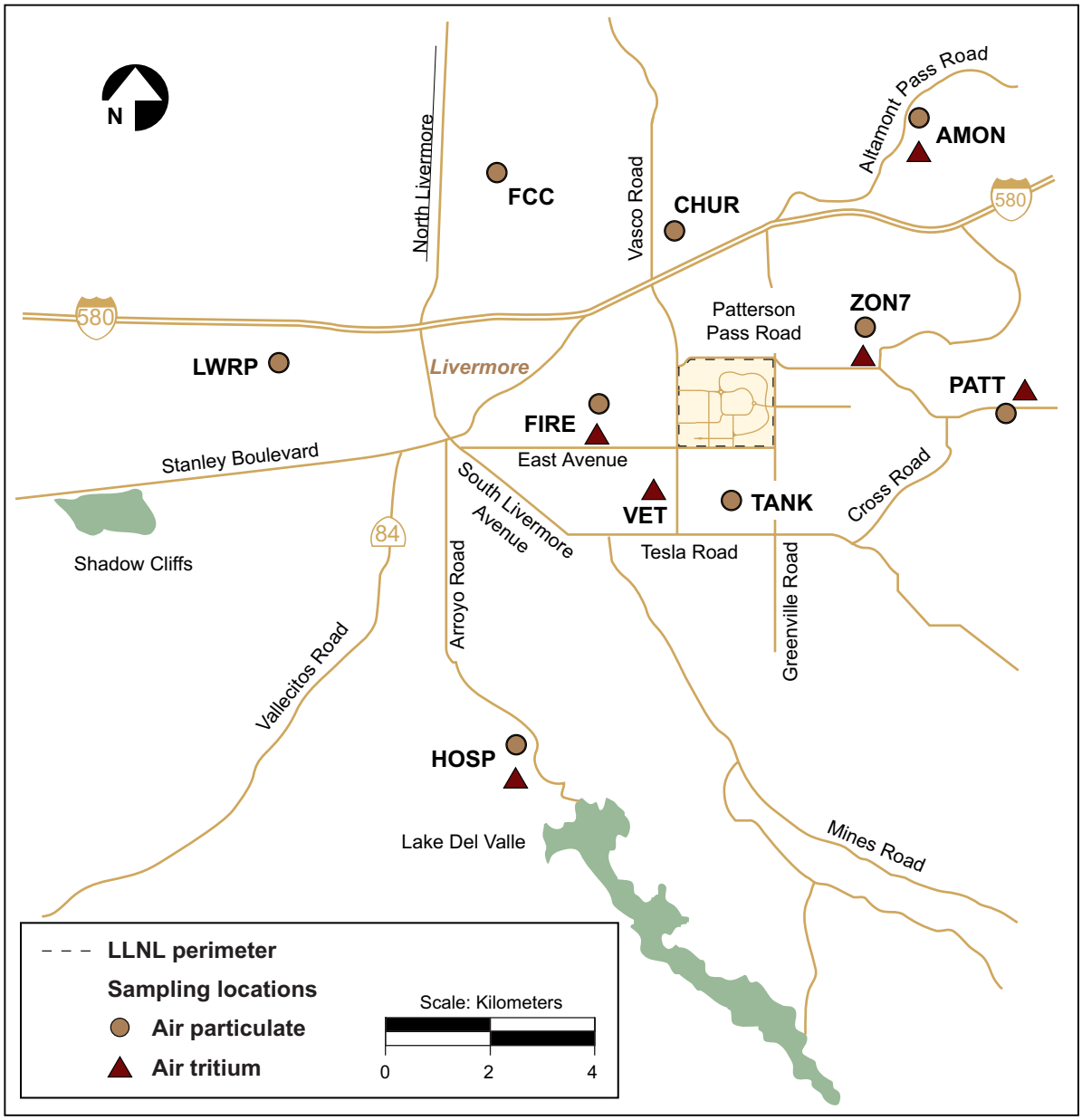


Figure 3-4. Air particulate and tritium sampling locations in the Livermore Valley, 2004

In general, air sampling locations are grouped in categories representing the following areas; perimeter, upwind, downwind, diffuse sources or areas of known contaminaton, and special interest locations. The mean results from locations CRED and VIS serve as the SW-MEI for NESHAPs minor source compliance. Because resuspension of soil at Site 300 is the minor source of greatest interest, the average of all on-site locations serves as the SW-MEI for NESHAPs minor source compliance.

Beryllium is monitored at six Livermore site perimeter locations as required by the BAAQMD. Although there is no requirement to monitor beryllium at Site 300, as a best management practice, it is monitored at three locations on-site and at the new location (TCDF) north of Site 300.

Sample Analysis

Gross alpha and gross beta activities are determined by gas flow proportional counting; plutonium isotopes by alpha spectrometry; uranium isotopes by inductively coupled plasma-mass spectrometry; gamma emitters by gamma spectroscopy; and tritium by freeze-dried vacuum distillation followed by liquid scintillation counting. Procedures for analysis are summarized in the *Environmental Monitoring Plan* (Woods 2005). Beryllium metal concentration is determined by inductively coupled plasma-mass spectrometry. See **Table 3-4** for the frequency of analysis at each location. In addition to using the analytical methods summarized in this section, the analytical laboratory also runs a series of quality control tests that include laboratory control spikes, blanks and duplicates. The analytical laboratory reports the actual instrumentation values, including negative results that arise when background measurements are higher than those of the samples.

Because plutonium research occurs at the Livermore site, plutonium analyses are performed individually for all Livermore locations. However, plutonium is not used at Site 300; therefore, a composite from all locations is analyzed.

Uranium use at the Livermore site is very minimal so a composite from all the Livermore site perimeter locations is created and analyzed for uranium activity. However, at Site 300, where depleted uranium is used in explosives testing, specific locations are analyzed for uranium activity.

Results

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, uranium, and tritium. 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. The activities shown in the tables located in the file "Ch3 Ambient Air" included on the report CD, which display monthly and biweekly data, are measured concentrations and their associated $\pm 2\sigma$ counting errors.

Particle size distribution of 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) environmental regulatory guide allowable limit (U.S. DOE 1991) using total particles collected.

Gross Alpha and Gross Beta Concentrations

The primary sources of alpha and beta activities are naturally occurring radioisotopes. **Figure 3-5** shows the three-year history of median monthly gross alpha and gross beta activities for the Livermore site perimeter, Livermore Valley, and Site 300 sampling locations. These data are slightly lower than last year but follow a pattern similar to previous years with a seasonal increase in the fall and early winter months. As soils dry out during the summer months, the resuspended particulate can build up and increase until the winter rains begin. In many cases there is an inverse relationship between rainfall and particulate activity indicating that the increases in activity may be from particulate mass from resusupended soils rather than LLNL airborne sources. Routine isotopic gamma results of site composite samples indicate that higher activities are the result of naturally occurring isotopes (uranium, thorium, potassium, and lead) which are also routinely found in local soils.

In 2004, the typical gross alpha activity (annual median value) for the Livermore site perimeter was 21 µBq/m^3 (0.57 fCi/m^3); for the upwind and downwind Livermore Valley stations, the value was 20 µBq/m^3 (0.54 fCi/m^3); and for Site 300, the value was 26 µBq/m^3 (0.70 fCi/m^3). The annual gross beta median for all upwind and downwind locations was 260 µBq/m^3 (7.0 fCi/m^3); for the Livermore site perimeter it was 270 µBq/m^3 (7.3 fCi/m^3; and for Site 300 it was 310 µBq/m^3 (8.5 fCi/m^3). Location CHUR (an upwind location) recorded high gross alpha and beta activity during November; samples were recounted but remained higher than normal. A gamma scan is being performed to determine what isotope is causing this spike in activity. See the section "Gamma-Emitting Radionuclides" in this chapter for more information.

Site 300 is less developed and has more barren soil compared to the Livermore site. As a result, Site 300 air samples tend to collect more particulate from resusupended soils. The pattern of activity as seen in **Figure 3-5** however is very similar to the Livermore site air samples with a increase in the fall and early winter months then a decrease during the winter as rains reduce the resuspension effect. The highest weekly gross alpha sample measured at Site 300 was 240 µBq/m^3 (6.5 fCi/m^3) at WOBS. This sampler is near locations where open-air shots have occurred (Building 851 bunker and the Contained Firing Facility [Building 801]). In addition, there were two shots during December that most likely contributed to the elevated gross alpha values. The overall annual median gross alpha value at Site 300 was 26 µBq/m^3 (0.70 fCi/m^3).

The highest Site 300 onsite weekly gross beta value was 1432 µBq/m^3 (39 fCi/m^3) recorded at WOBS which also coincides with a shot at Site 300. The overall annual median beta value for Site 300 was 310 µBq/m^3 (8.4 fCi/m$^{3)}$.

Gamma-Emitting Radionuclides

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 by LLNL. This analysis also reveals emissions from global fallout sources such as aboveground tests and the Chernobyl accident (Holland et al. 1987). Composite

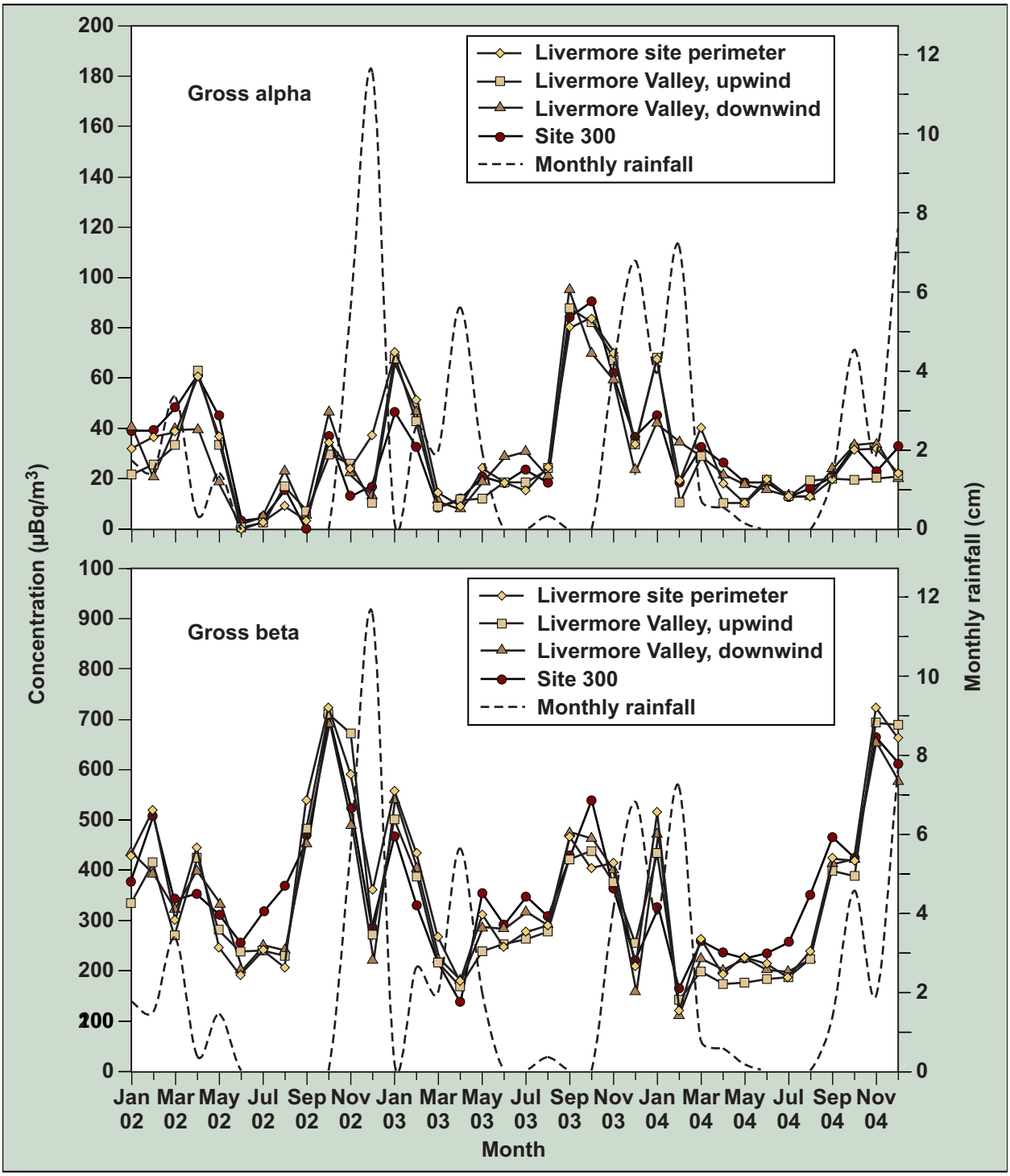


Figure 3-5. Three-year history of monthly median gross alpha and gross beta activities for all particulate samples grouped by area, along with corresponding monthly rainfall totals, 2002-2004

samples for the Livermore site and Site 300 are analyzed for an environmental suite of gamma-emitting radionuclide concentrations in air. Site composite samples are scanned for 47 isotopes with over 350 gamma rays. These include fission products, activation products, actinides, and naturally occurring products. The results for gamma composites for 2004 were within known background levels (see file "Ch3 Ambient Air" on report CD for analytical results). Occasionally weekly samples that are screened for gross alpha and beta are also gamma scanned to determine what isotope may be the cause of higher than usual activity. Such was the case for the sample mentioned above (CHUR). In this case the activity was determined to be caused by an increase in a naturally occurring isotope and not by LLNL operations.

Plutonium Concentrations

Historical environmental plutonium-239+240 activity for the past 20 years is shown in **Figure 3-6**. Locations HOSP and VIS represent typical upwind and onsite sampling locations. Plutonium concentrations at both of these sites have been decreasing as fallout diminishes and on-site surface areas of potential resuspension have been covered with pavement or buildings. LLNL analyzes all Livermore area samples individually, while a composite is created from all on-site Site 300 samples.

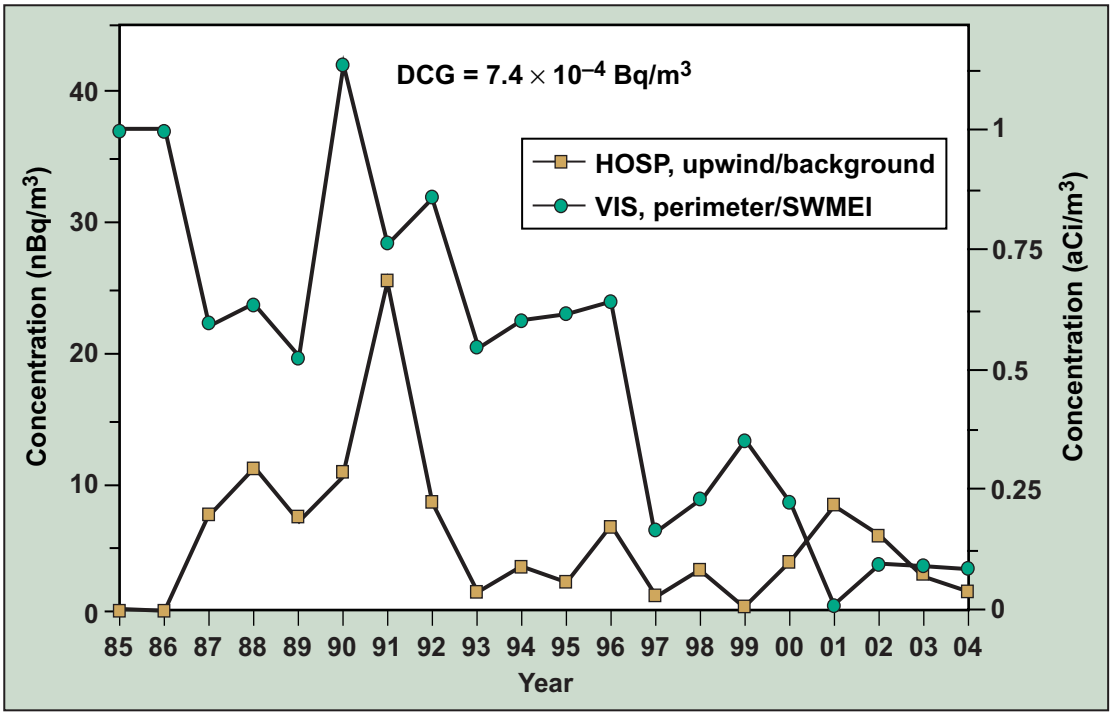


Figure 3-6. Calculated annual median concentrations of plutonium-239+240 for HOSP and VIS for the last 20 years

Plutonium-239+240 was detected in 13 of the 234 samples tested from Livermore area air samples. Six of those positive samples came from on-site samplers. These detections all came between June and October, when resuspension is potentially greatest. The highest recorded onsite plutonium-239+240 detection was at the SW-MEI (CRED) of 21 nBq/m^3 (0.57 aCi/m^3) (0.003% of the DCG), while the highest off-site plutonium value was recorded as 14 nBq/m^3 (0.38 aCi/m^3) at the TANK location in August. Plutonium was detected in only 1 of the 12 composite samples collected from Site 300 and this value was very close to the minimum detection limit. This value of 4.5 nBq/m^3 (0.12 aCi/m^3) (0.0006% of the DCG) was recorded in September and was lower than all but one (MET) of the maximum values for samples collected in Livermore. All positive detections for plutonium from either site were far below the DCG of 0.74 mBq/m^3.

Uranium Concentrations

Uranium ratios are used to determine the type of uranium present in the environment. Natural uranium has a mathematical ratio of uranium-235/uranium-238 of 0.00725 and depleted uranium has a uranium-235/uranium-238 ratio of 0.002.

Uranium isotopes are naturally occurring and all but one of the uranium-235 analyses had positive detections. The Livermore site monthly composites had a uranium-235 median concentration of 0.14 pg/m^3 and a uranium-238 median concentration of 22 pg/m^3. This has a median ratio of 0.007, which is considered natural uranium and typical of what has been recorded in the past. Only one sample, which was collected on the Livermore site during December, showed anything other that natural activity; in this case, a ratio of 0.002 was recorded which indicated the presence of depleted uranium. This activity is highly unlikely at the Livermore site and was suspicious because two very high uranium samples were collected from Site 300 in December. An investigation of the data was performed, and it was determined that handling and analytical sample processing most likely resulted in cross contamination between the Livermore site and Site 300 composites. The Livermore site composite was normal in January 2005. The standard operating procedures have been amended to eliminate the possibility for this type of cross contamination from occurring again.

The annual median uranium-235 concentration for all Site 300 locations was 0.17 pg/m^3 (or less than 0.00003% of the DCG) and the uranium-238 median concentration was 24 pg/m^3 (or less than 0.0008% of the DCG). As with the Livermore site, the Site 300 isotopic ratio for the annual median was 0.007, which is considered natural uranium. As with the December Livermore site composite, 7 of 9 samples collected from Site 300 during December recorded a uranium-235/uranium-238 ratio with a depleted uranium signature. These depleted uranium signatures are likely since there were several outdoor test shots with depleted uranium over a two month period. The highest uranium-238 value was 8660 pg/m^3 in December at WOBS (the second highest was 174 pg/m^3 at NPS, also in December). 8660 pg/m^3 is 3% of the DCG and is significantly higher than any other sample collected in recent years.

Tritium Concentrations

Tritium data presented in **Table 3-5** summarize the biweekly tritium data provided in data tables on the report compact disk (see file "Ch3 Ambient Air" on the report CD). Locations are grouped by expected concentrations of tritium. The highest concentrations of tritium are from the B331 and B624 samplers on the Livermore site near stored containers of tritium waste or tritium-contaminated equipment (the Building 331 waste accumulation area and the Building 612 Yard) that outgas tritium as HTO. The annual median concentration for 2004 for the B331 diffuse-source sampler was more than a factor of five times lower than in 2003 reflecting the large decrease in tritium operations at the Tritium Facility in 2004. The median concentration at the B624 sampler in the Building 612 Yard was only slightly lower than in 2003. Sampling at the Building 514 Tank Farm, continuous between August 1991 and December 2003, was discontinued because the facility underwent RCRA closure.

Table 3-5. Tritium in air samples (mBq/m^3), 2004

Sampling locations	Detection frequency	Mean	Median	IQR	Maximum	Median Percent of DCG[a]
Diffuse on-site sources	50 of 50	1420	435	1990	7470	0.0117
Livermore site	174 of 231	42.2	34.6	39.5	718	0.000935
Livermore Valley	48 of 155	6.35	4.59	21.1	57.7	0.000124
Site 300	3 of 26	–2.27	–0.325	21.5	31.5	_[b]

a DCG = Derived Concentration Guide of 3.7 x 10^6 mBq/m^3 for tritium in air

b Median percent DCG not calculated because the median is negative.

Samplers near the perimeter of the Livermore site exhibit the next highest air tritium concentrations. Of these locations, POOL exhibited the highest median concentration at just 0.0021% of the DCG. Concentrations at POOL were on average much lower than in 2003. Median concentrations for 2004 for on-site locations were on average about half of those for 2003. Much less variability was seen in the concentrations for 2004 compared with 2003. Because releases from the Tritium Facility were markedly reduced in 2004 compared with 2003, the high peak air tritium concentrations seen in 2003 are not seen in 2004—the mean of all maximum concentrations for all on-site locations for 2003 was 718 mBq/m^3 (19.4 pCi/m^3); for 2004 it was 161 mBq/m^3 (4.35 pCi/m^3).

For 2004, two of the locations near the perimeter (MESQ and MET) had median concentrations below the detection limit (about 25 mBq/m^3), while all of the median concentrations in the Livermore Valley and at Site 300 (**Table 3-5**; see also file "Ch3 Ambient Air" on report CD for biweekly data) were below the detection limit. Given the low tritium concentrations observed at the Livermore site perimeter, all samples from locations distant from the Livermore site are expected to exhibit tritium background concentrations that are below the detection limit. Similarly, because no operations at

LLNL release tritium to the environment at Site 300, concentrations at COHO are expected to be below the detection limit. Detections occurring at these sampling locations are artifacts of scintillation counting with a high counter background.

Beryllium Metal Concentrations

LLNL measures the monthly concentrations of airborne beryllium for the Livermore site, Site 300, and the off-site sampler located north of Site 300. (See file "Ch3 Ambient Air" on report CD for data.) The highest value at the Livermore site was 21 pg/m^3 which was recorded at location SALV in September. This value is only 0.21% of the BAAQMD ambient concentration limit for beryllium (10,000 pg/m^3). These data are similar to data collected from previous years.

Figure 3-7 is a plot of the median beryllium concentration at the Livermore site perimeter from 1975 through 2004. 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. LLNL monitors beryllium metals in air samples on the Livermore site as part of an agreement with the local BAAQMD.

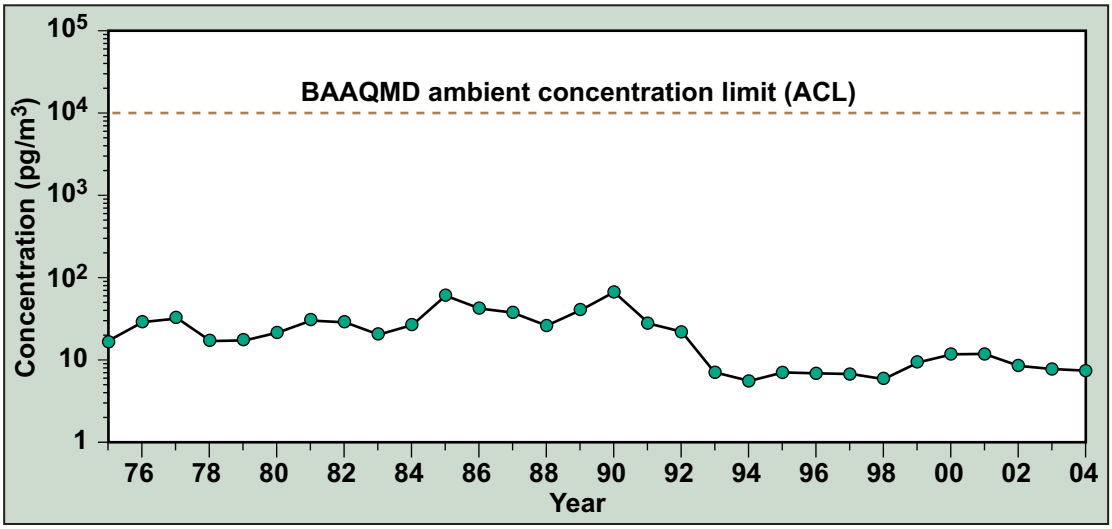


Figure 3-7. Median concentration of beryllium in air particulate samples taken at the Livermore site perimeter, 1975–2004

There is no regulatory requirement to monitor beryllium in San Joaquin County; however, LLNL analyzes samples from several Site 300 locations as a best management practice. The monthly median beryllium concentration for all Site 300 locations was 7.2 pg/m^3. The highest value for the Site 300 area samples occurred in the September sample at TCDF. This sample recorded a value of 23 pg/m^3, which is 0.12% of the ambient concentration limit.

Environmental Impact of Ambient Air

LLNL operations involving radioactive materials had little impact on radionuclide concentrations in ambient air during 2004. 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.

The diffuse tritium sources at Building 331 and the Building 612 Yard had a small, localized effect with minimal impact on the public. Any potential dose received by a member of the public from the diffuse sources is accounted for when doses are calculated based on tritium concentrations at the Livermore site perimeter. The mean tritium concentration for all Livermore site perimeter air tritium sampling locations in 2004 was about one-third lower than in 2003. Both mean and median concentrations of tritium in the Livermore Valley or at Site 300 were all well below detection limits. For a location at which the mean concentration is at or below the detection limit, inhalation dose from tritium is assumed to be less than 5 nSv/y (i.e., the dose from the detection limit of about 25 mBq/m^3).

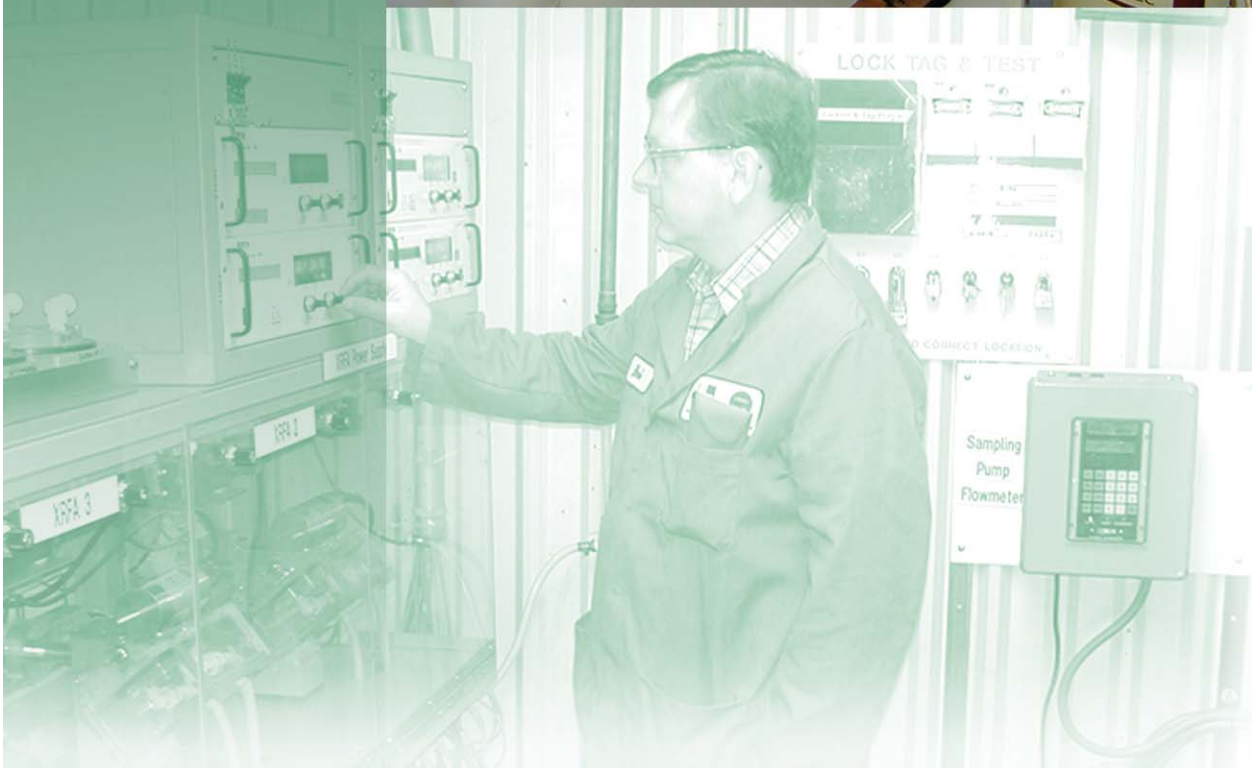
There are two Livermore site locations (CRED and VIS) with public access, at least during working hours. If it were assumed that a member of the public inhaled air continuously for a year at the maximum biweekly concentration at CRED (120 mBq/m^3) or VIS (72.2 mBq/m^3), the resulting doses would still be tiny (25 nSv/y and 15 nSv/y, respectively). Put another way, the maximum concentration at CRED is just 0.2% of concentration limits for minor sources set by the U.S. EPA in Table 2, Appendix E to 40 CFR 61 (Harrach 2005).

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 median for the Livermore site and Site 300 (excluding the off-site location, TCDF) are both 7.3 pg/m^3. These data are lower than estimated for natural background, well below standards, and do not indicate the presence of a threat to the environment or public health.

4

Water Monitoring Programs

Lily Sanchez
Richard A. Brown
Christopher G. Campbell
Allen R. Grayson
Henry E. Jones
Sandra Mathews
Michael A. Revelli
Duane Rueppel



Lawrence Livermore National Laboratory monitors a multifaceted system of waters that includes wastewaters, storm water, and groundwater, as well as rainfall and local surface waters. Water systems can also operate differently between the Livermore site and Site 300. For example, Site 300 is not serviced by a publicly owned treatment works as is the Livermore site, so different methods of treating and disposing of sanitary waste are used at the two LLNL sites. As described below, many different drivers determine the appropriate methods and locations among the various water monitoring programs.

In general, water samples are collected according to written standardized procedures appropriate for the medium (see Woods 2005). Sampling plans are prepared in advance by each network analyst, who is the LLNL staff person responsible for developing and implementing the specific monitoring programs or networks. The network analyst decides what analytes are to be sampled (see Appendix A) and at what frequency, incorporating any permit-specified analyses. Except for certain sanitary sewer and retention tank analytes, the analyses were usually performed by off-site California-certified contract analytical laboratories.

Sanitary Sewer Effluent Monitoring

In 2004, the Livermore site discharged an average of 1.25 million liters (ML) per day of wastewater to the City of Livermore sewer system, 4.7% of the total flow into the city's 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 4-1**). In 2004, Sandia/California generated approximately 11.3% of the total effluent discharged from the Livermore site. LLNL's wastewater contains both sanitary sewage and process wastewater and is discharged in accordance with permit requirements and the City of Livermore Municipal Code, as discussed below.

Livermore Site Sanitary Sewer Monitoring Complex

LLNL's sanitary sewer discharge permit (Permit 1250, 2003/2004 and 2004/2005) 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 cause upset or pass through to the Livermore Water Reclamation Plant (LWRP) treatment process or otherwise impact the public welfare. The effluent is continuously analyzed for flow, pH, regulated metals, and gamma radioactivity. If

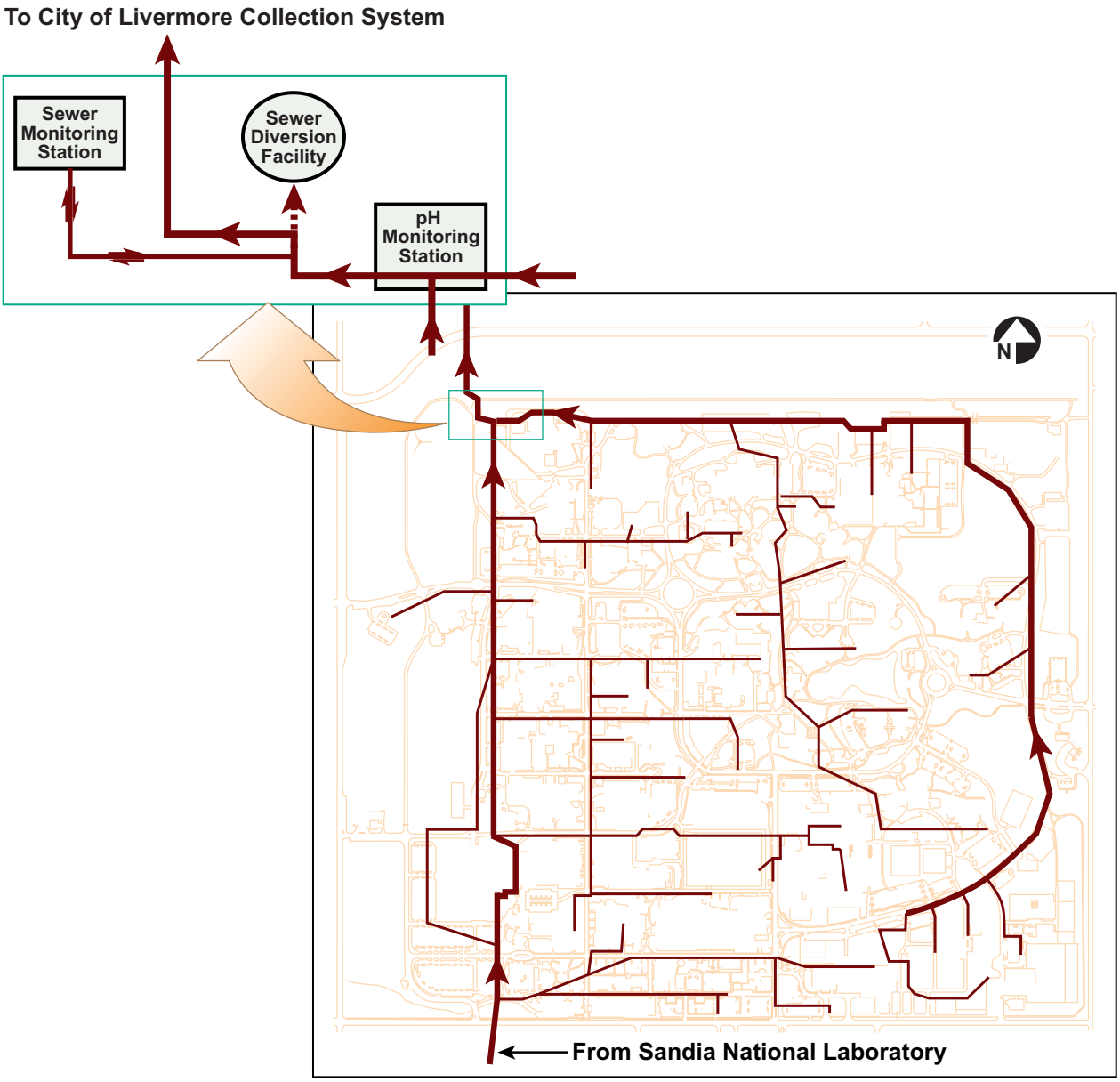


Figure 4-1. LLNL sanitary sewer system, monitoring stations, and diversion facility

concentrations above warning levels are detected the site effluent is automatically diverted to the Sewer Diversion Facility (SDF), and an alarm is registered at the LLNL Fire Dispatcher's Station, which is attended 24 hours a day. 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.

In addition to the continuous monitoring at the SMS, LLNL monitors pH at the upstream pH Monitoring Station (pHMS) (see **Figure 4-1**). The pHMS continuously monitors pH during peak flow hours 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.

LLNL maintains and operates a diversion system that activates automatically when either the SMS continuous monitoring system or the pHMS detects an anomalous condition. 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 potential 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 and then released to the sanitary sewer. All diverted sewage in 2004 was returned to the sanitary sewer.

Radiological Monitoring Results

Work Smart Standards (WSS) establish the standards of operation at LLNL (see Chapter 2), and include the standards for sanitary sewer discharges. For radioactive material releases, complementary (rather than overlapping) sections from Department of Energy (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. From 10 CFR Part 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 Part 20 limit on total tritium activity dischargeable during a single year (185 GBq [5 Ci]) is primary over the DOE Order 5400.5 concentration-based limit for tritium for facilities such as LLNL that generate wastewater in large volumes. In addition to the DOE average concentration discharge limit for tritium and the 10 CFR Part 20 annual total discharge limit for tritium, the LWRP established in 1999 an effluent concentration discharge limit for LLNL governing 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 following discussion includes the specific radioisotopes with potential to be found in the sanitary sewer effluent at LLNL with respect to the appropriate discharge limit. (All analytical results are included in the file "Ch4 LV Wastewater" provided on the report CD.)

LLNL determines the total radioactivity released from tritium, gross alpha emitters, and gross beta emitters from the measured radioactivity in the monthly effluent samples. The 2004 combined release of alpha and beta sources was 0.54 GBq (0.15 Ci), which is 0.054% of the corresponding 10 CFR Part 20 limit (37 GBq [1.0 Ci]). The combined total is the sum of the alpha and beta results shown in **Table 4-1**. The tritium total was 1.3 GBq (0.35 Ci), which is 0.72% of the 10 CFR Part 20 limit (185 GBq [5 Ci]).

Table 4-1. Estimated total radioactivity in LLNL sanitary sewer effluent, 2004

Radioactive emitter	Estimate based on effluent activity (GBq)[a]	Limit of sensitivity (GBq)
Tritium	1.34	1.12
Gross alpha sources	0.03	0.112
Gross beta sources	0.51	0.239

a 37 GBq = 3.7×10^{10} Bq = 1 Ci

Summary results and statistics for tritium measured in the sanitary sewer effluent from LLNL and LWRP are presented in **Table 4-2**. The total monthly activity is calculated by multiplying each monthly concentration by the total flow volume over which the sample was collected. (Per DOE guidance, all total annual results presented in this chapter for radioactive emitters are calculated by using the analytical results regardless of whether they were above or below the detection limit. [U.S. DOE 1991])

As shown in **Table 4-2**, the median monthly concentration and the maximum monthly average concentration of tritium were a small fraction of the DOE annualized discharge limit (370 Bq/mL [0.01 µCi/mL]). The maximum daily concentration for tritium was far below the permit discharge limit (12 Bq/mL [333 pCi/mL]).

The historical trend in the monthly concentration of tritium is shown in **Figure 4-2** (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 [0.01 µCi/mL]).

The concentrations of plutonium-239 and cesium-137 measured in the sanitary sewer effluent from LLNL and LWRP, and LWRP sludge are presented in **Tables 4-3** and **4-4**, respectively. The plutonium and cesium results are from monthly composite samples of LLNL and LWRP effluent, and quarterly composites of LWRP sludge. For 2004, the annual total discharge of cesium-137 and the annual total plutonium-239 were far below the DOE DCG. Plutonium discharged in LLNL effluent is ultimately concentrated in LWRP sludge. The median plutonium concentration observed in 2004 sludge (**Table 4-4**), is many times lower than the EPA preliminary remediation goal for residential soil (93 mBq/dry g [2.5 pCi/dry g]) and is 18,500 times lower than the remediation goal for industrial or commercial soil (370 mBq/dry g [10 pCi/dry g]).

Table 4-2. Summary statistics of tritium in sanitary sewer effluents, LLNL and LWRP, 2004

Monitoring results			
	LLNL		LWRP
	Daily	Monthly	Monthly
Maximum (Bq/mL)	0.04[a]	0.006[b]	0.004[c]
Median (Bq/mL)	0.002	0.003	0.0006
LLNL annual total (GBq)	1.34		

Discharge limits for LLNL effluent			
	Discharge limit	Monitoring results as percentage of limit	
		Maximum	Median
LWRP permit daily (Bq/mL)	12	0.33%	0.02%
DOE annualized discharge limit for application of BAT[d] (Bq/mL)	370	0.002%[e]	0.0008%[e]
10 CFR 20 annual total (GBq)	185	0.7%	

a This daily result is for an August sample.

b This is the monthly value for May. All monthly values above limit of sensitivity are plotted in **Figure 4-2.**

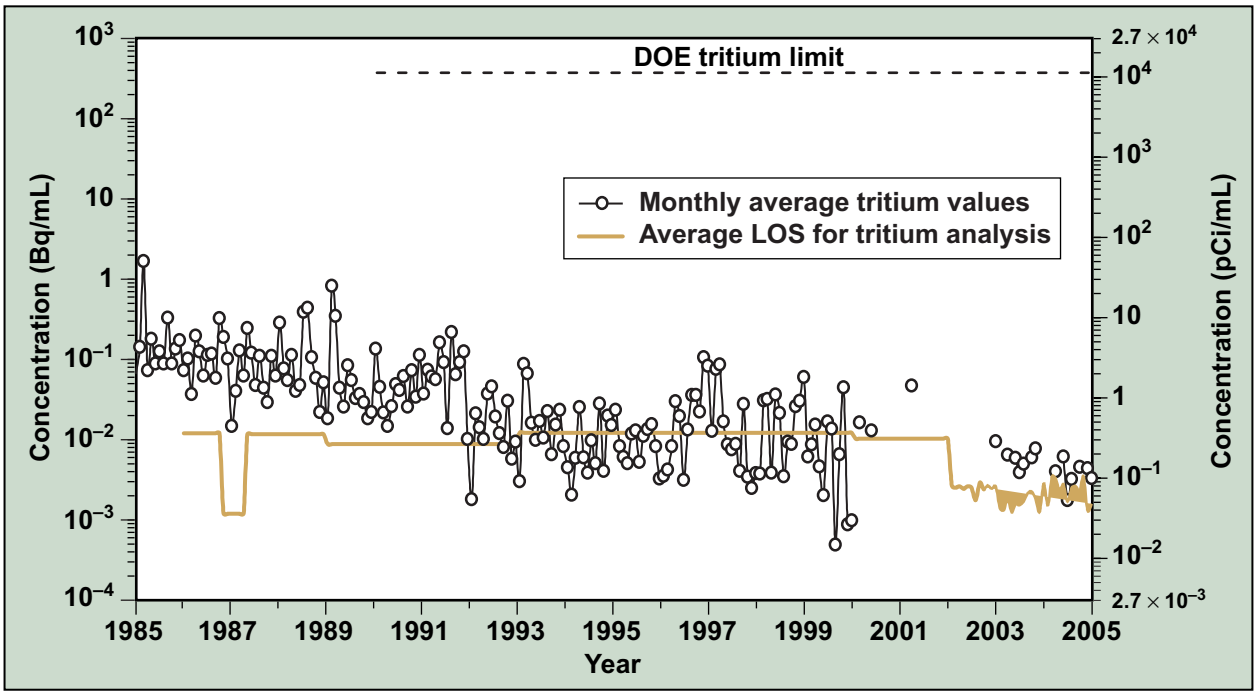
c This is the monthly result for March.

d The DOE annualized discharge limit for application of best available technology (BAT) is five times the derived concentration guide (DCG: ingested water) for each radionuclide released.

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

Figure 4-3 summarizes the cesium-137 and plutonium-239 monitoring data over the past 10 years. The historical levels for plutonium-239 observed since 1995 average approximately 1 µBq/mL (3×10^{-5} pCi/mL). These historical levels generally are 0.0003% of the DOE DCG for plutonium-239. The cyclic nature of the data in **Figure 4-3** suggests a potential frequency relationship in LLNL sewer lines for radionuclide buildup and subsequent liberation by line cleaning. Regardless, the higher plutonium and cesium concentrations are all well below applicable DOE DCGs.

LLNL also compares annual discharges with historical values to evaluate the effectiveness of ongoing discharge control programs. **Table 4-5** summarizes the radioactivity in sanitary sewer effluent over the past 10 years. During 2004, a total of 1.3 GBq (0.35 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 during the past 10 years.



Note: Only values above the limit of sensitivity (LOS) of the analytical method used are plotted.

Figure 4-2. Historical tritium concentrations in the Livermore site sanitary sewer effluent

Nonradiological Monitoring Results

LLNL monitors sanitary sewer effluent for chemical and physical parameters at different frequencies depending on the intended use of the result. For example, LLNL's wastewater discharge permit requires LLNL to collect monthly 24-hour composites, weekly composites, and daily composites. Once a month, a 24-hour, flow-proportional composite is collected and analyzed; this is referred to as the monthly 24-hour composite in the discussion below. The weekly composite refers to the flow-proportional samples collected over a 7-day period continuously throughout the year. The daily composite refers to the flow-proportional sample collected over a 24-hour period, also collected continuously throughout the year. LLNL's wastewater discharge permit specifies that the effluent pollutant limit (EPL) is equal to the maximum pollutant concentration allowed per 24-hour composite sample. Only when a weekly composite sample concentration is at or above 50% of its EPL are daily samples collected during the corresponding period analyzed to determine if any of their concentrations are above the EPL.

To better understand the characteristics of the Livermore site sanitary sewer effluent, LLNL also tracks flow-weighted monthly concentrations for all regulated metals in LLNL's sanitary sewer effluent; **Table 4-6** presents the flow-weighted monthly concentrations for 2004. To obtain these concentrations, each weekly composite is weighted by the total flow volume for the period during which the sample was collected. This flow-weighted monthly concentration represents the characteristic concentration for that

Table 4-3. Cesium and plutonium in LLNL and LWRP sanitary sewer effluents, 2004

Month	Cesium-137 (μBq/mL)				Plutonium-239 (nBq/mL)			
	LLNL		LWRP		LLNL		LWRP	
	Radioactivity	MDC[a]	Radioactivity	MDC[a]	Radioactivity	MDC[a]	Radioactivity	MDC[a]
Jan	0.80 ± 2.8	3.5	–1.03 ± 4.4	3.9	5.291 ± 5.4	6.7	2.72 ± 3.7	5.1
Feb	9.07 ± 37	37	—[b] ± —[b]	—[b]	60.31 ± 16	6.9	–1.40 ± 3.7	7.5
Mar	0.00 ± 0.0	53	18.7 ± 60	52	38.85 ± 14	7.7	11.8 ± 17	19
Apr	2.68 ± 24	21	–0.07 ± 21	19	19.72 ± 9.0	5.8	–1.90 ± 5.0	10
May	–3.23 ± 21	19	–1.57 ± 22	19	40.33 ± 14	6.4	4.88 ± 4.4	3.2
Jun	0.68 ± 3.8	3.4	0.68 ± 3.8	3.5	22.72 ± 9.1	5.5	–2.10 ± 24	32
Jul	1.54 ± 3.6	3.3	0.39 ± 4.0	3.6	13.47 ± 7.4	6.3	0.00 ± 0.0	82
Aug	5.00 ± 4.3	4.0	1.38 ± 3.6	3.3	23.13 ± 9.1	5.8	1.62 ± 4.1	6.5
Sep	0.79 ± 3.4	3.1	–2.98 ± 4.2	3.5	16.50 ± 7.4	4.6	10.4 ± 6.3	5.4
Oct	0.64 ± 3.8	3.4	1.53 ± 5.4	5.0	14.80 ± 7.3	5.3	–3.36 ± 2.8	10
Nov	1.46 ± 7.0	6.1	3.36 ± 5.9	5.4	14.62 ± 12	16	5.40 ± 7.2	9.9
Dec	1.33 ± 6.9	6.1	0.68 ± 6.0	5.3	46.62 ± 11	4.0	0.24 ± 2.2	4.2
Median	1.06		0.68		21.22		0.93	
	Annual LLNL total discharge by radioisotope							
	Cesium-137				**Plutonium-239**			
Bq/y[c]	8.3×10^{5}				1.16×10^{4}			
Ci/y	2.3×10^{-5}				3.1×10^{-7}			
	Fraction of limit [d]							
DOE 5400.5 DCG[e]	3.2×10^{-6}				6.9×10^{-8}			

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 measured concentration exhibiting a 2σ counting uncertainty greater than or equal to the measured concentration is considered a nondetection (see Chapter 8).

a MDC = minimum detectable concentration

b The sample could not be analyzed due to an inadvertent error at the analytical laboratory.

c 1 Ci = 3.7×10^{10} Bq

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

e DCG = Derived Concentration Guide

Table 4-4. Radioactivity of cesium and plutonium in LWRP sludge, 2004

Month	Cesium-137 (mBq/dry g)[a]	Plutonium-239 (mBq/dry g)[a]
Mar	<1.01	0.126 ± 0.033
Jun	<0.98	0.101 ± 0.051
Sep	<0.99	0.132 ± 0.029
Dec	<1.01	0.141 ± 0.024
Median	1.00	0.129

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

a Results are reported as radioactivity (the measured concentration and ± 2σ counting uncertainty). A measured concentration exhibiting a 2σ counting uncertainty greater than or equal to 100% is considered to be a nondetection and is reported with a less than (<) symbol. See Chapter 8.

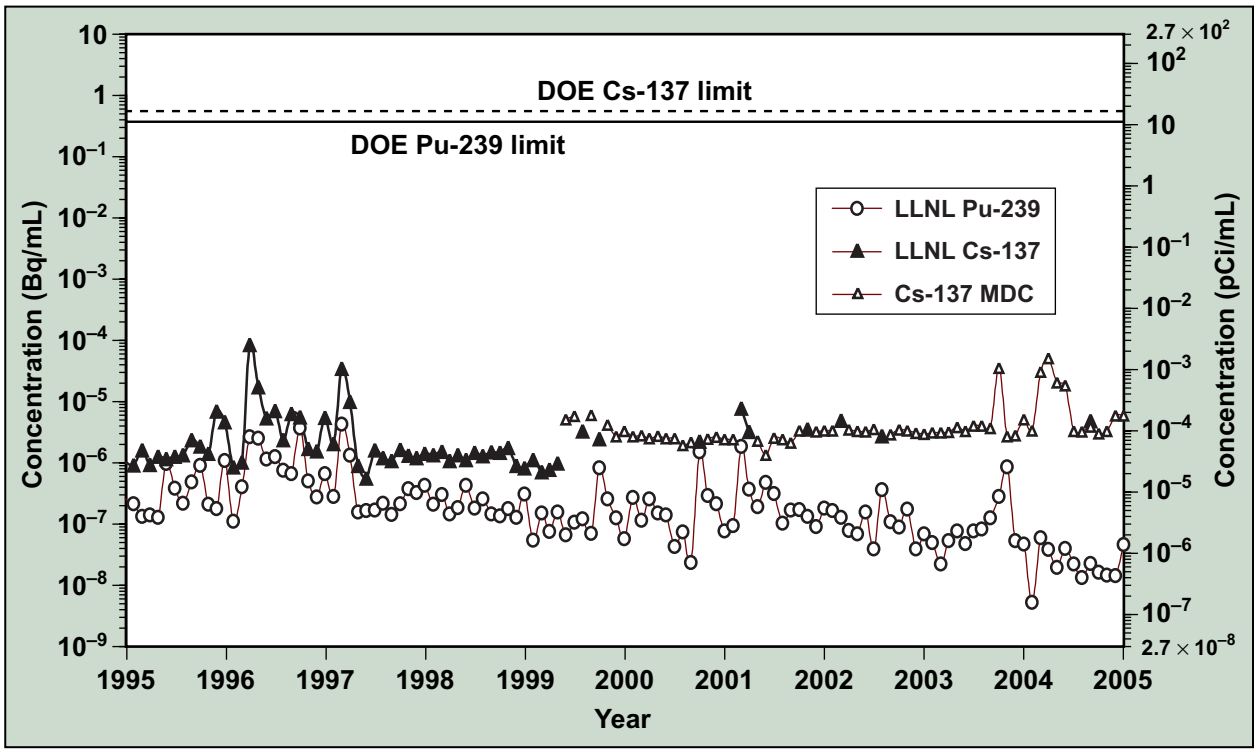


Figure 4-3. Average monthly plutonium and cesium concentrations in LLNL sanitary sewer effluent

Table 4-5. Historical radioactive liquid effluent releases from the Livermore site, 1994–2004

Year	Liquid effluent (GBq)	
	Tritium	Plutonium-239
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	0.77×10^{-4}
1999	7.1	0.68×10^{-4}
2000	5.0	0.96×10^{-4}
2001	4.9	1.1×10^{-4}
2002[b]	0.74	0.42×10^{-4}
2003[b]	1.11	0.51×10^{-4}
2004[b]	1.34	1.16×10^{-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.

b Starting in 2002, following DOE guidance, actual analytical values were used to calculate total instead of LOS values.

month. In 2004, the flow-weighted monthly concentrations were generally typical of the values seen in recent years. In **Table 4-6**, the 2004 median flow-weighted concentration for each metal is shown and compared with the EPL. The median flow-weighted monthly concentrations for the nine regulated metals remained essentially unchanged, less than 10% variation, from the corresponding 2003 values for all nine regulated metals. These flow-weighted monthly concentration median values were less than 10% of the EPLs for all but copper, lead, and zinc, which were at 18%, 11%, and 15% of the wastewater discharge permit limit, respectively.

Figure 4-4 presents historical trends for the monthly 24-hour composite sample results from 2000 through 2004 for eight of the nine regulated metals; cadmium is not presented because this metal was not detected above the practical quantitation limit (PQL) of 0.005 mg/L. (Typical PQLs for the regulated metals in LLNL sanitary effluent are shown in **Table 4-6**. Sample results for the 2004 monthly 24-hour composites are included in the file "Ch4 LV Wastewater" provided on the report CD.) All of the monthly 24-hour composite samples were in compliance with LLNL's wastewater discharge permit limits. As noted in recent years, the concentrations of silver, arsenic, chromium, mercury (other than the August value of 0.002 mg/L, an analytical artifact resulting from matrix interference), and nickel remain very close to their respective

Table 4-6. Flow-weighted monthly concentrations for regulated metals in LLNL sanitary sewer effluent (mg/L), 2004

Month	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Jan	0.012	0.0026	<0.0050	0.020	0.17	0.00033	0.0095	0.014	0.48
Feb	<0.010	0.0027	<0.0050	0.020	0.15	0.00037	0.0081	0.013	0.42
Mar	<0.010	0.0042	<0.0050	0.023	0.16	0.00055	0.0088	0.019	0.46
Apr	<0.010	0.0038	<0.0050	0.027	0.16	0.00038	0.0093	0.067	0.46
May	<0.010	0.0040	<0.0050	0.027	0.15	0.00042	0.0088	0.038	0.39
Jun	0.013	0.0063	<0.0050	0.030	0.20	0.00073	0.012	0.025	0.48
Jul	<0.010	0.0055	<0.0050	0.020	0.25	0.00034	0.011	0.035	0.38
Aug	0.010	0.0051	<0.0050	0.018	0.23	0.00051	0.010	0.028	0.34
Sep	<0.010	0.0057	<0.0050	0.021	0.30	0.00033	0.012	0.024	0.39
Oct	<0.010	0.0042	<0.0050	0.018	0.18	0.00031	0.010	0.018	0.43
Nov	<0.010	0.0034	<0.0050	0.020	0.18	0.00026	0.0093	0.012	1.88
Dec	<0.010	0.0044	<0.0050	0.018	0.23	0.00029	0.012	0.019	0.44
Median	<0.010	0.0042	<0.0050	0.020	0.18	0.00035	0.0097	0.021	0.44
IQR[a]	—[b]	0.0015	—[b]	0.0045	0.064	0.00012	0.0017	0.012	0.075
EPL[c]	0.20	0.06	0.14	0.62	1.0	0.01	0.61	0.20	3.00
Median fraction of EPL	<0.05	0.07	<0.04	0.03	0.18	0.04	0.02	0.11	0.15
PQL[d]	0.010	0.0020	0.0050	0.010	0.010	0.00020	0.0050	0.0020	0.020

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. See Chapter 8.

c EPL = Effluent pollutant limit (LLNL Wastewater Discharge Permit 1250, 2003/2004, and 2004/2005)

d PQL = practical quantitation limit (These limits are typical values for sanitary sewer effluent samples.)

PQLs. The other metals (copper, lead, and zinc) are regularly detected above their PQLs and continue to show an occasional elevated concentration. Even these elevated values, however, never exceeded 30% of their EPLs in 2004; copper, lead, and zinc peaked at 28%, 21%, and 16% of their respective EPLs.

The monthly 24-hour composite and weekly composite concentrations for 2004 are presented in **Figure 4-5** 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 of 0.005 mg/L in any of the weekly or monthly samples. As previously mentioned, all of the monthly 24-hour composite samples are

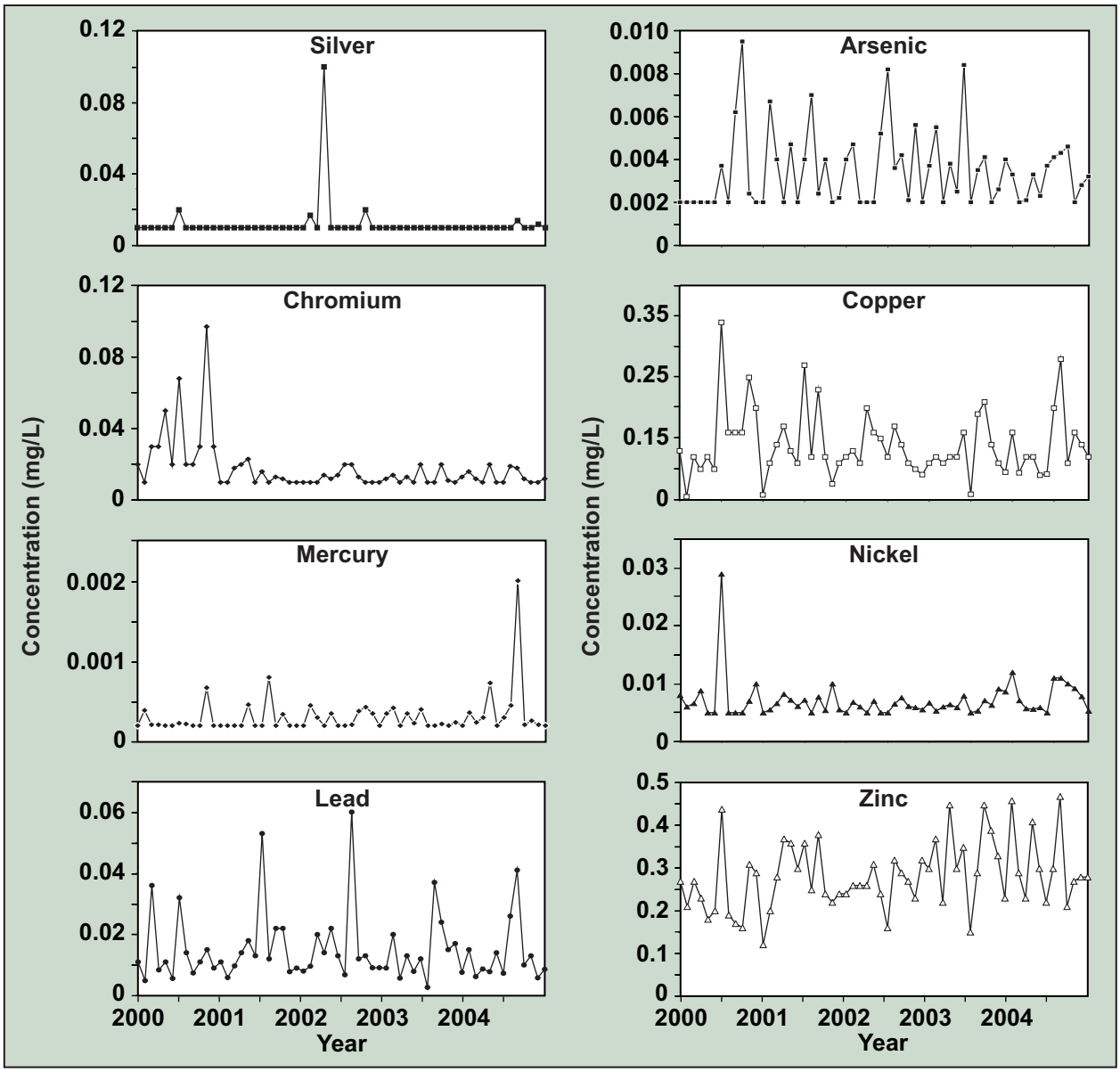


Figure 4-4. Monthly 24-hour composite sample concentrations for eight of the nine regulated metals in LLNL sanitary sewer effluent showing historical trends

well below 50% of their respective EPLs. Of the weekly composites, a total of four samples were identified for additional analyses based on concentrations above the permit-specified action limit.

These investigations examined two weekly samples for lead (from April and May at 126% and 59% of the EPL, respectively), one weekly sample for copper (from September at 68% of the EPL), and one weekly sample for zinc (from November at 193% of the EPL).

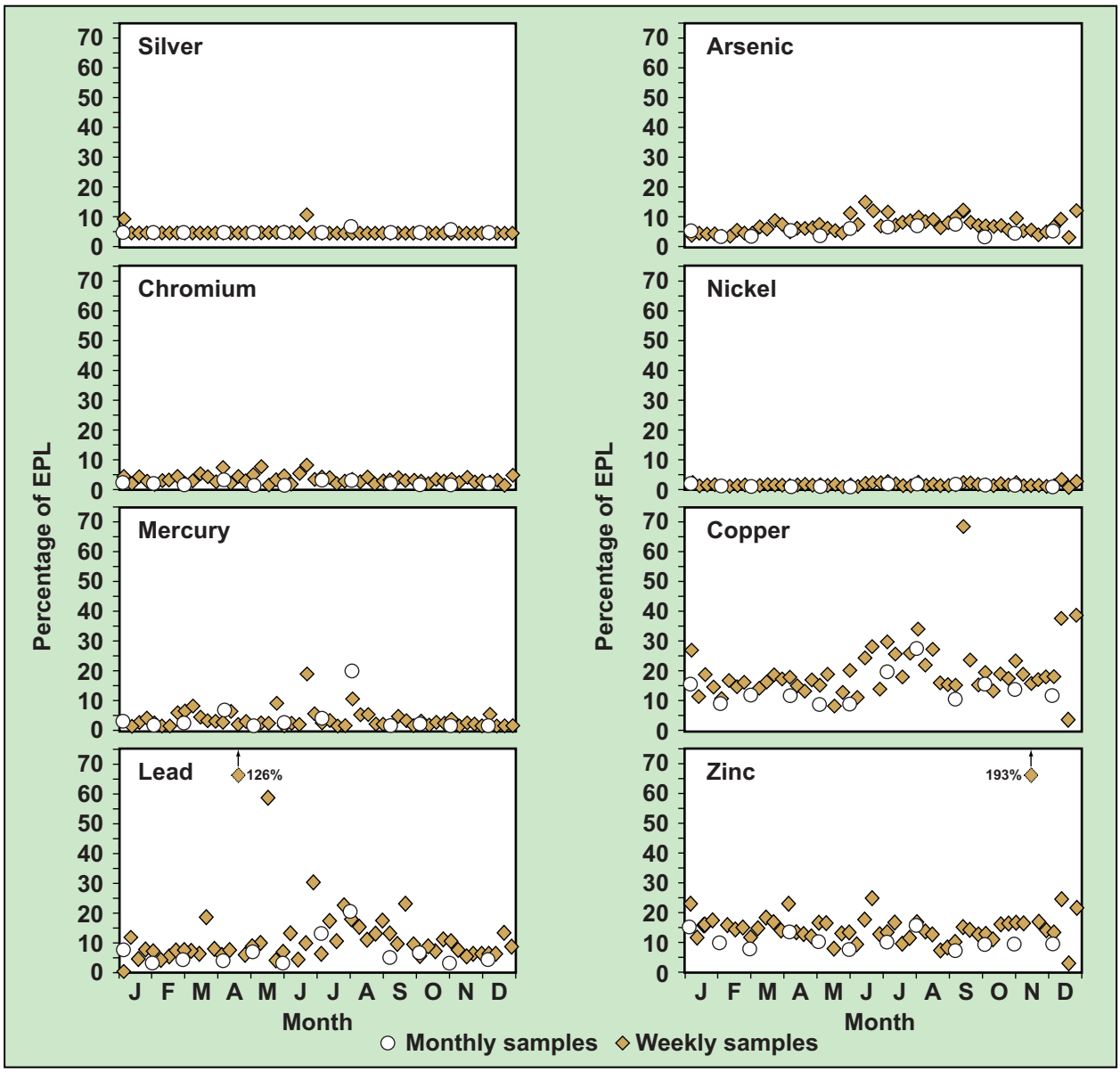


Figure 4-5. Results as percentages of effluent pollutant limits (EPLs) for eight of the nine regulated metals in LLNL sanitary sewer effluent, 2004

As required by the permit, the daily samples that correspond to the appropriate 7-day composite sampling periods were submitted to an off-site contract analytical laboratory for analysis. In each of these four cases, results from the 24-hour composite daily samples demonstrated that no metal concentration exceeded the wastewater discharge limits. Although the LWRP was advised of these elevated metal concentrations (initially detected in weekly composite samples), the results from the follow-up analyses of daily samples were also reported; confirming that there was no threat to the integrity of the

LWRP operations. (Note: Experience has demonstrated a number of limitations associated with the weekly composite sampling location used through 2004, impacting the homogeneity of effluent samples and resulting in anomalous concentration values for the permitted metals. To improve the quality of the weekly samples, the LWRP approved relocating LLNL's weekly composite sampler into the SMS facility alongside the existing daily composite sampling system. This location change became effective on December 30, 2004, and will apply to all the weekly composite samples reported for 2005.)

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 4-7**. (**Table 4-7** does not include the monthly metals results, which are plotted in **Figure 4-5**, or monthly monitoring results for analytes not detected in any of the 24-hour composite or grab samples. All analytical results are included in the file "Ch4 LV Wastewater" provided on the report CD.) The 2004 results are similar to typical values seen in previous years for the two regulated parameters, cyanide and total toxic organics (TTO; see chemicals with a "(g)" superscript in **Table 4-7**), and all other nonregulated parameters. Cyanide (permit limit 0.04 mg/L) was below analytical detection limits (0.02 mg/L) in both the April and September semiannual samples. The monthly TTO values ranged from <0.010 mg/L to 0.065 mg/L (with a TTO median value of 0.036 mg/L), well below the TTO permit limit of 1.0 mg/L. In addition to the organic compounds regulated under the TTO standard, six nonregulated organics were also detected in LLNL's sanitary sewer effluent: three volatile organic compounds (acetone, ethanol, and Freon 113) and three semivolatile organic compounds (benzoic acid, benzyl alcohol, and 3- & 4-methylphenol [m- and p-Cresol]).

In 2004, the SMS continuous monitoring system detected one inadvertent discharge outside the permitted pH range of 5 to 10. This event, with a pH slightly below 5, occurred off-hours (Sunday, March 7, 2004) when the upstream pHMS was off-line. As a result, a small front-end volume of low pH sanitary effluent was released to the LWRP system before the SMS initiated a diversion to the SDF. The LWRP was immediately notified of this low pH discharge; however, this incident did not represent a threat to the integrity of the operations of the LWRP. The lowest pH recorded for effluent contained in the March 7 release was 4.6.

Table 4-7. Monthly monitoring summary for physical and chemical characteristics of the LLNL sanitary sewer effluent, 2004[a]

Parameter	Detection frequency[b]	Minimum	Maximum	Median	IQR[c]
24-hour composite sample parameter (mg/L)					
Alkalinity					
Bicarbonate alkalinity (as $CaCO_3$)	12 of 12	190	330	230	42.5
Carbonate alkalinity (as $CaCO_3$)	7 of 12	<5	68	10.5	—[d]
Total alkalinity (as $CaCO_3$)	12 of 12	210	360	245	62.5
Anions					
Bromide	11 of 12	<0.1	0.6	0.25	0.25
Chloride	12 of 12	41	350	100	200
Fluoride	11 of 12	<0.05	0.39	0.19	0.1

Table 4-7. Monthly monitoring summary for physical and chemical characteristics of the LLNL sanitary sewer effluent, 2004[a] (continued)

Parameter	Detection frequency[b]	Minimum	Maximum	Median	IQR[c]
Nitrate (as N)	10 of 12	<0.1	0.83	0.20	0.38
Nitrate (as NO_3)	10 of 12	<0.5	3.7	0.86	1.6
Nitrate plus Nitrite (as N)	2 of 3[e]	<0.1	1.1	—[e]	—[d]
Nitrite (as NO_2)	4 of 12	<0.5	0.96	<0.5	—[d]
Orthophosphate	11 of 11[f]	9.3	20	16	5.5
Sulfate	12 of 12	<0.1	0.6	0.25	0.25
Nutrients					
Ammonia nitrogen (as N)	12 of 12	23	53	42	8.8
Total Kjeldahl nitrogen	12 of 12	35	74	57	13
Total phosphorus (as P)	12 of 12	5.4	11	8.5	1.7
Oxygen demand					
Biochemical oxygen demand	12 of 12	154	349	262	49.8
Chemical oxygen demand	12 of 12	404	712	522	150
Solids					
Settleable solids	12 of 12	5	40	27	11
Total dissolved solids (TDS)	12 of 12	208	970	379	441
Total suspended solids (TSS)	12 of 12	240	650	320	105
Volatile solids	12 of 12	320	820	405	143
Total metals					
Aluminum	12 of 12	0.3	0.74	0.42	0.18
Calcium	12 of 12	14	61	27	27
Iron	12 of 12	1.4	3.4	1.9	0.85
Magnesium	12 of 12	3.1	36	9.5	18
Potassium	12 of 12	17	27	20	4.3
Selenium	3 of 12	<0.002	0.0023	<0.002	—[d]
Sodium	12 of 12	34	240	71	110
Total organic carbon (TOC)	12 of 12	32	62	51	11
Grab sample parameter					
Semivolatile organic compounds (µg/L)					
Benzoic acid	8 of 12	<10	110	<22	—[d]
Benzyl alcohol	11 of 12	<10	650	12	—[d]
Bis(2-ethylhexyl)phthalate[g]	4 of 12	<5	<30	<5.4	—[d]
Butylbenzylphthalate[g]	2 of 12	<2	12	<2	—[d]
Dibutylphthalate[g]	3 of 12	<2	32	<3	—[d]
Diethylphthalate[g]	11 of 12	<10	29	21	—[d]
Phenol[g]	7 of 12	<2	41	<8.5	—[d]
m- and p-Cresol	7 of 12	<2	54	<9.9	—[d]
Total oil and grease (mg/L)[h]	8 of 8	9.5	38	24.5	8.8
Volatile organic compounds (µg/L)					
1,4-Dichlorobenzene[g]	5 of 12	<0.5	2.2	<0.5	—[d]
Acetone	12 of 12	110	520	290	180
Bromodichloromethane[g]	8 of 12	<0.5	3	1.5	—[d]
Bromoform[g]	7 of 12	<0.5	3	0.55	—[d]

Table 4-7. Monthly monitoring summary for physical and chemical characteristics of the LLNL sanitary sewer effluent, 2004[a] (continued)

Parameter	Detection frequency[b]	Minimum	Maximum	Median	IQR[c]
Bromomethane[g]	1 of 12	<1	5.6	<1	—[d]
Chloroform[g]	12 of 12	1.5	17	3.9	7.6
Dibromochloromethane[g]	7 of 12	<0.5	4.5	1.4	—[d]
Dibromomethane[g]	2 of 12	<0.5	0.78	<0.5	—[d]
Ethanol	2 of 12	<800	8300	<800	—[d]
Freon 113	2 of 12	<0.5	61	<0.5	—[d]
Toluene[g]	5 of 12	<0.5	1.3	<0.5	—[d]

a The monthly sample results plotted in **Figure 4-5** and nondetected values are not included 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%, or there is no range, or there are fewer than six results for a sample parameter, the interquartile range is omitted.

e Due to a change in analytical methods, the contract laboratory reported this parameter in only 3 of 12 months. With so few data points, the median value is omitted.

f Analytical laboratory error (one sample was not analyzed within hold time)

g Priority toxic pollutant parameter used in assessing compliance with the total toxic organic (TTO) permit limit of 1 mg/L (1000 μg/L), LLNL Wastewater Discharge Permit 1250, 2003/2004, and 2004/2005

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

Categorical Processes

The U.S. Environmental Protection Agency (EPA) publishes Categorical standards 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. At LLNL, the federal Categorical requirements are incorporated into the wastewater discharge permit (1250 (04-05)), which is administered by the LWRP. The number of processes at LLNL under these standards is subject to periodic change as programmatic requirements dictate. During 2004, 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). Only those processes that discharge to the sanitary sewer require sampling, inspection, and reporting. Three of the 15 processes meet these criteria. In 2004, LLNL analyzed compliance samples for all regulated parameters from these three processes and demonstrated compliance with all federal Categorical discharge limits. 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. These 12 nondischarging processes are evaluated semiannually. Wastewater from these nondischarging processes is either recycled or

contained for eventual removal and appropriate disposal by LLNL's RHWM Division. Because these processes do not discharge directly or indirectly to the sanitary sewer, they are not subject to the monitoring and reporting requirements contained in the applicable standard.

As required in LLNL's Wastewater Discharge Permit, compliance with Permit requirements is demonstrated by semiannual sampling and reporting. LWRP Source Control staff performed the required annual inspection and sampling of the three discharging categorical processes in 2004. LLNL Environmental staff sample the same processes semiannually. These compliance samples were analyzed for all regulated parameters and the resulting data collected demonstrate compliance with all federal and local pretreatment limits. Of the three discharging categorical processes, the Building 153 microfabrication facility released the largest volume of water to the sanitary sewer. As a further environmental safeguard, LLNL sampled each volume retained at Building 153 prior to discharge to the sanitary sewer. These monitoring data were reported to the LWRP in July 2004 and January 2005 semiannual wastewater reports (Grayson 2004, 2005).

Discharges of Treated Groundwater

LLNL's groundwater discharge permit (1510G, 2002-2004) allows treated groundwater from the Livermore site Ground Water Project (GWP) to be discharged in the City of Livermore sanitary sewer system. (See Chapter 7 for more information on the GWP.) During 2004, there were six discharges to the sanitary sewer from the GWP. The total volume of treated groundwater discharged to sanitary sewer was 18,645 liters. In each of these discharge events, the groundwater released to the sanitary sewer originated from the lower zone, beneath the LLNL site. These volumes of groundwater were acquired at one of the on-site treatment facilities and used to condition new ion exchange resin columns. These six events were separately sampled and discharged to the sanitary sewer during 2004, all in compliance with self-monitoring permit provisions and discharge limits of the permit. Complete monitoring data are presented in the *Ground Water Discharge Annual Self-Monitoring Report for 2004* (Revelli 2005a).

Environmental Impact of Sanitary Sewer Effluent

During 2004, no discharges exceeded any discharge limits for release of radioactive materials to the sanitary sewer. The data are comparable to the lowest historical values. All the values reported for radiological releases are a fraction of their corresponding limits. Overall, LLNL achieved near perfect compliance with the provisions of its wastewater discharge permit for nonradioactive materials; only one release of nonradiological constituents outside permissible limits (a short pH discharge of 4.6, which was slightly below the 5.0 pH limit) was detected.

The data demonstrate that LLNL has continued the trend of excellent control of radiological and nonradiological discharges to the sanitary sewer. Monitoring results for 2004 reflect an extremely effective year for LLNL's wastewater discharge control program and indicate no adverse impact to the LWRP or the environment from LLNL sanitary sewer discharges.

Site 300 Sewage Ponds and Surface Impoundments

Wastewater samples collected from the influent to the sewage evaporation pond, within the sewage evaporation pond, and flow to the sewage percolation pond; and wastewater samples collected from discharges to the Class II surface impoundments (surface impoundments) from photographic processes, Chemistry Area processes, and Explosives processes were obtained in accordance with the written standardized procedures summarized in the *Environmental Monitoring Plan* (Woods 2005).

Sewage Evaporation and Percolation Ponds

Sewage generated at buildings in the General Services Area at Site 300 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 collectively referred to as sewage ponds) are specified in the Monitoring and Reporting Program (MRP) for Waste Discharge Requirements Order No. 96-248 (WDR 96-248). The monitoring requirements include both wastewater monitoring and groundwater monitoring to detect potential impacts of the sewage on groundwater quality. Wastewater is sampled quarterly at a sampling point (ISWP) in the line running into the sewage pond and within the sewage evaporation pond (ESWP). Overflows into the adjacent percolation pond are also permitted under WDR 96-248 and are sampled as needed in the discharge line (DSWP) from the sewage pond to the percolation pond. Nine groundwater monitoring wells are sampled semiannually to provide information on the groundwater quality in the vicinity of the sewage ponds. All sampling locations are shown in **Figure 4-6**. The wells are screened in three different geological formations: Qal, $Tnbs_1$, and $Tnsc_1$ (see Chapter 7). $Tnbs_1$ (Neroly Formation lower blue sandstone unit) is the regional aquifer.

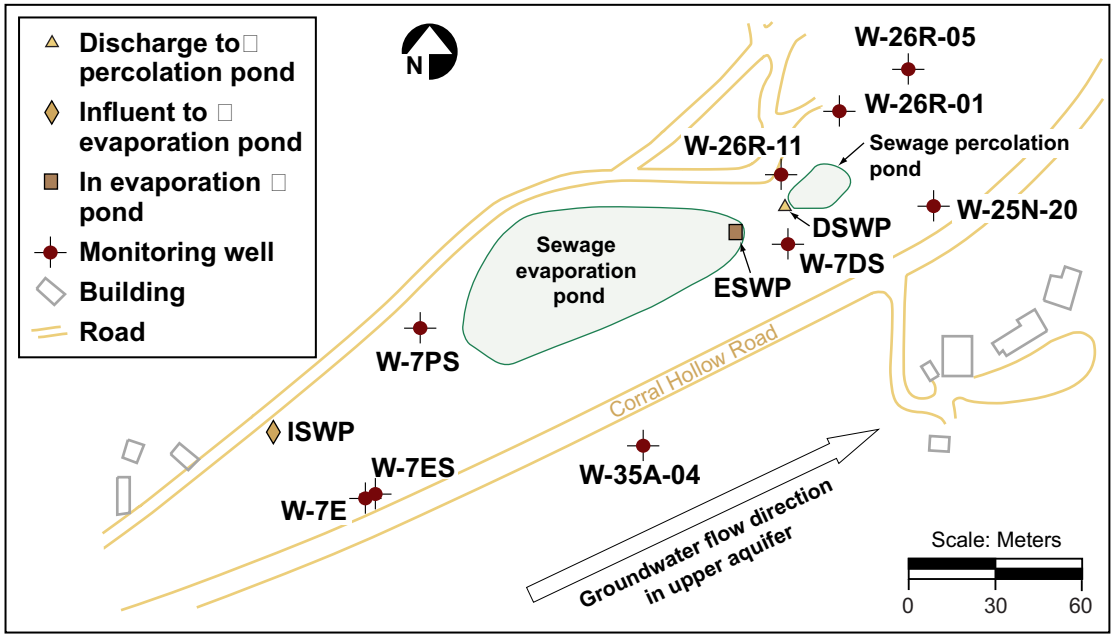


Figure 4-6. Sewage evaporation and percolation ponds, compliance groundwater monitoring wells, and wastewater monitoring locations, 2004

All wastewater parameters for the sewage evaporation and percolation ponds complied with permit provisions and specifications throughout 2004. There was one continuous overflow from the sewage evaporation pond to the percolation pond that began in late December 2003 and continued into the first quarter of 2004. This permitted discharge was sampled twice and reported to the Central Valley Regional Water Quality Control Board (CVRWQCB). For details, see *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Annual/Fourth Quarter Report 2004* (Brown 2005b). All of the monitored groundwater constituents were also in compliance with permit limits.

Surface Impoundments

WDR 96-248 also establishes the basis for compliance monitoring of two connected surface impoundments at Site 300 that receive wastewater and rinsewater discharges from the Explosives Process Area, chemistry buildings, and photographic processes. This includes monitoring of various influent waste streams to the surface impoundments. Influent monitoring complements administrative control of chemicals that could degrade the polyethylene liners of the impoundments. A two-tiered monitoring program comprising weekly visual inspections of the leachate collection and removal systems, and quarterly sampling of monitoring wells is in place to detect any release of chemicals from the surface impoundments.

Wastewater discharges from each of these three processes (explosives, chemistry, and photography) to the surface impoundments are analyzed for constituents of concern (COCs) that have been found, or are likely to be found, in the process water from each specified process area. The monitoring program contained in WDR 96-248 establishes limits for discharges of COCs into the surface impoundments. In addition, no hazardous or radioactive waste is allowed in the surface impoundments.

Influent waste streams are monitored at a prescribed frequency for area-specific COCs. Annual monitoring was performed on discharges from the Explosives Process Area: Buildings 806/807 and 817. (Building 809 is also included in this area but was inactive in 2004.) Discharges from this area were discharged automatically into the surface impoundments. Wastewater from the Chemistry Area (Buildings 825 and 826, and the Building 827 Complex) is held in retention tanks until analytical results indicate that all COCs are within discharge limits. No discharges occurred from the retention tanks at Buildings 825, 826, or 827A; several discharges from Buildings 827C, 827D, and 827E to the surface impoundments occurred in 2004. Photographic process rinsewaters from Buildings 801 and 851 were sampled before being discharged, but were released to the surface impoundments prior to obtaining sample results. Discharges to the surface impoundments from retention tanks at Buildings 801 and 851 were discontinued during the second quarter of 2004. Rinsewater from photographic processes at Building 823 was discharged automatically to the surface impoundments. Quarterly samples were collected and analyzed of those discharges from Building 823 to satisfy the requirements of WDR 96-248.

No release of water to ground from the surface impoundments occurred during 2004. For a detailed account of compliance monitoring of the Site 300 surface impoundments, see *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Annual/Fourth Quarter Report 2004* (Brown 2005b).

The two leachate collection and removal systems were monitored weekly for the presence of liquids to identify potential leaks. None were observed during 2004. No water has been observed in the leachate collection and removal system since liner repairs were made in 1997.

LLNL is required to obtain groundwater samples quarterly from four monitoring wells (see **Figure 4-7**) and has established statistical concentration limits for COCs in groundwater beneath the surface impoundments. These requirements are part of the MRP for the surface impoundments detailed in WDR 96-248. Sporadic detections of ammonia and of the plasticizer compound bis(2-ethylhexyl)phthalate have occurred since 2000. However, because these chemicals have also been detected in method blank samples, LLNL has determined that these COCs were not present in the groundwater samples but were due to laboratory contamination of the samples.

Explosive compounds (HMX, RDX, and breakdown products) 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 present surface impoundments where it infiltrated the soil; some of the explosives wastewater reached groundwater. Because of

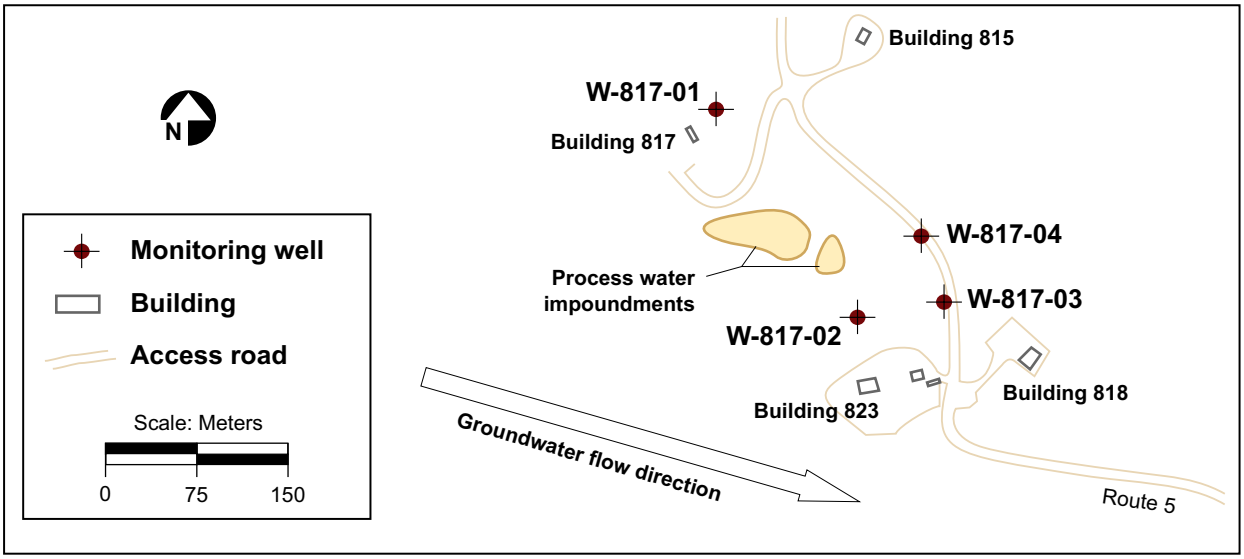


Figure 4-7. Locations of compliance groundwater monitoring wells in the Explosives Process Area, 2004

this past practice, it is necessary under regulations to discriminate between new releases from the surface impoundments and past releases from the unlined ponds. (Background concentrations were statistically calculated for each COC based on historical data from all four monitoring wells. Any sample concentration exceeding background concentration, and by a retest sample, is assumed to come from a new release of that COC.) (See also Chapter 7.) A few concentrations of the energetic compounds PETN, RDX, and 4-amino-2,6-dinitrotoluene that exceeded statistical limits in downgradient monitor wells during the third quarter were determined to be statistical outliers. As statistical outliers, it was not necessary to report them to the CVRWQCB as exceeding statistical limits. LLNL continues to monitor and to track these concentrations. For details, see *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Annual/Fourth Quarter Report 2004* (Brown 2005b).

A split above the waterline in the HDPE liner of the upper surface impoundment was discovered October 13 together with several other weak places or striations. The damage was reported to the CVRWQCB on October 14, observed by the CVRWQCB on October 25, and repaired on November 4, 2004. The surface impoundments are being closed in 2005 because the HDPE liner has exceeded its useful life. An alternate method of wastewater disposal was agreed upon.

Percolation Pits

Percolation pits designed to accept discharges from mechanical equipment are located at Site 300 Buildings 806A, 827A, 827C, 827D, and 827E. In other 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 of the percolation pits. If an overflow should occur, it is sampled and analyzed to determine concentrations of any metals present. During 2004, all of the percolation pits operated normally with no overflows. Percolation pits at Buildings 827C and 827D contained standing water throughout the fourth quarter (Brown 2005b).

Environmental Impact of Sewage Ponds and Surface Impoundments

All discharges from the Site 300 sewage evaporation pond to the percolation pond, as well as discharges to the surface impoundments from the Explosives Process Area, chemistry buildings, and photographic processes were in compliance with discharge limits. Groundwater monitoring related to these areas indicates that there were no measurable impacts to the groundwater from these LLNL wastewater discharges.

Storm Water Compliance and Surveillance Monitoring

To assess compliance with permit requirements, LLNL monitors storm water at the Livermore site in accordance with 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). For construction projects that disturb 0.4 hectares (1 acre) of land or more LLNL also met the storm water compliance monitoring requirements of the California NPDES General Permit for Storm Water Discharges Associated with Construction Activity (WDR 99-08-DWQ, NPDES Permit No. CAS000002) (SWRCB 1999) and subsequent modifications.

Site 300 storm water monitoring also meets the requirements of the *Post-Closure Plan for the Pit 6 Landfill Operable Unit* (Ferry et al. 1998), which includes specific monitoring and reporting requirements. In addition to the storm water quality constituents required by the closure plan, LLNL monitors other constituents to provide a more complete water quality profile. Appendix A includes the current list of analyses conducted on storm water, including analytical methods and typical reporting limits.

Storm water monitoring at both sites also 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 5400.5, Radiation Protection of the Public and the Environment.

At all monitoring locations at both the Livermore site and Site 300, grab samples are collected from the storm water runoff flowing in the storm drains and stream channels. 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 into the water samples. Sample vials for volatile organics are filled before sample bottles for all other constituents and parameters. 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. LLNL is not required to test for fish toxicity at Site 300.

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 on-site activities with no run-on from off-site sources. These samples provide the information necessary to maintain compliance with the SWRCB.

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 during the first hour of one storm event per month in the wet season (defined as October of one year through April [Livermore site] or May [Site 300] of the following year) to observe runoff quality and twice during the dry season to identify any dry weather flows. Influent sampling is also required at the Livermore site. In addition, annual facility inspections are required to ensure that the best management practices (BMPs) to control storm water pollution are implemented and adequate.

Constituent Criteria

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 are not intended to be interpreted as effluent limits (U.S. EPA 2000). Rather, the values are levels that the EPA has used to determine if storm water discharged from any given facility merits further monitoring. Although these criteria are not directly applicable, they are used as comparison criteria to help LLNL evaluate its 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 4-8**). 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, LLNL also compares water samples 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* (CVRWQCB 1998), state and federal maximum contaminant levels (MCLs), and U.S. EPA ambient water quality criteria (AWQC). The greatest importance is placed on the site-specific comparison criteria calculated from historical concentrations in storm runoff.

Storm Water Inspections

Each directorate at LLNL conducts an annual inspection of its facilities to verify implementation of the storm water pollution prevention plans (SWPPPs) and to ensure that measures to reduce pollutant discharges to storm water runoff are adequate. LLNL's associate directors certified in 2004 that their facilities complied with the provisions of LLNL's storm water pollution prevention plans. LLNL submits annual storm water monitoring reports to the SFBRWQCB and to the CVRWQCB with the results of sampling, observations, and inspections (Brown 2004a,b).

For each construction project permitted by WDR 99-08-DWQ, LLNL conducts visual observations of construction sites before, during, and after storms to assess the effectiveness of BMPs. Annual compliance certifications summarize these inspections. Annual compliance certifications for 2004 covered the period of June 2003 through May 2004. When requested by the respective regional water quality control board (RWQCB), LLNL completes annual compliance status reports that cover the same reporting period. During the 2003/2004 reporting period, LLNL had active permits for seven projects located at the Livermore site (see **Table 2-3**). LLNL terminated the permits for four of the projects that were completed during 2004: the Central Cafeteria, East Avenue Security Upgrades, 5th Street, and the International Security Research Facility (formerly known as the Sensitive Compartmented Information Facility).

Table 4-8. Threshold comparison criteria for selected water quality parameters

Parameter	Livermore site	Site 300
Total suspended solids (TSS)	750 mg/L[a]	1,700 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
Beryllium	1.6 μg/L[a]	1.6 μg/L[a]
Chromium(VI)	15 μg/L[a]	not monitored
Copper	13 μg/L[c]	not monitored
Lead	15 μg/L[d]	30 μg/L[a]
Zinc	350 μg/L[a]	not monitored
Mercury	above RL[e]	1 μg/L[a]
Diuron	14 μg/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 radioactivity	0.34 Bq/L[a]	0.90 Bq/L[a]
Gross beta radioactivity	0.48 Bq/L[a]	1.73 Bq/L[a]

Note: The sources of values above these are examined to determine if any action is necessary.

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 Ambient water quality criteria (AWQC)

d California and EPA drinking water action level

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

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 4-8**).

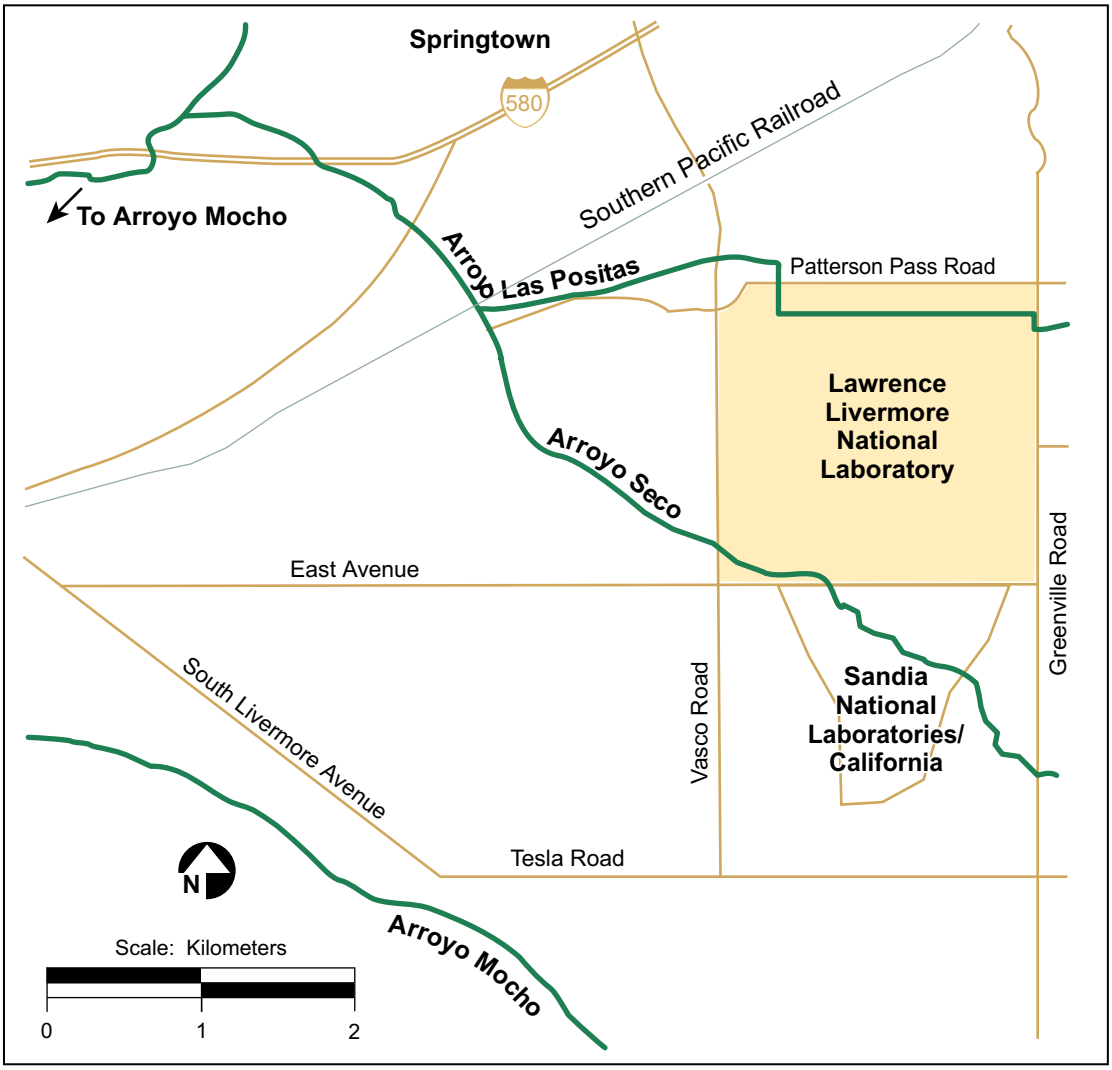


Figure 4-8. Surface waterways in the vicinity of the Livermore site

The Drainage Retention Basin (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 4-9**). 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.

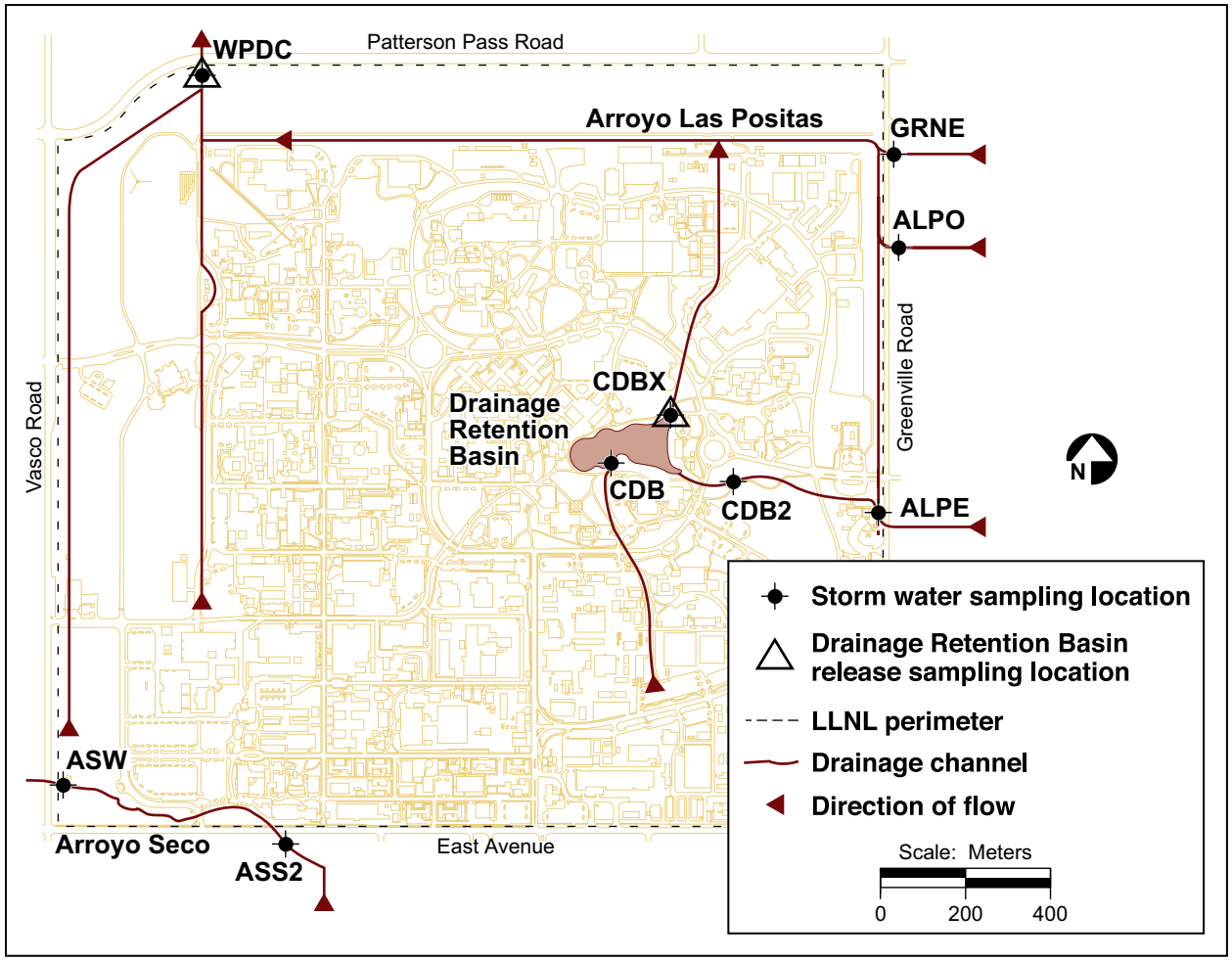


Figure 4-9. Storm water runoff and Drainage Retention Basin sampling locations, Livermore site, 2004

The routine Livermore site storm water runoff monitoring network consists of nine sampling locations (**Figure 4-9**). Six locations characterize storm water either entering (influent: ALPE, ALPO, ASS2, and GRNE) or exiting (effluent: ASW and WPDC) the Livermore site. Sampling locations CDB and CDB2 are internal sites used by LLNL staff, outside the requirements of the storm water permit, to characterize storm water runoff quality entering the DRB; location CDBX characterizes water leaving the DRB. LLNL collected samples at all nine locations on February 2, February 26, and October 26, 2004.

As required by WDR 95-174, grab samples were also 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.

Radiological Monitoring Results

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 4-9**. (Complete analytical results are included in the file "Ch4 Storm Water" provided on the report CD.) Tritium activities at site effluent sampling locations were less than 1% of the MCL. Gross alpha and gross beta radioactivity in the storm water samples collected during 2004 were generally low, with medians around background levels. Gross alpha and gross beta activities exceeded LLNL-specific comparison criteria on February 2, 2004, at influent location ALPO. Activities in samples collected at this location are due to upstream discharges. As radioactive constituents are more likely to be associated with sediments, this result is not an indicator of unusual water quality.

Table 4-9. Statistics on radioactivity in storm water from the Livermore site, 2004[a]

Parameters	Tritium (Bq/L)	Gross Alpha (Bq/L)	Gross Beta (Bq/L)
MCL	740	0.555	1.85
Influent			
Median	0.23	0.060	0.205
Minimum	–0.33	0.022	0.088
Maximum	1.4	0.700	1.2
Effluent			
Median	1.3	0.062	0.135
Minimum	–1.5	0.014	0.099
Maximum	4.1	0.130	0.460

a See Chapter 8 for an explanation of calculated values.

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 2004, there were no plutonium results above the detection limit of 0.0037 Bq/L (0.10 pCi/L).

Nonradiological Monitoring Results

In addition to radioactivity, storm water was analyzed for other water quality parameters. Sample results were compared with the comparison criteria in **Table 4-8**. Of interest 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 and LLNL conducts no further investigation. (Complete analytical results are included in the file "Ch4 Storm Water" provided on the report CD.) Constituents that exceeded comparison criteria for effluent and/or influent locations are listed in **Table 4-10**. Many of the values above threshold comparison criteria for the Livermore site were found at influent tributaries to Arroyo Las Positas. For instance, all diuron concentrations above threshold limits are at influent locations east of the Livermore site as has occurred in past years and have been explained in Campbell et al. (2004). For most of the data that exceeded LLNL thresholds, the effluent results were either lower than or approximately equal to influent results, indicating that the LLNL activities had no impact. Exceptions to this include copper at ASW on February 2 and zinc at WPDC on February 2 and February 25. Upstream activities near the Livermore site that may explain the influent water quality include a small vineyard and cattle ranching that are potential sources for suspended sediment, nitrogen (including nitrate), and diuron and bromacil (herbicides) with their attendant effect on chemical oxygen demand. Other metals detected are likely associated with elevated suspended sediment loading. LLNL will continue to examine copper and zinc concentrations in storm water runoff to determine if further action is necessary.

LLNL conducted both acute and chronic fish toxicity analyses on storm water samples collected on October 26 from effluent location WPDC in order to catch the first flush of runoff that occurs at the beginning of the wet season. WDR 95-174 states that an acceptable survival rate for the toxicity monitoring is 20% lower than a control sample. The testing laboratory provides water for the control sample, which consists of EPA synthetic moderately-hard water. Thus, a difference of more than 20% between location WPDC and the 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 2004, survival in the acute test at WPDC was 95%, while the control sample survival rate was 100% (**Table 4-11**). Chronic toxicity tests using the fathead minnows exposed to different concentrations of the storm water for seven days also found no significant toxicity. The results show that LLNL's effluent water sample shows no toxicity, either acute or chronic, to the fathead minnows.

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 natural continuously flowing streams are present in the Site 300 area. Elk Ravine is the major drainage 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 toward the San Joaquin River Basin. Some smaller canyons in the northeast portion of the site drain to the north and east toward Tracy.

Table 4-10. Water quality parameters in storm water runoff above LLNL-specific threshold comparison criteria, Livermore site in 2004

Parameter	Date	Location	Influent, Effluent, or Internal[a]	Result (mg/L)	LLNL threshold criteria (mg/L)
Nonradioactive (mg/L)					
Total suspended solids	2/2	ALPO	Influent	1900	750
Chemical oxygen demand	2/2	ALPO	Influent	230	200
Beryllium	2/2	ALPO	Influent	0.0018	0.0016
Copper	2/2	ASW	Effluent	0.017	0.013
	2/2	ALPE	Influent	0.023	0.013
	2/2	ALPO	Influent	0.069	0.013
	2/2	CDB	Internal	0.018	0.013
	2/2	ACB2	Internal	0.020	0.013
	2/2	WPDC	Effluent	0.030	0.013
	2/25	ALPE	Influent	0.022	0.013
	2/25	ALPO	Influent	0.021	0.013
	2/25	CDB	Internal	0.013	0.013
	2/25	CDB2	Internal	0.014	0.013
	2/25	WPDC	Effluent	0.013	0.013
Diuron	10/26	ALPE	Influent	0.043	0.016
	10/26	CDBX	Internal	0.052	0.016
Lead	2/2	ALPO	Influent	0.025	0.015
	2/2	WPDC	Effluent	0.016	0.015
Mercury	2/25	CDB	Internal	0.00021	0.0002
Nitrate (as NO_3)	10/26	ALPE	Influent	11.5	10
	10/26	GRNE	Influent	18.4	10
Zinc	2/2	WPDC	Effluent	0.63	0.35
	2/25	WPDC	Effluent	0.35	0.35
Radioactive (Bq/L)					
Gross alpha	2/2	ALPO	Influent	0.703 ± 0.26	0.34
Gross beta	2/2	ALPO	Influent	1.17 ± 0.26	0.48

a Internal sites are located on site and discharge into the arroyos. Samples from internal sites provide additional data on storm water constituents at the Livermore site. However, because the analyses from these sampling locations are not permit driven, the data were not reported in the annual monitoring report (Brown 2004a).

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. Several artificial surface water bodies at

Table 4-11. Chronic toxicity test results for fish (fathead minnow) assay from location WPDC, Livermore site, October 26, 2004

Storm water percent solution	Average percent survival
Lab Control	100
12.5	100
25	100
50	100
75	90[a]
100	95

a Two of the four replicates tested at this concentration were affected by a contaminant pathogen unrelated to the storm water sample, as identified by the analytical laboratory. Correcting for these results, average survival would be 95%.

Site 300 are in fact wastewater treatment units discussed above. Three wetlands created by now-discontinued flows from cooling towers located at Buildings 827, 851, and 865 were maintained in 2004 by discharges of potable water.

In 2004, storm water runoff was characterized at six sampling locations that could be affected by specific Site 300 activities. In addition, off-site location CARW is used to characterize Corral Hollow Creek upstream and, therefore, is unaffected by Site 300 industrial storm water discharges. Prior to the beginning of the rainy season 2004–2005, the off-site location CARW was moved to the east to location CARW2, and on-site location NLIN was moved up stream, to the northwest, in Elk Ravine for easier access for sampling technologists to location NLIN2. (Off-site location CARW and on-site location NLIN have been discontinued as of the rainy season 2004–2005.) Off-site location GEOCRK is used to characterize Corral Hollow Creek downstream of Site 300. These locations are shown in **Figure 4-10**.

The Site 300 storm water permit specifies sampling a minimum of two storms per rainy season. Typically, a single storm does not produce runoff at all Site 300 locations because Site 300 receives relatively little rainfall and is largely undeveloped with few paved areas. Therefore, at many locations, a series of large storms is required to saturate the ground before runoff can occur. At some of the sampling locations in some years, there is not enough rain to generate runoff over an entire rainy season. On February 2, storm water samples were collected and analyzed from location N883. A major storm on February 25 generated runoff everywhere, and storm water samples were collected from the remaining three locations that flowed then. The next major storm sampled was on October 19.

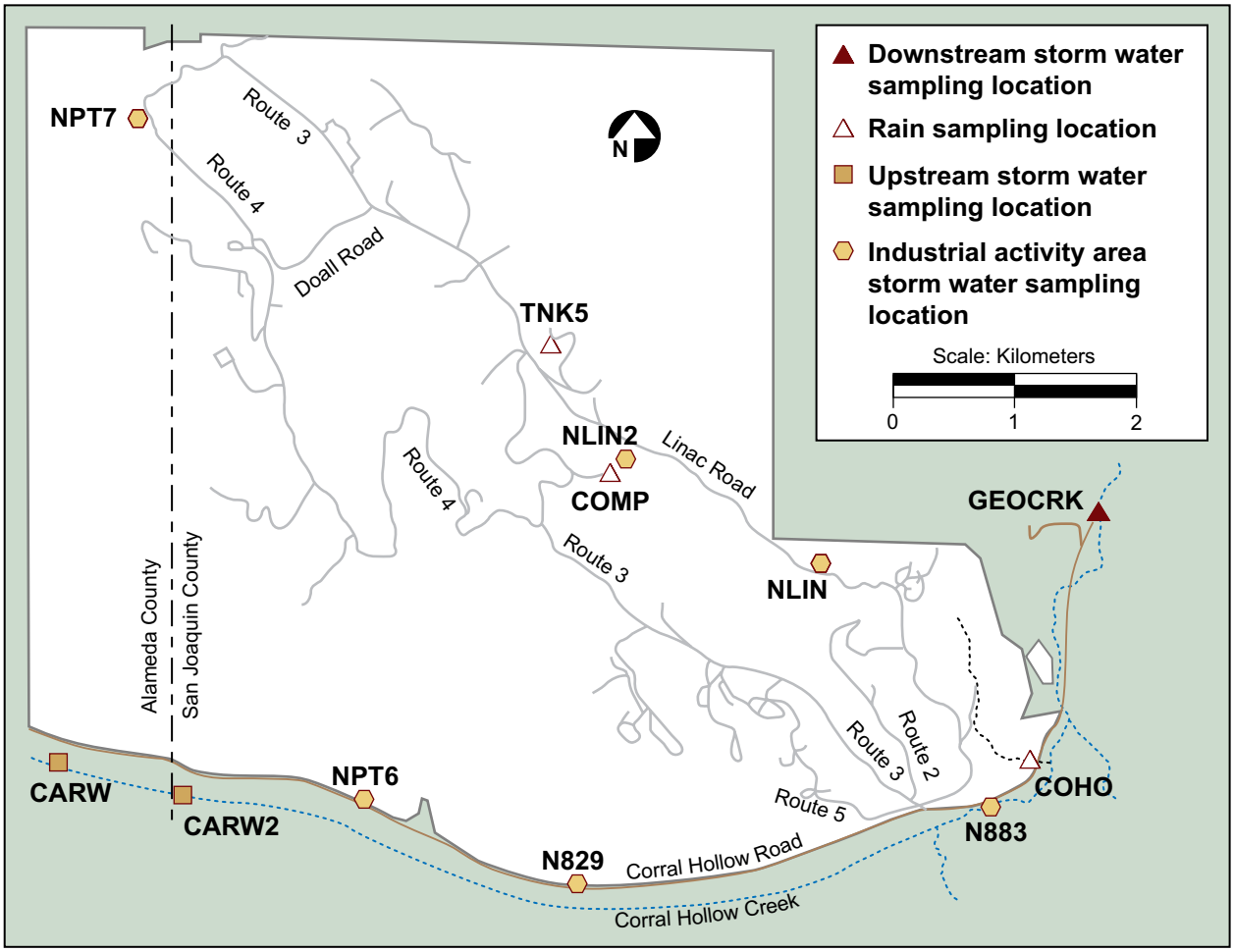


Figure 4-10. Storm water and rainwater sampling locations at Site 300, 2004

Radiological Monitoring Results

Storm water sampling and analysis was performed for gross alpha and gross beta radioactivities, uranium isotopes, and tritium, and results were compared with the comparison criteria in **Table 4-8**. (Complete analytical results are included in the file "Ch4 Storm Water" provided on the report CD.) Concentrations of gross alpha or beta radioactivities exceeding Site 300's threshold concentrations are reported in **Table 4-12**. Tritium activities at all sampled locations were less than 1% of the MCL and less than Site 300's threshold concentration. Gross alpha and gross beta radioactivity in the storm water samples collected from effluent location NLIN on February 25 and those collected from upstream location CARW2 on October 19 exceeded LLNL's site-specific criteria. Both of those samples were associated with higher than normal TSS concentrations. Previous environmental sampling has shown that suspended sediments from this area contain significant quantities of naturally occurring uranium and its daughter decay products that

Table 4-12. Water quality parameters in storm water runoff above LLNL-specific threshold comparison criteria, Site 300, 2004

Parameter	Date	Location	Upstream or Effluent,	Result	Threshold criteria
Nonradioactive (mg/L)					
Total suspended solids	2/25	NLIN	Effluent	4400	1700
Beryllium[a]	10/19	CARW2	Upstream	0.0026	0.0016
Lead[a]	10/19	CARW2	Upstream	0.037	0.030
Radioactive (Bq/L)					
Gross alpha[b]	2/25 10/19	NLIN CARW2	Effluent Upstream	1.5 1.2	0.90 0.90
Gross beta[b]	2/25 10/19	NLIN CARW2	Effluent Upstream	2.6 2.1	1.73 1.73

a Total metals including particulates

b Total radiation including particulates

account for the elevated gross alpha and beta radioactivity. No concentration of gross alpha or gross beta radioactivity measured in downstream location GEOCRK exceeded the site-specific threshold concentrations.

Nonradiological Monitoring Results

Site 300 storm water samples were analyzed for nonradiological water quality parameters, and sample results were compared with the comparison criteria in **Table 4-8**. Of most interest would be the constituents that exceed comparison criteria at GEOCRK, the downstream location, and whose concentrations are lower in influent than at location GEOCRK. During 2004 no constituent concentrations exceeded comparison criteria at GEOCRK. Constituents that exceeded comparison criteria for effluent and upstream locations are listed in **Table 4-12**. Concentrations of TSS in a storm water sample collected from location NLIN on February 25 reached 4400 mg/L, greater than the Site 300 threshold value of 1700 mg/L. High TSS concentrations are not unusual in large storms generating runoff in Elk Ravine. Concentrations of beryllium (2.6 µg/L) and lead (37 µg/L) in storm water samples collected from upstream location CARW2 on October 19 exceeded their site-specific criteria for those metals. Although the TSS associated with the October 19 sample (1100 mg/L) was less than the site-specific criteria, it is likely that the metals concentrations are associated with particulates carried in the storm water runoff. (Complete analytical results are included in the file "Ch4 Storm Water" provided on the report CD.)

Because of a Comprehensive Environmental Response Compensation Liability Act (CERCLA) remedial investigation finding of past releases of dioxins and polychlorinated biphenyls (PCBs) related to activities in the vicinity of Building 850, analysis for these compounds was conducted on runoff samples collected on February 25 from location NLIN and on October 19 from location NLIN2, the storm water sampling location

downstream from Building 850. It was also conducted for downstream off-site location GEOCRK. The intent of the sampling was to determine whether these constituents are being released down Elk Ravine and, eventually, off site in storm water runoff. (Complete analytical results are included in the file "Ch4 Storm Water" provided on the report CD.) No PCBs were detected in those samples. All dioxins detected were below the equivalent federal MCL of 30 pg/L.

The federal MCL for dioxin is for the congener 2,3,7,8-TCDD, the most toxic dioxin. The other dioxin congeners reported have varying degrees of toxicity. EPA has assigned toxicity equivalency factors (TEFs) to specific dioxin congeners. 2,3,7,8-TCDD is assigned a TEF of 1; the other dioxin congeners have TEFs less than 1. The toxicity equivalency (TEQ) is determined by multiplying the concentration of a dioxin congener by its TEF. **Table 4-13** shows the concentrations of dioxin compounds that were detected at locations NLIN2 and GEOCRK in those samples along with their TEQs. These values are well below the concentrations of similar dioxins measured in 2002 (see *LLNL Site 300 Annual Storm Water Monitoring Report for Waste Discharge Requirements 97-03-DWQ Annual Report 2002–2003* [Sanchez 2003]). LLNL will continue to monitor storm water concentrations to determine if any trends are developing.

Table 4-13. Total toxicity equivalents of dioxin congeners in storm water runoff (pg/L) at Site 300, October 19, 2004

Dioxin cogener	NLIN2 concentration	TEQ[a]	GEOCRK concentration	TEQ[a]
1,2,3,4,6,7,8-HpCDD	13	0.13	54	0.54
Total-HpCDD	25	0.00	93	0.00
Total-OCDD	120	0.12	390	0.39

a Toxicity Equivalents compared to 2,3,7,8-TCDD

Environmental Impact of Storm Water

Storm water runoff from the Livermore site did not have any apparent environmental impacts in 2004. Tritium activities in storm water runoff effluent were less than 1% of the drinking water MCL. Gross alpha and gross beta activities in effluent samples were both less than 25% of their respective MCLs. The fish toxicity tests showed no discernible toxicity in Livermore site storm water runoff. Site 300 storm water runoff monitoring continues to show that contaminants may be transported as part of suspended sediments, but not at concentrations harmful to humans or the environment.

Groundwater

Groundwater monitoring affirms LLNL'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 groundwaters of the two monitored areas are not connected; 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 onto grazing land.

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, contamination can be detected 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 higher than natural background 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 the sources of other contaminants, such as nitrate and perchlorate, are the objects of continuing study.

Beginning in January 2003, LLNL implemented a new CERCLA comprehensive compliance monitoring plan at Site 300 (Ferry et al. 2002) that adequately covers the DOE requirements for on-site groundwater surveillance; LLNL monitoring related to CERCLA activities is described in Chapter 7. Additional monitoring programs at Site 300 comply with numerous federal and state controls such as 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, the latter discussed previously in this chapter. Compliance monitoring is specified in WDRs issued by the CVRWQCB and in landfill closure and post-closure monitoring plans. (See **Table 2-2** for a summary of LLNL permits.)

The WDRs and post-closure plans specify wells and effluents to be monitored, 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 closed facilities, such as those that have undergone CERCLA or RCRA closure, and their monitoring networks. As described in a previous section, LLNL conducts additional operational monitoring of wastewater effluents discharged to surface impoundments and sewage evaporation and percolation ponds to comply with WDRs. Quarterly and annual written reports of analytical results, inspection findings, and maintenance activities are required for each compliance monitoring network.

Typically, because they are both accurate and sensitive, analytical methods approved by EPA are used to measure dissolved constituents in water. Appendix A lists 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). The listed methods are not all used for samples from each groundwater monitoring location. Rather, for cost effectiveness, only those contaminants that have been detected historically or that might result from continuing LLNL operations are monitored at each groundwater sampling location. However, present-day administrative, engineering, and maintenance controls at both LLNL sites are specifically tailored to prevent releases of potential contaminants to the environment.

During 2004, 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) (Goodrich and Depue 2003). These protocols cover sampling techniques and specific information concerning the chemicals that are routinely analyzed for in groundwater. Different sampling techniques were applied to different wells depending on whether they were fitted with submersible pumps, or had to be bailed. All of the chemical and radioactivity analyses of groundwater samples were performed by California-certified analytical laboratories. For comparison purposes only, some of the results are compared with drinking water limits (MCLs); however, the MCLs do not apply as regulatory limits to any of these groundwaters.

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 from LLNL. Rain and storm water runoff in the Livermore Valley, which recharge local aquifers, contain small amounts of HTO from natural sources, past worldwide atmospheric nuclear weapons tests, and atmospheric emissions from LLNL. (See Chapters 3 and 6 for further discussion of air emissions, and other parts of this chapter for further discussion of rain and storm water runoff.)

Groundwater is recharged at the Livermore site, primarily from arroyos by rainfall. Groundwater flow beneath the Livermore site is generally southwestward. An overview of groundwater flow is provided in Chapter 1 and is discussed in detail in the *CERCLA Remedial Investigation Report for the LLNL Livermore Site* (Thorpe et al. 1990) and in the *LLNL Ground Water Project 2004 Annual Report* (Karachewski et al. 2005).

Groundwater samples were obtained during 2004 from 23 of 25 water wells in the Livermore Valley (see **Figure 4-11**) and measured for tritium activity. Two wells were either dry or could not be sampled during 2004.

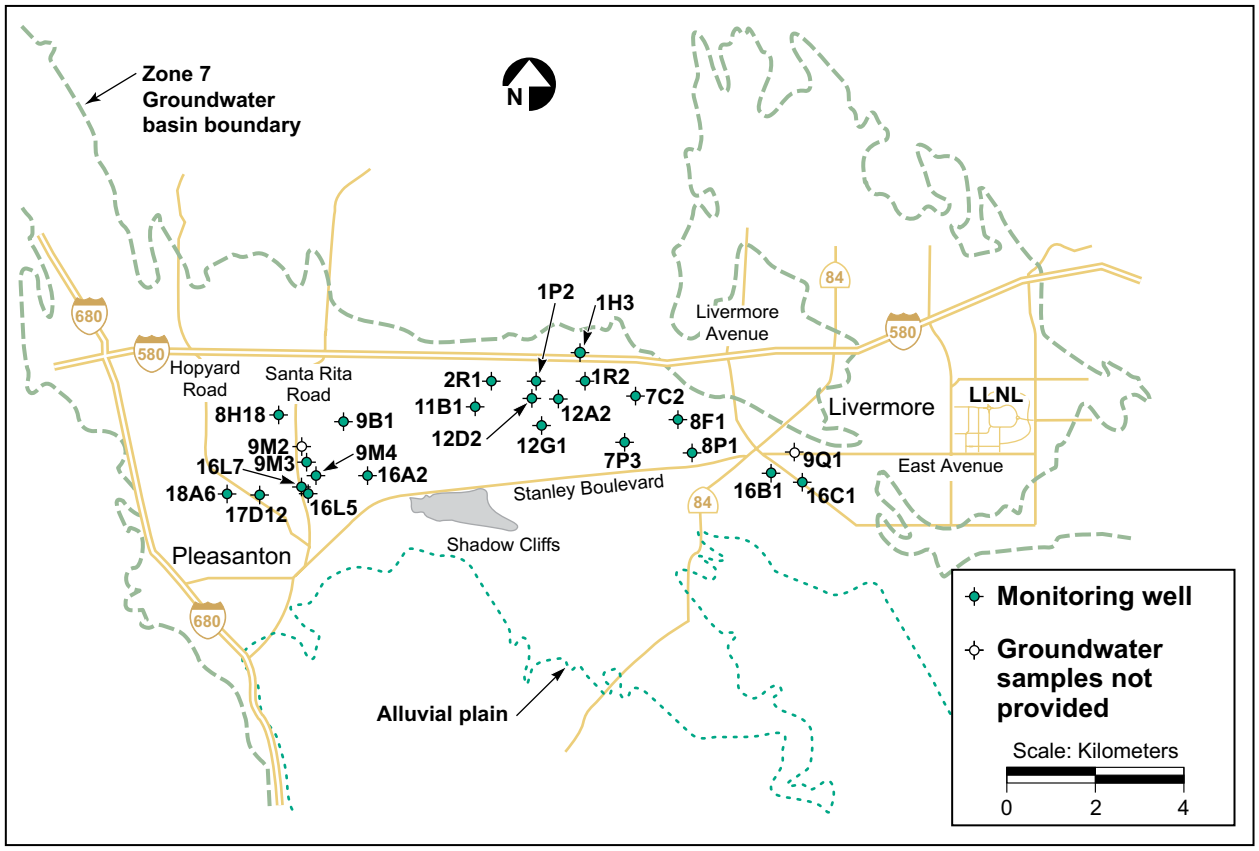


Figure 4-11. Locations of off-site tritium monitoring wells in the Livermore Valley, 2004

Tritium measurements of Livermore Valley groundwaters are contained in the file "Ch4 LV Groundwater" provided on the report CD. They continue to show very low and decreasing activities compared with the 740 Bq/L (20,000 pCi/L) MCL established for drinking water in California. The maximum tritium activity measured off site was in the groundwater at well 12D2, located about 11 km west of LLNL (see **Figure 4-11**). The measured activity there was 5.4 Bq/L (150 pCi/L) in 2004, less than 1% of the MCL.

Livermore Site Perimeter

LLNL designed a surveillance monitoring program to complement the Livermore Site GWP (discussed in Chapter 7). 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 4-12**). These seven wells, located in the regions of groundwater Treatment Facilities (TF) A, B, and C (see **Figure 7-2**) are located at or beyond the

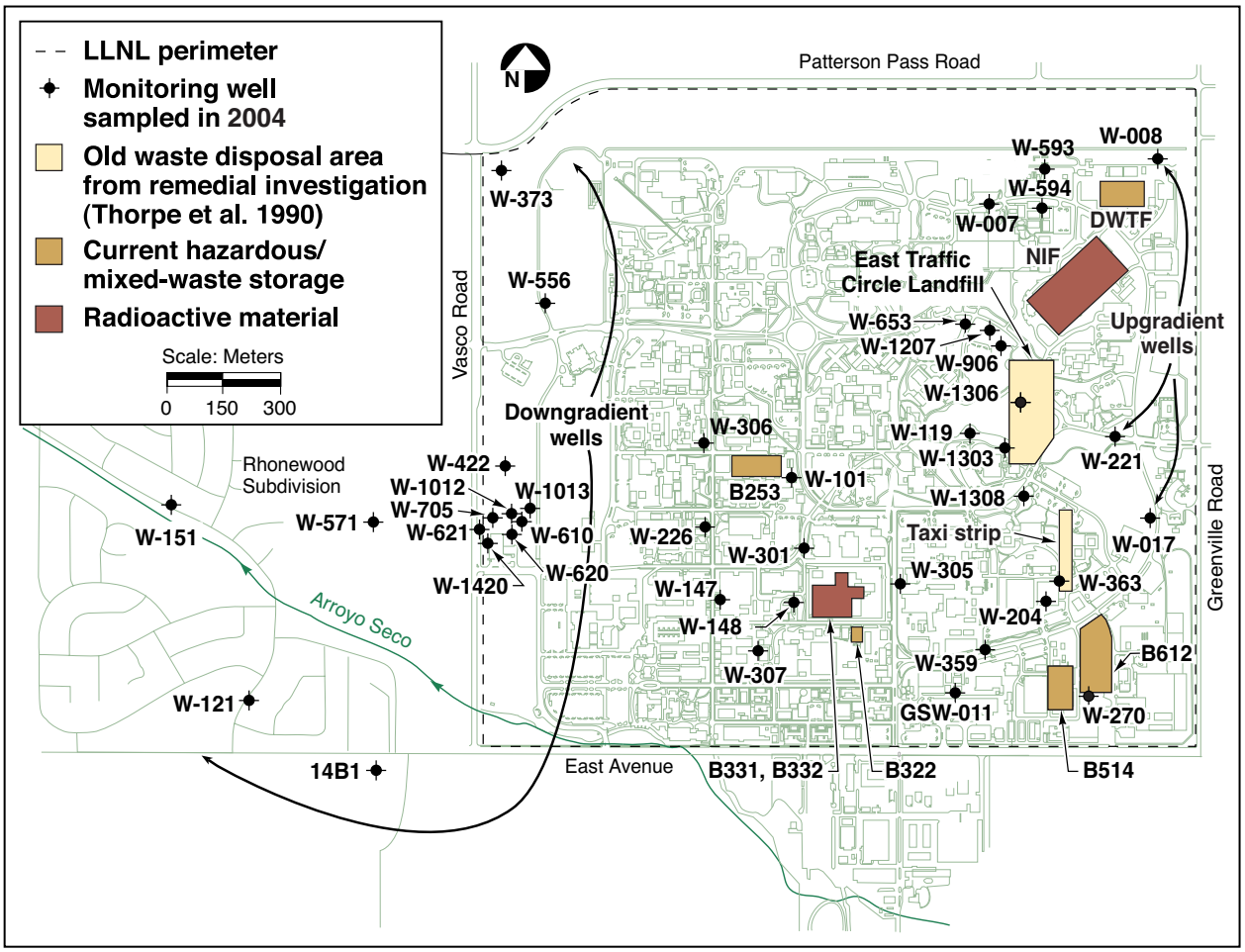


Figure 4-12. Locations of routine surveillance groundwater monitoring wells at the Livermore site, 2004

hydrologically downgradient boundary of the Livermore site. The western perimeter wells are screened (depth range from which groundwater is drawn) in the uppermost aquifers near the areas where groundwater is being remediated. As discussed in Chapter 7, the alluvial sediments have been divided into nine hydrostratigraphic units (HSUs) dipping gently westward, which are shown in **Figure 7-1**. 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 in 2004 for pesticide and herbicide compounds that are used on site and off site, for nitrate, for hexavalent chromium (chromium(VI)), and for certain radioactive constituents including plutonium.

To detect contaminants as soon as possible, the seven western downgradient wells (except for well 14B1) 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 during this reporting period for pesticides, herbicides, radioactive constituents, nitrate, and chromium(VI).

Analytical results for the Livermore site background wells and perimeter wells are contained in the file "Ch4 LV Groundwater" provided on the report CD. No pesticide or herbicide organic compounds were detected above analytical reporting limits in the groundwater during 2004. The inorganic compounds detected include dissolved trace metals and minerals, which occur naturally in the groundwater at variable concentrations. The concentrations detected in the groundwater samples from the background wells represent background values for 2004, although there have been variations in the concentrations since regular surveillance monitoring began in 1996.

Since 1996 concentrations of nitrate detected in groundwater samples from downgradient well W-1012 have been greater than the MCL of 45 mg/L. The nitrate concentrations detected in samples from this well during 2004 were reported at 61 and 45 mg/L; somewhat less than the values of 62 and 68 mg/L observed in 2003. Because of the hydrologic influence of TFB that pumps and treats groundwater from HSUs 1B and 2, groundwater with high nitrate concentrations is restrained from moving off site to the west. The highest concentrations measured in the downgradient off-site wells (screened in these HSUs) were below the MCL: 39 mg/L in monitoring well W-151 and 36 mg/L in monitoring well W-571. During 2004, concentrations of nitrate in on-site shallow background wells W-008 and W-221 ranged from 23 mg/L to 28 mg/L. Detected concentrations of nitrate in western perimeter wells, with the exception of well W-1012, ranged from 13 mg/L (in well W-373) to 39 mg/L (in well W-151).

Nitrate concentrations were also analyzed in groundwater samples collected from seven additional monitoring wells located nearby well W-1012 (**Figure 4-12**), similarly screened in HSUs 1B and 2. Again, other than well W-1012, no groundwater sample had a nitrate concentration greater than the MCL. 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).

Livermore Site

Groundwater sampling locations within the Livermore site include areas where releases to the ground may have occurred in the recent past, where previously detected COCs have low concentrations that do not require CERCLA remedial action, and where baseline information needs to be gathered for the area near a new facility or operation. 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. Well locations are shown in **Figure 4-12**. All analytical results are included in the file "Ch4 LV Groundwater" provided on the report CD.

The Taxi Strip and the East Traffic Circle Landfill areas within the Livermore site are two historic potential sources of groundwater contamination. Samples from monitoring wells screened in HSUs 2 (W-204) and 3A (W-363) downgradient from the Taxi Strip Area were analyzed in 2004 for copper, lead, zinc, americium-241, plutonium-238, plutonium–239, radium-226, radium-228, and tritium. Samples from monitoring wells screened at least partially in HSU 2 (W-119, W-906, W-1303, W-1306, and W-1308) within and downgradient from the East Traffic Circle Landfill were analyzed for the same elements as in the Taxi Strip Area. Plutonium-238 and plutonium-239+240 were reported above minimum detectable activities in one sample, collected in March 2004, from well W-1303. Retests of this well in September 2004 and February 2005 failed to confirm this detection. No other concentrations of plutonium or americium radioisotopes were detected above the radiological laboratory's minimum detectable activities. Concentrations of tritium and radium isotopes remain well below drinking water MCLs.

Of the trace metals (copper, lead, and zinc), only zinc was detected in any of these monitoring wells during 2004. The maximum zinc concentration reported (40 µg/L in well W-204) is more than two orders of magnitude below the secondary MCL for zinc in drinking water (5 mg/L).

Although the National Ignition Facility (NIF) has not yet begun full operations, LLNL obtains a baseline of groundwater quality prior to start of operations. During 2004, 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. Another new facility where groundwater baseline information is being acquired 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 2004 and were also analyzed for tritium.

Monitoring results from the wells near NIF and DWTF show no detectable concentrations of tritium present, above the limit of sensitivity of the analytical method, in the groundwater samples collected during 2004. Monitoring will continue near these facilities to determine baseline conditions.

The old hazardous waste/mixed waste storage facilities around Area 514 and Building 612 are also a potential source of contamination. They are monitored by wells W-270 and W-359 (screened in HSU 5), and well GSW-011 (screened in HSU 3A). Groundwater from these wells was sampled and analyzed for general minerals, gross alpha, gross beta, americium-241, plutonium-238, plutonium-239, radium-226, and tritium in 2004. No significant contamination was detected in the groundwater samples collected from wells W-270, W-359, or GSW-011 downgradient from this area in 2004.

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 Livermore site's 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). In 2004, the samples obtained from monitoring wells W-226 and W-306 (screened in HSUs 1B and 2, respectively) contained dissolved chromium at elevated concentrations. Concentrations of chromium(VI) were measured as 23 µg/L at well W-226 and 38 µg/L at well W-306. The accumulated sediment in the catch basin is a potential source of several metals (Jackson 1997). No concentration of either dissolved chromium or chromium(VI) was greater than the MCL of 50 µg/L for total chromium in drinking water.

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 4-12**). Possible contaminants include plutonium and tritium from these respective facilities. Plutonium is 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 well W-301 is screened in HSU 2. Groundwater samples collected from these wells during 2004 showed no detectable concentration, above the limit of sensitivity for the analytical method, of either plutonium-238 or plutonium-239.

In August 2000, relatively elevated tritium activity was measured in the groundwater sampled at well W-148 (115 ± 5.0 Bq/L [3100 ± 135 pCi/L]) that 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 tritium and plutonium contents remain below environmental levels of concern.

Site 300 and Environs

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, general radioactivity (gross alpha and gross beta), uranium activity, and tritium activity.

Figure 4-13 shows the locations of numerous wells and three springs at or near Site 300 that are used for groundwater surveillance monitoring. The locations of compliance monitoring wells are shown in **Figures 4-14**, **4-15**, **4-16**, and **4-17**. 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 surface or sub-surface operations at Site 300.

Twelve groundwater monitoring locations are off site. Two are springs, identified as MUL2 and VIE1, which are located near the northern boundary of Site 300. Off-site surveillance well VIE2 is located 6 km west of Site 300 in the upper reaches of the Livermore Valley watershed. Eight off-site surveillance locations are wells located near the southern boundary of Site 300 in or adjacent to the Corral Hollow Creek floodplain.

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 4-13**). 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 that are reported in this chapter are given below. Networks of wells 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, 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. (Chapter 7 includes a summary of Site 300 stratigraphy and hydrogeology. All analytical data from 2004 are included in the file "Ch4 S300 Groundwater" provided on the report CD.)

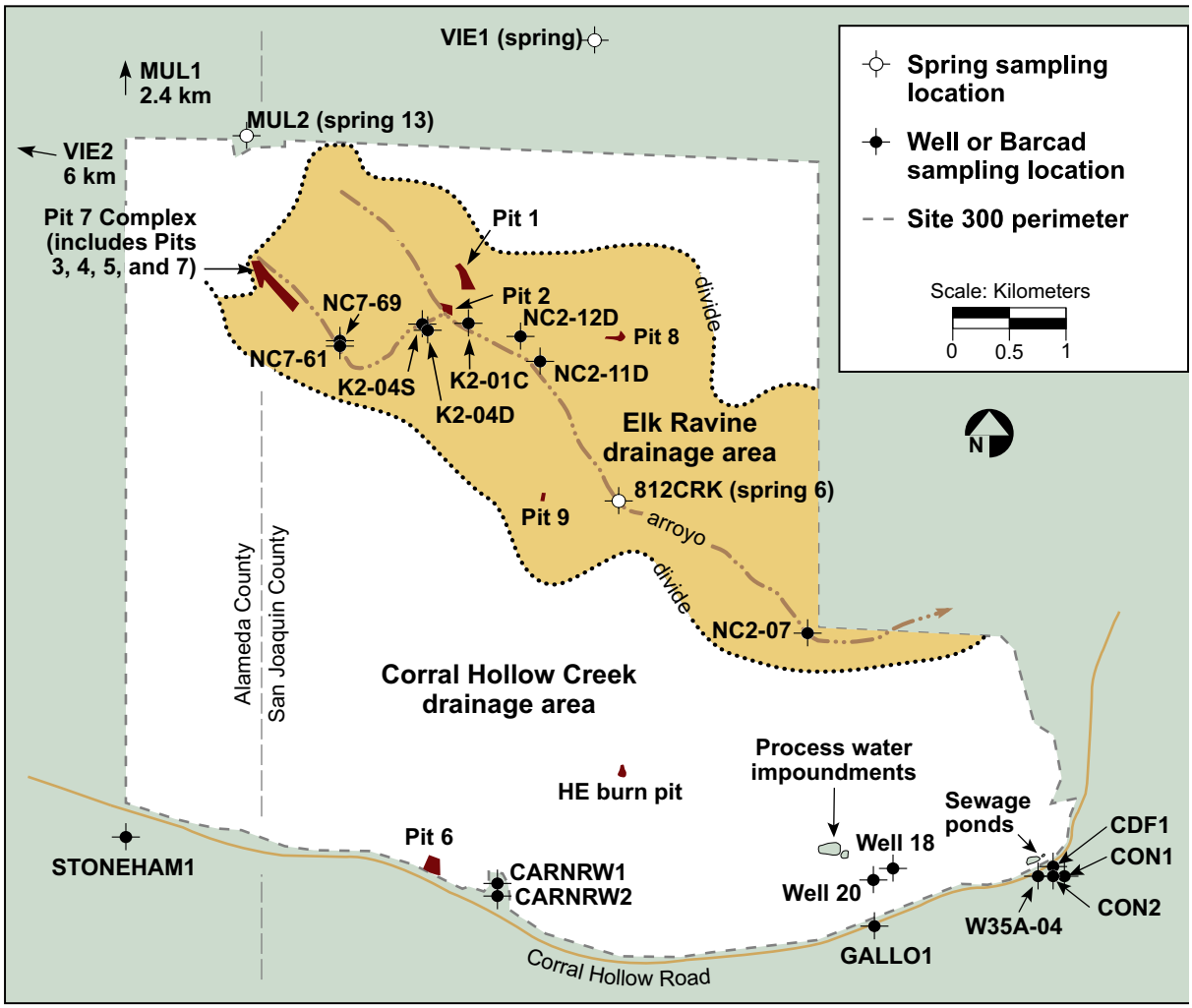


Figure 4-13. Locations of surveillance groundwater wells and springs at Site 300, 2004

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 4-13**). Storm water runoff in the Elk Ravine drainage area collects in arroyos and quickly infiltrates into the ground. Groundwater from wells 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

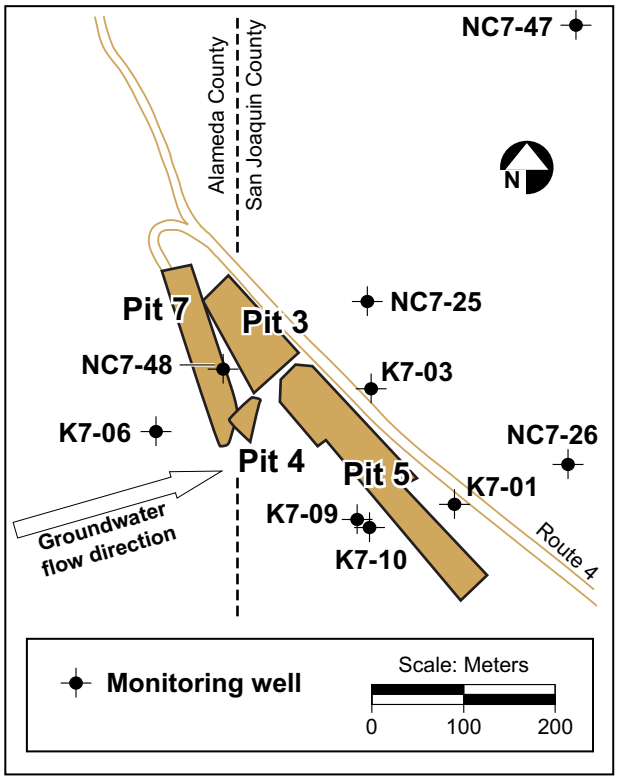


Figure 4-14. Locations of Pit 7 compliance groundwater monitoring wells, 2004

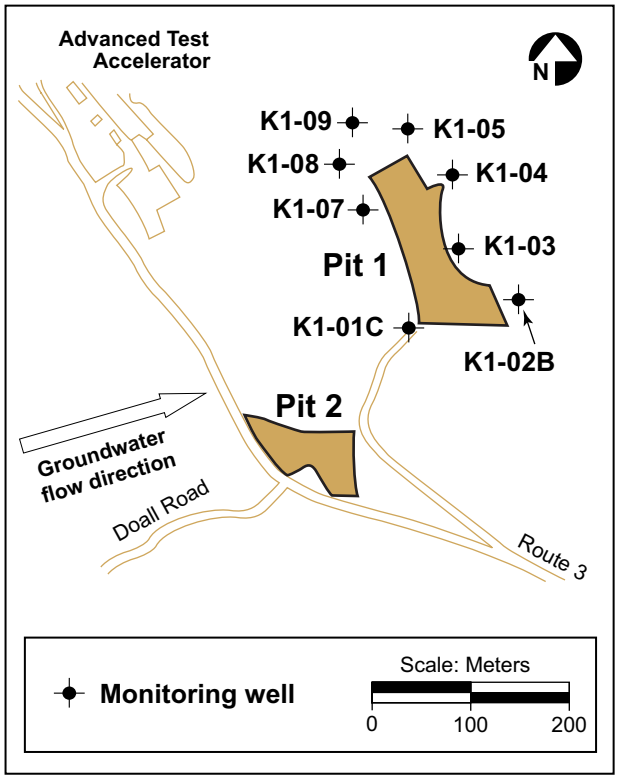


Figure 4-15. Locations of Pit 1 compliance groundwater monitoring wells, 2004

with the headwaters area and proceed downstream. (See Chapter 7 for a review of groundwater contamination in this drainage area as determined from numerous CERCLA remedial 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 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 4-14**). 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, uranium-238, beryllium, lead, and other metals in trace amounts. In

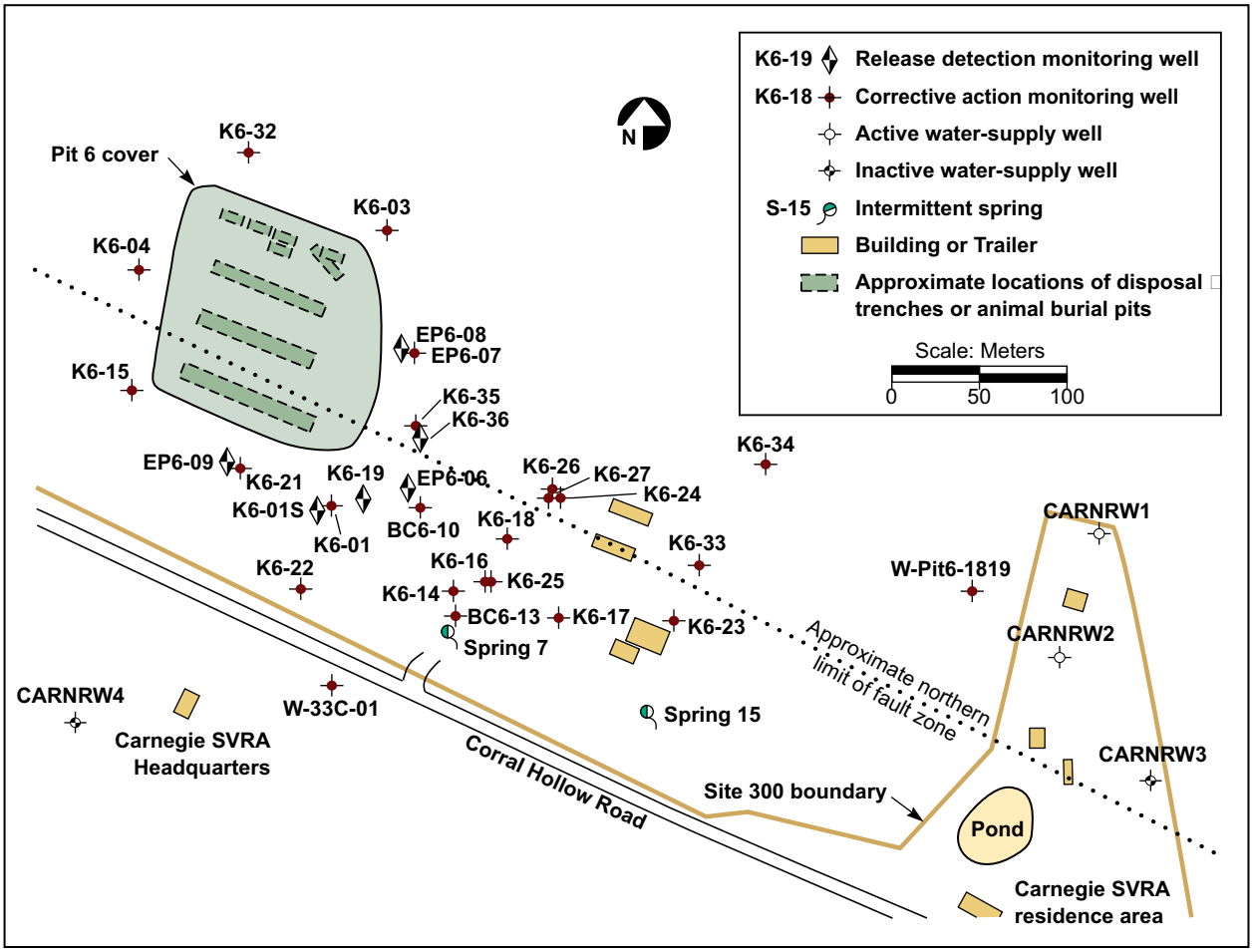


Figure 4-16. Locations of Pit 6 compliance groundwater monitoring wells and springs, 2004

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 quarterly during 2004 from the Pit 7 monitoring well network. Samples were analyzed for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium, radium, uranium, and thorium), explosive compounds (HMX and RDX), and volatile organic compounds (VOCs). Field measurements of groundwater depth, temperature, pH, and specific conductance were obtained at each well at the time of sample collection.

No new release of COCs to groundwater from Pit 7 is evident in the chemical data obtained during 2004. The COCs detected in groundwater include several metals, depleted uranium, tritium, and several VOCs. These are associated with releases that

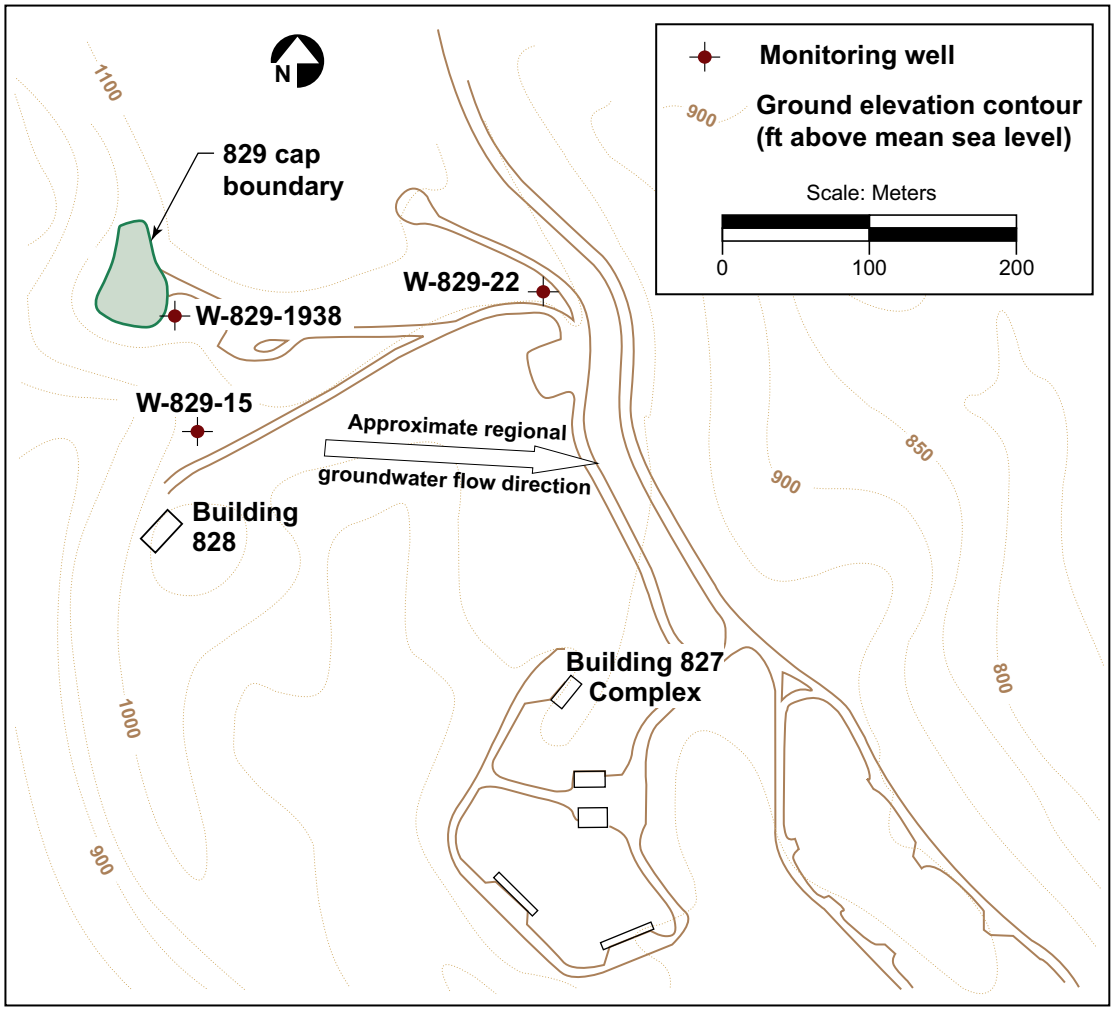


Figure 4-17. Locations of Building 829 closed burn pit compliance groundwater monitoring wells

occurred prior to 2004. 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 4-14**). 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 1982/1983 and 1997/1998, 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 7 for a review of CERCLA activities regarding groundwater contamination in the upper reaches of the Elk Ravine drainage area. For a detailed account of Pit 7 compliance monitoring during 2004, including

tables and graphs of groundwater COC analytical data, see *LLNL Experimental Test Site 300 Compliance Monitoring Program for RCRA-Closed Landfill Pits 1 and 7, Annual Report for 2004* (Campbell and MacQueen 2005).

Elk Ravine

Groundwater samples were obtained on five various dates in 2004 from the widespread Elk Ravine surveillance monitoring network (see **Figure 4-13**). Samples were analyzed for inorganic constituents (mostly metallic elements), VOCs, general radioactivity (gross alpha and beta), tritium and uranium activity, and explosive compounds (HMX and RDX).

No new release of COCs from LLNL operations in Elk Ravine to groundwater is indicated by the chemical and radioactivity data obtained during 2004. 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 Appendix A.

Concentrations of arsenic range up to 46 µg/L (well NC2-07) in Elk Ravine monitoring wells. 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 (location 812CRK on **Figure 4-13**), which is used by the indigenous wildlife there, contains concentrations of naturally occurring arsenic (29 µg/L arsenic in 2004).

Tritium activity was relatively elevated above background in many of the shallow groundwater surveillance samples obtained during 2004 from Elk Ravine. Tritium, as HTO, has been released in the past in the vicinity of Building 850. 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.

The majority of the Elk Ravine surveillance network tritium measurements made during 2004 support earlier CERCLA studies that show that the tritium in the plume is diminishing over time because of natural decay and dispersion (Ziagos and Reber-Cox 1998). For example, tritium activity in groundwater at well NC7-61 has decreased from 6500 Bq/L (1.8×10^5 pCi/L) in 1996 to 1500 Bq/L (4.1×10^4 pCi/L) in 2004. 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 yet reached the surveillance monitoring perennial spring location 812CRK, which is approximately one mile upstream from where the Site 300 boundary crosses Elk Ravine.

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 nonradioac-

tive elements including arsenic, barium, chromium, selenium, vanadium, and zinc are all within the natural ranges of concentrations typical of groundwater elsewhere in the Altamont Hills.

Pit 1

Monitoring requirements for the Pit 1 landfill, which was closed under RCRA in 1993, are also specified in WDR 93-100 administered by the CVRWQCB (1993 and 1998) and in 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 4-15**. 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 2004 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.

No release of COCs to groundwater from Pit 1 is evident in the monitoring data collected during 2004. A detailed account of Pit 1 compliance monitoring during 2004, including tables and graphs of groundwater COC analytical data, is in *LLNL Experimental Test Site 300 Compliance Monitoring Program for RCRA-Closed Landfill Pits 1 and 7, Annual Report for 2004* (Campbell and MacQueen 2005).

During 2004, average tritium activities measured above background level (about 4 Bq/L [100 pCi/L]) in the groundwater at Pit 1 monitoring wells K1-01C (21 Bq/L [570 pCi/L]), K1-02B (150 Bq/L [4000 pCi/L]), K1-03 (27 Bq/L [730 pCi/L]), and K1-08 (7.0 Bq/L [190 pCi/L]). The tritium activity in the groundwater sampled at these wells represents a distal lobe of the Building 850 tritium plume. Measurements of radium, thorium, and uranium made during 2004 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 41 µg/L in 2004 in groundwater at Pit 1 monitoring wells K1-05 (13 µg/L), K1-08 (23 µg/L), and K1-09 (41 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 northwest of the affected wells (Webster-Scholten 1994; Taffet et al. 1996).

Corral Hollow Creek Drainage Area

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) and in the *Compliance Monitoring Plan/Contingency Plan for Interim Remedies at Lawrence Livermore National Laboratory Site 300* (Ferry et al. 2002). 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 storm water 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 4-16**. 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).

Two Pit 6 groundwater monitoring programs, which operate under CERCLA, ensure compliance with all regulations. They are (1) the Detection Monitoring Program (DMP), designed to detect any new release of COCs to groundwater from wastes buried in the Pit 6 landfill, and (2) the Corrective Action Monitoring Program (CAMP), which monitors the movement and fate of historical releases. **Figure 4-16** shows the locations of Pit 6 and the wells used to monitor the groundwater there.

To comply with monitoring requirements, LLNL obtained groundwater samples monthly, quarterly, semiannually, and annually during 2004 from specified Pit 6 monitoring wells. DMP samples were obtained quarterly and were analyzed for beryllium and mercury, general radioactivity (gross alpha and beta), tritium and uranium activity, specified VOCs, nitrate and perchlorate. CAMP samples were measured for VOCs, tritium activity, nitrate and perchlorate. Field measurements of groundwater depth, temperature, pH, and specific conductance were obtained at each well at the time of sample collection.

No new release of COCs from Pit 6 is indicated by the chemical analyses of groundwater samples obtained from Pit 6 monitoring wells during 2004. 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 during 2004. These COCs include tritium, perchlorate, trichloroethylene (TCE), perchloroethylene (PCE), and cis-1,2-dichloroethene (cis-1,2-DCE). All contaminant plumes associated with Pit 6 are confined to shallow depths. None has been detected beyond the Site 300 boundary. For a detailed account of Pit 6 compliance monitoring during 2004, 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 2004* (Campbell and Blake 2005).

Building 829 Closed HE Burn Facility

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) as modified by the *Hazardous Waste Facility Post-Closure Permit for the Building 829 HE Open Burn Facility* (DTSC 2003).

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. The facility included three shallow, unlined pits constructed in unconsolidated sediments that cap the ridge (Tps formation). The facility was used to thermally treat explosives process waste generated by operations at Site 300 and similar waste from explosives research operations at the Livermore site. 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 ($Tnbs_2$).

Based on groundwater samples recovered from boreholes, previous CERCLA remedial investigations determined that the perched groundwater near 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 more than 100 m of unsaturated Neroly Formation sediments that include interbeds of claystone and siltstone.

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 soil and the perched water-bearing zone, and to monitor the deep regional aquifer for the appearance of any potential contaminants from the closed burn facility.

This monitoring program remained in effect through the first quarter of 2003, at which time LLNL began implementation of the provisions specified in the *Hazardous Waste Facility Post-Closure Permit for the B829 Facility* (DTSC 2003). Following the guidance outlined in the DTSC *Technical Completeness* (DTSC 2002) assessment, LLNL installed one additional groundwater monitoring well at the point of compliance within three meters of the edge of the capped High Explosive Open Burn Treatment Facility. This well (W-829-1938) was screened in the regional aquifer, the uppermost aquifer beneath the Building 829 facility. Since the first quarter of 2004, well W-829-1938 has been sampled as part of the permit-specified groundwater monitoring network (**Figure 4-17**). Also shown in **Figure 4-17** are two previously existing wells (W-829-15 and W-829-22) that were used throughout 2004 for quarterly collection of groundwater samples from the regional aquifer.

As planned for compliance purposes, LLNL obtained groundwater samples quarterly during 2004 from the Building 829 monitoring well network. Groundwater samples from the 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.

No new release of COCs to groundwater from the closed HE burn facility is indicated by the monitoring data obtained during 2004. For a detailed account of compliance monitoring of the closed HE burn pit during 2004, 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 2004* (Revelli 2005b).

During 2004, no organic or explosive COCs were detected above their respective reporting limits in groundwater samples from any of the three monitoring wells. The inorganic constituents that were detected in samples from the two established wells (W-829-15 and W-829-22) show concentrations that do not differ significantly from background concentrations for the deep aquifer beneath the HE Process Area (Webster-Scholten 1994). Although zinc and mercury were detected in routine quarterly samples from well W-829-22, these results were subsequently invalidated.

With one exception, the concentrations of inorganic COCs detected in the new well (W-829-1938) were consistent with background concentrations reported for the other wells that were also sampled for this network. Only nickel, detected in two of the quarterly samples from well W-829-1938 (at 14 µg/L and 5.1 µg/L), had not previously been detected in groundwater samples from this monitoring network. Nickel, however,

is typically found in Site 300 groundwater at background concentrations of 21 µg/L (Webster-Scholten 1994). Continued quarterly sampling at well W-829-1938 through 2005 will provide additional data to better establish background concentrations and statistically determined limits of concentrations in accordance with state regulations.

Water Supply Well

Water supply well 20, located in the southeastern part of Site 300 (**Figure 4-13**), is a deep, high-production well. The well is screened in the Neroly lower sandstone aquifer ($Tnbs_1$) and can produce up to 1500 L/min of potable water. As planned for surveillance purposes, LLNL obtained groundwater samples quarterly during 2004 from well 20. Groundwater samples were analyzed for inorganic COCs (mostly metals), VOCs, general radioactivity (gross alpha and gross beta), and tritium activity.

Quarterly measurements of groundwater from well 20 do not differ significantly from previous years. As in past years, the primary potable water supply well at Site 300 showed no evidence of contamination. Gross alpha, gross beta, and tritium activities were very low and are indistinguishable from background level activities.

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 2004. 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 4-13**). Well W35A-04 is a DOE CERCLA well that was installed off site for monitoring purposes only. The 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 concentrations of dissolved constituents in the groundwater beneath the Corral Hollow Creek flood plain.

Groundwater samples were obtained quarterly during 2004 at six of the off-site surveillance well locations south of Site 300. As planned, CARNRW1 and CON2 samples were analyzed for VOCs; samples from well CARNRW1 were also sampled for perchlorate 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 annual analyses were conducted on third-quarter samples for uranium activity and extractable organic compounds (EPA method 625).

Groundwater samples were obtained once (annually) during 2004 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, and extractable organic compounds (EPA method 625).

Generally, no COC attributable to LLNL operations at Site 300 was detected in the off-site groundwater samples. 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. As in past years, TCE was detected at concentrations of less than 1 µg/L in the groundwater samples obtained from well GALLO1. 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 generally indistinguishable from background activities. Groundwater samples collected from CARNRW1 and CARNRW2 during October had elevated tritium activities; however, continued monitoring did not replicate these results. It appears likely that these results are related to laboratory error (Campbell and Blake 2005).

Environmental Impact on Groundwater

Groundwater monitoring at the Livermore site and Site 300 and their environs indicates that LLNL operations have minimal impact on groundwater beyond the site boundaries. During 2004, neither radioactivity nor concentrations of elements or compounds detected in groundwater were confirmed to be above potable water MCLs.

Other Monitoring Programs

Rainwater

Rainwater is sampled and analyzed for tritium activity in support of DOE Order 5400.5, Radiation Protection of the Public and the Environment. LLNL collects rainwater samples according to written standardized procedures which are summarized in the *Environmental Monitoring Plan* (Woods 2005). Rainwater is collected in stainless-steel buckets at fixed locations. The buckets are in open areas and are mounted 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 low reporting limit of about 3.7 Bq/L (100 pCi/L). All analytical results are included in the file "Ch4 Other Waters" provided on the report CD.

Livermore Site and Environs

Historically, the tritium activity measured in rainwater in the Livermore Valley was caused by atmospheric emissions of HTO from stacks at LLNL's Tritium Facility (Building 331), and prior to 1995, from the former Tritium Research Laboratory at Sandia/California. During 2004, tritium activity in air-moisture and, thence, in rainwater at the Livermore site and in the Livermore Valley, resulted primarily from atmospheric emissions of HTO from stacks at Building 331. Atmospheric emission of HTO from Building 331 in 2004 was approximately 0.61 TBq (16.5 Ci), down from 4.1 TBq (110 Ci) in 2003. Other sources include the Waste Management Area (WMA) at Building 612 and the newly operating DWTF (see Chapter 3).

Rain sampling locations are shown in **Figure 4-18**. The fixed locations are used to determine the areal extent of detectable tritium activity in rainwater. A new rain-tritium sampling location, DWTF, was established in mid-year 2003. During 2004, LLNL collected sets of rainwater samples following three rain events in the Livermore Valley and two rain events at Site 300. All of the rainwater sampling dates correspond to storm water runoff sampling.

Although the Livermore site rainwater has exhibited elevated tritium activities in the past (Gallegos et al. 1994), during 2004, no on-site measurement of tritium activity was above the MCL of 740 Bq/L (20,000 pCi/L) established by the EPA for drinking water. As in past years, the on-site rainwater sampling location B343 showed the highest tritium activity for the year, 19 Bq/L (510 pCi/L), for the rain event that was sampled on February 27. The maximum tritium activity measured in an off-site rainwater sample during 2004 was 3.2 Bq/L (86 pCi/L) in the rainwater sample obtained on February 26 from location AMON (**Figure 4-18**). The maximum off-site activity equals 0.4% of the MCL for tritium activity in drinking water.

Site 300 and Environs

Three on-site locations (COHO, COMP, and TNK5) were positioned to collect rainfall for tritium activity measurements at Site 300 during 2004 (**Figure 4-10**). During 2004, only two rain events were sampled. As in past years, none of the rainwater samples from monitoring locations at Site 300 during 2004 had tritium activities above the analytical laboratory reporting limit of 3.7 Bq/L.

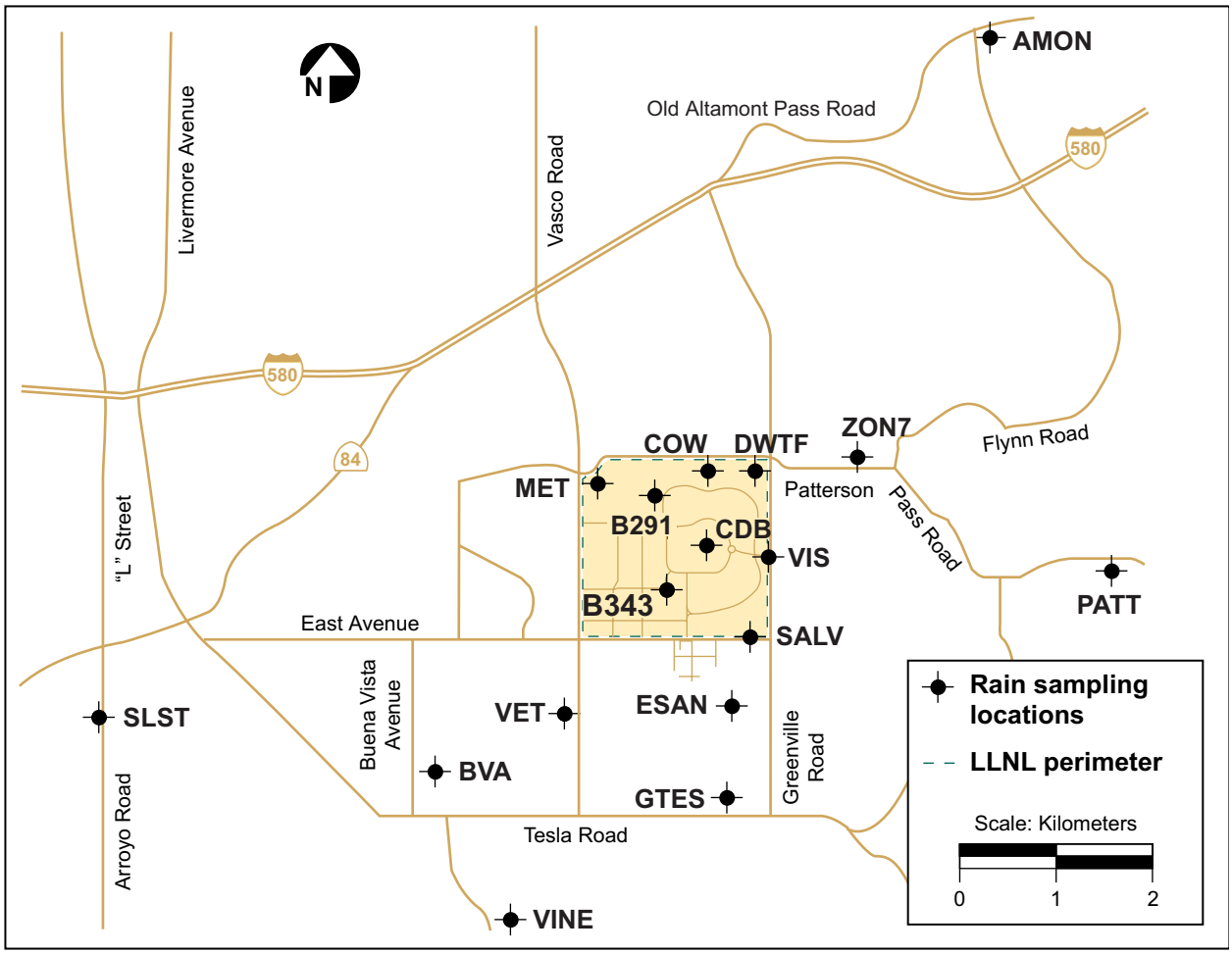


Figure 4-18. Rain sampling locations, Livermore site and Livermore Valley, 2004

Livermore Valley Surface Waters

LLNL conducts additional surface water surveillance monitoring in support of 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 4-19. Off-site 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. The on-site pool was closed during the second quarter of 2004, so sampling at location POOL was discontinued. Also, monitoring at the residence known as the PALM location was discontinued after

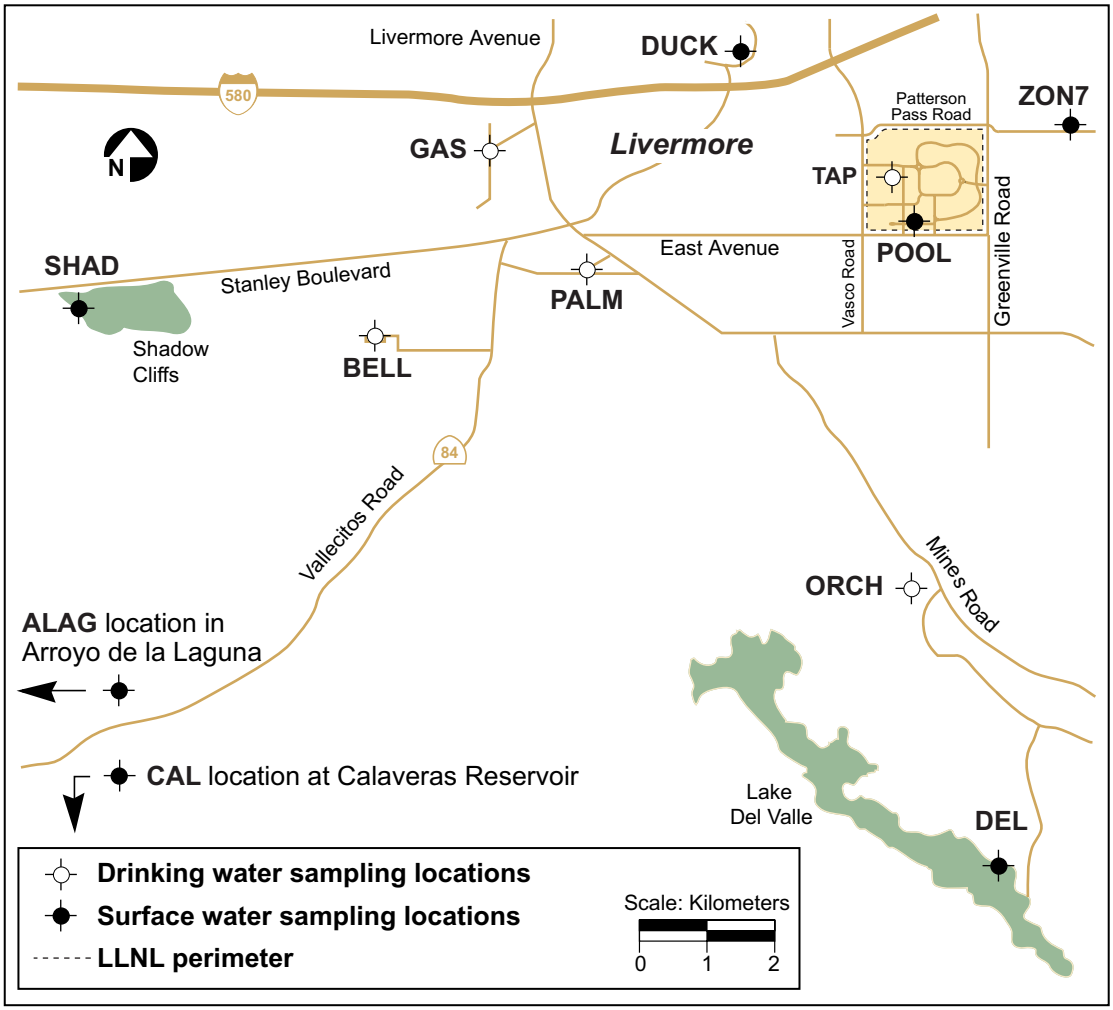


Figure 4-19. Livermore Valley surface and drinking water sampling locations, 2004

the first quarter of 2004 due to lack of access to LLNL staff. Radioactivity data from drinking water sources are used to calculate drinking water statistics (see **Table 4-14**).

Samples are analyzed according to written standardized procedures summarized in the *Environmental Monitoring Plan* (Woods 2005). LLNL sampled these locations semiannually, in March and July 2004, for gross alpha, gross beta, and tritium. The on-site swimming pool location (POOL) was sampled in March for gross alpha and gross beta, and in March and April for tritium. All analytical results are included in the file "Ch4 Other Waters" provided on the report CD.

The median activity for tritium in surface and drinking waters was estimated from calculated values to be below the analytical laboratory's minimum detectable activities, or minimum quantifiable activities. The maximum tritium activity detected (3.05 ± 1.96 Bq/L [82 ± 53 pCi/L]) was less than 1% of the MCL of 740 Bq/L (20,000 pCi/L) in

residential well water from an off-site residence location known as ORCH, located south of LLNL along Mines Road (**Figure 4-19**). Median activities for gross alpha and gross beta radiation in surface and drinking water samples were both less than 5% of their respective MCLs. Maximum activities detected for gross alpha and gross beta, respectively, were 0.068 Bq/L (1.8 pCi/L) and 0.317 Bq/L (8.6 pCi/L); both were less than 20% of their respective MCLs (see **Table 4-14**). Historically, concentrations of 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 is nearly equal to, or in many cases greater than, the calculated values so that no trends are apparent in the data.

Table 4-14. Radioactivity in surface and drinking waters in the Livermore Valley, 2004

Locations	Tritium (Bq/L)	Gross alpha (Bq/L)	Gross beta (Bq/L)
All locations			
Median	–0.110	0.017	0.098
Minimum	–1.90	–0.020	0.019
Maximum	3.05	0.068	0.317
Interquartile range	1.075	0.014	0.061
Drinking water locations			
Median	0.242	0.008	0.077
Minimum	–1.48	–0.02	0.02
Maximum	3.05	0.040	0.317
Interquartile range	1.15	0.02	0.099
Drinking water MCL	740	0.555	1.85

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

Historical median tritium values in surface and drinking waters in the Livermore Valley since 1988 are shown in **Figure 4-20**. Since 1988, when measurements began, water in the LLNL swimming pool has had the highest tritium activities because it is close to tritium sources within LLNL. After the first quarter of 2004 and the draining of the swimming pool, the Drainage Retention Basin became the closest routinely monitored source to the Tritium Facility at Building 331.

Drainage Retention Basin Release

The DRB was constructed and lined in 1992 after remedial action studies indicated that infiltration of storm water from the existing basin increased dispersal of groundwater contaminants. Located in the center of the Livermore site, the DRB can hold approximately 45.6 ML (37 acre-feet) of water. Previous *Environmental Reports* detail the

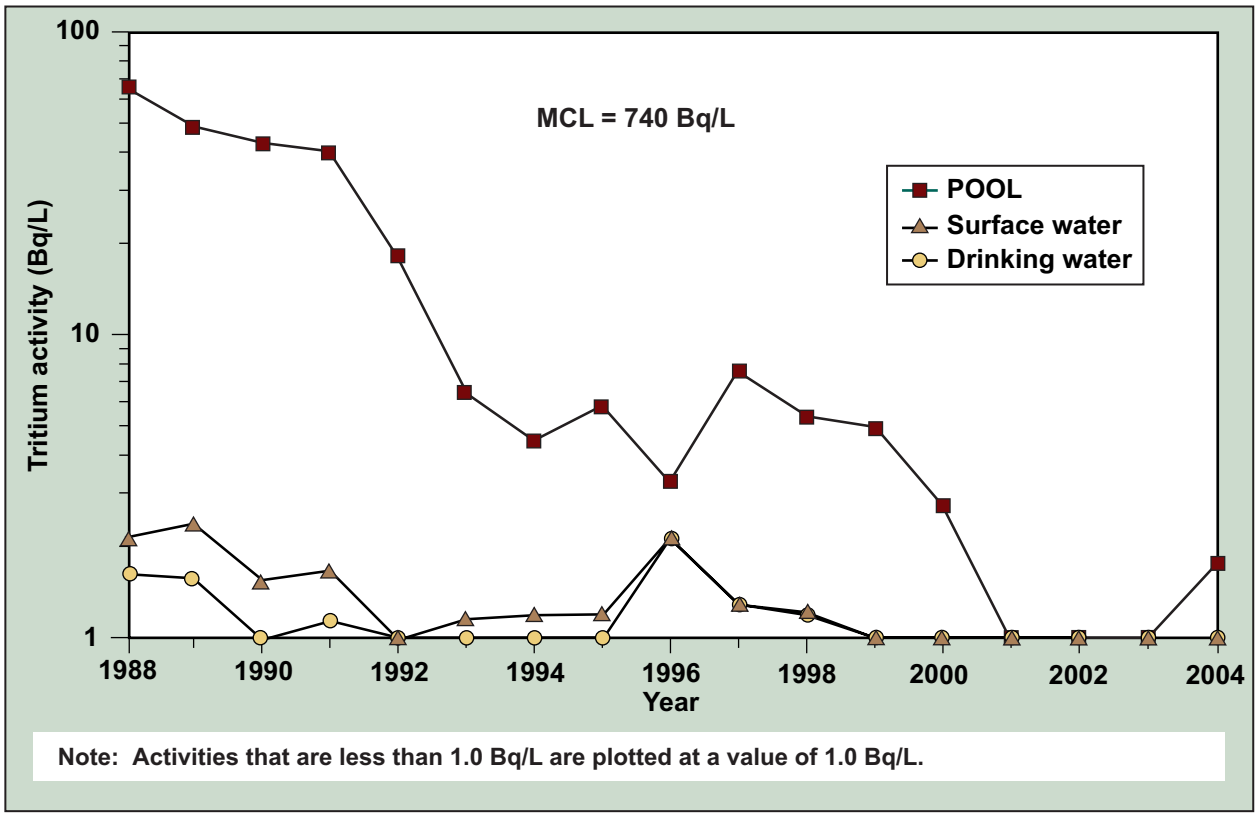


Figure 4-20. Annual median tritium activity in Livermore Valley surface and drinking water, 1988 to 2004

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 TFD and TFE, and from related portable treatment units. These discharges contribute a year-round source of water entering and exiting the DRB. Discharge rate is approximately 100 gpm. Storm water runoff still dominates wet weather flows through the DRB, but discharges from the treatment facilities now constitute a substantial portion of the total water passing through the DRB.

The SFBRWQCB regulates discharges from the DRB. The document *Drainage Retention Basin Monitoring Plan Change* (Jackson 2002) lists constituents of interest, sample frequencies, and discharge limits based on 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 ROD established 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 federal Clean Water Act, federal and state Safe Drinking Water Acts, and the California Porter-Cologne Water Quality Control Act. See Appendix B for the limits used.

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 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 Livermore site outfall at location WPDC during the first release of the rainy season, and from a minimum of one additional release (chosen in conjunction with storm water runoff sampling). During the dry season, samples are collected from each discrete discharge event or monthly while discharge is continuous. Discharge sampling locations CDBX and WPDC are shown in **Figure 4-9**. 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.

Written standardized sample collection procedures are summarized in the *Environmental Monitoring Plan* (Woods 2005). State-certified laboratories analyze the collected samples for chemical and physical parameters. All analytical results are included in the file "Ch4 Other Waters" provided on the report CD.

Water releases typically occurred continuously to maintain relatively low nutrient levels in the DRB and because treatment facility discharge to the DRB exceeded the evaporation rate. Samples collected at CDBX and WPDC exceeded only the pH discharge limits. The higher pH readings seen in the DRB discharge samples during the summer and fall correspond to the peak of the summer and fall algae blooms within the DRB. During 2004, total dissolved solids and specific conductance continued to reflect the levels found in groundwater discharged to the DRB. While some metals were detected, none were above discharge limits. All organics, pesticides, and PCBs were below analytical discharge limits. Gross alpha, gross beta, and tritium levels were well below discharge limits.

LLNL collects and analyzes samples for acute fish toxicity using fathead minnow (*Pimphales promelas*) and for chronic toxicity using three species (fathead minnow, water flea daphnid [*Ceriodaphnia dubia*], and green algae [*Selanastrum capricomutum*]). LLNL collects acute toxicity samples at the first wet-season release and from each discrete dry season release from location CDBX. Samples for chronic fish toxicity were collected at location CDBX at the first wet-season release. Aquatic bioassay for toxicity showed no toxicity effects in DRB discharge water.

Site 300 Drinking Water System

LLNL samples large-volume discharges from the Site 300 drinking water distribution system that reach surface water drainage courses in accordance with the requirements of WDR 5-00-175, NPDES General Permit No. CAG995001. 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 and their monitoring requirements are:

- Drinking water storage tanks—discharges that have the potential to reach surface waters are monitored.
- System flushes—one flush per pressure zone per year is monitored for flushes that have the potential to reach surface waters.
- Dead-end flushes—all flushes that have the potential to reach surface waters, and for any discharge that continues for more than four months are monitored.

Discharges must comply with the effluent limits for residual chlorine and pH established by the permit, that is, residual chlorine must not be greater than 0.02 mg/L, and the pH must be between 6.5 and 8.5. Discharges are also visually monitored 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.

Sample collection procedures are discussed in the *Lawrence Livermore National Laboratory Site 300 Water Suppliers' Pollution Prevention and Monitoring and Reporting Program* (Mathews 2000). Grab samples are collected in accordance with written standardized procedures summarized in the *Environmental Monitoring Plan* (Woods 2005). 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.

Small volumes of water (less than 2000 gallons) were discharged in the first and fourth quarters of 2004, as a result of routine pressure tests conducted by the Site 300 fire department. Because of the nature of fire department activities, these small-volume discharges were not monitored. The annual pressure zone testing, required by the CVRWQCB, was completed during the third quarter, when LLNL conducted flushing of the drinking water system for water quality purposes. These system flush releases were monitored and met the effluent limits. All 2004 releases from the Site 300 drinking

water system quickly percolated into the drainage ditches or streambed, and did not reach Corral Hollow Creek, the receiving water (Raber 2004). Monitoring results are detailed in the quarterly self monitoring reports to the CVRWQCB.

Site 300 Cooling Towers

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 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. Total dissolved solids (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 4-21**

Written standardized sample collection procedures are summarized in the *Environmental Monitoring Plan* (Woods 2005). To determine the effects of the cooling tower blowdown on Corral Hollow Creek, LLNL quarterly monitors pH, 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 4-21**).

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 using calibrated meters, are used to monitor Corral Hollow Creek. LLNL also performs the required visual observations that are recorded on 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.

Monitoring results in 2004 indicate that all discharges from the Buildings 801 and 836A cooling towers were below the maximum TDS (2400 mg/L) and pH (10) values that were previously imposed for discharges to surface water drainage courses under WDR 94-131. The blowdown flows from these towers were typical of volumes reported in recent years, except for one unusually high flow recorded on May 6 at the Building 836A tower. On this one day, the flow from that tower was reported as 58,148 L/day,

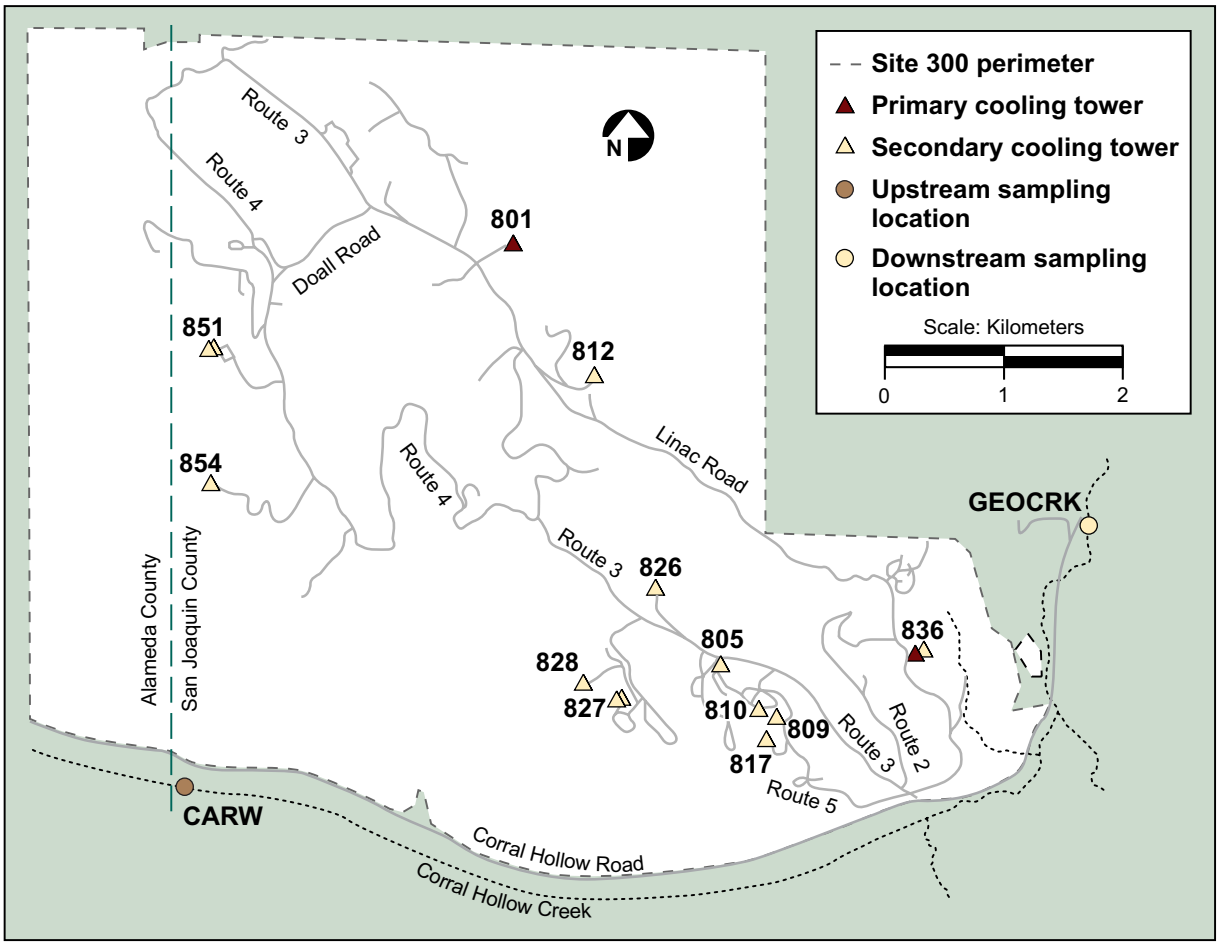


Figure 4-21. Cooling tower locations and receiving water monitoring locations, Site 300, 2004

approximately a factor of six above the next highest value. Flow readings for the preceding (April 19) and following (May 17) observation periods were 2256 L/day and 6783 L/day, respectively, indicating that this high flow was a transient event. Nevertheless, no flow was observed at either the CARW or GEOCRK locations during the period in question. **Table 4-15** 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 dry or no flow conditions for both sampling locations throughout most of 2004. Only on October 18 was there adequate flow to measure pH. The resulting field pH measurements were 7.88 and 7.96 for CARW and GEOCRK locations, respectively, indicating essentially no change between the upstream and downstream locations. Visual observations of Corral Hollow Creek were performed each quarter, and no visible oil, grease, scum, foam, or floating suspended materials were noted in the creek during 2004.

Table 4-15. Summary data from monitoring of primary cooling towers, Site 300, 2004

Test	Tower no.	Minimum	Maximum	Median	Interquartile range	Number of samples
Total dissolved solids (TDS) (mg/L)	801	955	1,680	1,120	—[a]	4
	836A	880	1,280	1,063	—[a]	4
Blowdown (L/day)	801	0	58,148	7,435	4,826	25[b]
	836A	0	5,443	2,406	2,592	26
pH (pH units)	801	8.9	9.1	9.0	—[a]	4
	836A	8.7	9.0	8.8	—[a]	4

a Not enough data points to determine

b One biweekly blowdown reading could not be collected because the area around Tower 801 was closed due to a lightning alert.

No drinking water or cooling tower water releases from Site 300 reached Corral Hollow Creek. There is no evidence of any adverse environmental impact on surrounding waters resulting from these LLNL activities during 2004.

5

Terrestrial Monitoring

Gretchen M. Gallegos
Nicholas A. Bertoldo
Richard A. Brown
Lisa Paterson
S. Ring Peterson

Introduction

Lawrence Livermore National Laboratory measures the radioactivity present in soil, sediment, vegetation, and wine. LLNL also measures absorbed gamma radiation dose at ground level receptors from terrestrial and atmospheric sources. The LLNL monitoring program is designed to measure any changes in environmental levels of radioactivity and to evaluate any increase in radioactivity that might have resulted from LLNL operations. All monitoring activity follows U.S. Department of Energy (DOE) guidance. Monitoring on site or in the vicinity of the Livermore site or Site 300 detects radioactivity released from LLNL that may contribute to radiation dose to the public or to biota; monitoring at distant locations not impacted by LLNL operations detects naturally occurring background radiation.

Terrestrial pathways from LLNL operations leading to potential radiation dose to the public include resuspension of soils, infiltration of constituents of runoff water through arroyos to groundwater, ingestion of locally grown foodstuffs, and external exposure to contaminated surfaces and radioactivity in air. Potential ingestion doses are calculated from measured concentrations in vegetation and wine; doses from exposure to ground level external radiation are obtained directly from thermoluminescent dosimeters (TLDs) deployed for environmental radiation monitoring. Potential dose to biota (see Chapter 6) is calculated using a simple screening model that requires knowledge of radionuclide concentrations in soils, sediments, and surface water.

Surface soil samples are analyzed for plutonium and gamma-emitting radionuclides. Gamma-emitting radionuclides in surface soils include uranium isotopes, which are used to provide data about the natural occurrence of uranium as well as data about the effects of explosive tests at Site 300, some of which contain depleted uranium. Other gamma-emitting, naturally occurring nuclides (potassium-40 and thorium-232) provide additional data about local background conditions, and the long-lived fission product cesium-137 provides information on global fallout from historical nuclear weapons testing. In addition, soils at Site 300 are analyzed for beryllium, a potentially toxic metal used there. With the addition of tritium, a similar suite of nuclides is analyzed in the sediments. Vadose zone soil concentrations are compared with de minimis concentrations for tritium and background concentrations for metals. Vegetation and wine samples are measured for tritium alone because tritium is the only nuclide released from LLNL that can be measured in these products. Cosmic radiation accounts for about half the absorbed gamma dose measured by the TLDs; naturally occurring isotopes of the uranium-thorium-actinium decay series provide the dose from natural background radiation found in the earth's crust. By characterizing the background radiation, LLNL can determine what, if any, excess dose can be attributed to laboratory operations.

Surface soils near the Livermore site and Site 300 have been sampled since 1971. Around the Livermore site, sediments (from selected arroyos and other drainage areas) and vadose zone soils have been sampled since 1988 and 1996, respectively; sampling of sediments or vadose zone soils is not warranted at Site 300. LLNL has been monitoring tritium in

vegetation since 1966 and has performed routine vegetation sampling on and around the Livermore site and Site 300 since 1971. External radiation has been monitored around the Livermore site since 1973 and around Site 300 since 1988.

Sampling for all media is conducted according to written, standardized procedures summarized in the *Environmental Monitoring Plan* (Woods 2005).

LLNL also monitors wildlife and plants at the Livermore site and Site 300, and carries out research relevant to the protection of rare plants and animals. Some monitoring and research programs are required by existing permits, while additional monitoring programs are designed to track the distribution and abundance of rare species. In addition, baseline surveys are conducted to determine distribution of special status species on LLNL property. Monitoring and research of biota on LLNL property is conducted to ensure compliance with 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.

Soil and Sediment Monitoring

There are 6 soil and 4 sediment sampling locations on LLNL's Livermore site (**Figure 5-1**); 13 soil sampling locations in the Livermore Valley, including 6 at the Livermore Water Reclamation Plant (LWRP) (**Figure 5-2**); and 14 soil sampling locations at or near Site 300 (**Figure 5-3**). 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 and areas around explosives tests areas at Site 300, are also sampled.

Surface sediment and vadose zone soil samples are collected from selected arroyos and other drainage areas at and around the Livermore site; these locations (**Figure 5-1**) largely coincide with selected storm water sampling locations (see Chapter 4). 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. 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). The collocation of sampling for these media facilitates comparison of analytical results.

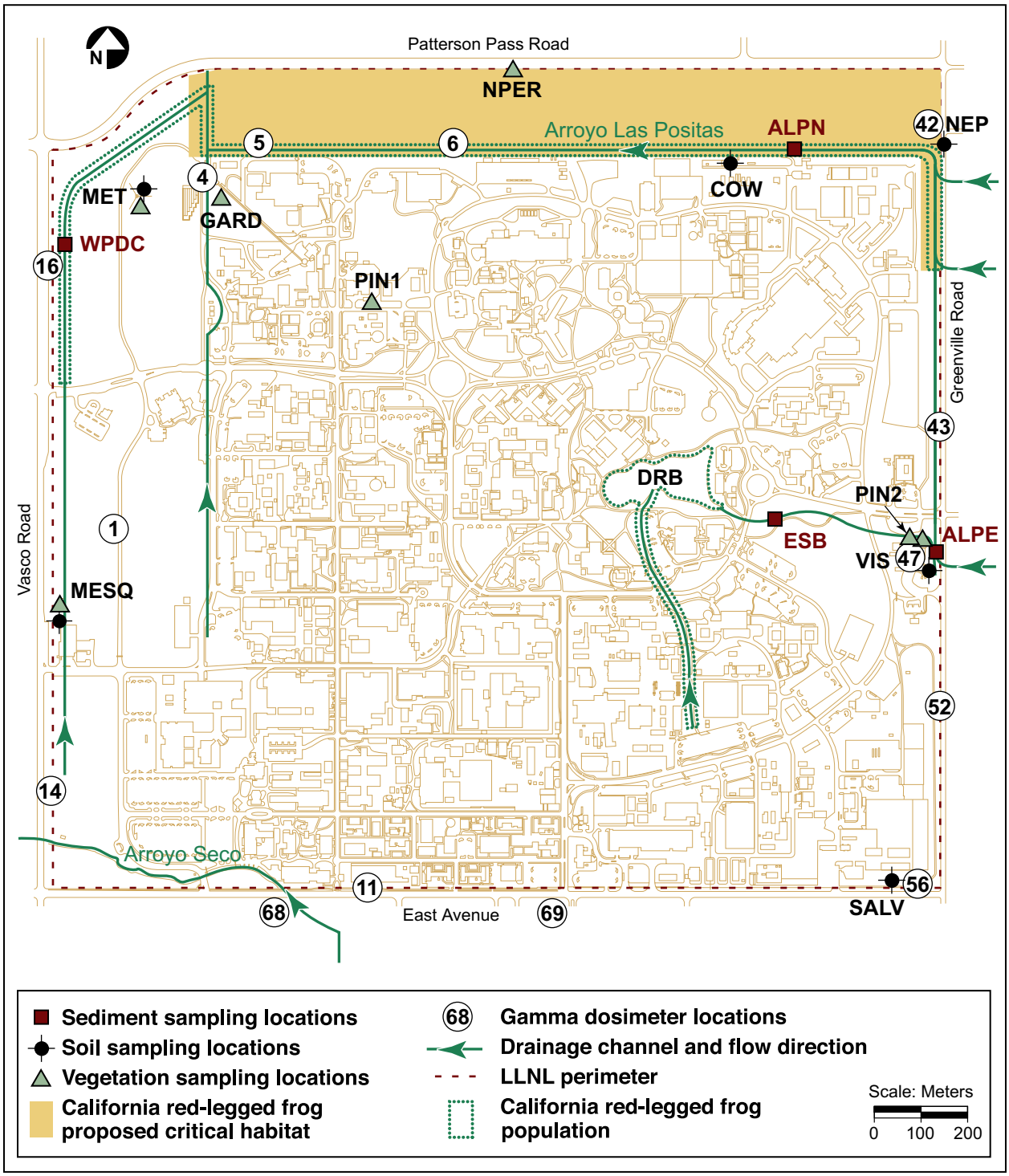


Figure 5-1. Sampling locations, Livermore site, 2004

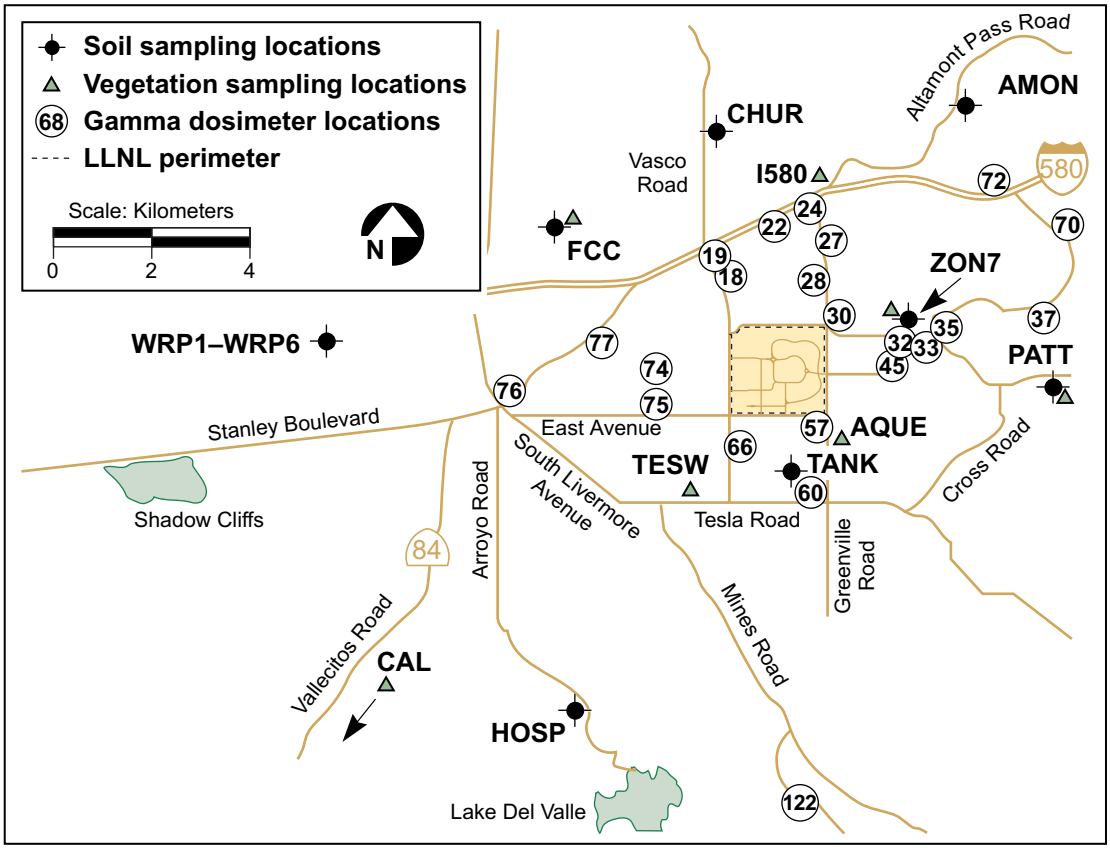


Figure 5-2. Sampling locations, Livermore Valley, 2004

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. Two 1-m squares are chosen from which to collect the sample. Each sample is a composite consisting of 10 subsamples that are collected with an 8.25 cm diameter stainless steel core sampler at the corners and the center of each square. Surface sediment samples are collected in a similar manner. Ten subsamples, 5-cm deep, are collected at 1-m intervals along a transect of the arroyo or drainage channel. At one of the subsample locations, a 15-cm deep sample is acquired for tritium analysis; this deeper sample is necessary to obtain sufficient water in the sample for tritium analysis. Vadose zone samples are collected at the same location as the tritium subsample. A hand auger is used to collect a 30- to 45-cm deep sample for metals analysis, and an electric drive coring device is used to collect a sample 45- to 65-cm deep for analysis for polychlorinated biphenyls (PCBs).

In 2004, 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. Annual sediment samples collected at the

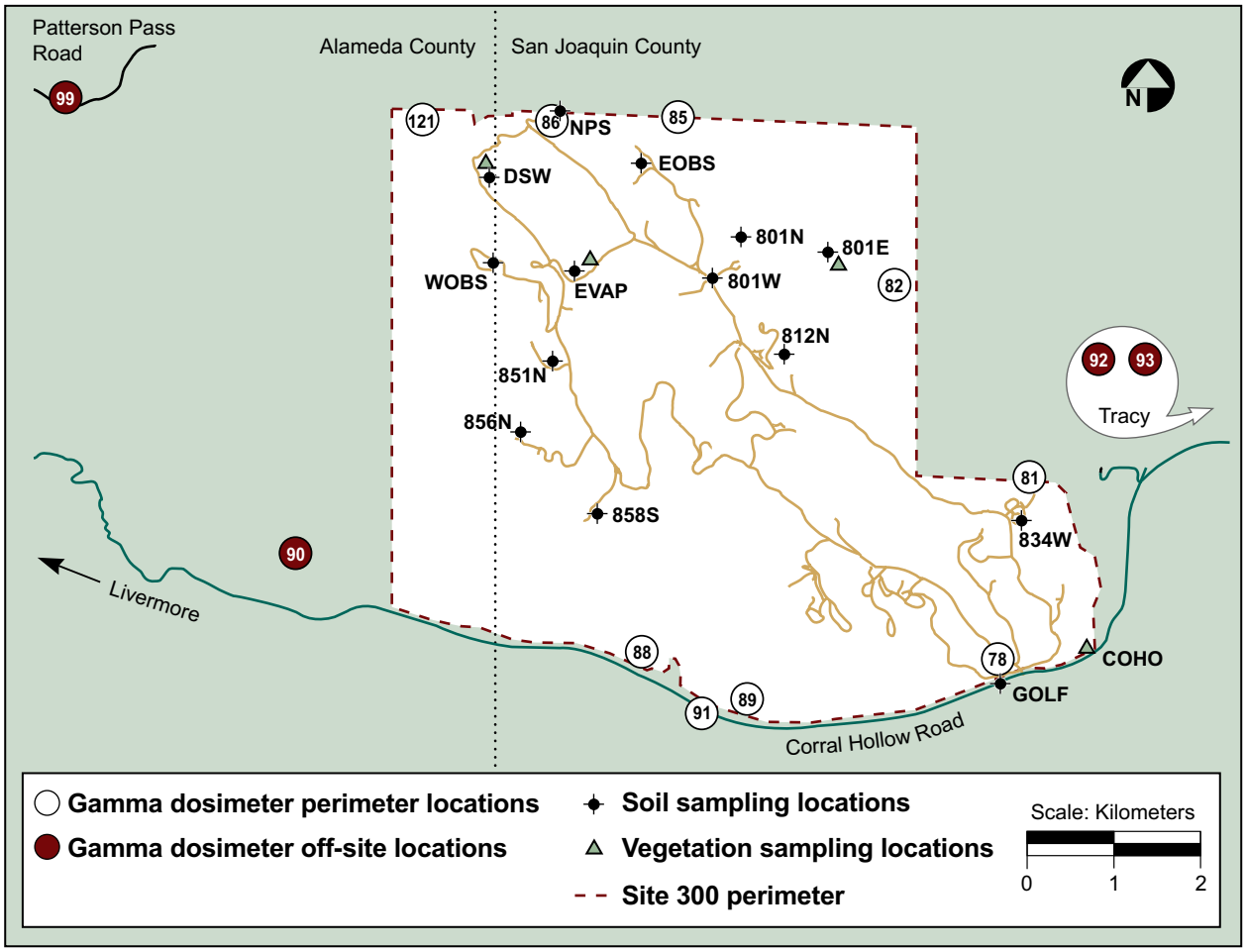


Figure 5-3. Sampling locations at Site 300 and off-site, 2004

Livermore site were analyzed for plutonium, gamma-emitting radionuclides, and tritium. Vadose zone samples were analyzed for total and soluble metals; one vadose zone location was analyzed for PCBs.

Prior to radiochemical analysis, surface soil and sediment samples are dried, sieved, ground, and homogenized. The plutonium content of a 100-g sample aliquot is determined by alpha spectrometry. Other sample aliquots (300-g) are analyzed by gamma spectrometry using a high-purity germanium (HPGe) detector for 47 radionuclides, including fission products, activation products from neutron interactions on steel, actinides, and natural products. The 10-g subsamples for beryllium analyses are analyzed by atomic emission spectrometry.

Vadose zone soil samples are analyzed by standard EPA methods. In 2004, as in the previous four years, a vadose zone soil sample from location ESB (**Figure 5-1**) was also analyzed for PCBs.

Radiological Monitoring Results

Tables 5-1 through 5-3 present data on the concentrations of plutonium-238 and plutonium-239+240 in the Livermore Valley surface soils and sediments; data for americium-241, which is only detected at LWRP; and data for tritium, which is only measured in surface sediments. Data for cesium-137, potassium-40, thorium-232, uranium-235, and uranium-238 in surface soils from the Livermore Valley sampling locations are included in the file "Ch5 Soil" provided on the report CD.

The concentrations and distributions of all observed radionuclides in soil for 2004 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. In 2004, the measured plutonium-239+240 value for VIS was

Table 5-1. Plutonium activity concentrations in Livermore Valley soil, 2004

Location	Plutonium-238 (mBq/dry g)	Plutonium-239+240 (mBq/dry g)
L-AMON-SO	0.0075 ± 0.0021	0.093 ± 0.0094
L-CHUR-SO	0.0038 ± 0.0037	0.11 ± 0.015
L-COW-SO	0.0058 ± 0.0019	0.025 ± 0.0042
L-FCC-SO	0.0041 ± 0.0016	0.037 ± 0.0053
L-HOSP-SO	0.0051 ± 0.0019	0.038 ± 0.0055
L-MESQ-SO	0.0055 ± 0.0020	0.025 ± 0.0041
L-MET-SO	0.0017 ± 0.0011	0.050 ± 0.0061
L-NEP-SO	0.0078 ± 0.0031	0.046 ± 0.0077
L-PATT-SO	0.0034 ± 0.0042	0.023 ± 0.0072
L-SALV-SO	0.015 ± 0.0031	0.051 ± 0.0064
L-TANK-SO	0.0067 ± 0.0020	0.095 ± 0.0098
L-VIS-SO	0.022 ± 0.0043	0.47 ± 0.037
L-ZON7-SO	0.0050 ± 0.0012	0.056 ± 0.0051
Median	**0.0055**	**0.050**
IQR[a]	**0.0034**	**0.056**
Maximum	**0.022**	**0.47**

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 8.

a IQR = Interquartile range

Table 5-2. Plutonium and americium activity concentrations in LWRP soil, 2004

Location	Plutonium-238 (mBq/dry g)	Plutonium-239+240 (mBq/dry g)	Americium-241 (mBq/dry g)
L-WRP1-SO	0.45 ± 0.034	9.6 ± 0.65	4.8 ± 1.4
L-WRP2-SO	0.25 ± 0.020	4.4 ± 0.30	2.8 ± 2.3
L-WRP3-SO	0.057 ± 0.0083	0.96 ± 0.073	<0.77
L-WRP4-SO	0.027 ± 0.0043	0.51 ± 0.038	<0.51
L-WRP5-SO	0.074 ± 0.0086	1.7 ± 0.12	<1.1
L-WRP6-SO	0.069 ± 0.0076	1.2 ± 0.085	<0.51
Median	**0.072**	**1.5**	**<0.94**
IQR[a]	**0.15**	**2.7**	**—[b]**
Maximum	**0.45**	**9.6**	**4.8**

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 8.

a IQR = Interquartile range

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

Table 5-3. Plutonium and tritium activity concentrations in surface sediment, 2004

Location	Plutonium-238 (mBq/dry g)	Plutonium-239+240 (mBq/dry g)	Tritium (Bq/L)
L-ALPE-SD	0.0016 ± 0.0010	0.025 ± 0.0041	2.1 ± 3.0
L-ALPN-SD	0.0041 ± 0.0017	0.017 ± 0.0032	0.0096 ± 2.9
L-ESB-SD	0.12 ± 0.011	1.3 ± 0.094	1.9 ± 3.0
L-WPDC-SD	0.00019 ± 0.00060	0.0054 ± 0.0018	0.63 ± 2.9
Median	**0.0029**	**0.021**	**1.3**
IQR[a]	**—[b]**	**—[b]**	**—[b]**
Maximum	**0.12**	**1.3**	**2.1**

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 8.

a IQR = Interquartile range

b Interquartile range not calculated because of high incidence of nondetections

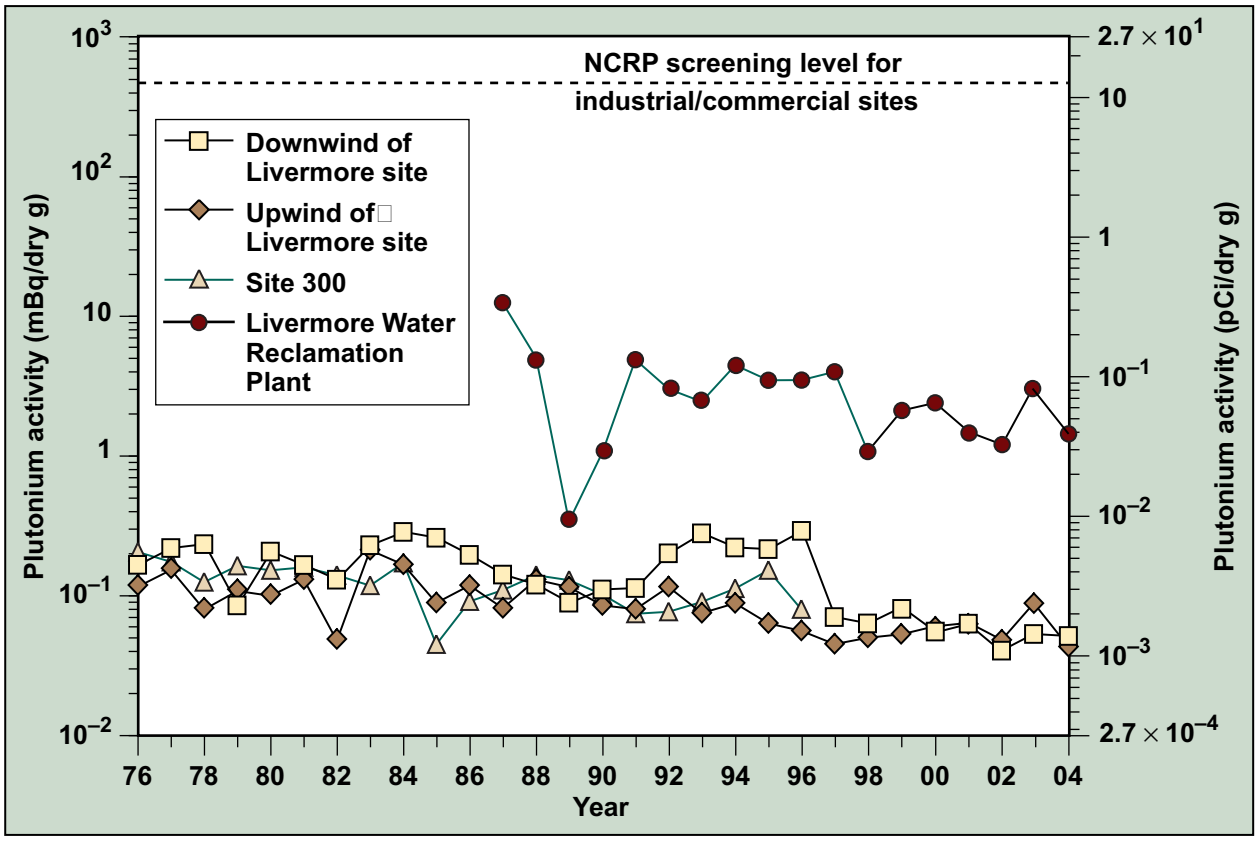
0.47 mBq/dry g (1.28×10^{-2} pCi/dry g), a value that is approximately equal to the 95% upper confidence level for the 95th percentile calculated for background data (i.e., 0.48 mBq/dry g [1.3×10^{-2} pCi/dry g]) (LLNL 1998, Appendix D). The slightly higher values at and near the Livermore site have 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 ceased operating the solar evaporators in 1976 and no longer engages in any other open-air treatment of plutonium-containing waste.

A sediment sampling location, ESB, also shows the effects of historic operation of the solar evaporators; it is in the drainage area for the southeast quadrant at LLNL. The measured value for plutonium-239+240 at this location for 2004 was 1.3 mBq/dry g (3.6×10^{-2} pCi/dry g). All tritium concentrations were less than the range of concentrations for previous years; all results were below the detection limit.

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 again detected at LWRP sampling locations. In addition, americium-241 was detected in two LWRP samples; it is most likely caused by the natural radiological decay of the trace concentrations of plutonium-241 that were present in the releases to the sewer.

Historical 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 5-4**. 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 2004 included sampling locations VIS, PATT, NEP, COW, AMON, SALV, and ZON7, compared with the upwind data. Notable variability in plutonium-239+240 is also seen in samples from LWRP. Because the plutonium-239+240 is likely to be present in discrete particles, the random presence or absence of the particles dominates the measured plutonium-239+240 in any given sample.

Table 5-4 presents data on the concentrations of uranium-235, uranium-238, and beryllium in soil from the Site 300 sampling locations; 2004 soils data for Site 300 for cesium-137, potassium-40, and thorium-232 are included in the file "Ch5 Soil" provided on the report CD. The concentrations and the distributions of all observed radionuclides in Site 300 soil for 2004 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. The highest measured value for 2004 occurred at 812N. The uranium-235 to uranium-238 ratio in this sample equals that ratio for depleted uranium (i.e., 0.002). Such values at Site 300 result from the use of depleted uranium in explosive experiments.



Note: Upwind and downwind designations are relative to the center of the Livermore site.
NCRP = National Council on Radiation Protection and Measurements

Figure 5-4. Median plutonium-239+240 activities in surface soils, 1976–2004

Nonradiological Monitoring Results

Analytical results for metals are compared with site-specific natural background concentrations for metals. (See the file "Ch5 Soil" provided on the report CD for the background concentrations and analytical results for metals.)

All total metals concentrations at the Livermore site were within site background, with the exception of zinc at location ESB. Livermore site groundwater surveillance monitoring (see Chapter 4) will determine any impacts on site groundwater. Since 2000, Aroclor 1260 (a PCB) has been detected at location ESB. In 2004, it was again detected at location ESB at a concentration of 3.7 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 4). The detected concentrations are below the federal and state hazardous waste limits.

Table 5-4. Uranium and beryllium concentrations in Site 300 soil, 2004

Location	Uranium-235[a] (μg/dry g)	Uranium-238[b] (μg/dry g)	U235/U238 ratio	Beryllium (mg/kg)
3-801E-SO	0.020 ± 0.098	2.3 ± 1.1	0.0087 ± 0.0060	<0.5
3-801N-SO	0.029 ± 0.013	5.7 ± 1.6	0.0051 ± 0.0027	0.64
3-801W-SO	0.029 ± 0.015	4.3 ± 1.6	0.0067 ± 0.0043	<0.5
3-812N-SO	0.36 ± 0.025	180 ± 37	0.0020 ± 0.00043	9.3
3-834W-SO	0.017 ± 0.012	1.9 ± 1.5	0.0089 ± 0.0095	0.61
3-851N-SO	0.030 ± 0.014	4.3 ± 2.0	0.0070 ± 0.0046	0.67
3-856N-SO	0.021 ± 0.0083	2.2 ± 0.77	0.0095 ± 0.0050	<0.5
3-858S-SO	0.023 ± 0.015	2.0 ± 0.79	0.012 ± 0.0088	<0.5
3-DSW-SO	0.035 ± 0.012	5.6 ± 1.6	0.0063 ± 0.0028	<0.5
3-EOBS-SO	0.025 ± 0.012	2.1 ± 1.7	0.012 ± 0.011	<0.5
3-EVAP-SO	0.033 ± 0.010	4.9 ± 1.5	0.0067 ± 0.0029	<0.5
3-GOLF-SO	0.021 ± 0.012	1.8 ± 1.5	0.012 ± 0.012	<0.5
3-NPS-SO	0.022 ± 0.0093	2.0 ± 0.91	0.011 ± 0.0067	<0.5
3-WOBS-SO	0.015 ± 0.0086	1.5 ± 1.0	0.010 ± 0.0088	<0.5
Median	**0.024**	**2.3**	**0.0088**	**<0.5**
IQR[c]	**0.0087**	**2.8**	**0.0041**	**—[d]**
Maximum	**0.36**	**180**	**0.012**	**9.3**

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 8.

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 2.15 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.

Beryllium results for soils at Site 300 (**Table 5-4**) were within the ranges reported since sampling began. The highest value, 9.3 mg/kg, was found at B812, which is an area that has been used for explosives testing. This value is much less than the 110 mg/kg detected at B812 in 2003. These differing results reflect the particulate nature of the contamination.

Environmental Impact on Soil and Sediment

Livermore Site

Routine surface soil, sediment, and vadose zone soil sample analyses indicate that the impact of LLNL operations on these media in 2004 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 9.6 mBq/dry g (0.26 pCi/dry g) for plutonium-239+240 measured at LWRP is 2% 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 **Tables 2-1** and **5-5**. These studies have consistently shown that the concentrations of radionuclides in local soils are below levels of health concern.

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 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 NCRP recommended screening level for commercial sites of 313 µg/g (3.9 Bq/g or 105 pCi/g). Historically, some measured concentrations of uranium-238 near Building 812 have been greater than the screening level. A CERCLA remedial investigation is underway at the Building 812 firing table area to define the nature and extent of contamination.

Vegetation and Foodstuff Monitoring

Vegetation sampling locations at the Livermore site (**Figure 5-1**) and in the Livermore Valley (**Figure 5-2**) are divided into four groups (Near, Intermediate, Far, and PIN1) for statistical evaluation. Tritium from LLNL operations may be detected at the Near and Intermediate locations depending upon wind direction and the magnitude of the releases. Near locations (AQUE, GARD, MESQ, NPER, MET, PIN2, and VIS) are onsite or within 1 km of the LLNL site perimeter; Intermediate locations in the

Table 5-5. Special soil and sediment 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
1976	Evaluation of the Use of Sludge Containing Plutonium as a Soil Conditioner for Food Crops	Myers et al. 1976
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 Public Health Assessment Plutonium 239 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.

Livermore Valley (I580, PATT, TESW, and ZON7) are greater than 1 and less than 5 km from the LLNL perimeter. Far locations are unlikely to be affected by LLNL operations; one background location (CAL) is more than 25 km distant, and the other (FCC) is about 5 km from the Livermore site but generally upwind. The PIN1 location is a pine tree rooted in an area of known tritium groundwater contamination on the Livermore site. Sampling of both PIN1 and PIN2 was discontinued at the end of 2004 due to an infestation of red turpentine beetles in PIN1 and because doses from minor sources no longer need to be calculated for compliance with NESHAPs regulations (see Chapter 6).

There are four monitoring locations for vegetation at Site 300 (**Figure 5-3**). Vegetation at locations DSW and EVAP exhibit variable tritium concentrations due to uptake of contaminated groundwater by roots. At the two other locations, 801E and COHO, the only potential source of tritium uptake is the atmosphere.

Wines for sampling in 2004 were purchased from supermarkets and wine merchants in Livermore. Wines represent the Livermore Valley, two regions of California, and the Rhone Valley in France. In 2004, the wine sampling network was cut by more than half; judicious choice of wines can provide as much information as was obtained from the larger network.

Water is extracted from vegetation by freeze-drying and counted for tritiated water (HTO) using liquid scintillation techniques. Both HTO and organically bound tritium (OBT) are detected in wine using helium-3 mass spectrometry, but the relative fractions of each are not determined.

Vegetation Monitoring Results

All concentrations of tritium in Livermore vegetation for 2004 are shown in **Table 5-6**. The highest mean and maximum concentrations in vegetation for 2004 were at the Near location NPER. NPER is not the location at which the highest concentrations are normally expected. The high concentration in vegetation at NPER occurred during the two-week period when concentrations at the DWTF ambient air tritium sampler were more than eight times higher than the biweekly mean for 2004 (see file "Ch3 Ambient Air" provided on the report CD).

Median values for each set of sampling locations are graphed in **Figure 5-5** to show the trend in tritium concentrations in vegetation since 1972. Concentrations at the Far and Intermediate locations have been below the detection limits for several years. In 2003 and 2004, the median concentrations for Near locations were also below detection limits. The lower limit of detection (LLD) has varied over the years, and a comparison of results based on the recent mean value of the LLD of about 2.0 Bq/L (54 pCi/L) eliminates variability arising from uncertain counting statistics at these low levels. The value for the median for Near locations for 2003 was 1.8 Bq/L (49 pCi/L); for 2004, it was 1.5 Bq/L (40 pCi/L). Although the changes in these concentrations may reflect the lower tritium emissions in 2004 compared with 2003, it can only be by chance, because statistically there is no difference between them.

As in the past, concentrations in PIN1, because of the contaminated groundwater source, were much higher than those in other vegetation. In 2004, PIN2, the pine at location VIS that is only exposed to atmospheric tritium, exhibited concentrations indistinguishable from the herbaceous VIS samples. All Near sample concentrations were statistically different from concentrations in PIN1.

All samples at Site 300 locations 801E and COHO were below detection limits. Median concentrations at locations 801E and COHO have been at or below detection limits since 1991. Tritium in vegetation at DSW and EVAP continues its erratic pattern dating from 1983, with high concentrations at times and nondetections at other times, depending upon whether or not the roots are taking up contaminated groundwater. The median concentrations at DSW and EVAP for 2004 were lower than those in 2003. The highest concentration (360 Bq/L [9700 pCi/L]) was observed at EVAP.

Table 5-6. Quarterly concentrations of tritium in plant water (Bq/L) and mean annual ingestion doses, 2004

	First quarter	Second quarter	Third quarter	Fourth quarter	Median	Mean	Mean dose[a] (nSv/y)
Sampling locations within 1 km of the Livermore site perimeter							
AQUE	1.4 ± 1.4	1.5 ± 1.9	–0.016 ± 2.6	1.5 ± 1.5	1.5	1.1	< 10[b]
GARD	–0.042 ± 1.3	0.39 ± 1.9	–0.070 ± 2.7	4.1 ± 1.7	0.17	1.1	< 10[b]
MESQ	0.27 ± 1.4	1.7 ± 2.0	1.8 ± 2.8	1.1 ± 1.6	1.4	1.2	< 10[b]
MET	–0.60 ± 1.3	5.4 ± 2.1	0.70 ± 2.6	2.3 ± 1.6	1.5	2.0	< 10[b]
NPER	1.2 ± 1.4	5.2 ± 2.1	13 ± 3.0	1.3 ± 1.6	3.3	5.2	25
PIN2	2.4 ± 1.5	6.0 ± 2.1	2.4 ± 3.1	4.5 ± 1.7	3.5	3.8	__[c]
VIS	0.54 ± 1.4	5.4 ± 2.1	0.16 ± 2.6	0.96 ± 1.5	0.75	1.8	< 10[b]
PIN1[d]	22 ± 2.4	44 ± 3.4	210 ± 6.7	84 ± 4.0	64	90	__[e]
Sampling locations from 1 to less than 5 km from the Livermore site perimeter							
I580	–1.7 ± 1.2	1.7 ± 2.0	–0.31 ± 2.7	2.3 ± 1.6	0.70	0.50	< 10[b]
PATT	–0.57 ± 1.3	2.2 ± 2.0	0.38 ± 2.7	1.5 ± 1.6	0.94	0.88	< 10[b]
TESW	1.4 ± 1.4	2.0 ± 2.0	–2.0 ± 2.6	1.7 ± 1.6	1.6	0.77	< 10[b]
ZON7	–0.77 ± 1.3	3.1 ± 2.1	0.86 ± 2.7	1.5 ± 1.5	1.2	1.2	< 10[b]
Sampling locations more than 5 km from the Livermore site perimeter							
CAL	–1.1 ± 1.3	1.9 ± 2.0	0.063 ± 2.6	0.58 ± 1.6	0.32	0.36	< 10[b]
FCC	–2.2 ± 1.2	–2.3 ± 1.5	–1.4 ± 2.6	–0.081 ± 1.5	–1.8	–1.5	< 10[b]
Sampling locations at Site 300							
COHO	–2.1 ± 1.2	1.0 ± 1.9	–1.8 ± 2.9	–0.91 ± 1.4	–1.4	–0.95	< 10[b]
801E	–0.38 ± 1.3	2.0 ± 2.0	3.0 ± 3.1	–0.02 ± 1.5	0.99	1.2	< 10[b]
DSW[d]	13 ± 2.0	3.4 ± 2.0	4.5 ± 3.0	3.0 ± 1.7	4.0	6.0	29
EVAP[d]	14 ± 2.0	5.8 ± 2.1	360 ± 9.0	18 ± 2.2	16	99	490

Note: Radioactivities are reported as the measured concentration and an uncertainty ($\pm 2\sigma$ counting error). If the concentration is less than or equal to the uncertainty, the result is considered to be a nondetection. See Chapter 8.

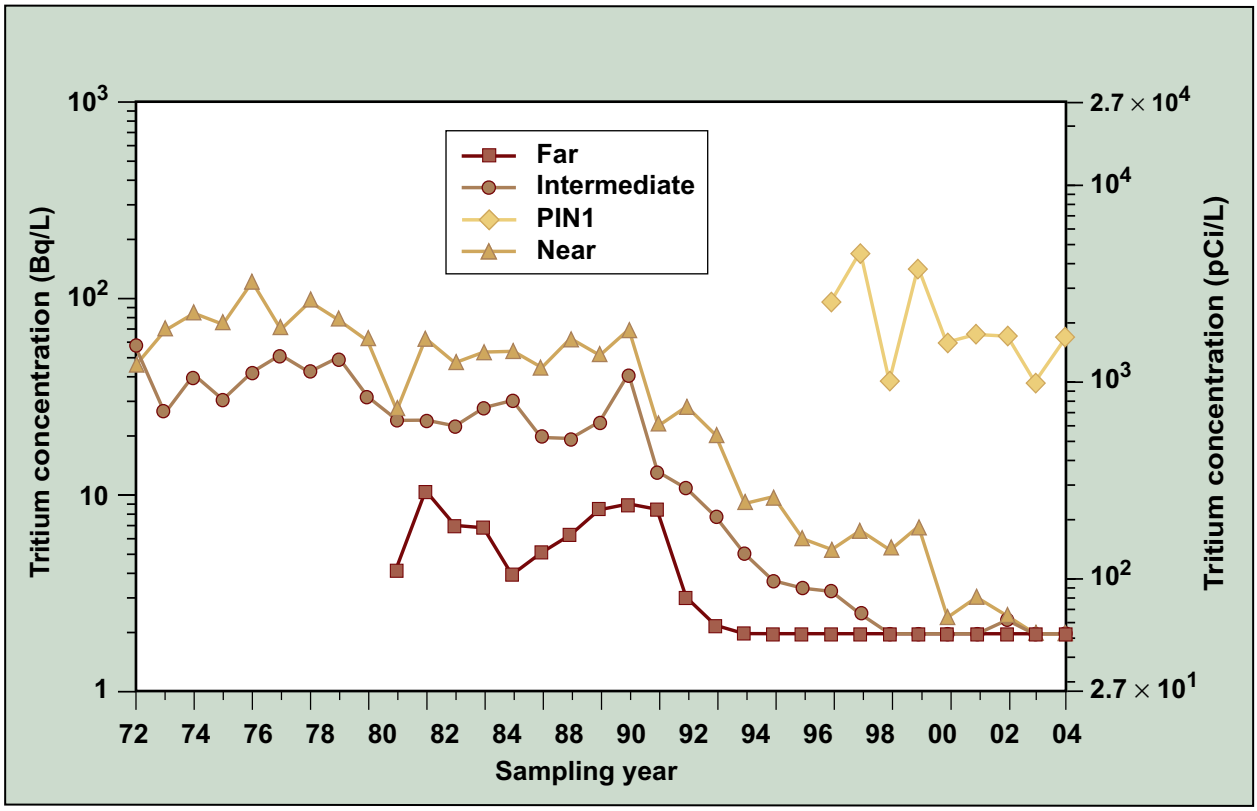
a Ingestion dose is based on conservative assumptions that an adult's diet is exclusively vegetables with this tritium concentration, and that meat and milk are derived from livestock fed on grasses with the same concentration of tritium. See **Table 6-6**.

b When concentrations are less than the detection limit (about 2.0 Bq/L), doses can only be estimated as being less than the dose at that concentration.

c Doses were not calculated because pine trees are not ingested by human beings. Concentrations from PIN2 are included with NEAR vegetation because plant water tritium concentrations are similar among plant types.

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

e Between 1997 and 2002, PIN1 was treated as a diffuse source (because pine needles are not eaten by human beings) and a dose was calculated. Beginning in 2003, for NESHAPs compliance, ambient air monitoring at LLNL accounts for minor diffuse sources, so a dose was not calculated.



Note: When median values are below 2.0 Bq/L (54 pCi/L; below the lower limit of detection), values are plotted as 2.0 Bq/L to eliminate meaningless variability.

Figure 5-5. Median tritium concentrations in Livermore Site and Livermore Valley plant water samples, 1972 to 2004

Wine Monitoring Results

The mean concentration (0.88 Bq/L [24 pCi/L]) of Livermore Valley wines sampled in 2004 is essentially the same as the mean (0.89 Bq/L [24 pCi/L]) for 2003; California wines continue to reflect residual historical bomb fallout and cosmogenic tritium levels (Table 5-7). The two wines from the Rhone Valley in France are as high or higher than any European wine previously sampled by LLNL and vinted after 1991 (Figure 5-6); this is not surprising because the Rhone Valley is home to numerous nuclear reactors used for power production. The highest concentration in a Livermore Valley wine (1.4 Bq/L [38 pCi/L]) was from a wine made from grapes harvested in 2000. Both Rhone Valley wines were vinted in 2001.

The wines purchased in 2004 represent vintages from 2000 to 2003. Thus, to compare the effect of LLNL operations on local wines, concentrations at the time of laboratory analysis must be corrected for the radiological decay that has occurred since the approximate date of harvest. Decay-corrected concentrations of tritium in wine for the

Table 5-7. Tritium in retail wine (Bq/L), 2004[a]

Sample	Area of production		
	Livermore Valley	California	Europe
1	0.57 ± 0.19	0.22 ± 0.19	3.5 ± 0.39
2	0.59 ± 0.20	0.52 ± 0.19	5.9 ± 0.62
3	0.86 ± 0.20		
4	0.87 ± 0.20		
5	1.0 ± 0.21		
6	1.4 ± 0.23		
	Dose (nSv/y)[b]		
	1.4	0.51	5.8

Note: Radioactivities are reported here as the measured concentration and an uncertainty (±2σ counting error).

a Wines from a variety of vintages were purchased and analyzed in 2004. The concentrations reported are those at the time the bottle was opened.

b This dose is calculated based on consumption of 52 L wine per year at maximum concentration (see Chapter 6).

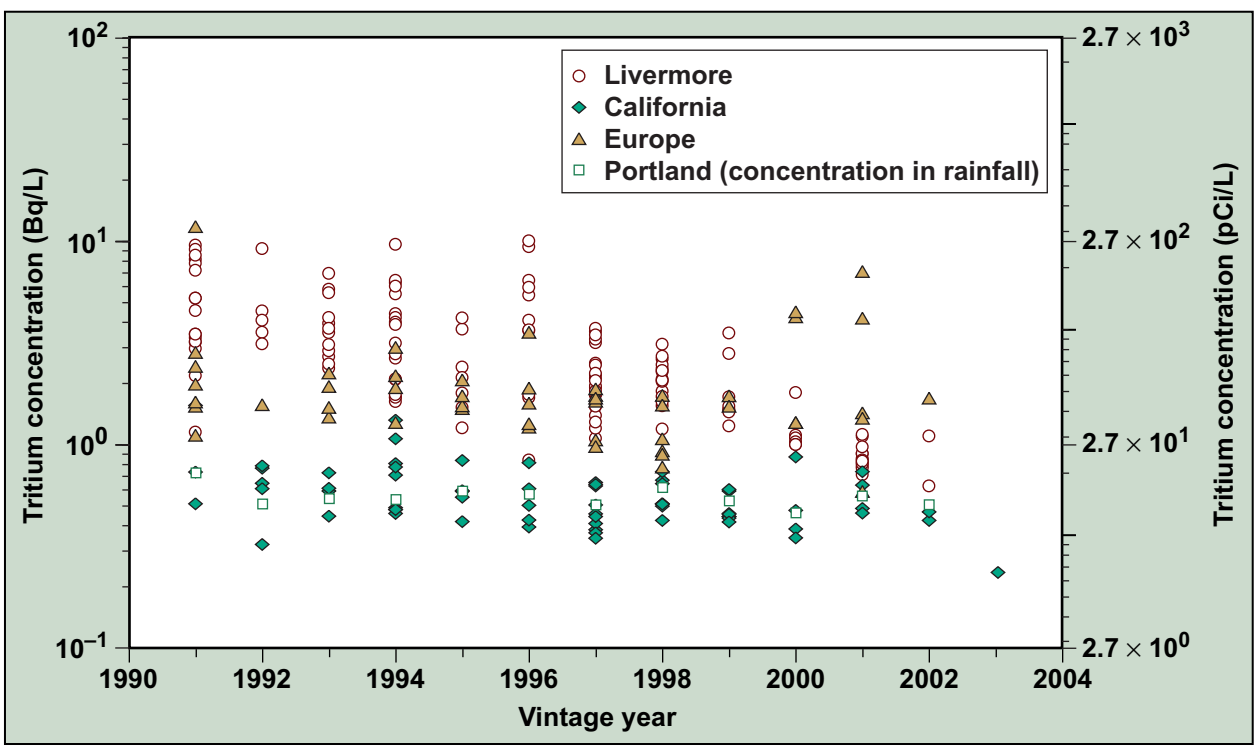


Figure 5-6. Tritium concentrations in all retail wines sampled since 1991 decay-corrected from the sampling year to the vintage year

Livermore Valley, California, and Europe are shown in **Figure 5-6** for the years from 1991 to present. Concentrations in all sampled wines are shown. The concentration of tritium in rainfall at Portland, Oregon (IAEA/WMO 2004) is also shown to demonstrate the similarity between tritium concentrations in California wines and background tritium concentrations on the Pacific coast (no similar data exist for California).

Because only a small number of bottles of Livermore Valley, California, and European (Rhone Valley) wine were sampled in 2004, a statistical comparison cannot be made. However, it is clear that Livermore Valley wines range in concentration from essentially no different than other California wines to about a factor of three higher. The tritium concentrations in the Rhone Valley wines sampled are distinctly higher than those of the Livermore Valley wines.

Environmental Impact on Vegetation and Wine

Vegetation

Hypothetical annual ingestion doses for mean concentrations of tritium in vegetation are shown in **Table 5-6**. These doses were calculated using the transfer factors from **Table 6-6** based on U.S. Nuclear Regulatory Commission Regulatory Guide 1.109 (U.S. NRC 1977). All doses are estimated based on measured concentrations of HTO in vegetation and consequent dose from HTO ingestion.

The hypothetical annual ingestion dose, based on highest observed mean HTO concentration in vegetation for 2004, is 25 nSv (2.5 µrem/y). This is lower than the 37 nSv in 2003 due to decreased tritium emissions. Since 1989, after which concentrations in vegetation have decreased noticeably (**Figure 5-5**), the hypothetical annual ingestion dose based on the maximum observed mean has decreased by a factor of 25; the decrease for any one location is much greater than this because vegetation sampling locations in 1989 were either off-site or upwind from tritium sources (i.e., NPER or another potentially high perimeter location was not sampled in 1989).

Doses calculated based on Regulatory Guide 1.109 neglect the increased contribution from OBT. However, according to a conclusion by a panel of tritium experts, "the dose from OBT that is ingested in food may increase the dose attributed to tritium by not more than a factor of two, and in most cases by a factor much less than this." (ATSDR 2002). Thus the maximum estimated ingestion dose from LLNL operations for 2004 is at most 50 nSv (5.0 µrem/y).

To demonstrate compliance with NESHAPs, between 1997 and 2002, location PIN1 was treated as a diffuse source of tritium, and a hypothetical dose to the maximally exposed individual at the nearest perimeter location was calculated using the dispersion and dose model CAP88-PC. Mean annual doses from PIN1 have always been less than 9.0 pSv (0.9 nrem). In 2003, LLNL obtained permission from the U.S. Environmental Protection Agency (EPA) to demonstrate compliance by using monitoring data in place of modeling dose from releases from minor sources. Any tritium released by PIN1 is

sampled by the air tritium monitoring network. There is thus no reason to calculate a dose from PIN1 in 2004. Furthermore, sampling of PIN1 and PIN2 was terminated at the end of 2004 because it is no longer necessary.

LLNL operations at the Livermore site release small quantities of HTO to the immediate environs that can be measured by conventional methods in vegetation. The ingestion dose calculated based on HTO concentrations in vegetation but that also accounts for OBT (50 nSv; 5.0 µrem/y) is just 1/60,000 of the average annual background dose in the United States from all sources and just 1/2000 the dose from a typical chest x-ray (Schleien and Terpilak 1984). This dose is calculated on the assumption that all the vegetables, milk, and meat ingested have concentrations that represent the location of the sampled vegetation. This is an improbable scenario because the average person lives farther from the Livermore site than the location of the highest vegetation concentrations and grows just a small fraction of total food ingested. Thus the likely potential dose received will be considerably smaller than this already tiny dose (see **Table 6-8**). During 2004 at Site 300, no tritium was released to the atmosphere from LLNL operations. Consequently, vegetation concentrations are below detection limits except at locations of contaminated groundwater (see Chapter 7, "Remediation Activities and Monitoring Results" section). The contaminated groundwater resulting from past activities does affect concentrations in vegetation at locations DSW and EVAP. The dose calculated from these elevated concentrations is entirely hypothetical, because vegetation at Site 300 is not ingested by either livestock or people. The mean dose for 2004 for location EVAP, which exhibited the higher concentrations of the two locations, would be 490 nSv (49 µrem), which is very small.

Wine

For Livermore Valley wines purchased in 2004, the highest concentration of tritium (1.4 Bq/L [38 pCi/L]) is just 0.19% of the Environmental Protection Agency's standard for maximal permissible levels of tritium in drinking water (740 Bq/L [20,000 pCi/L]). Dose from drinking 1 L per day of the Livermore Valley wine with the highest concentration purchased in 2004 would be 9.7 nSv/y (0.97 µrem/y). A more realistic dose estimate, based on moderate drinking (1 L per week)[1] at the mean of the Livermore Valley wine concentrations (0.88 Bq/L [24 pCi/L]) is 0.87 nSv/y (0.087 µrem/y). Both doses explicitly account for the added contribution of OBT[2].

Local wineries are sufficiently distant from the Livermore site that tritium in wines can only be detected reliably using an ultra-sensitive method. The potential dose from drinking Livermore Valley wines, including the contribution of OBT, even at the high consumption rate of 1 L per day, is about 1/300,000 of the average annual background dose from naturally occurring sources of radiation.

1. Moderate consumption is higher than the average consumption of wine in California (15.7 L/y) (Avalos 2005).
2. Dose from wine is calculated by summing the dose from HTO in the water fraction of wine and the dose from OBT in the organic fraction of wine. Dose coefficients for HTO and OBT are those of the International Commission on Radiation Protection (1996). The organic component of wine (estimated from grape juice) increases the dose by 6% over what it would be had wine no organic fraction.

Ambient Radiation Monitoring

Gamma radiation in the environment comes from two natural sources. The first source is the *terrestrial component*, which is caused by the radioactive decay of parent elements formed in the earth's crust 4.5 billion years ago (e.g., uranium-238, thorium-232, and potassium-40) and their respective daughter radiations.The second source is from the *cosmic component* of external radiation, which induces secondary radiations from interactions with atmospheric nuclei in the upper atmosphere. These cosmic interactions result in the production of meson, neutron, gamma, and electron radiations at the earth's surface (Eisenbud 1987).

LLNL's ambient radiation monitoring program is designed to distinguish any LLNL operational contribution from these natural sources by sampling a significant number of locations to validate the large natural background.

Methods and Reporting

Exposure to external radiation is measured by correlating the interaction of ionizing energy with its effect on matter which absorbs it. The roentgen (R) was adopted as the special unit of exposure dose by the International Commission on Radiological Units in 1956 and is defined as the charge required to ionize a given volume of air (2.58×10^{-4} coulombs per kilogram of air) (Roesch and Attix 1968).

It is this equivalency that is used to determine the quantity of ambient radiation measured by portable thermoluminescent dosimeters (TLDs) placed in the surrounding community. LLNL uses the Panasonic UD-814AS1 TLD, which contains three crystal elements of thallium-activated calcium sulfate ($CaSO_4$).

As the TLD absorbs ionizing energy, electron–hole pairs are created in the crystal lattice, trapping this absorbed energy in the crystal's excited state. The absorbed energy in the TLD crystal is released in the form of light emission upon heating the TLD to extreme temperature. This light emission, which is proportional to the TLD absorbed dose, is then collected by a photomultiplier tube and compared to its glow curve, as it is termed, which is calibrated to a known standard of cesium-137 gamma energy of 662 keV. The result of the TLD exposure is then reported in the International System (SI) unit of sievert (Sv) from the calculated dose in mR (1×10^{-3} R).

In order to compare LLNL dose contributions with the natural background, the analysis is divided into three groups:

- Livermore site locations—shown in **Figure 5-1**
- Livermore Valley locations—shown in **Figure 5-2**
- Site 300 and the local offsite vicinity, and sites in the city of Tracy—shown in **Figure 5-3**

As policy, the State of California Radiological Health Branch maintains several collocated TLD sample sites around the LLNL perimeter and Livermore Valley for independent monitoring comparison.

In order to obtain a true representation of the local site exposure and determine any dose contribution from LLNL operations, an annual environmental monitoring compliance assessment is done in accordance with DOE 450.1 through a quarterly deployment cycle. TLDs are deployed at a 1 meter height, adhering to the guidance of *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. DOE 1991).

For the purposes of reporting comparisons, data is reported as a "standard 90-day quarter," with the dose reported in millisievert (mSv; 1 mSv = 100 mrem).

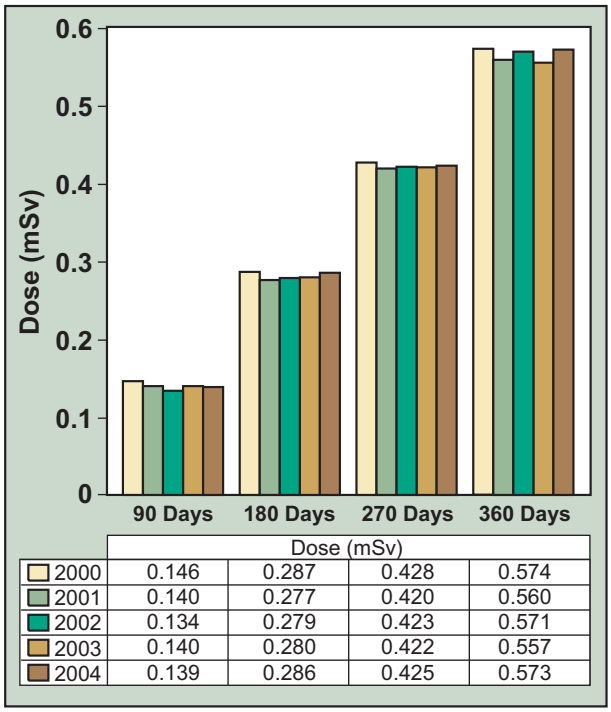
Monitoring Results

In **Figures 5-7** through **5-10**, the quarterly average cumulative doses in mSv for 2004 are presented for the Livermore site, the Livermore Valley, on-site at Site 300 and off-site at Site 300 along with five years of quarterly doses from 2000 to 2004.

Figure 5-7 illustrates the average cumulative dose for the Livermore site perimeter for successive 90 day periods for the entire year. The graph indicates a stable trend in the site-wide annual dose when compared to previous years. Similarly, comparing the data of **Figure 5-8**, which represents the Livermore Valley, the same trend is readily observable. Likewise, when doses for Site 300 (**Figure 5-9**) are compared to the doses for the off-site locations (**Figure 5-10**), the same trends are evident.

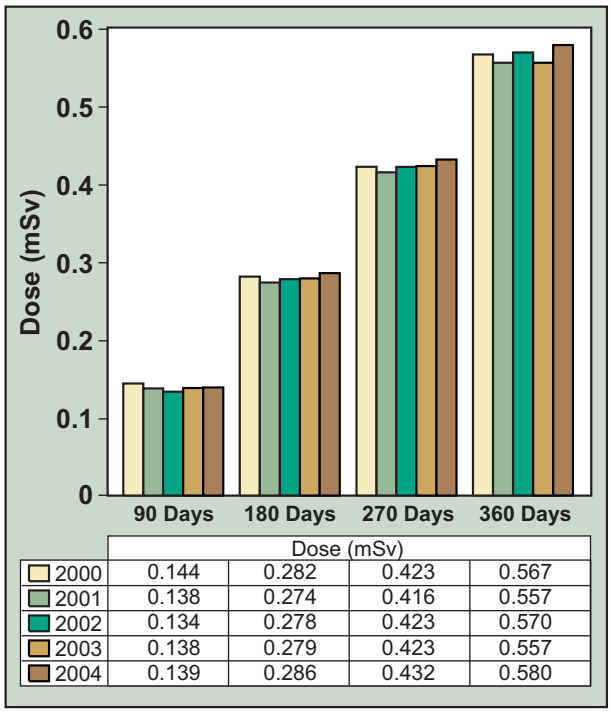
Tabular data for each individual sampling location illustrate the quarterly variation (see file "Ch5 Ambient Radiation" provided on the report CD). Missing data are due to lost or damaged samples. When actual site location data are compared for the same time period of 5 years, similarities are noted. This is indicative of the local and seasonal variations that are smoothed in the site-wide averages.

From year to year, the exposure of the TLD at one sampling site changes very little. Local variation is largely due to changes in the local distribution of the radon flux as a product of decay from the uranium and thorium series on some small level and from changes in the cosmic radiation flux. For example, when the data for the Livermore site



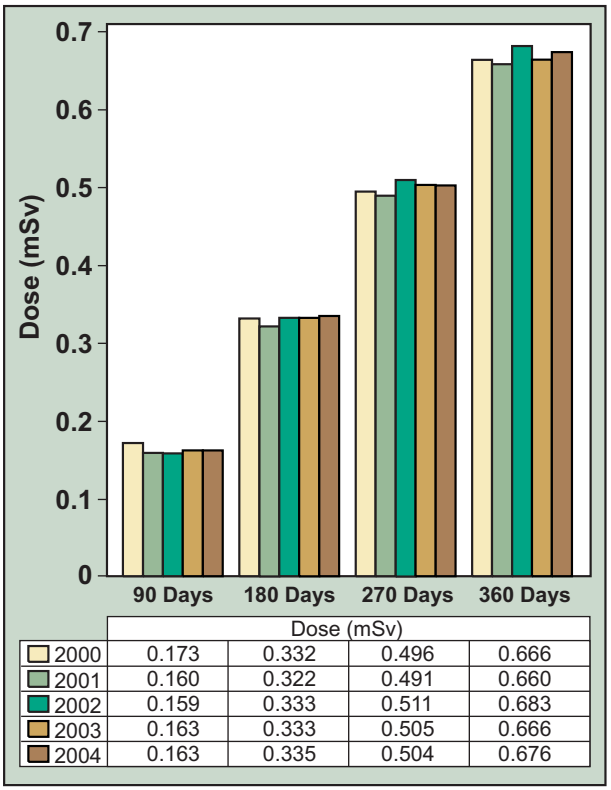
	Dose (mSv)			
2000	0.146	0.287	0.428	0.574
2001	0.140	0.277	0.420	0.560
2002	0.134	0.279	0.423	0.571
2003	0.140	0.280	0.422	0.557
2004	0.139	0.286	0.425	0.573

Figure 5-7. Livermore site perimeter cumulative dose (mSv), 2000 through 2004



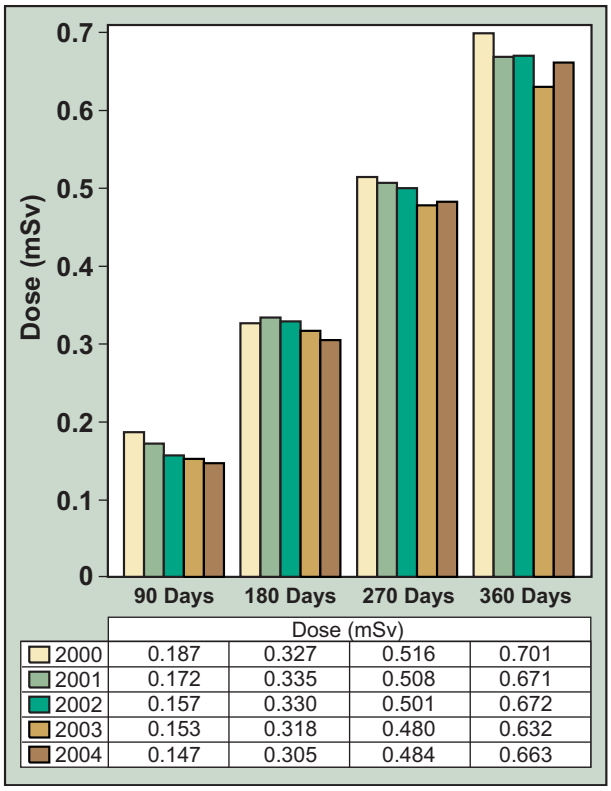
	Dose (mSv)			
2000	0.144	0.282	0.423	0.567
2001	0.138	0.274	0.416	0.557
2002	0.134	0.278	0.423	0.570
2003	0.138	0.279	0.423	0.557
2004	0.139	0.286	0.432	0.580

Figure 5-8. Livermore Valley cumulative dose (mSv), 2000 through 2004



	Dose (mSv)			
2000	0.173	0.332	0.496	0.666
2001	0.160	0.322	0.491	0.660
2002	0.159	0.333	0.511	0.683
2003	0.163	0.333	0.505	0.666
2004	0.163	0.335	0.504	0.676

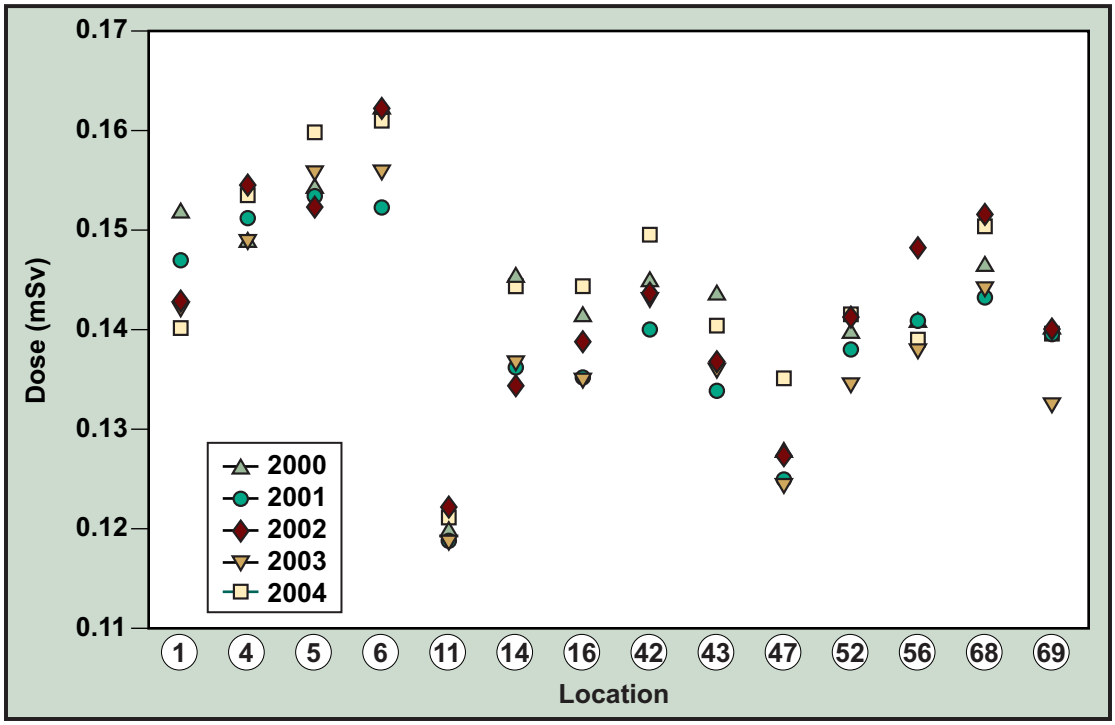
Figure 5-9. Site 300 on-site cumulative dose (mSv), 2000 through 2004



	Dose (mSv)			
2000	0.187	0.327	0.516	0.701
2001	0.172	0.335	0.508	0.671
2002	0.157	0.330	0.501	0.672
2003	0.153	0.318	0.480	0.632
2004	0.147	0.305	0.484	0.663

Figure 5-10. Site 300 environs cumulative dose (mSv), 2000 through 2004

perimeter are examined for the 5 year period by location (**Figure 5-11**), the local variation is readily observed. This is due primarily to the natural soil variability. Similar variability is seen within the other location groups (**Figures 5-12** and **5-13**).



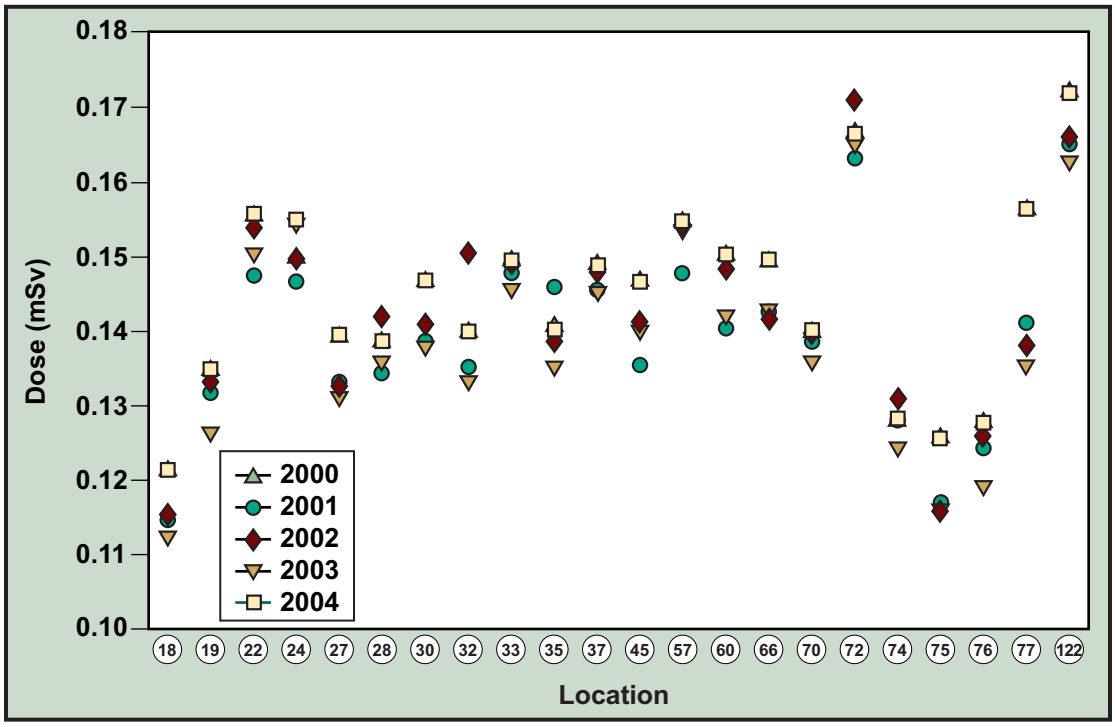
Note: See **Figure 5-1** for locations.

Figure 5-11. Livermore site perimeter annual average dose from 2000 to 2004

Environmental Impact from Laboratory Operations

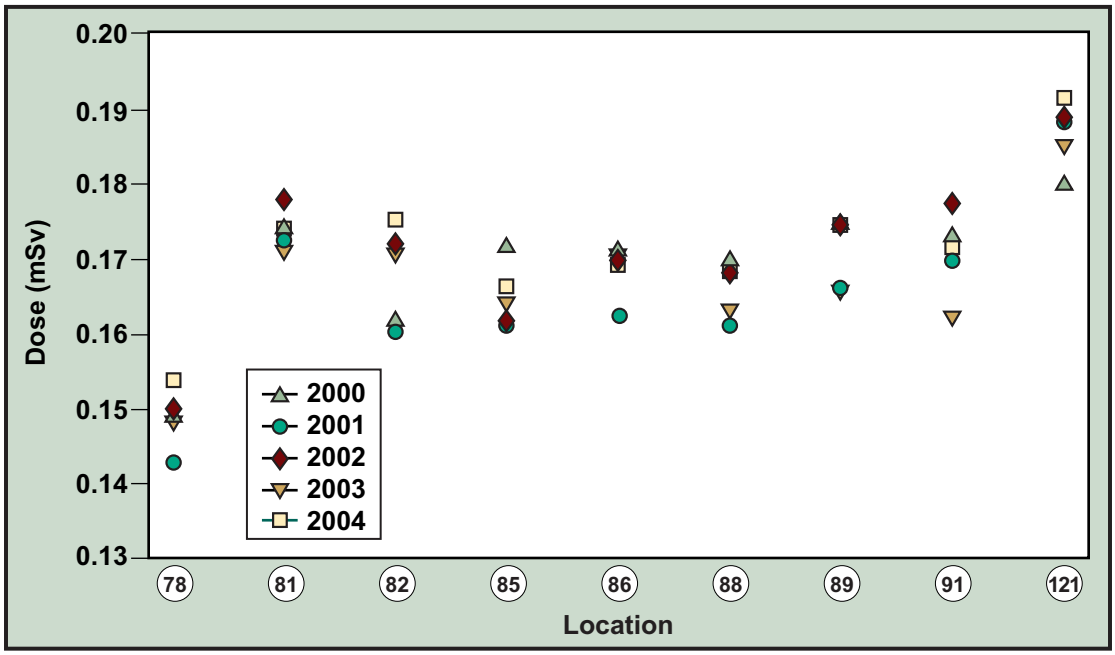
There is no evidence to conclude that there is any environmental impact or increase in direct gamma radiation as a result of LLNL operations as measured by the TLD network for the year 2004. The radiation dose trends remain consistent with annual location average levels for each sample site. Although some locations have had anomalous annual values in comparison to the long term trend for these locations, the trends would have continued at those sample sites had there been any contamination effecting the dose at that site. This is the most important reason for long term trend analysis and why these spurious excursions are not considered alarming.

As depicted in **Figure 5-14**, the annual average gamma radiation dose from 2000 to 2004 is statistically equivalent and shows no discernible impact due to operations conducted at LLNL.



Note: See **Figure 5-2** for locations.

Figure 5-12. Livermore Valley annual average dose from 2000 to 2004



Note: See **Figure 5-3** for locations.

Figure 5-13. Site 300 annual average dose from 2000 to 2004

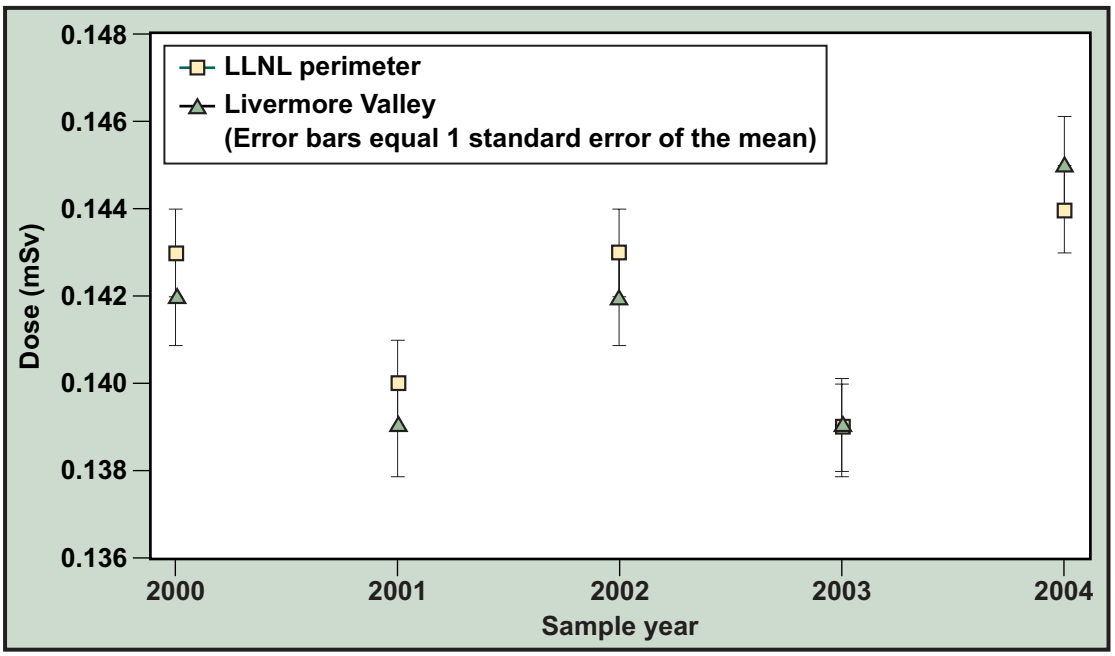


Figure 5-14. Annual average gamma radiation dose comparison for Livermore site and the Livermore Valley

Special Status Wildlife and Plants

Special status wildlife and plant monitoring efforts at LLNL are focused on species and associated habitats considered to be rare, threatened, or endangered. This includes species listed under the California or Federal Endangered Species Acts; species considered of concern by the California Department of Fish and Game, and the U.S. Fish and Wildlife Services (USFWS); and species that require inclusion in NEPA and CEQA documents.

Locations of species of particular interest are shown in **Figure 5-1** for the Livermore site and **Figure 5-15** for Site 300. A list of species known to occur at Site 300, including state and federally listed species, is found in Appendix C. (A similar list has not been prepared for the Livermore site.)

Five species that are listed under the federal or California endangered species acts are known to occur at Site 300: the California tiger salamander (*Ambystoma californiense*), California red-legged frog (*Rana aurora draytonii*), Alameda whipsnake (*Masticophus lateralis euryxanthus)*, valley elderberry longhorn beetle (*Desmocerus californicus dimorphus)*, and the large-flowered fiddleneck (*Amsinckia grandiflor*a). Although there are no recorded observations of the federally endangered San Joaquin kit fox (*Vulpes*

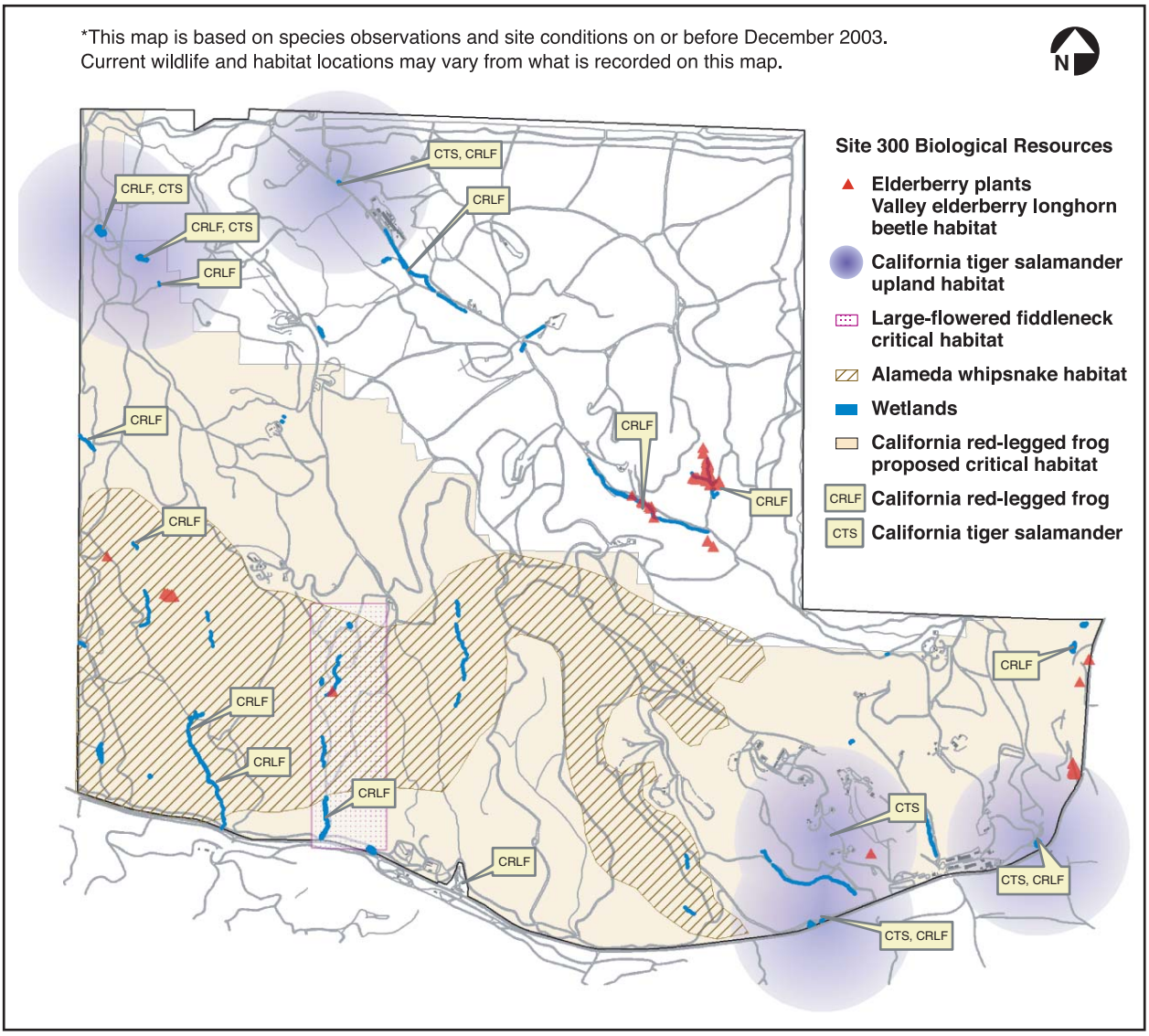


Figure 5-15. Distribution of federal and California threatened and endangered plants and wildlife, Site 300, 2004

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. California threatened Swainson's Hawks (*Buteo swainsoni*) and California endangered Willow Flycatchers (*Empidonax traillii*) have been observed at Site 300, but breeding habitat for these species does not occur at Site 300. The California red-legged frog is also known to occur at the Livermore site.

In 2001, the 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, was rescinded in 2002 due to a court decision. Critical habitat for the California red-legged frog was proposed again in April of 2004 (USFWS 2004a). This new proposal includes the same LLNL areas as the 2001 designation. 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. Critical habitat was also proposed for the California tiger salamander in 2004. Proposed critical habitat for the California tiger salamander is not found at Site 300 or the Livermore site (USFWS 2004b). 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.

Several other species that are considered rare or otherwise of special interest by the federal and state governments also occur at Site 300 and the Livermore site. These species include California Species of Special Concern, California Fully Protected Species, federal Species of Concern, species that are the subject of the federal Migratory Bird Treaty Act, and those species included in the California Native Plant Society's (CNPS's) *Inventory of Rare and Endangered Plants* (CNPS 2001). In particular, monitoring programs have been developed for the Tricolored Blackbird (*Agelaius tricolor*), a California species of special concern, and the White-tailed Kite (*Elanus leucurus*), a California fully protected species.

Including the federally endangered large-flowered fiddleneck, eight species of rare plants are known to occur at Site 300. Three of these species, the large-flowered fiddleneck, the big tarplant (*Blepharizonia plumosa*, also known as *Blepharizonia plumosa* subsp *plumosa*), and the diamond-petaled poppy (*Eschscholzia rhombipetala*), are included in the CNPS List 1B (CNPS 2001). These species are considered rare and endangered throughout their range. An additional species, the round-leaved filaree (*Erodium macrophyllum*) is currently included on CNPS List 2 (CNPS 2001). This list includes species that are rare or endangered in California and elsewhere. The four remaining rare plant species, the gypsum-loving larkspur (*Delphinium gypsophilum* subsp. *gypsophilum*), California androsace (*Androsace elongata* subsp. *acuta*), stinkbells (*Fritillaria agrestis*), and hogwallow starfish (*Hesperevax caulescens*), are all included on the CNPS List 4 (CNPS 2001). List 4 plants are uncommon enough to warrant monitoring, but are not considered rare. Past surveys have failed to identify any rare plants on the Livermore site (Preston 1997, 2002).

The following sections describe results from LLNL special status wildlife and plant studies and surveys. For an estimate of LLNL's dose to biota, see the "Special Topics on Dose Assessment" section in Chapter 6.

Compliance Activities

California Red-Legged Frog

California red-legged frogs occur at the Livermore site and Site 300. Livermore site populations of the California red-legged frog were monitored in accordance with the 1997 and 1998 amended USFWS Biological Opinion for the Arroyo Las Positas Maintenance Project. The 1998 Biological Opinion allows for a checkerboard pattern of Arroyo sections ranging in length from one hundred feet to three hundred feet to be managed annually for excess in-stream vegetation. No stream maintenance was conducted in Arroyo Las Positas in 2004.

Thirty-seven egg masses were observed and quantified in 2001, 32 in 2002, 31 in 2003, and 9 in 2004. Oviposition sites tended to be shallow, and all egg masses were located in water less than 50 cm deep. Most egg masses were within one meter of the shore and near the surface. Egg masses were usually deposited on vegetation that provided structure and to a lesser extent rigidity, such as attached inflorescences, but unattached debris including downed branches and decomposing vegetation was also used for oviposition.

Most 1 m^2 quadrats centered on egg masses included a portion of the stream bank and a portion of the hydrated stream channel; as a result, cover estimates include emergent wetland species that occur in the stream channel and upland and facultative wetland species that occur on the banks of the stream just above the water level. Egg masses were located in areas with approximately 64% cover of open water.

Grasses and emergent wetland species covered a similar percentage of the quadrats. The most common species were the exotic grass barnyard grass (*Echinochloa crus-galli)* and two emergent wetland species, tall flatsedge (*Cyperus eragrostis*) and watercress (*Rorippa nasturtium-aquaticum)*. One tree species, *Salix exigua*, was found in the vegetation quadrats. *S. exigua* was only found near 3 of the 40 egg masses located in Arroyo Las Positas in 2003 and 2004.

Surveys for adult frogs were conducted in locations at Site 300 (intermittent drainages, springs, and ponds) and the Livermore Site (Arroyo Las Positas, Arroyo Seco, and portions of artificial drainage channels). These surveys consisted of walking the perimeter of the stream or pond at night between May 1 and November 1 and surveying in and around the wetland areas using a flashlight. The location of California red-legged frog populations in 2004 are shown in **Figures 5-1** and **5-15**.

Alameda Whipsnake

In 2002, LLNL began participation in a study, in cooperation with the USFWS and four other agencies, to determine the effects of prescribed burns on federally threatened Alameda whipsnakes. 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 prescribed burns

necessary for Site 300 operation in areas that support Alameda whipsnakes. The study area consists of a control site and a burn site that are vegetated by a mosaic of coastal scrub and annual grasslands. Baseline studies were conducted in spring and fall of 2002 and spring of 2003 at Site 300 and consisted of live trapping Alameda whipsnakes, recording the location of individuals, and marking the snakes for future identification.

There was a total of 22 Alameda whipsnakes captures (9 at the control site and 13 in the burn site) during baseline monitoring in the spring and fall of 2002, and 12 captures (7 in the control site and 5 in the burn site) in the spring of 2003. A prescribed burn was conducted at the burn site in the summer of 2003, and the first season of post-burn monitoring was conducted in the fall of 2003. One Alameda whipsnake was captured in the control site in the fall of 2003, and no Alameda whipsnakes were captured in the burn site. Post-burn trapping of Alameda whipsnakes continued in the spring and fall of 2004. In 2004, there was a total of 14 Alameda whipsnake captures during spring trapping (8 in the control area and 6 in the burn area), and no Alameda whipsnakes were captured during the fall trapping period. To date, no conclusions have been made about the effect of the Site 300 prescribed burns on Alameda whipsnakes.

Invasive Species Control Activities

Bullfrog (*Rana catesbeiana*) control activities continued in 2004 in compliance with the 1998 amended USFWS Biological Opinion for the Arroyo Las Positas Maintenance Project. Bullfrog egg masses were removed from the Drainage Retention Basin weekly during spring and summer of 2004. Four nighttime surveys for adult bullfrogs were conducted in the summer of 2004. During these surveys, bullfrogs were identified by a qualified biologist and removed. The control program appears to be stabilizing or reducing the overall numbers of bullfrogs after the original introduction in 1999 and subsequent population explosion.

Arroyo Mocho Road Improvement and Anadromous Fish Passage Project

In 2004, the Environmental Protection Department (EPD) and the UTel Department collaborated on an ambitious project to remove a low flow crossing at Arroyo Mocho, a major tributary to Alameda Creek. The crossing had served as the primary access to the LLNL's Arroyo Mocho Pump Station. The crossing had eroded over the years and was in danger of failure due to undermining by the stream. Furthermore, the crossing and subsequent eroded conditions were impassable to steelhead trout (*Oncorhynchus mykiss*), a federally threatened anadromous fish.

Since Arroyo Mocho is relatively pristine, extreme care was taken by LLNL to replace the crossing with a freestanding bridge while preserving biota habitat and restoring the natural flow characteristics of the stream to facilitate passage by steelhead. The EPD/UTel team worked closely with a construction contractor during the summer to complete the project. EPD Wildlife Biologists were on hand throughout the project and

successfully translocated hundreds of amphibians, reptiles, and fish out of harms way. Once the bridge was in place, native plants previously collected and raised elsewhere were planted in the project area to complete restoration activities.

Surveillance Monitoring

Wildlife

Nesting Bird Surveys

LLNL conducts nesting bird surveys to ensure LLNL activities comply with the Migratory Bird Treaty Act and do not result in impacts to nesting birds. White-tailed Kites, a California fully protected species, annually nest in the trees located along the north, east, and south perimeters of the Livermore site. LLNL surveyed potential White-tailed Kite nesting sites using binoculars or a spotting scope during the spring of 2004; three pairs of White-tailed Kites successfully fledged a total of nine young. Although White-tailed Kites are also known to occasionally nest at Site 300, site-wide kite surveys were not conducted at Site 300 in 2004 because they do not typically nest in areas where they may be affected by programmatic activities.

Avian Monitoring Program

An avian monitoring program was initiated in 2001 to obtain background information for the draft *Site-wide Environmental Impact Statement for the Continued Operation of Lawrence Livermore National Laboratory and Supplemental Stockpile Stewardship and Management Programmatic Environmental Impact Statement* (see Chapter 2 for more information on the draft environmental impact statement). A constant effort mist netting station was also established spanning 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 through August 2004). Birds captured in the mist nets were identified to species, banded, aged, sexed, measured, and weighed before being released. All of the species identified in these surveys are listed in Appendix C.

Rare Plants

LLNL conducted restoration and/or monitoring activities in 2004 for four of the eight rare plant species known to occur at Site 300: the large-flowered fiddleneck, the big tarplant, the diamond-petaled poppy, and the round-leaved filaree. The results of this work are described in more detail in a biannual progress report (Paterson et al. 2005).

Large-Flowered Fiddleneck

LLNL established an experimental population of large-flowered fiddleneck at Site 300 in the early 1990s 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 large-flowered fiddleneck populations, and further developing habitat restoration and maintenance techniques for this species. This experimental population is divided into two smaller subpopulations: the flashing subpopulation (the original experimental population) and the fire frequency subpopulation. One extant native population

of large-flowered fiddleneck is also found at Site 300. The experimental and native populations were censused during March 2004. During the 2004 spring census, the location and size of each large-flowered fiddleneck plant was recorded in addition to information about the vegetation community in which large-flowered fiddleneck occurred.

The native population continued to be very small in 2004. The native population had only three plants in 2004, which is the smallest population size recorded since 1980. The number of *A. grandiflora* in the flashing and fire frequency experiment subpopulations has also been low recently. Because of the low population numbers in native and experimental populations, LLNL obtained funding from the U.S. Bureau of Land Management to enhance the seed bank of the flashing subpopulation at Site 300 and a second experimental population at Lougher Ridge in Black Diamond Mines Regional Park. A total of 2400 large-flowered fiddleneck seeds from the LLNL-maintained seed bank were planted at the Site 300 experimental population in the fall of 2002.

In 2003, even after the seed bank enhancement of the previous winter, only 69 *A. grandiflora* were found in the flashing subpopulation. Site 300 seedlings suffered from a great deal of herbivory in the winter of 2003, which may have caused many of the plant deaths. There was also an unusual rain pattern during the 2002/2003 rainy season. After a wet December (3.55 inches rainfall) in 2002, there was only a total of 2.0 inches of rain in January through March of 2003. This lack of rainfall early in 2003 may have decreased the survivorship of plants, from the 2002 seed sowing, that germinated after the December rains.

Because of the poor success in 2002, the seed bank enhancement was repeated in the Site 300 and Lougher Ridge subpopulations during the fall of 2003. In the spring of 2004, there were 753 *A. grandiflora* in the flashing experimental population. Unfortunately, these plants were very small and weren't expected to produce much seed. As a result of the 2002 and 2003 seed bank enhancement projects, several conclusions could be made about the methods used to enhance the germination and survival of *A. grandiflora* grown from seed in the experimental populations. Germination in the common garden was high, which indicates that the seed from most seed sources was quite viable. It is likely that seeds had lower germination rates at the two field locations due to two factors: granivory and unsuitable microconditions. Seeds that were not eaten but were unable to germinate due to nonoptimal conditions in 2004 may germinate in future years when conditions are better.

A. grandiflora seed stored in the seed bank at LLNL does appear to lose some viability with age, as demonstrated in the 2002 and 2003 seed bank enhancement projects. Germination studies have also shown that greenhouse and common garden-grown *A. grandiflora* seeds have increased germination rates compared to field grown seeds (unpublished data). This increased germination rate may be due to decreased seed dormancy because of an extremely favorable environment when the seeds were produced rather than due to increased seed viability. Seedlings also grew larger and showed less signs of herbivory when plots were covered in plastic netting designed to exclude birds.

LLNL is also beginning to see results in the long-term fire frequency experiment begun in 2001. The native perennial grass *Poa secunda* is most abundant in plots that are burned annually. Previous research shows that *A. grandiflora* is more successful in plots dominated by *P. secunda* compared to plots dominated by exotic annual grasses (Carlsen et al. 2000), but early results from the fire frequency experiment show that *A. grandiflora* is more abundant in the unburned control plots dominated by dense annual grasses than in the burned plots. Data from plots burned at an intermediate density are not yet available. Clearly there are a variety of factors affecting the success of *A. grandiflora* populations.

While prescribed burns help to produce a plant community dominated by *P. secunda*, predation is also higher in plots that have been burned. Because of the extremely high rates that have been observed in some years, seed predation is very likely a significant factor in determining *A. grandiflora* population sizes.

While LLNL has uncovered some clues to the successful restoration of *A. grandiflora* populations and continues to work to sustain the existing experimental and native populations, the reasons for the sharp declines in this population in recent years are still unclear. Seed bank enhancement efforts are more successful when plots are netted and seeds from greenhouse or common garden experiments are used, but the resulting plants can be small and produce little seed. LLNL can promote the establishment of a native perennial grassland with prescribed burns, but seed predation is quite high in these burned areas.

Big Tarplant

The distribution of big tarplant was mapped using a handheld GPS in October and November 2004. This distribution was compared, using a GIS (Geographic Information System), to the distribution of prescribed burns conducted at Site 300 in 2004 and in previous years. The big tarplant distribution decreased throughout Site 300 in 2004.

Research conducted by LLNL indicates that the annual prescribed burns conducted at Site 300, particularly the edges (or ecotones) between burned and unburned areas, play a role in the abundance of this rare species at Site 300 (Carlsen and Espeland submitted). At Site 300, big tarplant occurs in large numbers in areas that are routinely burned. This is interesting, because at the time of the annual spring burns at Site 300, the plant is a small green seedling, and thus very susceptible to fire damage. It is possible that the larger Site 300 big tarplant population is acting as a group of semi-isolated subpopulations known as a metapopulation. Smaller subpopulations may establish or disappear, depending on fire uniformity and intensity. Although fire is fatal to individual big tarplants directly in its path, it may provide the amount of disturbance necessary to reduce competition with other plant species (such as exotic annual grasses) and allow for subpopulation establishment, thus maintaining the metapopulation.

Diamond-Petaled California Poppy

There are currently three populations of diamond-petaled California poppy (*Eschscholzia rhombipetala)* known to occur at Site 300. Although this species is not listed under the federal or California endangered species acts, it is extremely rare and is only currently known to occur at Site 300 and one additional location in San Luis Obispo County. A

census of the three Site 300 populations was conducted in March 2004, during which LLNL recorded the size and location of each diamond-petaled poppy plant and the vegetation community in which this species occurs.

In 2004, a new population (site 3) of *E. rhombipetala* was discovered at Site 300. Containing 389 *E. rhombipetala*, site 3 had the largest population of this species observed at Site 300 since monitoring began in 1998. In 2000 through 2002, site 1 contained over 180 *E. rhombipetala* each year, but in 2003 and 2004 this site contained fewer than 20 plants. 2004 was the third spring LLNL censused site 2. Site 2's population size has followed a similar pattern as site 1. Site 2 contained 76 *E. rhombipetala* in 2002 when this population was first discovered, and in 2003 and 2004 *E. rhombipetala* numbers were extremely small at site 2 (1 plant in 2003 and 2 plants in 2004).

The new population differs from the old population in several ways. Site 3 is found at the bottom of a small stable bowl shaped valley, while site 1 and site 2 are located on steep northwest facing hillsides in areas that are disturbed by slumping soil. *E. rhombipetala* at site 1 and site 2 is also often found in association with the native perennial grass, *P. secunda*, which was not found at site 3. In addition, *E. rhombipetala* at site 3 are larger and have more floral units then plants at sites 1 and 2.

Using vegetation data from site 1 and site 2 collected in 1999 through 2002, there was a positive association of *E. rhombipetala* presence with bare ground. This, in addition to the better performance of plants in the active slump, seemed to indicate that some level of disturbance is necessary for plants of this species to do well. Vegetation data collected at site 3 seems to contradict this. While the disturbance of slumping soils at site 1 and site 2 clearly benefits *E. rhombipetala* at site 1 and site 2, some other factors appear to be in place to promote *E. rhombipetala* at site 3.

Round-Leaved Filaree

One population of round-leaved filaree was located at Site 300 during a site-wide botanical survey conducted in 2002 (Preston 2002), and a second population was located in 2003 during surveys of the fire trail system. In 2004, an additional four populations were found in the northwestern corner of the site during wildlife surveys. 2003 was the first year of monitoring round-leaved filaree at Site 300. During the spring of 2004, the extent of the six Site 300 populations was mapped using a handheld GPS and the size of each population was estimated. These six populations were estimated to contain almost 6000 round-leaved filaree plants.

Environmental Impacts on Special Status Wildlife and Plants

Through monitoring and compliance activities in 2004, LLNL has been able to avoid most impact to special status wildlife and plants.

Large-flowered fiddleneck and diamond petaled California poppy populations are located in remote areas of Site 300 away from programmatic impacts. Four of the six Site 300 round-leaved filaree populations are located in annually graded fire trails. In these fire trail populations, round-leaved filaree is restricted to the areas that are disturbed by grading. This disturbance appears to benefit the species and is not considered a negative impact. Although rare elsewhere, big tarplant is widely distributed throughout Site 300. Although individual big tarplants were disturbed by LLNL activities, including fire trail grading and well drilling, these impacts affected only a very small fraction of the Site 300 tarplant population and are not considered to be significant to this species.

LLNL activities did not result in impacts to California red-legged frogs at the Livermore site. In the Livermore site population of California red-legged frogs, breeding decreased in 2004 compared to 2003, 2002, and 2001 although this decrease is not a result of any impacts from LLNL activities. At Site 300, 2004 surveys of adult California red-legged frogs indicate that the existing small populations of California red-legged frogs continue to persist.

The bullfrog control program continued at the Livermore site in an effort to reduce competitive pressures from this invasive species on the California red-legged frogs. The control program appears to be stabilizing or reducing the overall numbers of bullfrogs after the original introduction and subsequent population explosion.

6

Radiological Dose Assessment

Gretchen M. Gallegos
S. Ring Peterson
Robert J. Harrach

Marie Curie

Introduction

LLNL assesses potential radiological doses to the public and biota from its operations in order to demonstrate compliance with regulatory standards that protect the public and the environment. This chapter describes the releases of radioactivity, pathways of exposure, applicable standards, assessment methods, and key data and concepts. It summarizes the radiological dose determinations, identifying trends over time and placing them in perspective with natural background and other sources of radiation exposure.

Releases of Radioactivity from LLNL Operations

Releases of radioactive material to air, for example in the form of air effluent dispersed from stacks, are by far the major source of public radiological exposures from LLNL operations. In contrast, releases to groundwater, surface water, and sanitary sewer water are not sources of direct public exposures because these waters are not directly consumed by the public. Consequently, measurements and modeling of radiological releases to air determine LLNL's dose to the public.

Data on radiological releases to air are gathered by three principal means: continuous monitoring of stack effluent at selected facilities (described in Chapter 3); routine surveillance ambient air monitoring for radioactive particles and gases, both on and off LLNL property (also described in Chapter 3); and radioactive material usage inventories. Of these three approaches, stack monitoring provides the most definitive characterization. Beginning in 2003, the extent of reliance on usage inventories declined in favor of increased utilization of ambient air monitoring data (see the "Compliance Demonstration for Minor Sources" section below).

Despite the emphasis on radiological releases to air and monitoring of stack air effluent and ambient air, it should be noted that LLNL's extensive environmental monitoring program, in place since the early 1970s, encompasses a variety of media. In addition to ambient and effluent air monitoring and the three categories of water monitoring already mentioned, LLNL samples rain water, soil, vegetation, and wine, and measures environmental (gamma) radiation. The monitoring program also includes a wide range of potential contaminants; it is not limited to radioactive ones. These monitoring programs are discussed in previous chapters in this report.

Radiation Protection Standards

The release of radionuclides from operations at LLNL and the resultant radiological impact to the public are regulated by both the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA).

The primary DOE radiation standards for protection of the public are 1 millisievert per year (1 mSv/y) (which equals 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 *Supplementary Topics on Radiological Dose* [available on report CD] 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.

The EPA's radiation dose standard for members of the public limits the EDE to 100 µSv/y (10 mrem/y) for air emissions. 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-average 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 a project is required. These requirements are spelled out in LLNL's *Environment, Safety, and Health (ES&H) Manual*, Document 31.2, "Radiological Air Quality Compliance."

Air Dispersion and Dose Models

Computational models are needed to describe the transport and dispersion in air of contaminants and the doses to exposed persons via all pathways. 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). The code evaluates the four principal pathways of exposure from air releases—internal exposures from inhalation of air and ingestion of foodstuff and drinking water (only for tritium), and external exposures through irradiation from contaminated ground and immersion in contaminated air. 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

primary 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. In addition, CAP88-PC provides the flexibility to use different ingestion pathway parameters; for the 2004 evaluation, LLNL took advantage of this capability and used updated assumptions for agricultural and food source parameters for CAP88-PC (see Harrach et al. 2005). Furthermore, an improved tritium model (NEWTRIT; Peterson and Davis 2002) that uses air concentrations predicted by CAP88-PC to address the dose from HT and the formation of and dose from organically bound tritium was again employed for purposes of comparison to the simple tritium model in CAP88-PC.

Identification of Key Receptors

When assessing probable off-site impacts, LLNL pays particular attention to doses received by three types of 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 who receives the greatest LLNL-induced EDE from all sources at a site. For LLNL to comply with NESHAPs regulations, the LLNL SW-MEI cannot receive an EDE as great or 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 one location 24 hours per day, 365 days per year, continuously breathing air having the predicted or observed radionuclide concentration, and consuming a specified fraction of food and drinking water that is affected by the same predicted or observed concentration caused by releases of radioactivity from the site. Thus, the SW-MEI dose is not received by any actual individual and is a conservative estimate of the highest possible dose that may be received by any member of the public. The location of the SW-MEI can change from one year to the next; it is sensitive to the frequency distribution of wind speeds and directions, as well as to locations of key sources on the site.

At the Livermore site, the SW-MEI in 2004 was located at the UNCLE Credit Union, about 10 m outside the controlled eastern perimeter of the site. This location lies 957 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 3170 m south-southeast of the firing table at Building 851. These SW-MEI locations are depicted in **Figure 6-1**.

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

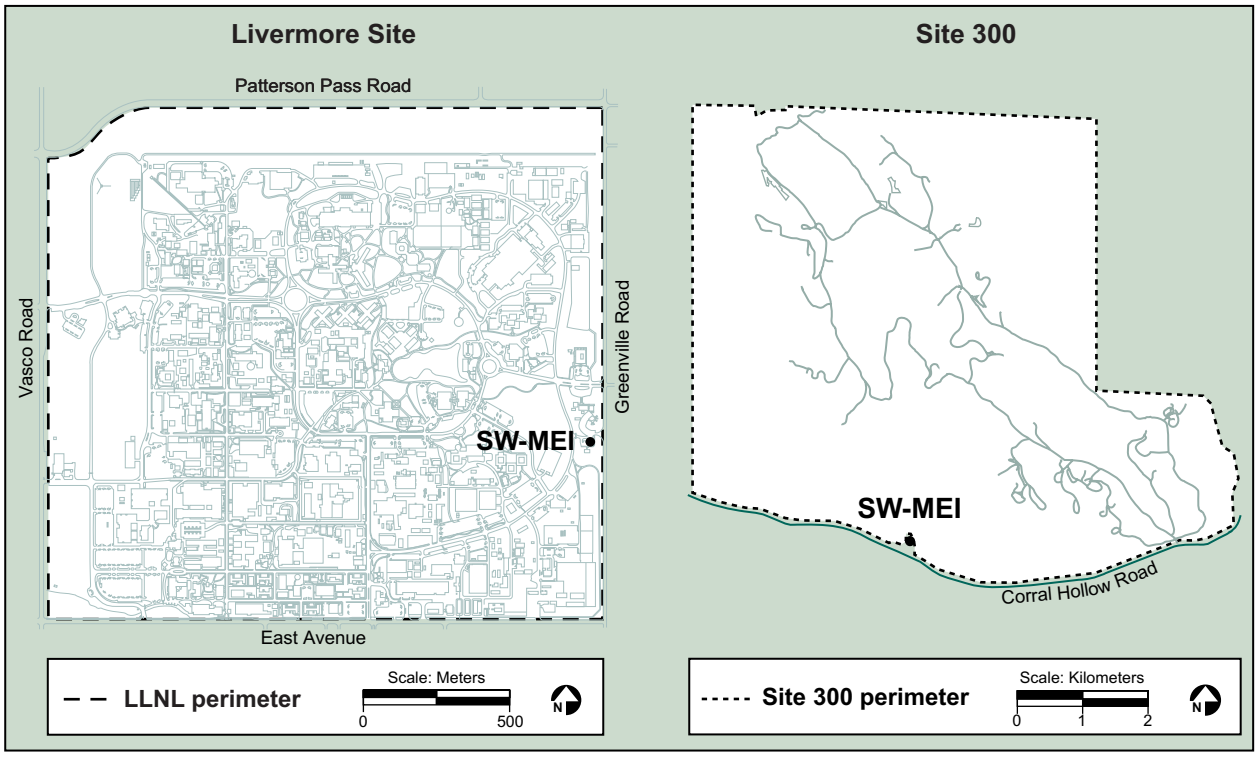


Figure 6-1. Location of the site-wide maximally exposed individual (SW-MEI) at the Livermore site and Site 300, 2004

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.

Results of 2004 Radiological Dose Assessment

This section summarizes the doses to the most-exposed public individuals from LLNL operations in 2004, 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 2004 was 0.079 µSv/y (0.0079 mrem/y). Of this, the dose attributed to diffuse emissions totaled 0.058 µSv (0.0058 mrem) or 73%; the dose due to point sources was 0.021 µSv (0.0021 mrem) or 27% of the total. The point source dose includes Tritium Facility elemental tritium gas (HT) emissions modeled as tritiated water (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 0.076 µSv (0.0076 mrem) to 0.065 µSv (0.0065 mrem).

The total dose to the Site 300 SW-MEI from operations in 2004 was 0.26 µSv (0.026 mrem). Point source emissions from firing table explosives experiments accounted for 97% of this total, while 0.0086 µSv (0.00086 mrem), or about 3%, was contributed by diffuse sources.

Table 6-1 shows the facilities or sources that accounted for more than 90% of the doses to the SW-MEI for the Livermore site and Site 300 in 2004. Although LLNL has nearly 150 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 each year 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. This procedure was implemented for the second time in assessing 2004 operations (see also *LLNL NESHAPs 2004 Annual Report* [Harrach et al. 2005]).

Dominant radionuclides at the two sites were the same as in recent years. Tritium accounted for about 96% 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 and the predominant radionuclide contributing to dose. For individual

Table 6-1. List of facilities or sources whose combined emissions accounted for more than 90% of the SW-MEI doses for the Livermore site and Site 300 in 2004

Facility (source category)	CAP88-PC dose (μSv/y)	CAP88-PC percentage contribution to total dose
Livermore site		
Building 331 stacks (point source)	0.014[a]	18
DWTF stack (point source)	0.0069[a]	9
Building 612 Yard (diffuse source)	0.053[a]	67
Site 300		
Building 851 Firing Table (point source)	0.25	97
Soil resuspension (diffuse source)	0.0086	3

a When LLNL's NEWTRIT model is used in CAP88-PC in place of CAP88-PC's default tritium model, the doses for Building 612 Yard and DWTF stack are reduced to 89% of the values shown, and that for the Building 331 stacks are reduced to 68% of the value shown.

doses calculated for tritium, the ingestion dose accounts for slightly more than the inhalation dose, approximately 53% and 47%, respectively. For uranium, the inhalation pathway dominates: 97% by the inhalation pathway versus 3% via ingestion. LLNL doses from air immersion and ground irradiation are negligible for both tritium and uranium.

The trends in dose to the SW-MEI from emissions at the Livermore site and Site 300 over the last 15 years are shown in **Table 6-2**. 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 higher than actually would be experienced by any member of the public.

Doses from Unplanned Releases

There were no unplanned atmospheric releases of radionuclides at the Livermore site or Site 300 in 2004.

Collective Dose

Collective dose, or population dose, for both LLNL sites was 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, inhalation, air immersion, and irradiation by contaminated ground surface.

Table 6-2. Doses (μSv) calculated for the sitewide maximally exposed individual (SW-MEI) for the Livermore site and Site 300, 1990 to 2004

Year	Total dose	Point source dose	Diffuse source dose
Livermore site			
2004	0.079[a]	0.021[a]	0.058
2003	0.44[a]	0.24[a]	0.20
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			
2004	0.26	0.25	0.0086
2003	0.17	0.17	0.0034
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.

Population centers affected by LLNL emissions include the 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 7.1 million residents included for the Livermore site collective dose determination, and 6.2 million for Site 300. Population data files (distribution of population with distance and direction) used for the present report are based on the LandSpan Global Population 2001 Database (Dobson et al. 2000).

The CAP88-PC result for potential collective dose attributed to 2004 Livermore site operations was 0.010 person-Sv (1.0 person-rem); the corresponding collective EDE from Site 300 operations was 0.0385 person-Sv (3.85 person-rem). These values are both within the normal range of variation seen from year to year.

Although collective doses from LLNL operations are tiny compared with doses from natural background radiation, they may be high compared with other DOE facilities due to large populations within 80 km of the sites. However, a large dose to a small number of people is not equivalent to a small dose to many people, even though the collective dose may be the same. Given that the population centers potentially affected by LLNL operations are distant from both the Livermore site and Site 300, the collective doses from LLNL operations are better described by breaking them down into categories of dose received by individuals in the population affected. The breakdown (or disaggregation) of collective dose by the level of the individual dose is shown in **Table 6-3**. It can be seen in **Table 6-3** that the individuals who make up about 98% of the population receive less than 0.01 µSv/y (1 µrem/y).

Table 6-3. Collective dose broken down by level of individual doses, 2004

Individual dose range (µSv/y)	Collective dose (person-Sv/y)	Individual dose range (mrem/y)	Collective dose (person-rem/y)	Percent total collective dose
Livermore site[a]				
0.01 to 0.1	0.0000271	0.001 to 0.01	0.00271	0.272%
0.001 to 0.01	0.000346	0.0001 to 0.001	0.0346	3.46%
0.0001 to 0.001	0.00934	0.00001 to 0.0001	0.934	93.4%
0.00001 to 0.0001	0.000283	0.000001 to 0.00001	0.0283	2.84%
Total	0.01	Total	1.0	100%
Site 300[b]				
0.01 to 0.1	0.000753	0.001 to 0.01	0.0753	1.96%
0.001 to 0.01	0.0139	0.0001 to 0.001	1.39	36.2%
0.0001 to 0.001	0.0238	0.00001 to 0.0001	2.38	61.8%
0.00001 to 0.0001	0	0.000001 to 0.00001	0	0%
Total	0.0385	Total	3.85	100%

a Dose from tritium

b Dose from Building 851 Firing Table

Doses to the Public Placed in Perspective

As a frame of reference to gauge the size of these LLNL doses, **Table 6-4** compares them to average doses received in the United States from exposure to natural background radiation and other sources. Collective doses from LLNL operations in 2004 are about 500,000 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 (combined) in 2004 are nearly 9,000 times smaller than ones received from background radiation in the natural environment.

Table 6-4. Comparison of background (natural and man-made) and LLNL radiation doses, 2004

Location/source	Individual dose[a]		Collective dose[b]	
	(μSv)	(mrem)	(person-Sv)	(person-rem)
Livermore site sources				
Atmospheric emissions	0.079	0.0079	0.010	1.0
Site 300 sources				
Atmospheric emissions	0.26	0.026	0.0385	3.85
Other sources[c]				
Natural radioactivity[d,e]				
Cosmic radiation	300	30	2,130	213,000
Terrestrial radiation	300	30	2,130	213,000
Internal (food consumption)	400	40	2,840	284,000
Radon	2,000	200	14,200	1,420,000
Medical radiation (diagnostic procedures)[e]	530	53	3,760	376,000
Weapons test fallout[e]	10	1.0	71	7,100
Nuclear fuel cycle	4	0.4	28	2,800

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 7.1 million people for the Livermore site and 6.2 million for Site 300), calculated with respect to distance and direction from each site. The Livermore site population estimate of 7.1 million people was used to calculate the collective doses for "Other sources".

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.

Special Topics on Dose Assessment

Compliance Demonstration for Minor Sources

Since 1991, LLNL has demonstrated compliance for minor sources through a labor-intensive inventory and modeling process. The dose consequences to the public for these sources were 8 to 20 orders of magnitude below the regulatory standard of 10 mrem/y and did not justify the level of effort expended in accounting for them. To better allocate resources, LLNL made a request to EPA, pursuant to the NESHAPs regulations, to use existing ambient air monitoring to demonstrate compliance for minor emissions sources. This request was made in March 2003 and granted by EPA in April 2003. This report marks the second year that LLNL is demonstrating NESHAPs compliance for minor sources by comparing measured ambient air concentrations at the location of the SW-MEI to concentrations limits set by the EPA in Table 2, Appendix E of 40 CFR 61. The radionuclides for which the comparison is made are tritium and plutonium-239+240 for the Livermore site SW-MEI and uranium-238 for the Site 300 SW-MEI. At the Livermore site, the average of the monitoring results for locations L-VIS and L-CRED represent the SW-MEI. At Site 300, the minor source that has the potential to have a measurable effect is the resuspension of depleted-uranium-contaminated soil. Because this is a diffuse source, the average of the results for all monitoring locations at the site are used to represent the SW-MEI.

The Table 2, Appendix E of 40 CFR 61 standards and the measured concentrations at the SW-MEI are presented in **Table 6-5**. As demonstrated by the calculation of the fraction of the standard, LLNL measured concentrations for tritium and plutonium-239+240, and uranium-238 in air are 0.0047 or less than the health protective standard for these radionuclides.

Estimate of Dose to Biota

Although mankind is protected from excess radiation dose by the methods outlined in this chapter, biota is not necessarily protected because of different exposure pathways (e.g., dose to a ground squirrel burrowing in contaminated soil). Thus LLNL calculates potential dose to biota from LLNL operations using the DOE guidance document, "DOE Standard: A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (U.S. DOE 2002), and the RAD-BCG (Biota Concentration Guides) Calculator (Version 2) in an Excel spreadsheet. Limits on absorbed dose to biota are 10 mGy/d (1 rad/d) for aquatic animals and terrestrial plants, and 1 mGy/d (0.1 rad/d) for terrestrial animals.

Table 6-5. Mean concentrations of radionuclides of concern at the location of the SW-MEI in 2004

Location	Nuclide	EPA concentration standard (Ci/m^3)	Detection limit (approximate) (Ci/m^3)	Mean measured concentration (Ci/m^3)	Measured concentration as a fraction of the standard
Livermore SW-MEI	Tritium	1.5×10^{-9}	1×10^{-12}	1.3×10^{-12} [a]	8.7×10^{-4}
Livermore SW-MEI	Plutonium-239	2.0×10^{-15}	5×10^{-19}	1.3×10^{-19} [b]	6.5×10^{-5}
Site 300 SW-MEI	Uranium -238	8.3×10^{-15}	3×10^{-20}	3.9×10^{-17} [c]	4.7×10^{-3}

a The tritium value includes contribution of emissions from the Tritium Facility, Building 612 Yard, DWTF, and Building 331 Waste Accumulation Area.

b The mean measured concentration for plutonium is less than the detection limit; only 3 of the 24 values comprising the mean were measured detections.

c The mean ratio for uranium-235/uranium-238 for 2004 is 0.0068, which is only slightly less than 0.00726, the ratio of these isotopes for naturally occurring uranium. This indicates that approximately 90% of the measured quantities of uranium-238 were caused by resuspension of soil containing naturally occurring uranium.

In the RAD-BCG Calculator, each radionuclide in each medium (soil, sediment, surface water) is assigned a derived concentration limit. For each concentration entered in the spreadsheet, a fraction of the derived concentration limit for that radionuclide is automatically calculated; the fractions are summed for each medium. For aquatic and riparian environments, if a concentration for water is entered, the calculator automatically assigns an expected concentration to the sediment, and vice versa.

For aquatic and riparian animals, the sum of the fractions for water exposure is added to the sum of the fractions for sediment exposure. Similarly, fractions for water and soil exposures 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 screening limit), the site has passed the screening analysis, and biota are assumed to be protected.

In the LLNL assessment, the maximum concentration of each radionuclide measured in soils, sediments, and surface waters during 2004, no matter whether measured on the Livermore site, in the Livermore Valley, or at Site 300, was entered into the screening calculation. This approach may result in an assessment that is unrealistically conservative, given that the maximum concentrations in the media are spread over a very large area, and no plant or animal could possibly be exposed to them all. Other assumptions increase the possibility that the estimated dose will be conservative. For example, while only gross alpha and gross beta are measured in water, it is assumed that gross alpha is represented by plutonium-239 and gross beta by strontium-90 to assure maximum dose. 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 they had higher concentrations than surface waters. Finally, when measurements were available for both runoff and sediment, the value that gave the highest fraction of the BCG was used.

Radionuclides measured by LLNL in 2004 that would contribute to a dose to biota were americium-241, cesium-137, tritium, plutonium-239 (also as a surrogate for gross alpha), thorium-232, uranium-235, and uranium-238; in addition, gross beta is represented by strontium-90. For LLNL, the sum of the fractions for the aquatic system was 0.573, and the sum for the terrestrial system was 0.046. Both the aquatic and terrestrial systems passed the screening test in spite of these improbable assumptions. However, for the aquatic system, results are more than double those in 2001, 2002, and 2003. This is primarily due to use in the screening model of surrogates (gross alpha and gross beta) in runoff instead of concentrations of radionuclides in surface water to which biota are likely to have been exposed. The sum of the fractions for the terrestrial system is similar to previous years.

A less artificial assessment of dose to aquatic biota from LLNL operations can be made using surface water concentrations from the Drainage Retention Basin (DRB) combined with sediment concentrations from the East Settling Basin (ESB). Sediment samples are not collected in the DRB, and water is ephemeral at the ESB. Nevertheless, concentrations may be expected to be similar given that water drains through the ESB to the DRB. Using these concentrations in the RAD-BCG Calculator, the sum of the fractions for aquatic exposure is 0.13, which is the same fraction as in 2003 and less than 25% of the fraction derived from the ultraconservative approach. It is clear that dose to biota from LLNL operations is below levels of regulatory concern.

Modeling Dose from Tritium — Comparison of Approaches

Because tritium has been and continues to be the principal radionuclide released to air in Livermore site operations (from a public dose standpoint), a comparison was made in 2004 of the approaches used at LLNL to model its dose impacts.

Since 1986, LLNL has calculated doses from releases of HTO (or total tritium modeled as HTO) to the atmosphere using the regulatory model CAP88-PC (since 1992) or its predecessor, AIRDOS-EPA. The dose calculated with AIRDOS-EPA or CAP88-PC uses source terms that represent the principal tritium sources at the site. As well, since 1979, using bulk transfer factors (**Table 6-6**) derived from equations in the Nuclear Regulatory Commission's (NRC) Regulatory Guide 1.109 (U.S. NRC 1977), LLNL has calculated potential ingestion doses from measured concentrations in vegetation (Chapter 5) and drinking water (Chapter 4), as well as doses from inhalation (Chapter 3). Both CAP88-PC and Regulatory Guide 1.109 only account for dose from HTO. More accurate assessments should account for dose from releases of HT and from ingestion of organically bound tritium (OBT); if OBT is ignored, ingestion dose may be underestimated by up to a factor of two (ATSDR 2002). Recently, another model, NEWTRIT (Peterson and Davis 2002), has been used to estimate inhalation and ingestion doses from releases of both HT and HTO; the ingestion dose accounts for both HTO and OBT. NEWTRIT uses observed or predicted air concentrations as input.

Table 6-6. Bulk transfer factors used to calculate inhalation and ingestion doses from measured concentrations in air, vegetation, and potential drinking water

Doses in μSv	Bulk transfer factors times observed mean concentrations
Inhalation and skin absorption	0.21 x concentration in air (Bq/m^3) (See Chapter 3)
Drinking water	0.013 x concentration in drinking water (Bq/L) (See Chapter 4)
Food Ingestion	0.0049 x concentration in vegetation (Bq/kg) (See Chapter 5); (factor obtained by summing contributions of 0.0011 for vegetables, 0.0011 for meat and 0.0027 for milk)

Note: The derivation for these bulk transfer factors can be found in Appendix C of *Environmental Report 2002* (Sanchez et al. 2003)

Hypothetical tritium doses predicted at the onsite location of the air tritium monitor, VIS (see Figure 3-1) using the three modeling approaches are compared in **Table 6-7**. All predictions were made for a hypothetical person living 100% of the time adjacent to the air tritium monitor at VIS and eating 100% locally grown food—these assumptions match those that have been used historically for the NRC Regulatory Guide 1.109 calculations rather than those employed for CAP88-PC. Because the air tritium monitor can only sample for HTO, no HT was included in the source term for CAP88-PC. Vegetation is also sampled at VIS.

Table 6-7. Comparison of hypothetical annual doses (nSv/y) at the VIS air tritium monitoring location calculated from predicted and observed concentrations of HTO in air

	CAP88-PC (from predicted air concentrations)[a]	NRC 1.109 (from mean air, vegetation, and tap water[b] concentrations)	NEWTRIT (from mean air tritium concentrations)
Inhalation and skin absorption	23	7.9	8.6
Food ingestion (vegetables; milk; meat)	73; 45; 27	2.0; 4.9; 2.0	22; 14; 7.1
Drinking water	1.3	< 27[c]	3.7
Food ingestion dose	145	9.0	43
Total dose	169	< 44	55

a Doses from CAP88-PC are based on the sum of the predicted HTO concentrations at VIS for the Tritium Facility stacks (1.63×10^{-2} Bq/m^3), the DWTF stack (5.18×10^{-3} Bq/m^3), the Building 612 Yard (0.059 Bq/m^3), and the Building 331 Waste Accumulation Area (2.48×10^{-3} Bq/m^3).

b Tap water is measured on the Livermore site but not at the VIS monitor location.

c All tap waters measured for tritium in 2004 were below the limit of detection.

The dose comparison shows about a factor of four difference between the lowest (NRC 1.109) and highest (CAP88-PC) dose predictions, each of which is based on valid assumptions. Differences are primarily due to predicted (0.083 Bq/m^3) versus observed

(0.0374 Bq/m^3) air concentrations and assumptions about intake rates and dose coefficients (see Appendix C of *Environmental Report 2002* [Sanchez et al. 2003]). When predicted air concentrations drive the doses, doses are normally higher than when observed air and vegetation concentrations drive the results. The total dose from CAP88-PC is the highest, as expected, and the NEWTRIT dose is within a factor of three of the CAP88-PC dose. All doses are far below any level of concern.

A more realistic, but still highly conservative, set of assumptions about the lifestyle of the hypothetical member of the public residing at the VIS monitor location (**Table 6-8**) lowers the annual dose from tritium to as low as about 20% of the lowest dose in **Table 6-7**, even while including tiny potential doses from other dose pathways.

Table 6-8. Doses for the tritium exposure of an individual residing at the location of the VIS air tritium monitor in 2004, based on observed HTO-in-air concentrations and using plausible but conservative assumptions (as indicated)

Source of dose	Annual dose (nSv/y)	Assumption
Inhalation	3.3	Breathes air at VIS 16 hours a day, all year
Ingesting food, including OBT	5.7	Raises and eats 25% homegrown leafy vegetables, fruit vegetables, fruits and root crops, no homegrown milk, beef, or grain but 12 kg/y homegrown chickens and 20 kg/y homegrown eggs. Assume the feed for the chickens is 50% homegrown; chickens drink water from outdoor pans at 50% air moisture.
Drinking water	[5.9][a]	Drinks 440 L/y of well water at average concentration of California groundwater
Drinking wine, including OBT	0.87	Drinks one liter bottle of Livermore Valley wine each week at the mean concentration for 2004
Immersion	0.045	Swims in the LLNL pool 50 hours per year (pool closed in June 2004)
All sources	10[a]	

a Drinking water dose is not included in a realistic estimate of the dose impacts of LLNL releases of tritium to the atmosphere because Livermore drinking water is unaffected by LLNL operations. Nevertheless, inclusion of a drinking water dose demonstrates that the dose attributable to LLNL is not much different than background, especially given that all doses shown include background.

Environmental Impact

The annual radiological dose from all emissions at the Livermore site and Site 300 in 2004 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 2004 were:

- Livermore site: 0.079 µSv (0.0079 mrem)—27% from point-source emissions, 73% from diffuse-source emissions. The point source emissions include gaseous tritium modeled as tritiated water vapor for compliance purposes, as directed by EPA Region IX.
- Site 300: 0.26 µSv (0.026 mrem)—97% from explosive experiments, which are classified as point-sources, 3% 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 2004 was estimated to be 0.010 person-Sv (1.0 person-rem) for the Livermore site and 0.0385 person-Sv (3.85 person-rem) for Site 300. These doses include potentially exposed populations of 7.1 million people for the Livermore site and 6.2 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 2004 were below one-half of one percent (0.5%) of the federal standard and were nearly 9,000 times smaller than the dose from background radiation. The population doses from LLNL operations in 2004 were about 500,000 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.

In conclusion, 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 2004.

7

Groundwater Investigation and Remediation

Charles D. Noyes
Michael J. Taffet

During 2004, groundwater investigations and remediations under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) continued at both the Livermore site and Site 300. LLNL samples and analyzes groundwater from areas of known or suspected contamination. Portions of the two sites where soil or groundwater contains or may contain chemicals of concern are actively investigated to define the hydrogeology and nature and extent of the contamination and its source. Where necessary, remediation strategies are developed and evaluated in preparation for a CERCLA removal action or through the feasibility study process. An approved remedy for each 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 3.3 km^2 (1.3 mi^2) is effectively one operable unit.

Livermore Site Ground Water Project

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, metals, and tritium to the groundwater and unsaturated sediment (unconsolidated subsurface material) in the post-Navy era. The Livermore site was placed on the U.S. Environmental Protection Agency National Priorities List in 1987.

An analysis of all environmental media showed that groundwater, and saturated and unsaturated sediments 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, chloroform, 1, 2-dichloroethylene, 1,1-dichloroethane, 1,2-dichloroethane, trichlorotrifluoroethane (Freon 113), trichlorofluoromethane (Freon 11), and carbon tetrachloride.

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 (see **Figure 7-1**). HSUs can be defined as sedimentary sequences whose permeable layers show evidence of hydraulic connection. Six of the nine HSUs contain contaminants at concentrations above their MCLs: HSUs 1B, 2, 3A, 3B, 4, and 5 (Blake et al. 1995; Hoffman et al. 2003). HSUs 1A, 6, and 7 do not contain contaminants of concern above action levels and are therefore not discussed further.

Remediation Activities and Monitoring Results

In 2004, the Livermore site Ground Water Project (GWP) treated about 1.2 billion liters of groundwater and removed approximately 86 kg of VOCs (**Table 7-1**). The GWP also brought new treatment facilities on line, installed wells, conducted hydraulic and pneumatic (soil vapor) 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 30 treatment facilities whose extraction wells are completed in the 6 HSUs containing contaminants of concern. Extraction wells at each facility are used to extract groundwater, which is then treated to remove VOCs. 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.

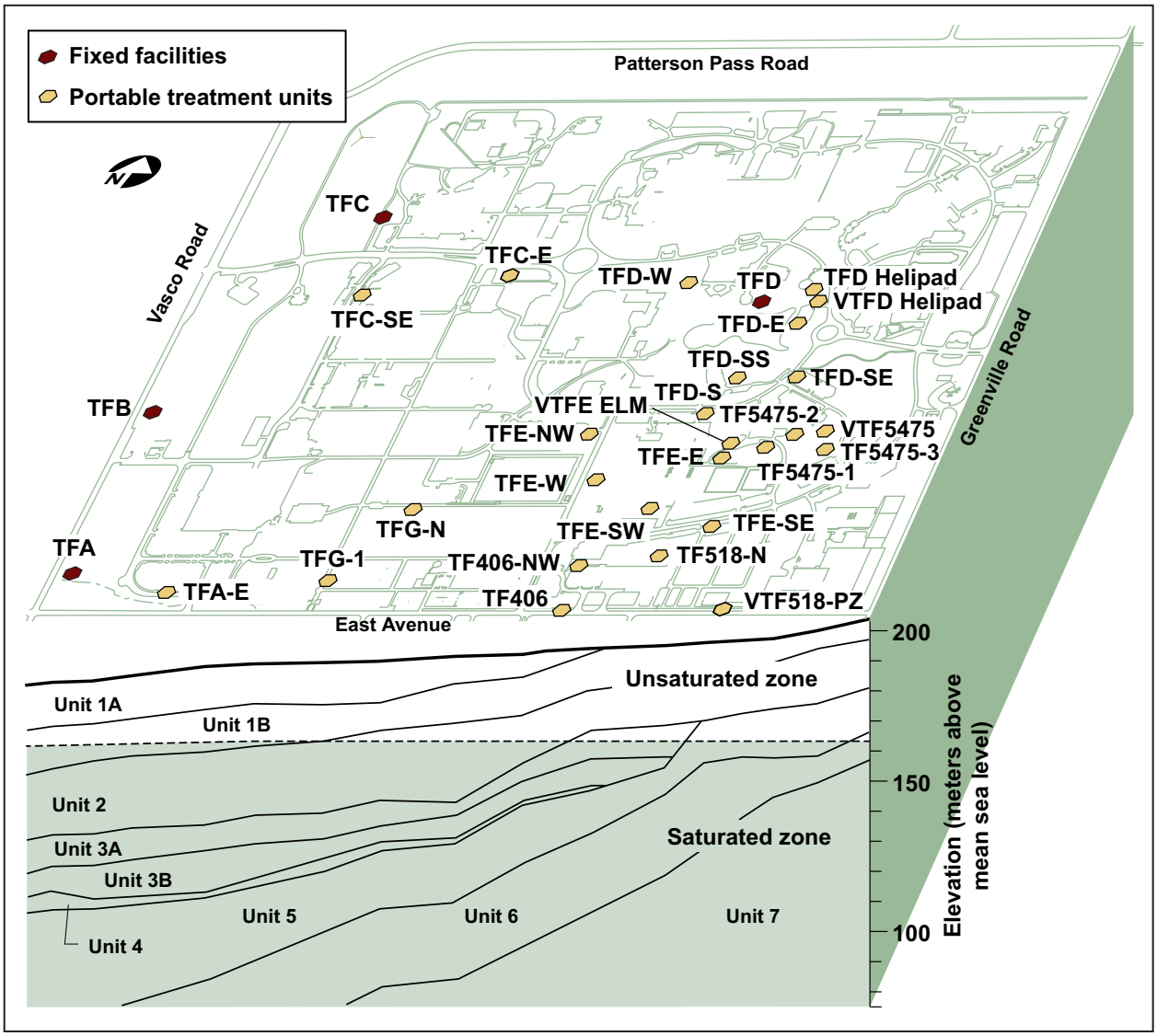


Figure 7-1. Map and cross section of the Livermore site showing hydrostratigraphic units and the locations of the treatment facilities

Of the 30 treatment facilities in operation in 2004, 26 are groundwater treatment facilities and 4 are a vapor treatment facilities (VTFs). A total of 80 groundwater extraction wells, 16 dual extraction wells, and 9 soil vapor extraction wells operated in 2004. Since operations began in 1989, approximately 9.7 billion liters of groundwater and approximately 2.6 million m^3 of vapor have been treated, and more than 1778 kg of VOCs have been removed. Table 7-1 shows both the 2004 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

Table 7-1. Volatile organic compounds removed from groundwater and soil at the Livermore site

Groundwater treatment facility[a]	Startup date	2004		Cumulative total	
		Water treated (ML)[b]	VOCs removed (kg)	Water treated (ML)	VOCs removed (kg)
TFA	9/89	480	8.9	4510	171.6
TFB	10/90	98.8	3.3	1011	62.5
TFC	10/93	109.0	5.6	825.6	66.1
TFD	9/94	311.5	53.9	2080	607.1
TFE	11/96	106.4	11.2	748.4	162.5
TFG	4/96	23.5	1.1	115.1	5.9
TF406	8/96	45.8	1.2	308.1	10.2
TF518	1/98	4.9	0.5	47.7	5.3
TF5475	9/98	0.4	0.2	3.0	5.5
Total[c]		1180	86	9649	1097
Vapor treatment facility		**Soil vapor treated ($10^3 m^3$)**	**VOCs removed (kg)**	**Soil vapor treated ($10^3 m^3$)**	**VOCs removed (kg)**
VTF518	9/95	0	0	427.2	153
VTF5475	1/99	319.8	46.2	1232	390.4
VTFE ELM	9/03	684.9	45.3	778.1	95.7
VTFD HPD	6/04	151.4	7.6	151.4	7.6
VTF518 PZ	9/04	28.7	34.1	28.7	34.1
Total[c]		1185	133	2617	681

a Includes fixed and portable units

b ML = million liters

c Totals rounded to nearest whole number

presented in **Figure 7-2**. GWP activities, such as the types of treatment used at the different facilities and total VOC isoconcentration maps for each HSUs, are further described in the *Ground Water Project 2004 Annual Report* (Karachewski et al. 2005).

In 2004, concentrations continued to decrease in most Livermore site VOC plumes. The decline in VOC concentrations is primarily attributed to active remediation and reflects the 86 kg of VOCs removed by the groundwater extraction wells during 2004 (**Table 7-1**). Notable trends and results of VOC analyses of groundwater received from the fourth quarter 2003 to the third quarter 2004 are discussed below.

VOC concentrations on the western margin of the site either declined or remained unchanged during 2004, indicating continued effective hydraulic control of the boundary plumes in the Treatment Facility (TF) A, TFB, and TFC areas. VOC

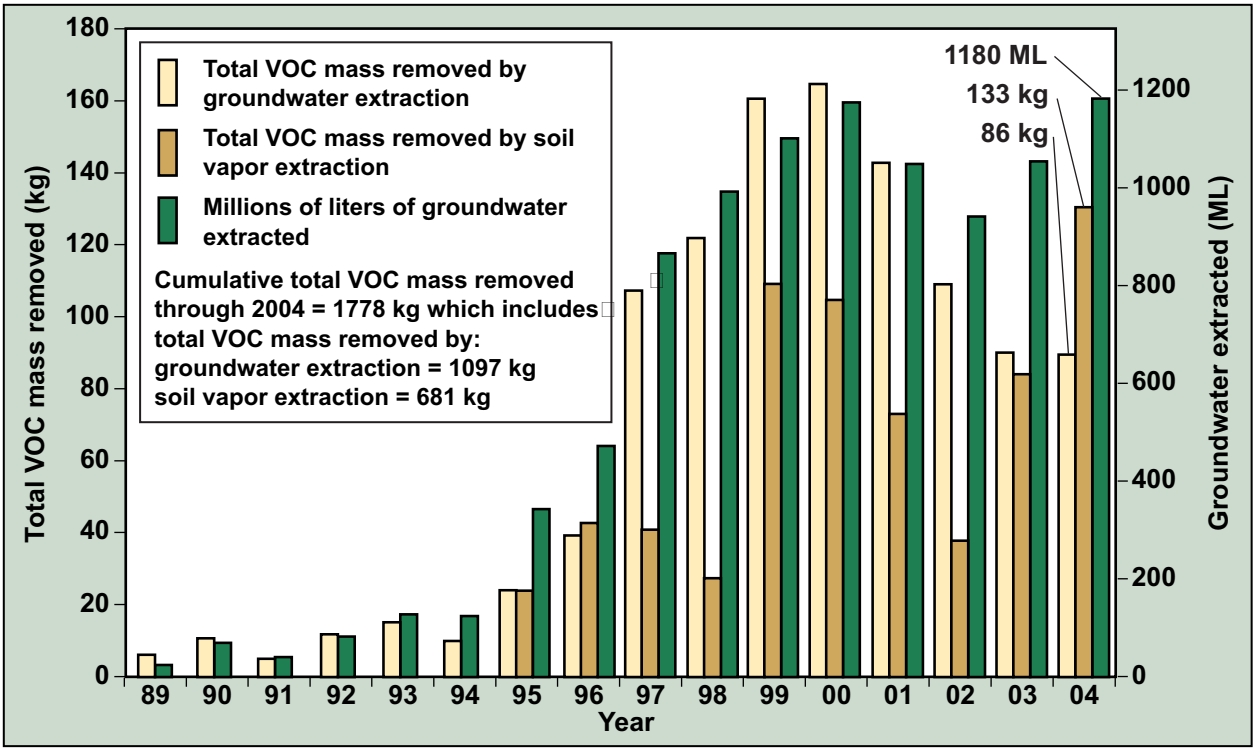


Figure 7-2. Total VOC mass removed and groundwater extracted from the subsurface of the Livermore site, 1989–2004

concentrations in the TFA, TFB, and TFC source areas remained unchanged as well. The offsite HSU 1B VOC plumes were below MCLs for all VOCs of concern except at two wells where PCE was slightly above the MCL (PCE was detected at 6 µg/L and 11 µg/L at wells W-506 and W-1425, respectively, in July 2004). The entire off-site and on-site TFA HSU 2 plume remained below 50 µg/L total VOCs again, for a second year. All offsite TFA HSU 3A wells remained below MCLs for all VOCs of concern.

VOC concentrations in a mobile HSU 2 plume located in the western TFE area continued to decline in 2004. Downgradient from the source area, total VOC concentrations decreased below 100µg/L, except at TFE-W extraction well W-305, and total VOCs in well SIP-331-001, located in the distal portion of the plume, declined from 80 µg/L in 2003 to 69 µg/L in 2004. Concentrations further downgradient to the west declined slightly, probably in response to continued pumping of TFG-North extraction well W-1807, located at the leading edge of the plume. Total VOC concentrations in the Old Salvage Yard in the southeastern part of the site, also known as the TFE Hotspot source area, remained elevated in 2004 (e.g., 1815 µg/L total VOCs at SIP-ETS-601, July 2004). 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 TFD Helipad area in 2004, in part due to the start of vacuum-enhanced groundwater extraction. For example, the total VOC concentrations in W-1651 declined from 1125 ppb in October 2003 to 400 ppb total VOCs in July 2004. In the TFE and T5475 areas, slight declines in VOC concentrations were observed in HSU 3A wells. Elsewhere in HSU 3A, concentrations remained largely unchanged.

In HSU 3B, variations in TCE concentration observed near TFD South suggest that VOCs within HSU 3B may be migrating out of the southern TFD East Traffic Circle source area toward the TFD South area. TCE in well W-1511 decreased from 750 µg/L in 2003 to 380 µg/L in 2004. Hydraulic containment of the HSU 3B source area and associated TCE groundwater plume will be addressed as part of an upcoming 2005 milestone. Elsewhere in HSU 3B, VOC concentrations remained largely unchanged.

Concentrations in both HSU 4 and HSU 5 remained relatively unchanged in 2004. In HSU 4, slight decreases in total VOC concentrations were noted in the western TFE area at wells W-304 and W-1211 as well as in the TFD area.

During 2004, tritium activities in groundwater from all wells in the TF5475 area remained below the 740 Bq/L (20,000 pCi/L) MCL and continued to decrease by natural decay. Except for one sample from UP-292-007 (803 Bq/L [21,700 pCi/L] in May 2004), tritium activities in the Building 292 area also remained below the MCL in 2004.

Groundwater Flow and Transport Modeling

Groundwater flow and contaminant transport models are used at the Livermore site to optimize the design and operation of remediation systems; to support ongoing subsurface characterization activities; and to improve LLNL's ability to forecast, monitor, and interpret the progress of the remediation program. An existing production model for the western portion of the site is currently used to optimize groundwater remediation. In 2004, LLNL continued development of a three-dimensional (3-D) basin-scale groundwater flow and transport model that incorporates the Livermore site HSU framework. The model is updated by incorporating remediation system improvements and hydrogeologic information from new wells. LLNL is currently improving this 3-D model to simulate the extensive extraction well field and the resultant dewatering observed at the eastern portion of the site. LLNL is also using this model to understand contaminant migration between adjacent HSUs and the role of source areas in affecting cleanup time.

In addition to groundwater flow and transport models, LLNL also developed a one-dimensional vadose zone model for the Building 514 Area to determine the potential impact from residual contamination in soil to groundwater. This model is used to support Resource Conservation and Recovery Act (RCRA) activities currently underway in the Building 514 Area.

Environmental Impacts

At the Livermore site, LLNL strives to reduce risks arising from chemicals released to the environment and to conduct all its restoration activities to protect environmental resources and to preserve the health and safety of all site workers. LLNL's Environmental Restoration project is committed to preventing present day and future human exposure to contaminated soil and groundwater, preventing further contaminant migration of concentrations above drinking water standards, reducing concentrations in groundwater, and minimizing contaminant migration from the unsaturated zone to the underlying groundwater.

Remedial solutions are implemented that have been determined to be most appropriate for individual areas of contamination. The selected remedial solutions have been agreed upon by DOE and the regulatory agencies with public input and are designed to achieve the goals of reducing risks to human health and the environment and to satisfying remediation objectives, regulatory standards for chemicals in water and soil, and other state and federal requirements. These remedial solutions include groundwater extraction and treatment, soil vapor extraction and treatment, or a combination of both.

Groundwater and soil vapor extraction and treatment at the Livermore site continue to reduce the mass of contaminants in the subsurface. During 2004, extraction wells yielded about 1.2 billion liters of groundwater. During the year, 1.2 million m^3 of vapor were also extracted. In 2004, the Livermore site treatment facilities removed approximately 219 kg of VOCs. Since remediation efforts began in 1989, more than 9.6 billion liters of groundwater and approximately 2.6 million m^3 of vapor have been treated, yielding about 1778 kg of removed VOCs.

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 7-3**. All characterized contaminant release sites have been assigned to one of eight OUs based on the nature, extent, and sources of contamination, and topographic and hydrologic considerations. The major contaminants of concern for each OU are listed in **Table 7-2**. CERCLA work at Site 300 is conducted under a Federal Facility Agreement (FFA) and other requirements. 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). Key milestone and deliverable due dates for 2004 are listed in **Table 7-3**. All milestone and deliverable due dates were met during 2004.

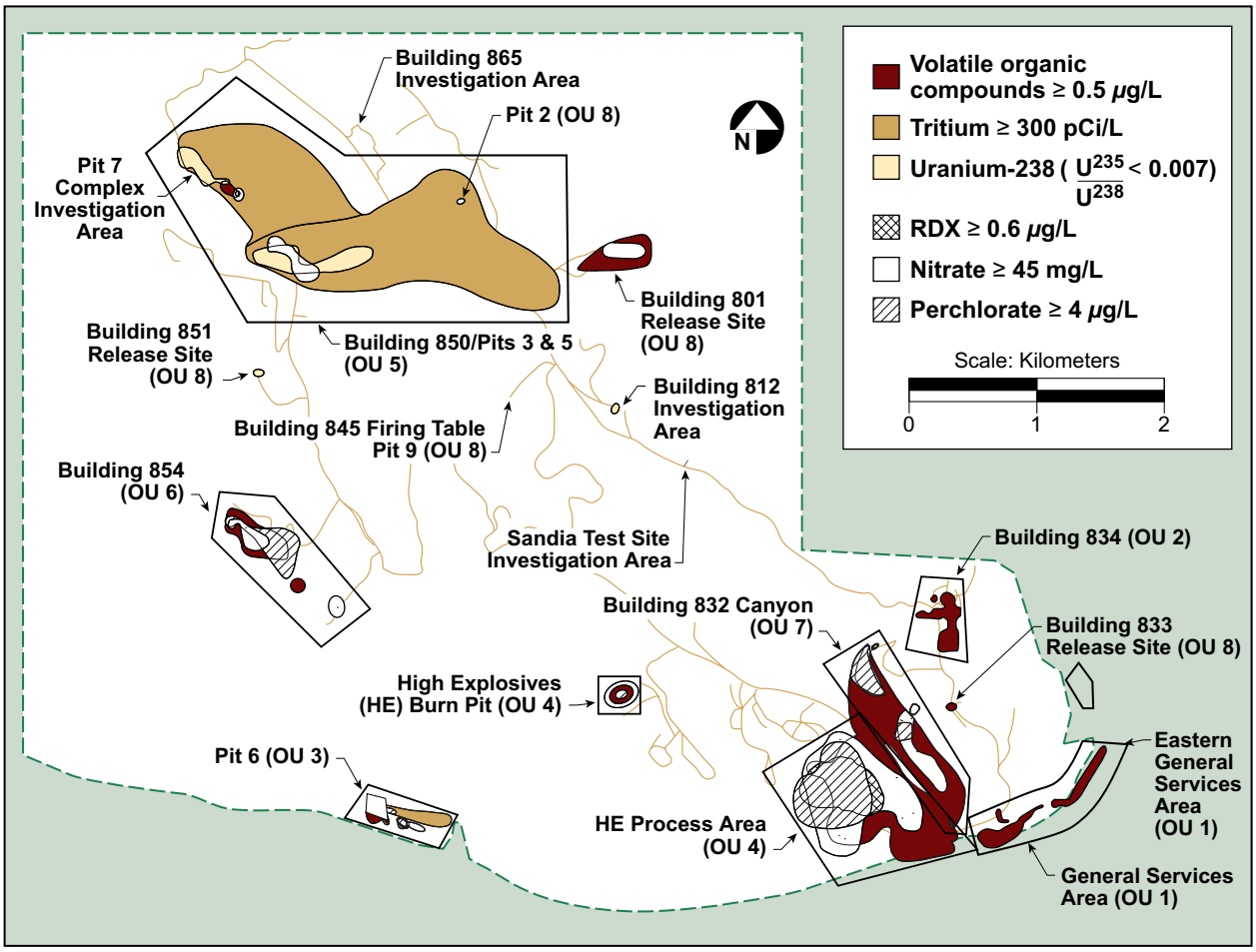


Figure 7-3. Environmental restoration operable units, investigation areas, and contaminants of concern

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 7-4**. Rocks exposed in the region are classified into three groups:

- Late Tertiary-Quaternary (0–5 million years ago)—alluvium and semi-lithified 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 sedimentary rocks and ophiolites) and Franciscan Complex (sheared and variably metamorphosed sedimentary and igneous rocks)

Table 7-2. 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-Wide Operable Unit (OU8)	VOCs (primarily TCE and Freon 113), nitrate, perchlorate, depleted uranium, tritium, metals, RDX

a See Acronyms and Abbreviations for list of acronyms.

Table 7-3. Calendar year 2004 deliverable and milestone dates for Site 300 environmental restoration activities outlined in the FFA and other agreements

Deliverable/Milestone	Due Date
Draft Remedial Investigation/Feasibility Study (RI/FS) for the Pit 7 Complex	March 3, 2004 (met)
Public Workshop for the Pit 7 Complex RI/FS	April 1, 2004 (met)
Final Building 850 Remedial Design report	June 30, 2004 (met)
Draft Final RI/FS for the Pit 7 Complex	July 29, 2004 (met)

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. It is the principal hydrologic unit within Site 300 and has been the focus of the detailed geologic and hydrogeologic studies conducted during recent years (summarized in the *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300*, [Webster-Scholten 1994]). The complete section of the Neroly Formation is about 150 m thick beneath Site 300.

The floodplain of Corral Hollow Creek lies along the southern boundary of Site 300 and borders portions of the General Services Area (GSA), the High Explosives Process Area, and the area of closed landfill Pit 6. Floodplain alluvium consists dominantly of coarse cobble-bearing terrace gravel derived from sources to the south, with lenses and local coverings of sandy silt and silty clay.

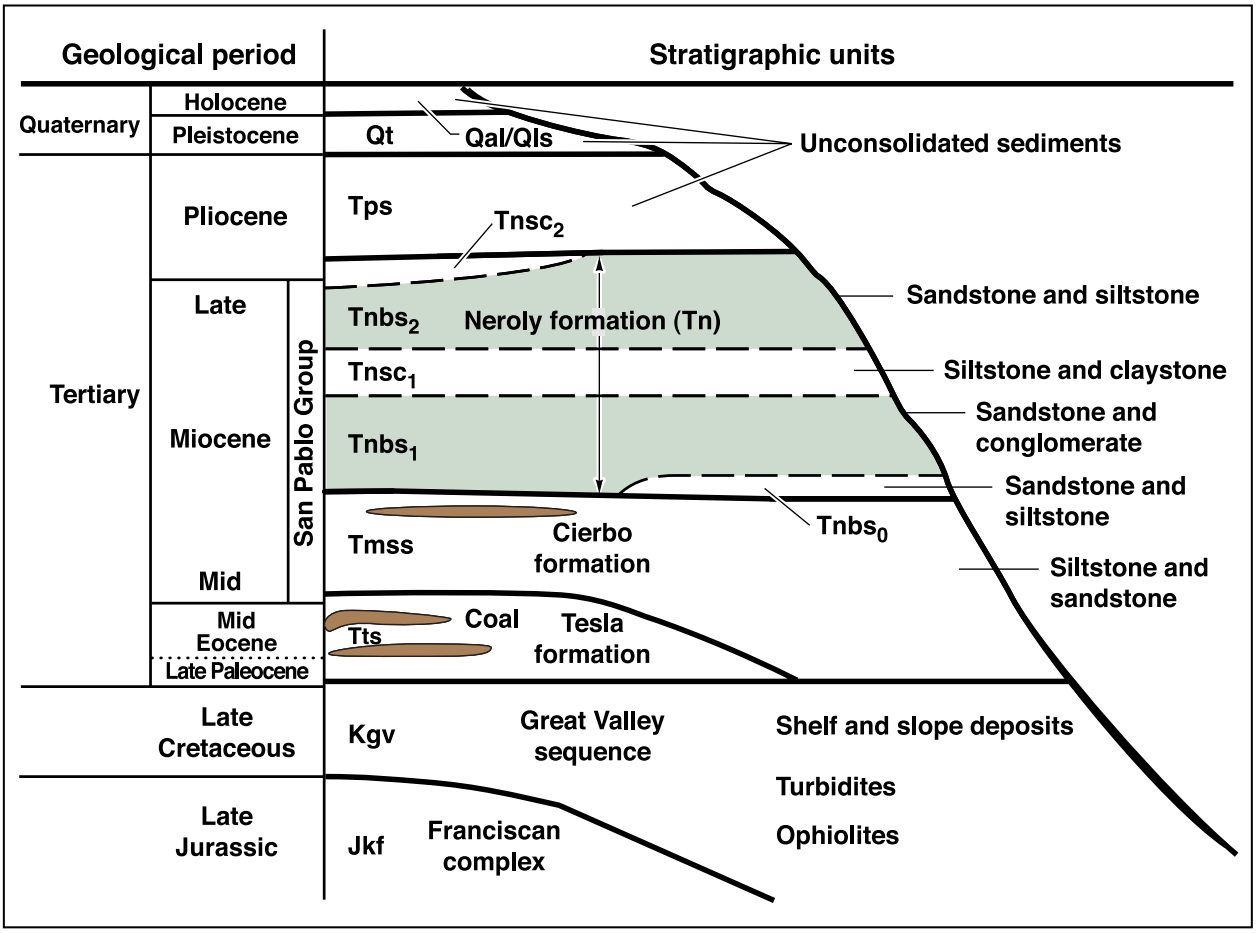


Figure 7-4. Site 300 stratigraphy

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 7-4**). 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 Building 834 areas and in the High Explosives Process Area. An extensive perched water-bearing zone also occurs in $Tnbs_0$ 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 7-5** 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 ($Tnbs_1$) and $Tnbs_0$.

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 waterbearing zones in the Building 832, Building 834, Building 854, and Building 829/High Explosives Burn Pit areas. Low rainfall and 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 rock 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.

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 in **Figure 7-3**.

Remediation Activities and Monitoring Results

This section presents a summary of monitoring and remediation results for contaminant release sites at Site 300. Detailed monitoring and remediation results for the central GSA, Building 834, High Explosives Process Area, Building 850, Building 854, Pit 6, Building 832 Canyon, and Site-Wide OUs are presented in the Compliance Monitoring Program (CMP) reports for Site 300 (Dibley et al. 2004, 2005). The *2004 Annual Compliance Report for Lawrence Livermore National Laboratory Site 300* (Dibley et al. 2005) is included on the report CD. The eastern GSA treatment system is not included in the CMP report; it operates under a separate waste discharge requirements permit and results are presented quarterly (Yow 2004a,b,c; Yow 2005). The results of ongoing and

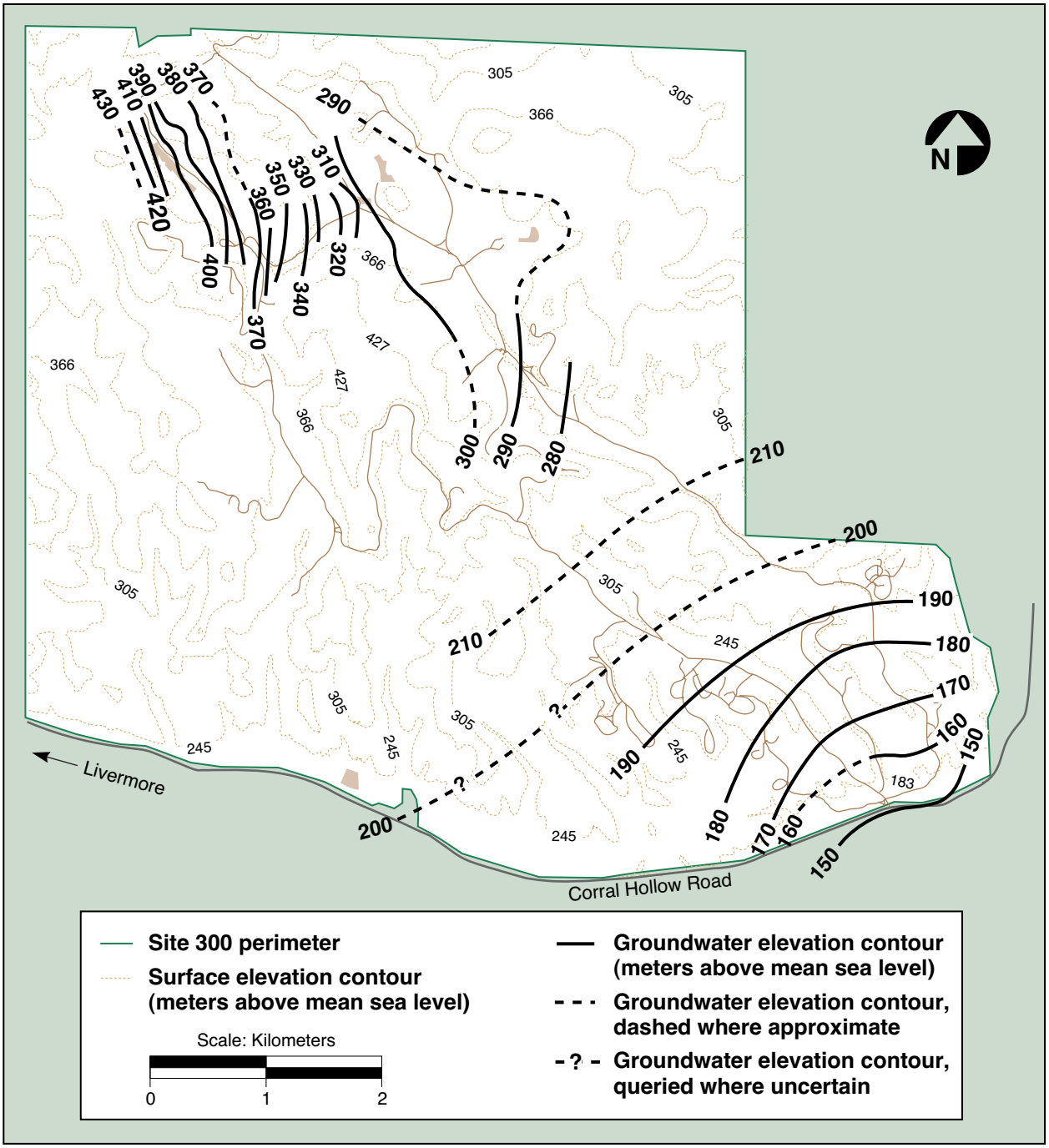


Figure 7-5. Approximate groundwater elevations in the principal continuous water-bearing zone at Site 300

planned investigations at the Pit 7 Complex, Building 865, Building 812, and Sandia Test Site are also not a part of the CMP report. Current information for each of these portions of Site 300 is presented at the end of this section.

At Site 300, there are three dedicated (non-portable) groundwater and soil vapor extraction and treatment facilities at the eastern GSA, central GSA, and Building 834 areas, respectively. There are also 10 portable treatment facilities at Site 300. All 10 of these facilities operated during calendar 2004. Thus, 13 treatment facilities that remove VOCs operated during 2004. Twenty-three wells that extract only groundwater, 8 wells that extract only soil vapor, and 13 wells that extract both groundwater and soil vapor were pumped and fed into treatment systems during 2004. In 2004, the 23 wells that extract only groundwater and the 13 wells that extract both groundwater and soil vapor yielded about 101 million L of groundwater. During the year, the 13 wells that extract both vapor and groundwater and the 8 wells that extract only vapor removed 2.07 million m^3 of vapor. In 2004, the Site 300 treatment facilities removed approximately 57.6 kg of VOCs. Since remediation efforts began in 1990, more than 1078 million L of groundwater and approximately 6.3 million m^3 of vapor have been treated, yielding about 291 kg of removed VOCs. **Table 7-4** summarizes 2004 and cumulative totals of volumes and masses of VOC contaminants removed from groundwater and soil vapor at each Site 300 OU. In addition to VOCs, in 2004, Site 300 treatment facilities removed from groundwater 0.3 g of perchlorate, 2.7 kg of nitrate, 0.45 g of the high explosive RDX, and 0.58 g of organo-silicate oil. Since remediation efforts began, 71.8 g of perchlorate, 705 kg of nitrate, 100 g of RDX, and 9.6 g of organosilicate oil have been removed.

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 seven treatment systems discharge to air by misting.

The eastern and central GSA contain maintenance and shop facilities and introduced contaminants to groundwater due to dry well and liquid storage activities. Groundwater influent TCE concentrations to the eastern GSA OU were reduced from 64 µg/L in January 1992 to 1.8 µg/L in December 2004. No longer do any off-site wells in the eastern GSA yield groundwater containing TCE concentrations in excess of the cleanup standard (maximum contaminant level; MCL) of 5 µg/L. LLNL estimates that 5 to 10 more years of groundwater extraction and treatment will be required before all groundwater VOC concentrations are below MCLs without continued remediation at the eastern GSA. TCE concentrations in shallow groundwater beneath the eastern GSA are shown on **Figure 7-6**.

Contaminated groundwater is extracted from six wells and vapor is extracted from seven wells screened in the Qt-$Tnsc_1$ HSU in the central GSA. Total VOC concentrations in the central GSA OU have been reduced from 9400 µg/L in 1993 to 3100 µg/L in June 2004. From 1994 through the end of 2004, total VOC concentrations in the central GSA soil vapor extraction influent stream were reduced from 450 $ppm_{v/v}$ to

Table 7-4. Volatile organic compounds removed from groundwater and soil at Site 300

Operable Unit	Startup date	2004		Cumulative total	
Groundwater Treatment		**Water treated (ML)[a]**	**VOCs removed (kg)**	**Water treated (ML)[a]**	**VOCs removed (kg)**
Eastern GSA	1991	83.1	0.17	979	6.56
Central GSA	1993	4.05	0.42	38.6	11.4
Building 834	1995	0.07	0.50	0.32	32.3
High Explosives Process Area	1999	7.37	0.14	25.5	0.40
Building 854	1999	2.59	0.38	17.6	7.12
Pit 6	1998	—[b]	—[b]	0.268	0.0014
Buildings 830 and 832	1999	3.55	0.59	16.7	1.26
Total		101	2.20	1078	59.1
Vapor Treatment		**Soil vapor treated ($10^3 m^3$)**	**VOCs removed (kg)**	**Soil vapor treated ($10^3 m^3$)**	**VOCs removed (kg)**
Central GSA	1994	53.0	0.19	2318	67.5
Building 834	1998	157.	55	1814	163
Building 832	1999	1858	0.25	2195	1.80
Total		2068	55.4	6328	232

a ML = 1 million liters

b Groundwater treatment is not routine at Pit 6. A hydraulic pump test with a portable treatment unit for TCE removal was conducted there in 1998.

0.4 $ppm_{v/v}$. Total VOC concentrations in individual central GSA soil vapor extraction wells have also been significantly reduced. Total VOC concentrations in groundwater beneath the central GSA are shown on Figure 2.1-3 of the *2004 Annual CMP Report* (Dibley et al. 2005).

At Building 834, prototype weapons components were subjected to a variety of environmental stresses including heat and pressure. TCE was used as a heat-exchange fluid and was circulated in piping that leaked. The maximum 2004 total VOC concentration in groundwater at Building 834 was 180,000 µg/L. Total VOC concentrations in Tpsg-hosted groundwater beneath the Building 834 area are shown on Figure 2.2-3 of the *2004 Annual CMP Report* (Dibley et al. 2005). (Tpsg is the gravel portion of the Tps unit shown in **Figure 7-4**.) Treatment facility modifications, including installation of new control systems, well head monitoring equipment, and wellfield expansion, were made throughout 2003 and were completed during 2004. Groundwater and soil vapor treatment were reinitiated on September 20, 2004. Twelve wells that extract both groundwater and soil vapor compose the extraction network. Although some VOC mass was destroyed by in situ bioremediation, this mass was not quantified.

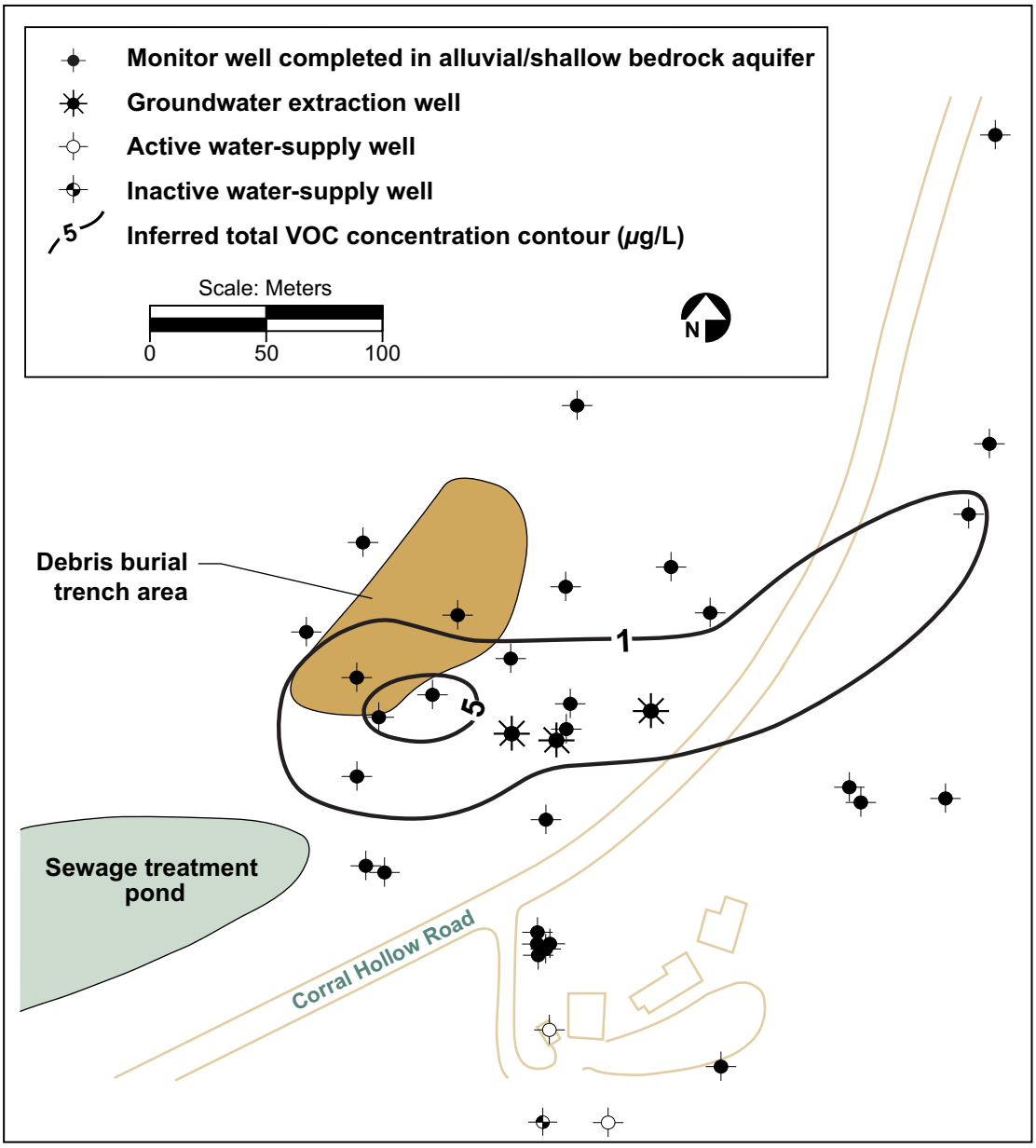


Figure 7-6. Total VOC concentrations in groundwater in the eastern GSA and vicinity (4th quarter 2004)

At the High Explosives Process Area OU, high explosives are pressed and formed. Surface spills from 1958 to 1986 resulted in the release of contaminants at the former Building 815 steam plant. Subsurface contamination is also attributed to HE waste water discharges to former unlined rinse-water lagoons. Six extraction wells in the OU pump groundwater that is treated at four treatment facilities (B815-SRC, B815-PRX, B815-DSB, and B817-SRC). Total VOC concentrations in groundwater beneath the

High Explosives Process Area are shown on Figure 2.4-3 of the *2004 Annual CMP Report* (Dibley et al. 2005). Maximum 2004 total VOC concentrations of 45 µg/L were detected in groundwater in the $Tnbs_2$ aquifer. ($Tnbs_2$ is the upper blue sandstone of the Neroly Formation shown in **Figure 7-4**.) The total VOC concentrations in source area wells have been reduced by about 40% since remediation began in 1999.

Building 850 is an explosives firing table. During 2004, the maximum detected tritium activity in groundwater at the Building 850 OU was 2176 Bq/L (58,800 pCi/L). Tritium activities in groundwater beneath the Building 850 OU are shown on Figure 2.5-3 of the *2004 Annual CMP Report* (Dibley et al. 2005). Monitored natural attenuation (MNA) is the selected remedy for the remediation of tritium in groundwater emanating from the Building 850 area. MNA continues to be effective for tritium in that the extent of the 740 Bq/L (20,000 pCi/L) MCL contour continues to diminish and the highest tritium activities continue to be located immediately downgradient of the firing table. The maximum 2004 total uranium activity in groundwater that contains some depleted uranium was 0.33 Bq/L (9.07 pCi/L). Total uranium activity continues to be below the 0.74 Bq/L (20 pCi/L) State MCL. The *Final Remedial Design for the Building 850 Subarea* (Taffet et al. 2004a) was submitted prior to the agreed upon regulatory due date.

The Building 854 OU is another site where weapons components were subjected to environmental stresses and where pipes containing TCE leaked. Two extraction wells pump groundwater that is treated at two treatment systems (B854-SRC and B854-PRX) that operate in the OU. The 2004 maximum total VOC concentration in groundwater was 180 µg/L, down from a historic maximum detected TCE concentration of 2900 µg/L. Total VOC concentrations in groundwater beneath the Building 854 OU are shown on Figure 2.6-3. of the *2004 Annual CMP Report* (Dibley et al. 2005).

Pit 6 is a landfill that received waste from 1964 to 1973. The landfill was capped and closed under CERCLA in 1997. MNA is the selected remedy for the remediation of VOCs in groundwater emanating from Pit 6. The maximum 2004 groundwater total VOC concentration was 5.2 µg/L. The maximum 2004 groundwater tritium activity was 68.8 Bq/L (1680 pCi/L). Total VOC and tritium concentrations in groundwater at Pit 6 are shown on Figures 2.3-3 and 2.3-4, respectively, of Dibley et al. 2005. Tritium activities in groundwater at the pit are shown on Figure 2.3-4 of the *2004 Annual CMP Report* (Dibley et al. 2005).

Building 832 Canyon OU facilities were used to test the stability of weapons components under a variety of environmental stresses. Contaminants were released from Buildings 830 and 832 through piping leaks and surface spills. Four groundwater extraction and treatment systems operate in the OU: B832-SRC, B830-SRC, B830-PRXN, and B830-DISS. B832-SRC and B830-SRC extract and treat groundwater and soil vapor. The other two facilities only treat groundwater. Nine extraction wells operate in the OU. The maximum 2004 groundwater total VOC concentration was 8800 µg/L. These maximum concentrations occur in the $Tnsc_{1b}$ hydrostratigraphic unit. ($Tnbs_{1b}$ is a subunit of $Tnbs_1$ shown in **Figure 7-4**.) Maximum 2004 total VOC concentrations of 2100 µg/L were detected in the Qal hydrostratigraphic unit. Total VOC concentrations measured during 2004 in groundwater from the$Tnsc_{1b}$ HSU at the Building 832

Canyon OU are shown on Figure 2.7-6 of the *2004 Annual CMP Report* (Dibley et al. 2005). Total 2004 VOC concentrations in the Qal HSU are shown on Figure 2.7-5. of that document.

The Site 300 Site-Wide OU is composed of release sites at which no significant ground water contamination and no unacceptable risk to human health or the environment is present. For this reason, a monitoring-only remedy was selected for these release sites, which include the Building 801 Firing Table, Building 833, Building 845 Firing Table/Pit 9, Pit 2, and Building 851 Firing Table areas. The results of routine monitoring of these sites are included in Section 2.8 and Chapter 3 of the *2004 Annual CMP Report* (Dibley et al. 2005).

The following sections describe the current status of investigations under way at four sites that are still under investigation and have not yet reached the Record of Decision for a final remedy to address environmental contamination. These areas are the Pit 7 Complex, Building 865, the Building 812 Firing Table, and the Sandia Test Site.

Ongoing and Planned Investigations and Cleanup Activities

Pit 7 Complex

The Pit 7 Complex is composed of four landfills—Pits 3, 4, 5, and 7—that received waste from explosives experiments conducted at Site 300 firing tables. Pits 3 and 5 have released tritium to groundwater. Pits 3, 5, and 7 have released depleted uranium to groundwater. The maximum tritium activity detected in groundwater in 2004 in the OU was 16,169 Bq/L (437,000 pCi/L) in $Tnbs_0$ bedrock. The maximum detected total uranium activity in groundwater that contained some depleted uranium was 4.16 Bq/L (112.4 pCi/L) and was detected in a sample from the Qal/weathered bedrock. Perchlorate, TCE, and nitrate also occur in Pit 7 Complex groundwater. **Figure 7-7** presents maps of tritium activities in groundwater in Qal/weathered bedrock and $Tnbs_0$ HSUs.

LLNL submitted the *Draft Final Remedial Investigation/Feasibility Study for the Pit 7 Complex* (Taffet et al. 2004b) prior to the September 30, 2004, milestone date established in the FFA (**Table 7-3**). The report presents details of the hydrogeology, nature and extent of contamination, and risk assessment and specifies remedial actions that can be applied to address the contamination.

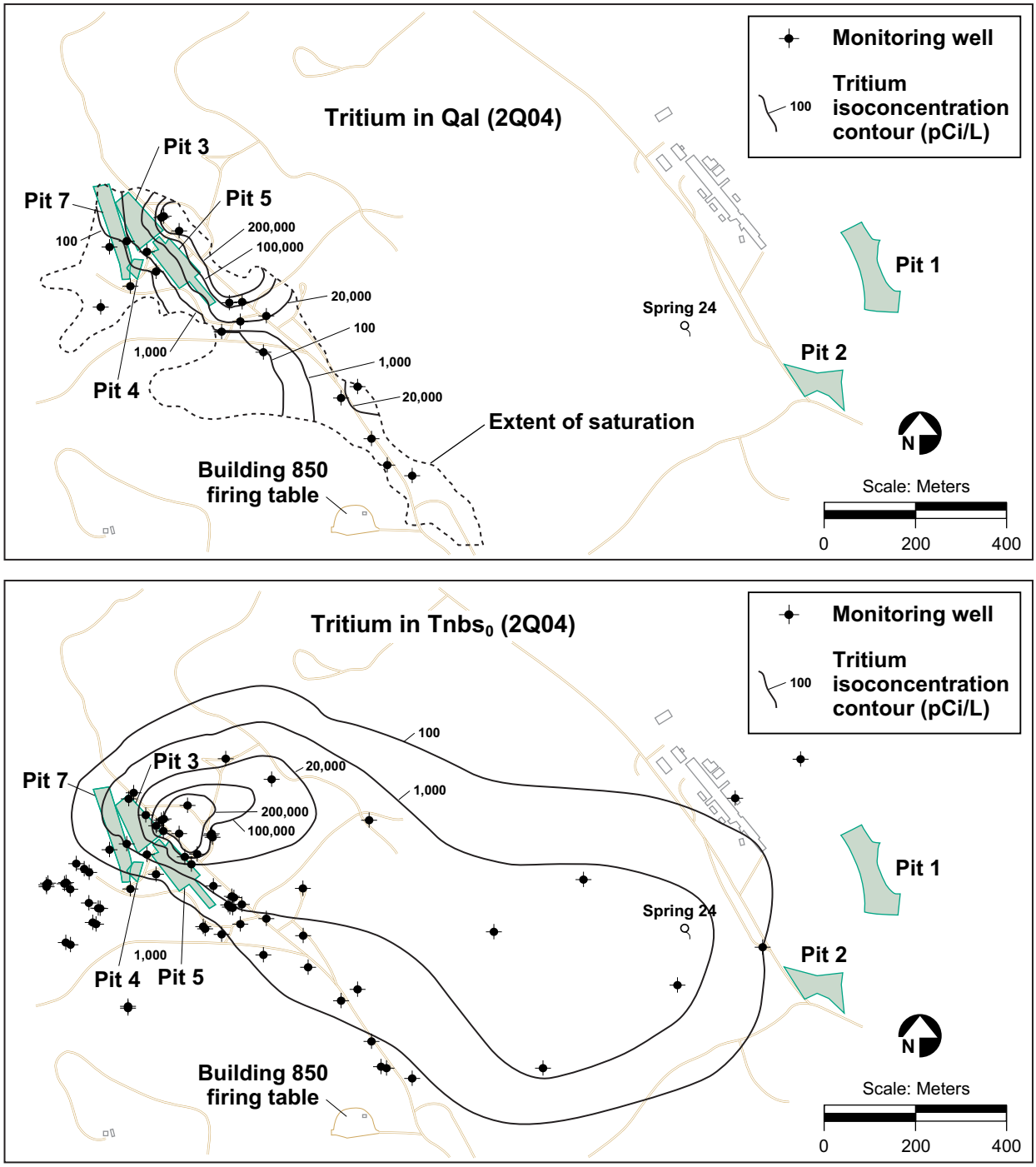


Figure 7-7. Tritium plume in Qal and $Tnbs_0$ (2nd quarter 2004)

Building 865

Building 865 is a former linear accelerator, the Advanced Testing Accelerator. Freon-113 was used as a degreaser there and has been released to groundwater. The maximum Freon-113 concentration detected in groundwater during 2004 was 290 µg/L. The federal and state MCL for Freon-113 in drinking water is 1200 µg/L.

During 2004, LLNL installed two monitoring wells as a part of the remedial investigation of Building 865. LLNL will complete a Characterization Summary report detailing the hydrogeology and nature and extent of contamination emanating from Building 865. This report is currently scheduled for submission to the regulatory agencies by September 30, 2006.

Building 812 Firing Table

Building 812 is an explosives test firing table. A remedial investigation is in process. During 2004, a maximum detected groundwater activity of total uranium, in which some of the uranium was due to addition of depleted uranium, was 0.75 Bq/L (20.3 pCi/L). LLNL will complete a Characterization Summary report detailing the hydrogeology and nature and extent of contamination emanating from Building 812. This report is currently scheduled for submission to the regulatory agencies by September 30, 2005.

Sandia Test Site

The Sandia Test Site was used in the past for several open air explosives experiments. During 2004, ten boreholes were drilled and soil and rock samples were collected and analyzed for metals and radionuclides. Three of these boreholes were completed as piezometers. Two of the piezometers were removed and backfilled after water samples were collected. Otherwise, no anthropogenic contamination has been observed in samples of water, soil, or rock collected from the Sandia Test Site. LLNL will complete a Characterization Summary report detailing the hydrogeology and nature and extent of contamination emanating at the site. This report is currently scheduled for submission to the regulatory agencies by September 30, 2006.

Environmental Impact

LLNL strives to reduce elevated risks arising from chemicals released to the environment at Site 300 and to conduct its activities to protect ecological resources. At each OU, LLNL proposes a range of remediation options that are applicable for each release site. The option that achieves the goals of reducing risks to human, health and the environment and satisfying remediation action objectives, regulatory standards for chemicals in water and soil, and other state and federal requirements is then negotiated by DOE and the regulatory agencies with public input. The agreed upon actions are implemented.

These actions have included groundwater and soil vapor extraction and treatment, source area (lagoon and landfill) capping, monitored natural attenuation, monitoring, and institutional controls

Groundwater and soil vapor extraction and treatment at Site 300 continue to reduce the mass of contaminants in the subsurface. As stated previously, during 2004, extraction wells yielded about 101 million L of groundwater. During the year, 2.07 million m^3 of vapor were also extracted. In 2004, the Site 300 treatment facilities removed approximately 57.6 kg of VOCs. Since remediation efforts began in 1990, more than 1078 million L of groundwater and approximately 6.3 million m^3 of vapor have been treated, yielding about 291 kg of removed VOCs. In addition to VOCs, during 2004, Site 300 treatment facilities removed from groundwater 0.3 g of perchlorate, 2.7 kg of nitrate, 0.45 g of the high explosive RDX, and 0.58 g of organosilicate oil. Since remediation efforts began, 71.8 g of perchlorate, 705 kg of nitrate, 100 g of RDX, and 9.6 g of organosilicate oil have been removed.

All ground-disturbing activities, such as well drilling, construction and operation of treatment systems, and groundwater sampling are planned and conducted to minimize disturbance of animal and plant habitat. A biologist inspects all sites and makes recommendations that are incorporated into the plan for each activity. Erosion controls and other recommendations made by the surface water hydrologist are also incorporated into the plans for ground-disturbing activities.

8

Quality Assurance

Lucinda M. Clark
Donald H. MacQueen

Introduction

Quality assurance (QA) is a system of activities and processes put in place to ensure that products or services meet or exceed customer specifications. Quality control (QC) consists of activities used to verify that deliverables are of acceptable quality and meet criteria established in the quality planning process. Lawrence Livermore National Laboratory conducted environmental monitoring activities during 2004 in accordance with the Environmental Protection Department Quality Assurance Management Plan (Revision 4), which is based on DOE Order 414.1A. This order sets forth policy, requirements, and responsibilities for the establishment and maintenance of plans and actions that assure quality in DOE programs using 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.

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. 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. The radiochemical methods used by LLNL laboratories are described in procedures created and maintained by the laboratory performing the analyses.

Quality Assurance Activities

Nonconformance reporting and tracking is a process used for ensuring that problems are identified, resolved, and prevented from recurring. EPD reports and tracks problems using Nonconformance Reports (NCRs).

The LLNL Environmental Protection Department (EPD) generated 17 NCRs related to environmental monitoring in 2004. Four of the NCRs were related to problems with analytical laboratories, five documented minor equipment malfunctions that did not result in lost samples, and the remaining eight documented errors made by sampling technologists.

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.

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.

QA staff also track and report planned environmental monitoring samples that are not collected. A summary of these lost samples appears in **Table 8-1**.

Analytical Laboratories

LLNL awarded new Blanket Service Agreements (BSAs) to six analytical laboratories in 2004. LLNL works closely with these analytical laboratories to minimize the occurrence of problems.

Analytical Laboratory Intercomparison Studies

LLNL uses the results of intercomparison program data to identify and monitor trends in performance and to draw attention to the need to improve laboratory performances. 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.

Two laboratories at Lawrence Livermore National Laboratory participated in the Mixed Analyte Performance Evaluation Program (MAPEP) sponsored by the U.S. Department of Energy (DOE) during 2004. (The Environmental Monitoring Laboratory intercomparison studies program for which data were reported in previous versions of this report was cancelled after the 2003 studies.) The two LLNL laboratories that participated in MAPEP are the Environmental Monitoring Radiological Laboratory (EMRL) and the Hazards Control Department's Analytical Laboratory (HCAL).

Table 8-1. Sampling completeness in 2004 for the Livermore site and Site 300

Environmental medium	Number of analyses planned	Number of analyses completed	Completeness (%)	Reason(s) for lost samples
Air particulate				
Radiological parameters (Livermore site)	1188	1152	97	No power at location (29), GFI tripped (4), motor problems (1), no access (1), not explained (1)
Beryllium (Livermore site)	96	96	100	
Radiological parameters (Site 300)	717	704	98	No access (11), no power (1), filter saturated with water (1)
Beryllium (Site 300)	46	46	100	
Air tritium				
Livermore site	489	480	98	Pump failure (5), insufficient flow (4)
Site 300	31	31	100	
Soil and Sediment				
Livermore site	42	42	100	
Site 300	30	30	100	
Arroyo sediment (Livermore site only)	21	21	100	
Vegetation and Foodstuffs				
Livermore site and vicinity	64	64	100	
Site 300	20	20	100	
Wine	12	12	100	
Thermoluminescent dosimeters (TLDs)				
Livermore site perimeter	56	53	95	Fence removed (3)
Livermore Valley	88	87	99	TLD found burned (1)
Site 300	52	49	94	Missing (2), lost in controlled burn (1)
Rain				
Livermore site	53	52	99	Bucket missing (1)
Site 300	10	8	80	No access (2)
Storm water runoff				
Livermore site	320	320	100	
Site 300	231	164	71	No flow at location (66), sample not analyzed by lab (1)

Table 8-1. Sampling completeness in 2004 for the Livermore site and Site 300 (continued)

Environmental medium	Number of analyses planned	Number of analyses completed	Completeness (%)	Reason(s) for lost samples
Drainage Retention Basin				
Field measurements	208	208	100	
Samples	72	72	100	
Releases	89	88	99	Samples not collected, no explanation (1)
Livermore site wastewater				
B196	926	926	100	
C196	314	312	99	Sampler error (2)
LWRP[a] effluent	48	47	98	Sample lost at laboratory (1)
Digester sludge	80	74	93	Digester #2 was closed October–December (6)
WDR 96-248				
Surface impoundment wastewater	58	58	100	
Surface impoundment groundwater	145	144	99	Not sampled (1)
Sewage ponds wastewater	34	34	100	
Sewage ponds groundwater	84	84	100	
Miscellaneous aqueous samples				
Other surface water (Livermore Valley only)	51	51	100	
Cooling towers (Site 300 only)	24	24	100	

a LWRP = Livermore Water Reclamation Plant

The results of EMRL's participation in the studies are presented in Table 8-2. According to the results, 33 of 38 reported results were determined to be acceptable, 2 results were acceptable with warning, and 3 results were unacceptable, based on established control limits.

Unacceptable results for plutonium-238 and plutonium-239/240 in the 04-RDF12 air filter study were the result of switching the active filter with a blank filter that was shipped with it. In the future, the active filter will be labeled upon receipt and the two blank filters that accompany the active filter will be dissolved along with the active filter to eliminate loss of activity. The three dissolved filters will be analyzed as one sample.

Table 8-2. EMRL performance in the MAPEP Intercomparison Program Studies for 2004

Study	Analyte	Result	Ref Value	Flag[a]	Acceptance Range[b]	Uncertainty Value
Air filter (Bq/sample)						
MAPEP-04-GrF12	Gross alpha	0.0520	0.37	A	>0.0-0.8	0.00289
MAPEP-04-GrF12	Gross beta	1.28	1.21	A	0.6-1.8	0.00983
MAPEP-04-RdF12	Cesium-134	2.95	2.9	A	2.03-3.77	0.225
MAPEP-04-RdF12	Cesium-137	2.42	1.96	W	1.40-2.60	0.328
MAPEP-04-RdF12	Cobalt-57	2.49	2.44	A	1.68-3.12	0.231
MAPEP-04-RdF12	Cobalt-60	2.35	2.35	A	1.61-2.99	0.191
MAPEP-04-RdF12	Manganese-54	2.42	3.03	W	2.10-3.90	0.441
MAPEP-04-RdF12	Plutonium-238	0.0172	0.13	N	0.09-0.17	0.00129
MAPEP-04-RdF12	Plutonium-239/240	0.012	0.09	N	0.06-0.12	0.00101
MAPEP-04-RdF12	Zinc-65	4.64	4.11	A	2.80-5.20	0.608
Aqueous (Bq/L)						
MAPEP-03-W11	Americium-241	0.0188	0.0144	A	_[c]	0.00157
MAPEP-03-W11	Cesium-137	127	124	A	86.80-161.20	13.4
MAPEP-03-W11	Cobalt-57	187	173	A	121.10-224.90	18.4
MAPEP-03-W11	Cobalt-60	130	121.8	A	85.26-158.34	7.83
MAPEP-03-W11	Manganese-54	162	155	A	108.50-201.50	19.8
MAPEP-03-W11	Plutonium-238	1.30	1.49	A	1.04-1.94	0.0722
MAPEP-03-W11	Plutonium-239/240	2.04	2.39	A	1.67-3.11	0.11
MAPEP-03-W11	Zinc-65	384	320	A	224.00-416.00	38.7
MAPEP-04-GrW12	Gross alpha	0.542	1.24	A	0.0-2.5	0.0172
MAPEP-04-GrW12	Gross beta	3.51	4.07	A	2.0-6.2	0.0744
MAPEP-04-MaW12	Americium-241	0.558	0.59	A	0.42-0.78	0.0241
MAPEP-04-MaW12	Cesium-134	189	208	A	145.60-270.40	15.6
MAPEP-04-MaW12	Cesium-137	250	250	A	175.00-325.00	37.9
MAPEP-04-MaW12	Cobalt-57	189	185	A	129.50-240.50	15.8
MAPEP-04-MaW12	Cobalt-60	165	163	A	114.10-211.90	11
MAPEP-04-MaW12	Manganese-54	250	267	A	186.90-347.10	24.8
MAPEP-04-MaW12	Plutonium-238	1.10	1.24	A	0.84-1.56	0.0608
MAPEP-04-MaW12	Zinc-65	217	208	A	145.60-270.40	29.6
Soil (Bq/kg)						
MAPEP-04-MaS12	Americium-241	73.1	67	A	46.88-87.06	3.62
MAPEP-04-MaS12	Cesium-134	350	414	A	290.08-538.72	18.4
MAPEP-04-MaS12	Cesium-137	830	836	A	585.34-1087.06	78.5
MAPEP-04-MaS12	Cobalt-57	403	400	A	279.72-519.48	29.4
MAPEP-04-MaS12	Cobalt-60	524	518	A	362.60-673.40	27.6
MAPEP-04-MaS12	Manganese-54	830	485	N	339.29-630.11	53.3

Table 8-2. EMRL performance in the MAPEP Intercomparison Program Studies for 2004 (continued)

Study	Analyte	Result	Ref Value	Flag[a]	Acceptance Range[b]	Uncertainty Value
MAPEP-04-MaS12	Plutonium-238	35.1	35.4	A	24.78-46.02	2.53
MAPEP-04-MaS12	Plutonium-239/240	47.4	41.8	A	29.27-54.35	3.19
MAPEP-04-MaS12	Potassium-40	627	604	A	422.80-785.20	82.4
MAPEP-04-MaS12	Zinc-65	769	699	A	489.51-909.09	76.7

a Acceptable (A flag) results have bias ≤20%. Results acceptable with warning (W flag) have bias >20% and bias ≤30%. Results with bias >30% (N flag) are not acceptable.

b Significant figures shown are those of the MAPEP program.

c Acceptance range not provided for this analysis.

The manganese-54 result for the 04-MaS12 soil study was unacceptable due to a transcription error. The actual result, 507 Bq/kg is in the acceptable range. A new report format was developed to prevent similar errors from occurring in the future.

The results of HCAL's participation in the 2004 MAPEP studies (see **Table 8-3**) indicate that five of five sample results fell within the 3σ acceptance control limits.

Table 8-3. HCAL performance in the MAPEP Intercomparison Program Studies for 2004

Study	Analyte	Result	Ref Value	Flag[a]	Acceptance Range	Uncertainty Value
			Air filter (Bq/sample)			
MAPEP-04-GrF12	Gross alpha	0.19	0.37	A	>0.0-0.8	0.04
MAPEP-04-GrF12	Gross beta	1.40	1.21	A	0.6-1.8	0.09
			Aqueous (Bq/L)			
MAPEP-04-GrW12	Gross alpha	1.09	1.24	A	0.0-2.5	0.21
MAPEP-04-GrW12	Gross beta	3.59	4.07	A	2.0-6.2	0.35
MAPEP-04-MaW12	Hydrogen-3	82.5	82.9	A	58.1-108	5.5

a Acceptable (A flag) results have bias ≤20%. Results acceptable with warning (W flag) have bias >20% and bias ≤30%. Results with bias >30% (N flag) are not acceptable.

HCAL also participated in three Environmental Resource Associates (ERA) performance evaluation studies in 2004. The results of these studies are presented in **Table 8-4**. Fourteen of 15 analytes reported by HCAL in these studies fell within acceptable limits. HCAL was unable to determine the cause of the unacceptable result for iron. No problems were identified in a review of the raw data, and the results for a duplicate sample as well as a follow-up sample were both in the acceptable range.

Table 8-4. HCAL performance in the ERA Intercomparison Program Studies for 2004

Study	Analyte	Reported Value	ERA Assigned Value	Control Limits	Warning Limits	Performance Evaluation
Radiological (pCi/L)						
RAD-59	Gross alpha	34.4	31.7	18.0-45.4	22.5-40.9	Acceptable
RAD-59	Gross beta	38.1	36.3	26.7-45.0	30.5-42.1	Acceptable
RAD-59	Tritium	20300	20700	17100-24300	18300-23100	Acceptable
Nonradiological (μg/L)						
WP-116	Aluminum	3090	3100	2670-3500	2810–3360	Acceptable
WP-116	Arsenic	299	299	248-352	266–335	Acceptable
WP-116	Beryllium	350	353	300-399	316–382	Acceptable
WP-116	Cadmium	709	729	622-827	657–793	Acceptable
WP-116	Chromium	336	322	279–365	294–351	Acceptable
WP-116	Copper	135	139	123-155	129–150	Acceptable
WP-116	Iron	253	216	187–250	197–239	Not Acceptable
WP-116	Lead	130	124	102-146	110–138	Acceptable
WP-116	Nickel	946	922	834–1030	866–997	Acceptable
WP-116	Silver	81.2	83.4	71.0–91.6	75.1–91.6	Acceptable
WP-116	Zinc	583	559	494–630	516–607	Acceptable
WP-118	Iron	104	102	85.7-122	91.7-116	Acceptable

Although contract laboratories are also required to participate in laboratory intercomparison programs, permission to publish their results for comparison purposes was not granted for 2004. See the following website to obtain MAPEP reports that include the results from all participating laboratories:
http://www.inel.gov/resl/mapep/reports.html

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.

Tables 8-5, **8-6**, and **8-7** present statistical data for collocated sample pairs, grouped by sample matrix and analyte. Samples from both the Livermore site and Site 300 are included. **Tables 8-5** and **8-6** are based on data pairs in which both values are detections (see "Data Presentation"). **Table 8-7** is based on data pairs in which either or both values are nondetections.

Table 8-5. Quality assurance collocated sampling: Summary statistics for analytes with more than eight pairs in which both results were above the detection limit

Media	Analyte	N[a]	%RSD[b]	Slope	r^2[c]	Intercept
Air	Gross alpha (variability)[d]	76	56.1	0.436	0.22	2.06×10^{-5} (Bq/m^3)
	Gross beta	102	20.1	0.964	0.87	6.24×10^{-6} (Bq/m^3)
	Beryllium (outliers)[e]	10	12.9	8.28	0.68	–41.2 (pg/m^3)
	Uranium-235 + 236	12	11.8	0.767	0.96	3.08×10^{-8} (μg/m^3)
	Uranium-238	12	13.1	0.748	0.94	5.16×10^{-6} (μg/m^3)
	Uranium-235/238 (outliers)[e]	12	1.08	1.01	0.54	–0.000201 (ratio)
	Tritium	20	14	1.07	0.99	–0.0235 (Bq/m^3)
Dose (TLD)	90-day radiological dose (outliers)[e]	30	3.53	0.597	0.39	5.88 (mrem)
Groundwater	Gross beta	16	16	0.98	0.88	–0.0233(Bq/L)
	Arsenic	16	4.64	0.995	1	0.000268 (mg/L)
	Barium	9	1.89	1	1	–0.00132 (mg/L)
	Bromide (outliers)[e]	10	13.6	0.596	0.69	0.22 (mg/L)
	Chloride	11	0	1.01	1	–0.864 (mg/L)
	Nitrate (as NO_3)	19	1.18	1.01	1	–0.246 (mg/L)
	Ortho-Phosphate	10	2.86	1	1	–0.000588 (mg/L)
	Potassium	18	4.52	1.02	1	–0.116 (mg/L)
	Sulfate	11	0.358	1	1	–0.636 (mg/L)
	Uranium-234+233	11	2.4	1.01	1	0.000177 (Bq/L)
	Uranium-238	11	5.04	1.01	1	–0.000586 (Bq/L)
Sewer	Gross beta	51	14.1	0.999	0.85	4.23×10^{-5} (Bq/mL)
	TDS	9	17.2	1.06	0.97	51.4 (mg/L)
	TSS	9	14.1	0.772	0.9	53.2 (mg/L)

a Number of collocated pairs included in regression analysis

b 75th percentile of percent relative standard deviations (%RSD) where $\%RSD = \left(\frac{200}{\sqrt{2}}\right)\frac{|x_1 - x_2|}{x_1 + x_2}$ and x_1 and x_2 are the reported concentrations of each routine-duplicate pair

c Coefficient of determination

d Outside acceptable range of slope or r^2 because of variability

e Outside acceptable range of slope or r^2 because of outliers

Table 8-6. 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
Aqueous	Gross beta	1	1.2	1.2	1.2
Groundwater	Gross alpha	6	0.89	0.2	1.4
	Tritium	6	0.86	0.13	1.2
	Radium-226	8	1.3	0.34	4.3
	Uranium-235 and uranium-236	8	0.84	0.5	1.3
Runoff (from rain)	Gross alpha	5	0.99	0.69	1.6
	Gross beta	5	1	0.72	1.5
	Uranium-234 and uranium-233	2	0.96	0.92	0.99
	Uranium-235 and uranium-236	1	1.5	1.5	1.5
	Uranium-238	2	1.1	1	1.2
Soil	Gross alpha	1	0.83	0.83	0.83
	Gross beta	1	0.95	0.95	0.95
	Cesium-137	4	1.1	0.95	1.3
	Potassium-40	4	1	0.95	1.1
	Plutonium-238	3	1.6	0.83	2.2
	Plutonium-239+240	3	1.3	1.1	1.4
	Radium-226	4	0.99	0.93	1.1
	Radium-228	4	0.99	0.97	1
	Thorium-228	4	0.98	0.94	1
	Uranium-235	4	0.86	0.61	0.98
	Uranium-238	4	0.96	0.78	1.1
Sewer	Gross alpha	2	0.96	0.89	1
	Tritium	2	0.97	0.68	1.3
Vegetation	Tritium	4	4.3	0.56	14

a Number of collated pairs used in ratio calculations

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 8-5** 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 8-1**. Allowing for normal analytical

Table 8-7. 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 [a]
Groundwater	Copper	1	17	5.9
	Total organic carbon	2	8	25
	Total organic carbon	2	8	25
	Tritium	1	16	6.3
Soil	Americium-241	1	4	25
Sewer	Gross alpha	1	50	2
	Bromoform	1	4	25
	Ethanol	1	4	25
	Freon 113	1	5	20

a Inconsistent pairs are those for which one of the results is more than twice the reporting limit of the other.

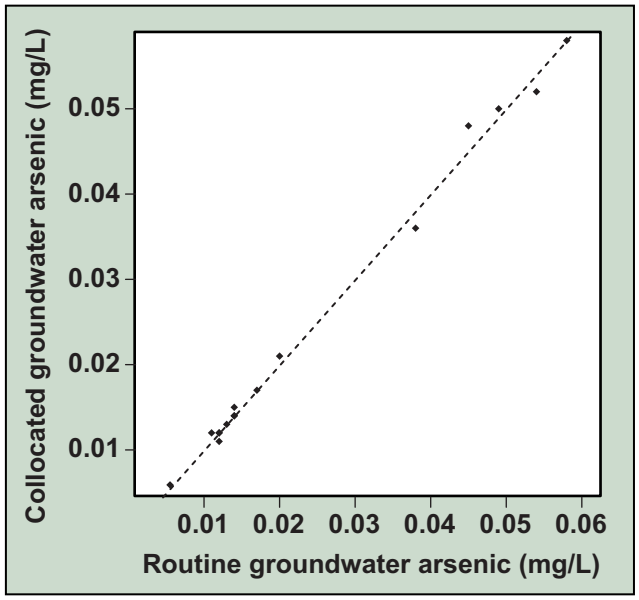


Figure 8-1. Example of data points that lie close to a line with slope equal to 1 and intercept equal to 0 using groundwater arsenic concentrations from collocated samples

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 8-5**. 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 8-6**. 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 8-7** 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 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 regulatory agency is involved.

Routine and collocated sample results show fairly good agreement: 90% of the pairs have a precision of 38% 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 22 data sets reported in **Table 8-5**, four did not meet the criterion for acceptability because of outliers. **Figure 8-2** illustrates a set of collocated pairs with two outliers.

The second category is data sets that do not meet the criterion for acceptability because results are highly variable. This tends to be typical of measurements at extremely low concentrations, as illustrated in **Figure 8-3**. Low concentrations of radionuclides on particulates in air highlight this effect, because a small number or 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 22 data sets in **Table 8-5**, one shows sufficient variability in results to make it fall outside the acceptable range.

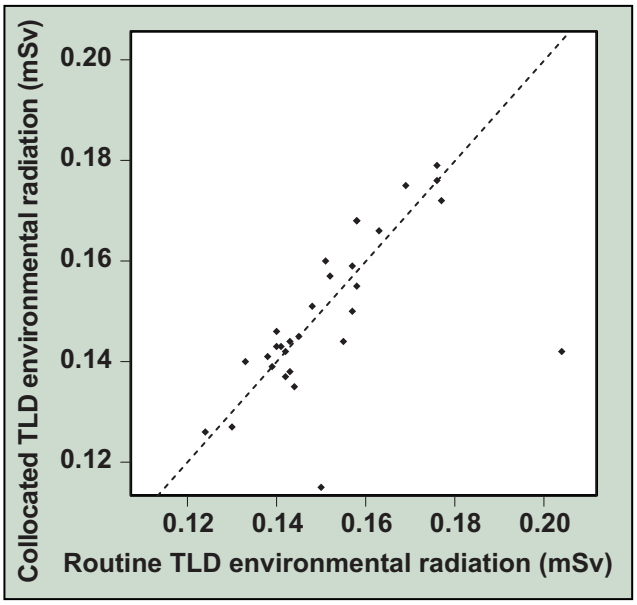


Figure 8-2. Example of data with two outliers using collocated TLD environmental radiation measurements

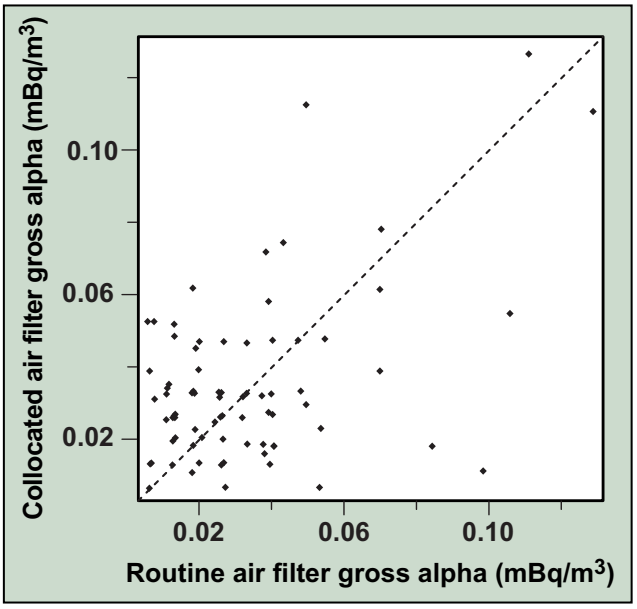


Figure 8-3. Example of variability using air filter gross alpha concentrations from collocated samples

Data Presentation

Most data tables provided in the report CD were created using computer scripts that retrieve data from the database, convert to SI units when necessary, calculate summary statistics for tables that include summary statistics, format data as appropriate, lay out the table into the desired rows and columns, and present a draft table. Final tables are included after review by the responsible analyst. Analytical laboratory data, and values calculated from analytical laboratory data, are normally displayed with two or at most three significant digits. Significant trailing zeros may be omitted.

Radiological Data

Most of the data tables display radiological data as a result plus-or-minus an associated 2σ uncertainty. This measure of uncertainty represents intrinsic variation in the measurement process, most of which is due to the random nature of radioactive decay (see also the section "Reporting Uncertainty in Data Tables" in this chapter). 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.

Some 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 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 by the analytical laboratory 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 and Summary Statistics

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 are calculated according to the *Environmental Monitoring Plan* (Woods 2005). The usual summary statistics are the median, which is a measure of central tendency, and interquartile range (IQR), which is a measure of dispersion (variability). However, some tables may present other measures, at the discretion of the responsible analyst.

The median indicates the middle of the data set. That is, half of the measured results are above the median, and half are below. 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. Different 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. To calculate the median, at least four values are required; to calculate the IQR at least six values are needed.

Summary statistics are calculated from values that, if necessary, have already been rounded (such as when units have been converted from pCi to Bq) and are then rounded to an appropriate number of significant digits. The calculation of summary statistics is also affected by the presence of nondetections. A nondetection indicates that no specific measured value is available; instead, the best information available is that the actual value is less than the reporting limit. Adjustments to the calculation of the median and IQR for data sets that include nondetections are described below.

For data sets with all measurements above the reporting limit and radiological data sets that include reported values below the reporting limit, all reported values, including any below the reporting limit, are included in the calculation of summary statistics.

For data sets that include one or more values reported as "less than the reporting limit," the reporting limit is used as an upper bound value in the calculation of summary statistics.

If the number of values is odd, the middle value (when sorted from smallest to largest) is the median. If the middle value and all larger values are detections then the middle value is reported as the median. Otherwise, the median is assigned a less-than (<) sign.

If the number of values is even, the median is halfway between the middle two values (i.e., the middle two when the values are sorted from smallest to largest). If both of the middle two values and all larger values are detections, then the median is reported. Otherwise, the median is assigned a less-than sign.

If any of the values used to calculate the 25th percentile is a nondetection, or any values larger than the 25th percentile are nondetections, then the IQR cannot be calculated and is not reported.

The median and the IQR are not calculated for data sets having no detections.

Reporting Uncertainty in Data Tables

The measurement uncertainties associated with results from analytical laboratories are represented in two ways. The first of these, significant digits, relates to the resolution of the measuring device. For example, if an ordinary household ruler with a metric scale is used to measure the length of an object in centimeters, and the ruler has tick marks every tenth centimeter, then the length can reliably and consistently be measured to the nearest tenth of a centimeter (i.e., to the nearest tick mark). However, an attempt to be more precise is not likely to yield reliable or reproducible results, because it requires a visual estimate of a distance between tick marks. The appropriate way to report such a measurement would be, for example, "2.1 cm." This would indicate that the "true" length of the object is nearer to 2.1 cm than to 2.0 cm or 2.2 cm (i.e., between 2.05 and

2.15 cm). This result is said to have two significant digits. Although not explicitly stated, the uncertainty is considered to be ± 0.05 cm. A more precise measuring device might be able to measure an object to the nearest one-hundredth of a centimeter; in that case a value such as "2.12 cm" might be reported. This value would have three significant digits and the implied uncertainty would be ± 0.005 cm. A result reported as "3.0 cm" has two significant digits. That is, the trailing zero is significant, and implies that the true length is between 2.95 and 3.05 cm; closer to 3.0 than to 2.9 or 3.1 cm.

When performing calculations with measured values that have significant digits, all digits are used. The number of significant digits in the calculated result is the same as that of the measured value with the fewest number of significant digits.

Most unit conversion factors do not have significant digits. For example, the conversion from milligrams (mg) to micrograms (µg) requires multiplying by the fixed (constant) value of 1000. The value 1000 is exact; it has no uncertainty and therefore the concept of significant digits does not apply.

The other method of representing uncertainty is based on random variation. For radiological measurements, there is variation due to the random nature of radioactive decay. As a sample is measured, the number of radioactive decay events is counted, and the reported result is calculated from the number of decay events that were observed. If the sample is recounted, the number of decay events will almost always be different—because radioactive decay events occur randomly. Uncertainties of this type are reported in this volume as 2σ uncertainties. A 2σ uncertainty represents the range of results expected to occur approximately 95% of the time, if a sample were to be recounted many times. A radiological result reported as, for example, "2.6 ± 1.2 Bq/g" would indicate that with approximately 95% confidence, the "true" value is in the range 1.4 to 3.8 Bq/g (i.e., 2.6 – 1.2 = 1.4 and 2.6 + 1.2 = 3.8).

The concept of significant digits applies to both the radiological result and its uncertainty. So, for example, in a result reported as "2.6 ± 1.2", both the measurement and its uncertainty have the same number of significant digits, that is, two. When expanding an interval reported in the "±" form, for example "2.4 ± 0.44", to a range of values, the rule described above for calculations involving significant digits must be followed. For example, 2.4 – 0.44 = 1.96. However, the measurements 2.4 and 0.44 each have two significant digits, so 1.96 must be rounded to two significant digits, i.e., to 2.0. Similarly, 2.4 + 0.44 = 2.84, and this must be rounded to 2.8. Therefore, a measurement reported as "2.4 ± 0.44 Bq/g" would represent an interval of 2.0 to 2.8 Bq/g.

When rounding a value having a final digit of "5", the software that prepared the tables follows the Institute of Electrical and Electronics Engineers (IEEE) Standard 754-1985, which is "go to the even digit". For example, 2.45 would round down to 2.4, and 2.55 would round up to 2.6.

Quality Assurance Process for the Environmental Report

Unlike the preceding sections, which focused on standards of accuracy and precision in data acquisition and reporting, the following discussion deals with actions to ensure that the content of this report is accurate and has not been corrupted during 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.

The formal QA procedure used for this report has always concentrated on ensuring that the data presented in tables and figures is the same as that reported by the analytical laboratory. Authors, contributors, and technicians have been enlisted to check the accuracy of sections other than those with which they were involved. Members of the Data Management Team (DMT) were excluded from this process because they prepared the tables. When checking values in tables and figures, checkers randomly selected 10% of the numbers and compared them to values in the reports provided by the analytical laboratories. If these values agreed with the reports, further checking was considered unnecessary. If there was disagreement, the checker compared another 10% of the data with the analytical values. If more errors were found, the entire table or figure was checked against the data in the database. This process included checking unit conversions (e.g., from English to SI units) and summary calculations (e.g., mean, interquartile range, fractions of various limits).

The above process was extremely time-consuming. In recent years, advances have been made that are tending to eliminate most of the potential for errors in simple supplementary data tables, such as are found primarily on the report CD. One of the advances is that, rather than sending printed reports that have to be hand-entered into the electronic database, the analytical laboratories now send reports electronically, and these are loaded directly into the database. This practice should result in perfect agreement between the database and data in printed reports from the laboratories. In practice, however, laboratory reporting is not perfect, so the DMT carefully checks all incoming data throughout the year, to make sure that electronic and printed reports from the laboratories agree. This aspect of QC, while not formally part of the QA process for the preparation of this environmental report, is essential to this report's accuracy. Because of this ongoing QC of incoming data, data stored in the database and available for the annual environmental report tables at the time the report is prepared are unlikely to contain errors.

Another advance is that scripts have been written to pull the data from the DMT database directly into the format of the table, including unit conversion and summary statistic calculations. All data tables found on the CD are prepared in this manner. For these tables, it is the responsibility of the appropriate analyst to check each year that the

table is up-to-date (e.g., new locations/analytes added, old ones removed), that the data agree with the data they have received from DMT, and that the summary calculations have been done correctly.

In 2005, LLNL staff checked tables and figures in the report as described above. Quality assurance of the data tables found on the report CD emphasized checking for problems with the scripts rather than for data accuracy. Forms to aid in the QC of tables and figures were distributed along with the appropriate figure, table, and text; a coordinator kept track of the process. 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. Completed QC forms and the corrected figures or tables were returned to the report editors, who, in collaboration with the contributor, ensured that corrections were made.

Appendix A: EPA Methods of Environmental Water Analysis

Table A-1. Inorganic constituents of concern in water samples, the analytical methods used to determine their concentrations, and their contractual reporting limits

Constituents of concern	Analytical method	Reporting limit[a,b]
Metals and minerals (mg/L)		
All alkalinities	EPA 310.1	1
Aluminum	EPA 200.7 or 200.8	0.05 or 0.2
Ammonia nitrogen (as N)	EPA 350.3, 350.2, or 350.1	0.03 or 0.1
Antimony	EPA 204.2 or 200.8	0.005
Arsenic	EPA 206.2 or 200.8	0.002
Barium	EPA 200.7 or 200.8	0.025 or 0.01
Beryllium	EPA 210.2 or 200.8	0.0005 or 0.0002
Boron	EPA 200.7	0.05
Bromide	EPA 300.0	0.5
Cadmium	EPA 213.2 or 200.8	0.0005
Calcium	EPA 200.7	0.5
Chloride	EPA 300.0	1 or 0.5
Chlorine (residual)	EPA 330.1 or 330.4	0.1
Chromium	EPA 218.2 or 200.8	0.01 or 0.001
Chromium(VI)	EPA 218.4 or 7196	0.002
Cobalt	EPA 200.7 or 200.8	0.025 or 0.05
Copper	EPA 220.2, 200.7 or 200.8	0.001, 0.01 or 0.05
Cyanide	EPA 335.2	0.02
Fluoride	EPA 340.2 or 340.1	0.05
Hardness, total (as $CaCO_3$)	SM 2320B	1
Iron	EPA 200.7 or 200.8	0.1
Lead	EPA 239.2 or 200.8	0.002 or 0.005
Magnesium	EPA 200.7 or 200.8	0.5
Manganese	EPA 200.7 or 200.8	0.03
Mercury	EPA 245.2 or 245.1	0.0002
Molybdenum	EPA 200.7 or 200.8	0.025
Nickel	EPA 249.2, 200.7 or 200.8	0.002, 0.005 or 0.1
Nitrate (as NO_3)	EPA 353.2, 354.1 or 300.0	0.5

Table A-1. Inorganic constituents of concern in water samples, the analytical methods used to determine their concentrations, and their contractual reporting limits (continued)

Constituents of concern	Analytical method	Reporting limit[a,b]
Metals and minerals (mg/L) (continued)		
Nitrite (as NO_2)	EPA 353.2, 354.1 or 300.0	0.5
Ortho-phosphate	EPA 300.0, 365.1 or 365.2	0.05
Perchlorate	EPA 314.0	0.004
Potassium	EPA 200.7	1
Selenium	EPA 270.2 or 200.8	0.002
Silver	EPA 272.2 or 200.8	0.001 or 0.0005
Sodium	EPA 200.7	1 or 0.1
Sulfate	EPA 300.0	1
Surfactants	EPA 425.1	0.5
Thallium	EPA 279.2 or 200.8	0.001
Total dissolved solids	EPA 160.1	1
Total suspended solids	EPA 160.2	1
Total Kjeldahl nitrogen	EPA 351.2 or 351.3	0.2
Total phosphorus (as P)	EPA 365.4 or SM 4500-P	0.05
Vanadium	EPA 200.7 or 200.8	0.02 or 0.025
Zinc	EPA 200.7 or 200.8	0.02 or 0.05
General indicator parameters		
pH (pH units)	EPA 150.1	none
Biochemical oxygen demand (mg/L)	SM 5210B	2
Conductivity (μS/cm)	EPA 120.1	none
Chemical oxygen demand (mg/L)	EPA 410.4	5
Dissolved oxygen (mg/L)	EPA 360.1	0.05
Total organic carbon (mg/L)	EPA 9060 or 415.1	1
Total organic halides (mg/L)	EPA 9020	0.02
Toxicity, acute (fathead minnow)	EPA 2000	027F%
Toxicity, chronic (fathead minnow)	EPA 1000	002 NOEC
Radioactivity (Bq/L)		
Gross alpha	EPA 900	0.074
Gross beta	EPA 900	0.11
Radioisotopes (Bq/L)		
Americium-241	U-NAS-NS-3050	0.0037
Plutonium-238	U-NAS-NS-3050	0.0037

Table A-1. Inorganic constituents of concern in water samples, the analytical methods used to determine their concentrations, and their contractual reporting limits (continued)

Constituents of concern	Analytical method	Reporting limit[a,b]
Plutonium-239+240	U-NAS-NS-3050	0.0037
Radon-222	EPA 913	3.7
Radium-226	EPA 903	0.0093
Radium-228	EPA 904	0.037
Thorium-228	U-NAS-NS-3050	0.009
Thorium-230	U-NAS-NS-3050	0.006
Thorium-232	U-NAS-NS-3050	0.006
Tritium	LLNL-RAS-011	3.7
Uranium-234	EPA 908	0.0037
Uranium-235	EPA 908	0.0037
Uranium-238	EPA 908	0.0037

a The significant figures displayed in this table vary by constituent. These variations reflect regulatory agency permit stipulations, or the applicable analytical laboratory contract under which the work was performed, or both.

b These reporting limits are for water samples with low concentrations of dissolved solids. If higher concentrations are present, limits are likely to be higher.

Table A-2. Organic constituents of concern in water samples and their contractual reporting limits of concentration, sorted by analytical method

Constituents of concern	Reporting limit (µg/L)[a,b]
EPA Method 413.1 or 1664	
Oil & Grease	1000
EPA Method 420.1	
Phenolics	5
EPA Method 502.2 (or 524.2)	
1,1,1,2-Tetrachloroethane	0.2
1,1,1-Trichloroethane	0.2
1,1,2,2-Tetrachloroethane	0.2
1,1,2-Trichloroethane	0.2
1,1-Dichloroethane	0.2
1,1-Dichloroethene	0.2
1,1-Dichloropropene	0.2
1,2,3-Trichlorobenzene	0.2
1,2,3-Trichloropropane	0.2
1,2,4-Trichlorobenzene	0.2
1,2,4-Trimethylbenzene	0.2
1,2-Dichlorobenzene	0.2
1,2-Dichloroethane	0.2
1,2-Dichloropropane	0.2
1,3,5-Trimethylbenzene	0.2
1,3-Dichlorobenzene	0.2
1,3-Dichloropropane	0.2
1,4-Dichlorobenzene	0.2
2,2-Dichloropropane	0.2
2-Chlorotoluene	0.2
4-Chlorotoluene	0.2
Benzene	0.2
Bromobenzene	0.2
Bromochloromethane	0.2
Bromodichloromethane	0.2
Bromoform	0.2
Bromomethane	0.2
Carbon tetrachloride	0.2
Chlorobenzene	0.2
Chloroethane	0.2
Chloroform	0.2
Chloromethane	0.2
cis-1,2-Dichloroethene	0.2
cis-1,3-Dichloropropene	0.5
Dibromochloromethane	0.2
Dibromomethane	0.2
Dichlorodifluoromethane	0.2
Ethylbenzene	0.2
Freon 113	0.2
Hexachlorobutadiene	0.2
Isopropylbenzene	0.2
m- and *p*-Xylene isomers	0.2
Methylene chloride	0.2
n-Butylbenzene	0.2
n-Propylbenzene	0.2
Naphthalene	0.2
o-Xylene	0.2
Isopropyl toluene	0.2
sec-Butylbenzene	0.2
Styrene	0.2
tert-Butylbenzene	0.2
Tetrachloroethene	0.2
Toluene	0.2
trans-1,2-Dichloroethene	0.2
trans-1,3-Dichloropropene	0.2
Trichloroethene	0.2
Trichlorofluoromethane	0.2
Vinyl chloride	0.2
EPA Method 507	
Alachlor	0.5
Atraton	0.5
Atrazine	0.5
Bromacil	0.5
Butachlor	0.5
Diazinon	0.5
Dichlorvos	0.5
Ethoprop	0.5
Merphos	0.5
Metolachlor	0.5
Metribuzin	0.5
Mevinphos	0.5
Molinate	0.5
Prometon	0.5

Table A-2. Organic constituents of concern in water samples and their contractual reporting limits of concentration, sorted by analytical method (continued)

Constituents of concern	Reporting limit (μg/L)[a,b]
Prometryn	0.5
Simazine	0.5
Terbutryn	0.5
EPA Method 524.2	
1,1,1,2-Tetrachloroethane	1
1,1,1-Trichloroethane	1
1,1,2,2-Tetrachloroethane	1
1,1,2-Trichloroethane	1
1,1-Dichloroethane	1
1,1-Dichloroethene	1
1,1-Dichloropropene	1
1,2,3-Trichlorobenzene	1
1,2,3-Trichloropropane	1
1,2,4-Trichlorobenzene	1
1,2,4-Trimethylbenzene	1
1,2-Dibromo-3-chloropropane	2
1,2-Dichlorobenzene	1
1,2-Dichloroethane	1
1,2-Dichloropropane	1
1,3,5-Trimethylbenzene	1
1,3-Dichlorobenzene	1
1,3-Dichloropropane	1
1,4-Dichlorobenzene	1
2-Chlorotoluene	1
4-Chlorotoluene	1
Benzene	1
Bromobenzene	1
Bromodichloromethane	1
Bromoform	1
Bromomethane	2
Carbon tetrachloride	1
Chlorobenzene	1
Chloroethane	2
Chloroform	1
Chloromethane	2
cis-1,2-Dichloroethene	1
cis-1,3-Dichloropropene	1
Dibromochloromethane	1
Dibromomethane	1
Dichlorodifluoromethane	2
Ethylbenzene	1
Ethylene dibromide	1
Freon 113	1
Hexachlorobutadiene	1
Isopropylbenzene	1
m- and *p*-Xylene isomers	1
Methylene chloride	1
n-Butylbenzene	1
n-Propylbenzene	1
Naphthalene	1
o-Xylene	1
Isopropyl toluene	1
sec-Butylbenzene	1
Styrene	1
tert-Butylbenzene	1
Tetrachloroethene	1
Toluene	1
trans-1,2-Dichloroethene	1
trans-1,3-Dichloropropene	1
Trichloroethene	0.5
Trichlorofluoromethane	1
Vinyl chloride	2
EPA Method 525	0.5
2,4-Dinitrotoluene	0.5
2,6-Dinitrotoluene	0.5
4,4'-DDD	0.5
4,4'-DDE	0.5
4,4'-DDT	0.5
Acenaphthylene	0.5
Alachlor	0.5
Aldrin	0.5
Anthracene	0.5
Aroclor 1016 (PCB)	0.5
Aroclor 1221 (PCB)	0.5
Aroclor 1232 (PCB)	0.5
Aroclor 1242 (PCB)	0.5
Aroclor 1248 (PCB)	0.5
Aroclor 1254 (PCB)	0.5

Table A-2. Organic constituents of concern in water samples and their contractual reporting limits of concentration, sorted by analytical method (continued)

Constituents of concern	Reporting limit (μg/L)[a,b]
Aroclor 1260 (PCB)	0.5
Atraton	0.5
Atrazine	0.5
Benzo(a)anthracene	0.5
Benzo(a)pyrene	0.5
Benzo(b)fluoranthene	0.5
Benzo(g,h,i)perylene	0.5
Benzo(k)fluoranthene	0.5
Bis(2-ethylhexyl)phthalate	0.5
Bromacil	0.5
Butachlor	0.5
Butylbenzylphthalate	0.5
Chlordane	0.5
Chloropropham	0.5
Chlorpyrifos	0.5
Chrysene	0.5
Di (2-ethylhexyl) adipate	0.5
Di-n-butylphthalate	0.5
Diazinon	0.5
Dibenzo(a,h)anthracene	0.5
Dichlorvos	0.5
Dieldrin	0.5
Diethylphthalate	0.5
Dimethylphthalate	0.5
Disulfoton	0.5
Endosulfan I	0.5
Endosulfan II	0.5
Endosulfan sulfate	0.5
Endrin	0.5
Endrin aldehyde	0.5
Ethoprop	0.5
Fluorene	0.5
Heptachlor	0.5
Heptachlor epoxide	0.5
Hexachlorobenzene	0.5
Hexachlorocyclopentadiene	0.5
Indeno(1,2,3-c,d)pyrene	0.5
Isophorone	0.5
Lindane	0.5

Constituents of concern	Reporting limit (μg/L)[a,b]
Merphos	0.5
Methoxychlor	0.5
Metolachlor	0.5
Metribuzin	0.5
Mevinphos	0.5
Pentachlorobenzene	0.5
Pentachlorophenol	0.5
Phenanthrene	0.5
Prometon	0.5
Prometryne	0.5
Propachlor	0.5
Pyrene	0.5
Simazine	0.5
Stirophos	0.5
Terbutryn	0.5
Toxaphene	
EPA Method 547	
Glyphosate	20
EPA Method 601	
1,1,1-Trichloroethane	0.5
1,1,2,2-Tetrachloroethane	0.5
1,1,2-Trichloroethane	0.5
1,1-Dichloroethane	0.5
1,1-Dichloroethene	0.5
1,2-Dichlorobenzene	0.5
1,2-Dichloroethane	0.5
1,2-Dichloroethene (total)	0.5
1,2-Dichloropropane	0.5
1,3-Dichlorobenzene	0.5
1,4-Dichlorobenzene	0.5
2-Chloroethylvinylether	0.5
Bromodichloromethane	0.5
Bromoform	0.5
Bromomethane	0.5
Carbon tetrachloride	0.5
Chlorobenzene	0.5
Chloroethane	0.5
Chloroform	0.5
Chloromethane	0.5

Table A-2. Organic constituents of concern in water samples and their contractual reporting limits of concentration, sorted by analytical method (continued)

Constituents of concern	Reporting limit (μg/L)[a,b]
cis-1,2-Dichloroethene	0.5
cis-1,3-Dichloropropene	0.5
Dibromochloromethane	0.5
Dichlorodifluoromethane	0.5
Freon 113	0.5
Methylene chloride	0.5
Tetrachloroethene	0.5
trans-1,2-Dichloroethene	0.5
trans-1,3-Dichloropropene	0.5
Trichloroethene	0.5
Trichlorofluoromethane	0.5
Vinyl chloride	0.5
EPA Method 602	
1,2-Dichlorobenzene	0.3
1,3-Dichlorobenzene	0.3
1,4-Dichlorobenzene	0.3
Benzene	0.4
Chlorobenzene	0.3
Ethylbenzene	0.3
m-Xylene isomers	0.4
o-Xylene	0.4
p-Xylene	0.4
Toluene	0.3
Total xylene isomers	0.4
EPA Method 608	
Aldrin	0.05
BHC, alpha isomer	0.05
BHC, beta isomer	0.05
BHC, delta isomer	0.05
BHC, gamma isomer (Lindane)	0.05
Chlordane	0.2
Dieldrin	0.1
Endosulfan I	0.05
Endosulfan II	0.1
Endosulfan sulfate	0.1
Endrin	0.1
Endrin aldehyde	0.1
Heptachlor	0.05
Heptachlor epoxide	0.05

Constituents of concern	Reporting limit (μg/L)[a,b]
Methoxychlor	0.5
4,4′-DDD	0.1
4,4′-DDE	0.1
4,4′-DDT	0.1
Toxaphene	1
EPA Method 615	
2,4,5-T	0.5
2,4,5-TP (Silvex)	0.2
2,4-D	1
2,4-Dichlorophenoxy acetic acid	2
Dalapon	10
Dicamba	1
Dichloroprop	2
Dinoseb	1
MCPA	250
MCPP	250
EPA Method 624	
1,1,1-Trichloroethane	1
1,1,2,2-Tetrachloroethane	1
1,1,2-Trichloroethane	1
1,1-Dichloroethane	1
1,1-Dichloroethene	1
1,2-Dichlorobenzene	1
1,2-Dichloroethane	1
1,2-Dichloroethene (total)	1
1,2-Dichloropropane	1
1,3-Dichlorobenzene	1
1,4-Dichlorobenzene	1
2-Butanone	20
2-Chloroethylvinylether	20
2-Hexanone	20
4-Methyl-2-pentanone	20
Acetone	10
Benzene	1
Bromodichloromethane	1
Bromoform	1
Bromomethane	2
Carbon disulfide	1
Carbon tetrachloride	1

Table A-2. Organic constituents of concern in water samples and their contractual reporting limits of concentration, sorted by analytical method (continued)

Constituents of concern	Reporting limit (μg/L)[a,b]
Chlorobenzene	1
Chloroethane	2
Chloroform	1
Chloromethane	2
cis-1,2-Dichloroethene	1
cis-1,3-Dichloropropene	1
Dibromochloromethane	1
Dibromomethane	1
Dichlorodifluoromethane	2
Ethylbenzene	1
Freon 113	1
Methylene chloride	1
Styrene	1
Tetrachloroethene	1
Toluene	1
Total xylene isomers	2
trans-1,2-Dichloroethene	1
trans-1,3-Dichloropropene	1
Trichloroethene	0.5
Trichlorofluoromethane	1
Vinyl acetate	1
Vinyl chloride	1
EPA Method 625	
1,2,4-Trichlorobenzene	5
1,2-Dichlorobenzene	5
1,3-Dichlorobenzene	5
1,4-Dichlorobenzene	5
2,4,5-Trichlorophenol	5
2,4,6-Trichlorophenol	5
2,4-Dichlorophenol	5
2,4-Dimethylphenol	5
2,4-Dinitrophenol	25
2,4-Dinitrotoluene	5
2,6-Dinitrotoluene	5
2-Chloronaphthalene	5
2-Chlorophenol	5
2-Methylphenol	5
2-Methyl-4,6-dinitrophenol	25
2-Methylnaphthalene	5

Constituents of concern	Reporting limit (μg/L)[a,b]
2-Nitroaniline	25
3,3′-Dichlorobenzidine	10
3-Nitroaniline	25
4-Bromophenylphenylether	5
4-Chloro-3-methylphenol	10
4-Chloroaniline	10
4-Chlorophenylphenylether	5
4-Nitroaniline	25
4-Nitrophenol	25
Acenaphthene	25
Acenaphthylene	5
Anthracene	5
Benzo[*a*]anthracene	5
Benzo[*a*]pyrene	5
Benzo[*b*]fluoranthene	5
Benzo[*g,h,i*]perylene	5
Benzo[*k*]fluoranthene	5
Benzoic acid	25
Benzyl alcohol	10
Bis(2-chloroethoxy)methane	5
Bis(2-chloroisopropyl)ether	5
Bis(2-ethylhexyl)phthalate	5
Butylbenzylphthalate	5
Chrysene	5
Di-*n*-butylphthalate	5
Di-*n*-octylphthalate	5
Dibenzo[*a,h*]anthracene	5
Dibenzofuran	5
Diethylphthalate	5
Dimethylphthalate	5
Fluoranthene	5
Fluorene	5
Hexachlorobenzene	5
Hexachlorobutadiene	5
Hexachlorocyclopentadiene	5
Hexachloroethane	5
Indeno[*1,2,3-c,d*]pyrene	5
Isophorone	5
m- and *p*-Cresol	5

Table A-2. Organic constituents of concern in water samples and their contractual reporting limits of concentration, sorted by analytical method (continued)

Constituents of concern	Reporting limit (μg/L)[a,b]
N-Nitroso-di-*n*-propylamine	5
Naphthalene	5
Nitrobenzene	5
Pentachlorophenol	5
Phenanthrene	5
Phenol	5
Pyrene	5
EPA Method 632	
Diuron	0.1
EPA Method 8082	
Polychlorinated biphenyls (PCBs)	0.5
EPA Method 8140	
Bolstar	1
Chlorpyrifos	1
Coumaphos	1
Demeton	1
Diazinon	1
Dichlorvos	1
Disulfoton	1
Ethoprop	1
Fensulfothion	1
Fenthion	1
Merphos	1
Methyl Parathion	1
Mevinphos	1
Naled	1
Phorate	1
Prothiophos	1
Ronnel	1
Stirophos	1
Trichloronate	1
EPA Method 8260	
1,1,1,2-Tetrachloroethane	0.5
1,1,1-Trichloroethane	0.5
1,1,2,2-Tetrachloroethane	0.5
1,1,2-Trichloroethane	0.5
1,1-Dichloroethane	0.5
1,1-Dichloroethene	0.5
1,2,3-Trichloropropane	0.5
1,2-Dibromo-3-chloropropane	0.5
1,2-Dichloroethane	0.5
1,2-Dichloroethene (total)	0.5
1,2-Dichloropropane	0.5
2-Butanone	0.5
2-Chloroethylvinylether	0.5
2-Hexanone	0.5
4-Methyl-2-pentanone	0.5
Acetone	10
Acetonitrile	100
Acrolein	50
Acrylonitrile	50
Benzene	0.5
Bromodichloromethane	0.5
Bromoform	0.5
Bromomethane	0.5
Carbon disulfide	5
Carbon tetrachloride	0.5
Chlorobenzene	0.5
Chloroethane	0.5
Chloroform	0.5
Chloromethane	0.5
Chloroprene	5
Dibromochloromethane	0.5
Dichlorodifluoromethane	0.5
Ethanol	1000
Ethylbenzene	0.5
Freon 113	0.5
Methylene chloride	0.5
Styrene	0.5
Tetrachloroethene	0.5
Toluene	0.5
Total xylene isomers	0.5
Trichloroethene	0.5
Trichlorofluoromethane	0.5
Vinyl acetate	20
Vinyl chloride	0.5
cis-1,2-Dichloroethene	0.5
cis-1,3-Dichloropropene	0.5

Table A-2. Organic constituents of concern in water samples and their contractual reporting limits of concentration, sorted by analytical method (continued)

Constituents of concern	Reporting limit (μg/L)[a,b]
trans-1,2-Dichloroethene	0.5
trans-1,3-Dichloropropene	0.5
EPA Method 8290	
1,2,3,4,6,7,8-HpCDD	0.00025
1,2,3,4,6,7,8-HpCDF	0.00025
1,2,3,4,7,8,9-HpCDF	0.00025
1,2,3,4,7,8-HxCDF	0.00025
1,2,3,6,7,8-HxCDD	0.00025
1,2,3,6,7,8-HxCDF	0.00025
1,2,3,7,8,9-HxCDD	0.00025
1,2,3,7,8,9-HxCDF	0.00025
1,2,3,7,8-PeCDD	0.0001
1,2,3,7,8-PeCDF	0.0001
2,3,4,6,7,8-HxCDF	0.00025
2,3,4,7,8-PeCDF	0.0001
2,3,7,8-TCDD	0.0001
2,3,7,8-TCDF	0.0001
OCDD	0.0005
OCDF	0.0005
EPA Method 8330	
HMX[c]	5 or 1
RDX[d]	5 or 1
TNT[e]	5

a The significant figures displayed in this table vary by constituent. These variations reflect regulatory agency permit stipulations, the applicable analytical laboratory contract under which the work was performed, or both.

b These reporting limits are for water samples with low concentrations of dissolved solids. If higher concentrations are present, limits are likely to be higher.

c HMX is octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine.

d RDX is hexahydro-1,3,5-trinitro-1,3,5-triazine.

e TNT is 2,4,6-trinitrotoluene.

Table A-3. Radioisotopes and reporting limits for gamma spectroscopic analysis of constituents of concern in groundwater[a]

Constituents of concern[b]	Typical reporting limit (Bq/L)
Actinium-228	3.1
Americium-241	1.8
Beryllium-7	3.7
Cesium-134	0.4
Cesium-137	0.3
Cobalt-57	0.2
Cobalt-60	0.4
Europium-152	0.9
Europium-154	1.0
Europium-155	1.0
Potassium-40	7.2
Radium-226	0.8
Thorium-228	0.5
Thorium-234	1.4
Uranium-235	1.3

a The significant figures displayed in this table vary by constituents of concern. These variations reflect the applicable analytical laboratory contract under which the work was performed.

b Not included are promethium-147 and thallium-208, reported above 46,000 and 72 Bq/L, respectively.

Appendix B: Constituents of Interest, Sampling Frequency, and Discharge Limits for Releases from the Drainage Retention Basin

Table B-1. DRB discharge analytes and sampling frequency for sampling locations CDBX and WPDC, and discharge limits from the amended CERCLA ROD applied at CDBX

Constituent	CDBX Frequency[a]	WPDC Frequency[a]	Discharge limits	
			Dry season[b]	Wet season[c]
pH (units)	W & D	W & D	6.5–8.5	6.5–8.5
Metals (μg/L)				
Antimony	W & D	W & D	6	NA
Arsenic	W & D	W & D	50	10
Beryllium	W & D	W & D	4	NA
Boron	W & D	W & D	NA	NA
Cadmium	W & D	W & D	5	2.2
Chromium (total)	W & D	W & D	50	NA
Chromium (VI)	W & D	W & D	NA	22
Copper	W & D	W & D	1300	23.6
Iron	W & D	W & D	NA	NA
Lead	W & D	W & D	15	6.4
Manganese	W & D	W & D	NA	NA
Mercury	W & D	W & D	2	2
Nickel	W & D	W & D	100	320
Selenium	W & D	W & D	50	10
Silver	W & D	W & D	100	8.2
Thallium	W & D	W & D	2	NA
Zinc	W & D	W & D	NA	220
Organics (μg/L)				
Volatile organic compounds (EPA Method 601)	W	_[d]	5	5
1,1-dichloroethane (1,1-DCA)	W	_[d]	5	5
1,1-dichloroethylene (1,1-DCE)	W	_[d]	5	5
1,2-dichloroethylene (1,2-DCE)	W	_[d]	NA	NA
cis-1,2-dichloroethylene (cis-1,2-DCE)	W	_[d]	5	5
trans-1,2-dichloroethylene (trans-1,2-DCE)	W	_[d]	5	5
1,2-dichloroethane (1,2-DCA)	W	_[d]	5	5
Carbon tetrachloride	W	_[d]	5	5
Total THM (chloroform, bromoform, chlorodibromomethane, bromodichlo-romethane)	W	_[d]	5	5
Tetrachloroethene	W	_[d]	4	4

Table B-1. DRB discharge analytes and sampling frequency for sampling locations CDBX and WPDC, and discharge limits from the amended CERCLA ROD applied at CDBX (continued)

Constituent	CDBX Frequency[a]	WPDC Frequency[a]	Discharge limits	
			Dry season[b]	Wet season[c]
Trichloroethylene (TCE)	W	_[d]	5	5
Vinyl chloride	W	_[d]	2	2
Acute toxicity				
Aquatic survival bioassay (96 hours)	W & D	W & D	90% survival median, 90 percentile value of not less than 70% survival	
Chronic toxicity				
Fathead minnow	W	_[d]	NA	NA
Water flea	W	_[d]	NA	NA
Green algae	W	_[d]	NA	NA
Radiological (pCi/L)				
Tritium	W	_[d]	20,000	20,000
Special studies or by request of RWQCB				
Polychlorinated biphenyls	W & D	_[d]	NA	NA
Herbicides (Bromicil by E507, Glyphosate by E547, Diuron by E632)	CDBX	_[d]	NA	NA
Chemical oxygen demand	CDBX	_[d]	NA	NA
Total organic carbon	CDBX	_[d]	NA	NA
Physical				
Turbidity (NTU)[e]	W & D	_[d]	>15	>15
Conductivity	W	W	NA	NA
Total suspended solids	W & D	W & D	NA	NA
Total dissolved solids	W	W	NA	NA
General minerals				
Total alkalinity	W	_[d]	NA	NA
Nitrate (as N)	W	_[d]	NA	NA
Nitrite (as N)	W	_[d]	NA	NA
Radiological (Bqi/L)		_[d]		
Alpha	W	_[d]	0.56	0.56
Beta	W	_[d]	1.85	1.85

a W = Monitoring occurs at the first DRB discharge of the wet season and at one or more additional discharges associated with storm water runoff monitoring. Toxicity testing is required only on the first release.

D = Monitoring occurs at each dry season release. For purposes of discharge sampling, the dry season is defined to occur from June 1 through September 30.

b Dry season limits apply to CDBX from April 1 to November 30.

c Wet season limits apply to CDBX from December 1 to March 31.

d Sampling not required for this parameter

e NTU = Nephelometric turbidity units

NA No limit applicable for this parameter

Appendix C: Wildlife Survey Results

Table C-1 includes species for which there are verified observations. It is not intended to be a complete list of Site 300 species

Table C-1. Site 300 wildlife species list

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 2002 Clark et al. 2002
Black-tailed jackrabbit	*Lepus californicus*		LLNL 2002 Clark et al. 2002
Heermann's kangaroo rat	*Dipodomys heermanni*		LLNL 2002 West 2002
California pocket mouse	*Chaetodipus californicus*		LLNL 2002 West 2002
San Joaquin pocket mouse	*Perognathus inornatus*	FSC	Clark et al. 2002
California ground squirrel	*Spermophilus beecheyi*		LLNL 2002
Valley pocket gopher	*Thomomys bottae*		LLNL 2002 West 2002
California vole	*Microtus californicus*		LLNL 2002 West 2002
House mouse	*Mus musculus*		LLNL 2002 West 2002
Dusky-footed woodrat	*Neotoma fuscipes*		LLNL 2002 West 2002
Brush mouse	*Peromyscus boylii*		LLNL 2002 West 2002
Deer mouse	*Peromyscus maniculatus*		LLNL 2002 West 2002
Western harvest mouse	*Reithrodontomys megalotis*		LLNL 2002 West 2002
Coyote	*Canis latrans*		LLNL 2002 Clark et al. 2002
Raccoon	*Procyon lotor*		LLNL 2002 Orloff 1986

Table C-1. Site 300 wildlife species list (continued)

Common Name	Scientific Name	Regulatory Status[a]	Source
Long-tailed weasel	*Mustela frenata*		LLNL 2002 Orloff 1986
Striped skunk	*Mephitis mephitis*		LLNL 2002 Orloff 1986
Western spotted skunk	*Spilogale gracilis*		LLNL 2002 Orloff 1986
American badger	*Taxidea taxus*		LLNL 2002 Clark et al. 2002
Bobcat	*Lynx rufus*		LLNL 2002 Clark et al. 2002
Mountain Lion	*Felis concolor*		LLNL 2002
Mule deer	*Odocoileus hemionus*		LLNL 2002 Clark et al. 2002
Wild pig	*Sus scrofa*		LLNL 2002 Clark et al. 2002
Herpetofauna			
California red-legged frog	*Rana aurora draytonii*	FT	LLNL 2002
Pacific tree frog	*Hyla regilla*		LLNL 2002
California tiger salamander	*Ambystoma californiense*	FT, CASSC	LLNL 2002
Western spadefoot toad	*Spea hammondii*	FSC, CASSC	LLNL 2002
Western toad	*Bufo boreas*		LLNL 2002
Alameda whipsnake	*Masticophis lateralis euryxanthus*	FT, ST	Swaim 2002
San Joaquin coachwhip	*Masticophis flagellum*	FSC, CASSC	LLNL 2002
Coast horned lizard	*Phrynosoma coronatum*	FSC, CASSC	LLNL 2002
California legless lizard	*Anniella pulchra*	FSC	Swaim 2002
Side-blotched lizard	*Uta stansburiana*		LLNL 2002 Swaim 2002
Western whiptail	*Cnemidophorus tigris*		LLNL 2002 Swaim 2002
Western fence lizard	*Sceloporus occidentalis*		LLN 2002 Swaim 2002
Western skink	*Eumeces skiltonianus*		LLN 2002 Swaim 2002
Gilbert skink	*Eumeces gilberti*		LLN 2002 Swaim 2002
Southern alligator lizard	*Gerrhonotus multicarinatus*		LLN 2002 Swaim 2002
Western yellow bellied racer	*Coluber constrictor*		LLN 2002 Swaim 2002
Pacific gopher snake	*Pituophis melanoleucus*		LLN 2002 Swaim 2002
Common kingsnake	*Lampropeltis getulus*		LLN 2002 Swaim 2002

Table C-1. Site 300 wildlife species list (continued)

Common Name	Scientific Name	Regulatory Status[a]	Source
Western rattlesnake	*Crotalus viridis*		LLN 2002 Swaim 2002
Night snake	*Hypsiglena torquata*		LLN 2002 Swaim 2002
Glossy snake	*Arizona elegans*		LLN 2002 Swaim 2002
Long-nosed snake	*Rhinocheilus lecontei*		LLN 2002 Swaim 2002
California black-headed snake	*Tantilla planiceps*		Swaim 2002
Birds			
Cooper's Hawk	*Accipiter cooperii*	CASSC, MBTA	LLNL 2003b
Sharp-shinned Hawk	*Accipiter striatus*	CASSC, MBTA	LLNL 2003b
Golden Eagle	*Aquila chrysaetos*	CASSC, MBTA	LLNL 2003b
Red-tailed Hawk	*Buteo jamaicensis*	MBTA	LLNL 2003
Rough-legged Hawk	*Buteo lagopus*	MBTA	LLNL 2003b
Red-shouldered Hawk	*Buteo lineatus*	MBTA	LLNL 2003b
Ferruginous Hawk	*Buteo regalis*	FSC, CASSC, MBTA	LLNL 2003b
Swainson's Hawk	*Buteo swainsoni*	ST, MBTA	LLNL 2003b
Northern Harrier	*Circus cyaneus*	CASSC, MBTA	LLNL 2003b
White-tailed Kite	*Elanus leucurus*	CAFPS, MBTA	LLNL 2003b
Osprey	*Pandion haliaetus*	CASSC, MBTA	LLNL 2003b
Bushtit	*Psaltriparus minimus*	MBTA	LLNL 2003b
Horned Lark	*Eremophila alpestris*	CASSC, MBTA	LLNL 2003b
Northern Shoveler	*Anas clypeata*	MBTA	LLNL 2003b
Cinnamon Teal	*Anas cuamptera*	MBTA	LLNL 2003b
Mallard	*Anas platyryynchos*	MBTA	LLNL 2003b
Bufflehead	*Blucephala albeola*	MBTA	LLNL 2003b
Common Goldeneye	*Bucephala clangula*	MBTA	LLNL 2003b
White-throated Swift	*Aeronautes saxatalis*	MBTA	LLNL 2003b
Great Egret	*Ardea alba*	MBTA	LLNL 2003b
Virginia Rail	*Rallus limicola*	MBTA	U.S. DOE and UC 1992
Cedar Waxwing	*Bombycilla garrulus*	MBTA	LLNL 2003b
Common Poorwill	*Phalaenoptilus nuttalii*	MBTA	LLNL 2003b
Blue-grosbeak	*Guiraca caerulea*	MBTA	LLNL 2003b
Black-headed Grosbeak	*Pheucticus melanocephalus*	MBTA	U.S. DOE and UC 1992
Lazuli Bunting	*Passerina amoena*	MBTA	LLNL 2003b
Turkey Vulture	*Cathartes aura*	MBTA	LLNL 2003b
Killdeer	*Charadrius vociferus*	MBTA	LLNL 2003b
Rock Dove	*Columba livia*		U.S. DOE and UC 1992
Mourning Dove	*Zenaida macroura*	MBTA	LLNL 2003b

Table C-1. Site 300 wildlife species list (continued)

Common Name	Scientific Name	Regulatory Status[a]	Source
Western Scrub Jay	*Aphelocoma californica*	MBTA	LLNL 2003b
American Crow	*Corvus brachyrhynchos*	MBTA	LLNL 2003b
Common Raven	*Corvus corax*	MBTA	LLNL 2003b
Greater Roadrunner	*Geococcyx californianus*	MBTA	LLNL 2003b
Bell's Sage Sparrow	*Amphispiza belli*	FSC, MBTA	LLNL 2003b
Black-throated Sparrow	*Amphispiza bilineata*	MBTA	LLNL 2003b
Rufous Crowned Sparrow	*Aimophila ruficeps*	MBTA	LLNL 2003b
Grasshopper Sparrow	*Ammodramus savannarum*	FSC, MBTA	LLNL 2003b
Lark Sparrow	*Chondestes grammacus*	MBTA	LLNL 2003b
California Towhee	*Carpodacus mexicanus*	MBTA	LLNL 2003b
Oregon Junco	*Junco hyemalis*	MBTA	LLNL 2003b
Lincoln's Sparrow	*Melospiza lincolnii*	MBTA	LLNL 2003b
Song Sparrow	*Melospiza melodia*	MBTA	LLNL 2003b
Vesper Sparrow	*Pooecetes gramineus*	MBTA	U.S. DOE and UC 1992
Fox Sparrow	*Passerella iliaca*	MBTA	LLNL 2003b
Savannah Sparrow	*Passerculus sandwichensis*	MBTA	LLNL 2003b
Golden-crowned Sparrow	*Zonotrichia atricapilla*	MBTA	LLNL 2003b
White-crowned Sparrow	*Zonotrichia leucophrys*	MBTA	LLNL 2003b
American Kestrel	*Falco columbarius*	MBTA	LLNL 2003b
Prairie Falcon	*Falca mexicanus*	CASSC, MBTA	LLNL 2003b
House Finch	*Carpodacus mexicanus*	MBTA	LLNL 2003b
Lesser Goldfinch	*Carduelis psaltia*	MBTA	LLNL 2003b
Cliff Swallow	*Petrochelidon pyrrhonota*	MBTA	LLNL 2003b
Northern Rough Winged Swallow	*Stelgidopteryx serripennis*	MBTA	LLNL 2003b
Tree Swallow	*Tachycineta bicolor*	MBTA	LLNL 2003b
Western Wood-pewee	*Contopus sordidulus*	MBTA	U.S. DOE and UC 1992
Red-winged Blackbird	*Agelaius phoeniceus*	MBTA	LLNL 2003b
Tricolored Blackbird	*Agelaius tricolor*	FSC, CASSC, MBTA	LLNL 2003b
Brewer's Blackbird	*Euphagus cyanocephalus*	MBTA	LLNL 2003b
Bullock's Oriole	*Icterus bullockii*	MBTA	LLNL 2003b
Brown-headed Cowbird	*Molothrus ater*	MBTA	LLNL 2003b
Western Meadowlark	*Sturnella magna*	MBTA	LLNL 2003b
Loggerhead Shrike	*Lanius ludovicianus*	FSC, CASSC, MBTA	LLNL 2003b
Northern Mockingbird	*Mimus polyglottos*	MBTA	LLNL 2003b
California Thrasher	*Toxostoma redivivum*	FSC, MBTA	LLNL 2003b
California Quail	*Callipepla californica*		LLNL 2003b
Oak Titmouse	*Baeolphus inornatus*	FSC, MBTA	LLNL 2003b
Yellow-rumped Warbler	*Dendroica coronata*	MBTA	LLNL 2003b
Black-throated Gray Warbler	*Dendroica nigrescens*	MBTA	LLNL 2003b

Table C-1. Site 300 wildlife species list (continued)

Common Name	Scientific Name	Regulatory Status[a]	Source
Yellow Warbler	*Dendroica petechia*	CASSC, MBTA	LLNL 2003b
Common Yellowthroat	*Geothlypis trichas*	CASSC, MBTA	LLNL 2003b
MacGillivary's Warbler	*Oporornis tolmiei*	MBTA	LLNL 2003b
Orange-crowned Warbler	*Vermivora bachmanii*	MBTA	LLNL 2003b
Wilson's Warbler	*Wilsonia pusila*	MBTA	LLNL 2003b
Double-crested Cormorant	*Phalacrocorax auritus*	CASSC, MBTA	LLNL 2003b
Wild Turkey	*Meleagris gallopavo*		LLNL 2003b
Northern Flicker	*Colaptes auratus*	MBTA	LLNL 2003b
Nuttal's Woodpecker	*Picoides nuttallii*	FSC, MBTA	LLNL 2003b
Acorn Woodpecker	*Melanerpes formicivorus*	MBTA	U.S. DOE and UC 1992
Pied-billed Grebe	*Podilymbus podiceps*	MBTA	LLNL 2003b
Phainopepela	*Phainopepla nitens*	MBTA	LLNL 2003b
Ruby-crowned Kinglet	*Regulus calendula*	MBTA	LLNL 2003b
Common Snipe	*Gallinago gallinago*	MBTA	LLNL 2003b
Greater Yellowlegs	*Tringa melanoleuca*	MBTA	LLNL 2003b
Burrowing Owl	*Athene cunicularia*	FSC, CASSC, MBTA	LLNL 2003b
Short-eared Owl	*Asio flammeus*	FSC, CASSC, MBTA	LLNL 2003b
Great horned Owl	*Bubo virginianus*	MBTA	LLNL 2003b
Western Screech Owl	*Otus kennicottii*	MBTA	LLNL 2003b
European Starling	*Sturnus vulgaris*		LLNL 2003b
Western Tanager	*Piranga ludoviciana*	MBTA	LLNL 2003b
Anna's Hummingbird	*Calypte anna*	MBTA	LLNL 2003b
Costa's Hummingbird	*Calypte costae*	FSC, MBTA	LLNL 2003b
Rufous Hummingbird	*Selasphorus rufus*	FSC, MBTA	LLNL 2003b
Allen's Hummingbird	*Selasphorus sasin*	MBTA	U.S. DOE and UC 1992
Rock Wren	*Salpinctes obsoletus*	MBTA	LLNL 2003b
Bewick's Wren	*Thyothorus ludovicianus*	MBTA	LLNL 2003b
House Wren	*Troglodytes aedon*	MBTA	LLNL 2003b
Hermit Thrush	*Catharus guttatus*	MBTA	LLNL 2003b
Swainson's Thrush	*Catharus ustulatus*	MBTA	LLNL 2003b
Varied Thrush	*Ixoreus naevius*	MBTA	LLNL 2003b
Mountain Bluebird	*Sialia currucoides*	MBTA	LLNL 2003b
Western Buebird	*Sialia mexicana*	MBTA	LLNL 2003b
American Robin	*Turdus migratorius*	MBTA	LLNL 2003b
Pacific-slope Flycatcher	*Empidonax difficillis*	MBTA	LLNL 2003b
Ash-throated Flycatcher	*Myiarchus cinerascens*	MBTA	LLNL 2003b
Western Wood-pewee	*Contopus sordidulus*	MBTA	U.S. DOE and UC 1992
Black Phoebe	*Sayornis nigricans*	MBTA	LLNL 2003b
Say's Phoebe	*Sayornis saya*	MBTA	LLNL 2003b

Table C-1. Site 300 wildlife species list (continued)

Common Name	Scientific Name	Regulatory Status[a]	Source
Western Kingbird	*Tyrannus verticalis*	MBTA	LLNL 2003b
Cassin's Kingbird	*Tyrannus vociferans*	MBTA	LLNL 2003b
Barn Owl	*Tyto alba*	MBTA	LLNL 2003b
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

PT = Proposed as threatened under the Federal Endangered Species Act

MBTA = Migratory Bird Treaty 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 D: Errata

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 2003 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 2003 SAER

The following changes have been made to the Internet version of the document.

- On page ix, in the caption for Figure 4-4, “fewer” was changed to “sewer”.
- On page 2-4, in the first sentence of the “Documentation” section, “*LLNL Ground Water Project 2003 Annual Report* (Dibley et al. 2004...” was changed to “*LLNL Ground Water Project 2002 Annual Report* (Dibley et al. 2003...”.

- On page 3-11, in Table 3-4, an "X" was added in the "Biweekly tritium" column in the "AMON" and "HOSP" rows.
- On page 4-12, in the caption for Figure 4-4, "fewer" was changed to "sewer".
- On page 6-15, in line 3 of the second paragraph, "one-third" was changed to "one-half".
- On page 6-15, in Table 6-8, the annual doses for Inhalation, Ingesting food, and All sources were changed from "1.6", "9.6", and "27" to "16", "29", and "46", respectively.
- On page R-5, the following references were added:
  - MacQueen, D. H., G. Gallegos, K. A. Surano (2002), *Livermore Big Trees Park:1998 Results*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-143311).
  - NCRP (1987a), *Ionizing Radiation Exposure of the Population of the United States*, Report No. 93, National Council on Radiation Protection and Measurements, Washington, DC.
  - NCRP (1987b), *Recommendations on Limits of Exposure to Ionizing Radiation*, Report No. 91, National Council on Radiation Protection and Measurements, Washington, DC.
- On page GL-7, in Table GL-1, the row under "Radiation dose" was changed from "1 rem; 0.01 sievert (Sv); 1 sievert (Sv); 100 rem" to "1 sievert (Sv); 100 rem; 1 rem; 0.01 sievert (Sv)".

References

Arnold, R. A. (2002), *Report on the threatened valley elderberry longhorn beetle and its elderberry food plant at the Lawrence Livermore National Laboratory – Site 300*, Entomological Consulting Services, Ltd. Pleasant Hill, CA.

ATSDR (2000), *Health Consultation, Lawrence Livermore National Laboratory, Big Trees Park 1998 Sampling,* Livermore, California, Federal Facilities Assessment Branch, Division of Health Assessment and Consultation, Agency for Toxic Substances and Disease Registry, Atlanta, Georgia, (CERCLIS No. CA2890012584).

ATSDR (2002), *Health Consultation, Tritium Releases and Potential Offsite Exposure, Lawrence Livermore National Laboratory (U.S. DOE), Livermore, Alameda County, California, EPA Facility ID: CA 2890012584; and Lawrence Livermore National Laboratory (U.S. DOE); Tracy, San Joaquin County, California, EPA Facility ID: CA 2890090002; and Savannah River Site (U.S. DOE), Aiken, Aiken, Barnwell and Allendale Counties, South Carolina, EPA Facility ID: SC1890008989.* Agency for Toxic Substances Disease Registry, Atlanta, Georgia. March 11, 2002.

ATSDR (2003), *ATSDR Final Public Health Assessment Plutonium 239 in Sewage Sludge Used as a Soil or Soil Amendment in the Livermore Community, Lawrence Livermore National Laboratory, Main Site (USDOE) Livermore, Alameda County, California, EPA Facility ID: CA2890012584.* Agency for Toxic Substances Disease Registry, Atlanta, Georgia, October 2003 (Public comment copy).

ATSDR (2004), *ATSDR Draft Public Health Assessment for Radioactive and Non-Radioactive Hazardous Substances at Lawrence Livermore National Laboratory Site in Livermore, California*, Agency for Toxic Substances Disease Registry, Atlanta, Georgia, February 2004.

ATSDR (2005), *Public Health Assessment, Lawrence Livermore National Laboratory Site 300 (USDOE), Tracy, San Joaquin County, California, EPA Facility ID: CA2890090002.* Agency for Toxic Substances Disease Registry, Atlanta, Georgia.

Attix, F. H. and W. C. Roesch (eds) (1968), *Radiation Dosimetry*, Second Edition, Volume I, *Fundamentals.* Academic Press, NY.

Avalos, G. (2005), "Vintners toast triumph as Supreme Court uncorks potential for out-of-state sales" *Contra Costa Times*, Tuesday, May 17, 2005.

Berg, L. L., E. N. Folsom, M. D. Dresen, R. W. Bainer, and A. L. Lamarre, eds. (1997), *Explanation of Significant Differences for Metals Discharge Limits at the Lawrence Livermore National Laboratory Livermore Site,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-125927).

Blake, R. G., C. M. Noyes, and M. P. Maley (1995), *Hydrostratigraphic Analysis—The Key to Cost-Effective Ground Water Cleanup at Lawrence Livermore National Laboratory*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-JC-120614).

Brown, R. (2004a), *Lawrence Livermore National Laboratory Livermore Site Annual Storm Water Monitoring Report for Waste Discharge Requirements 95-174, Annual Report 2003-2004*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-126783-04).

Brown, R. (2004b), *Lawrence Livermore National Laboratory Site 300 Annual Storm Water Monitoring Report for Waste Discharge Requirements 97-03-DWQ, Annual Report 2003–2004*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-144362-04).

Brown, R. (2005a), *Lawrence Livermore National Laboratory Livermore Site Annual Storm Water Monitoring Report for Waste Discharge Requirement 95-174 Annual Report 2003–2004*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-126783-04).

Brown, R. (2005b), *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Annual/Fourth Quarter Report 2004*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-125915-04-4).

Campbell, C. G., K. Folks, S. Mathews, and R. Martinelli (2004), Investigating sources of toxicity in stormwater: Algae mortality in runoff upstream of the Lawrence Livermore National Laboratory. *Environmental Practice.* 6(1): 23-35. UCRL-JC-147164

Campbell, C. and R. G. Blake (2005), *LLNL Experimental Test Site 300 Compliance Monitoring Program for the CERCLA-Closed Pit 6 Landfill, Annual Report for 2004*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-132057-04-4).

Campbell, C. and D. H. MacQueen (2005), *LLNL Experimental Test Site 300 Compliance Monitoring Program for RCRA-Closed Landfill Pits 1 and 7, Annual Report for 2004,* Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10191-04-4).

Carlsen, T.M., J.W. Menke, B.M. Pavlik (2000), Reducing competitive suppression of a rare annual forb by restoring native California perennial grasslands, *Restoration Ecology* 8(1)18-30.

Carlsen, T. M. and E. K. Espeland (submitted), Fire patchiness influences distribution and persistence of a rare California late-flowering forb Blepharizonia plumosa (Asterareae), submitted to *Plant Ecology.*

Carpenter, D. W., J. J. Sweeney, P. W. Kasameyer, N. R. Burkhard, K. G. Knauss, and R. J. Shelmon (1984), *Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-53316).

CDPH-BRH (1960-1970), *Radiological Health News*, State of California, Department of Public Health, Bureau of Radiological Health, 2151 Berkeley Way, Berkeley CA, Vol. 1, No. 1 October 1961-through-Vol. 8, No. 4 October 1969

Clark, H. O., D. A. Smith, B. L. Cypher, and P. A. Kelly (2002), *Mesocarnivore Surveys on Lawrence Livermore National Laboratory Site 300*, California State University, Stanislaus, Endangered Species Recovery Program, Fresno, CA.

CNPS (2001), *Inventory of Rare and Endangered Plants of California* (sixth edition), Rare Plant Scientific Advisory Committee, David P. Tibor, Convening Editor, California Native Plant Society, Sacramento, CA. 388pp.

CVRWQCB (1998), *The Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board, Central Valley Region, the Sacramento River Basin and the San Joaquin River Basin*, (fourth edition).

Dibblee, T. W., Jr. (1980), *Preliminary Geologic Map of the Midway Quadrangle, Alameda and San Joaquin Counties, California*, USGS Open File Report 80-535.

Dibley, V., R. Blake, T. Carlsen, M. Denton, R. Goodrich, S. Gregory, K. Grote, V. Madrid, C. Stoker, M. Taffet, and J. Valett (2004a), *2003 Annual Compliance Report for Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA, March 31, 2004 (UCRL-AR-206319).

Dibley, V., R. Blake, T. Carlsen, S. Chamberlain, W. Daily, Z. Demir, M. Denton, R. Goodrich, S. Gregory, V. Madrid, M. Taffet, J. Valett (2004b) *First Semester 2004 Compliance Monitoring Report, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-206769-04).

Dibley, V., T. Carlsen, S. Chamberlain, W. Daily, Z. Demir, M. Denton, R. Goodrich, S. Gregory, V. Madrid, M. Taffet, J. Valett (2005) *2004 Annual Compliance Monitoring Report for Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA, March 31, 2005 (UCRL-AR-206319-04).

Dobson, J. E., E. A. Bright, P. R. Coleman, R. C. Durfee, B. A. Worley (2000), *LandScan: A Global Population Database for Estimating Populations at Risk, Photogrammetric Engineering & Remote Sensing* Vol 66, No. 7, July 2000. pp.849–857; see also the Website http://.www.ornl.gov/sci/gist/landscan/index.htms.

Dresen, M. D., J. P. Ziagos, A. J. Boegel, and E. M. Nichols (eds.) (1993), *Remedial Action Implementation Plan for the LLNL Livermore Site*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-110532).

DTSC (2002), *Technical Completeness of Post-Closure Permit Application, Capped High Explosive Open Burn Treatment Facility, Lawrence Livermore National Laboratory, Site 300,* EPA ID No. CA-2890090002. Department of Toxic Substances Control, Berkeley, CA (Letter: October 23, 2002).

DTSC (2003), *Transmittal of Documents Relating to the Final Post Closure Permit Decision for Lawrence Livermore National Laboratory, Site 300*, EPA ID No. CA-2890090002. Department of Toxic Substances Control, Berkeley, CA (Letter: February 21, 2003).

Eisenbud (1987), *Environmental Radioactivity from Natural, Industrial, and Military Sources* (third edition), Academic Press Inc., San Diego, CA.

Ferry, L., T. Berry, and D. MacQueen (1998), *Post-Closure Plan for the Pit 6 Landfill Operable Unit, Lawrence Livermore National Laboratory, Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-128638).

Ferry, L., R. Ferry, W. Isherwood, R. Woodward, T. Carlsen, Z. Demir, R. Qadir, and M. Dresen, (1999), *Final Site-Wide Feasibility Study for Lawrence Livermore National Laboratory Site 300*, (UCRL-AR-132609).

Ferry, R., L. Ferry, M. Dresen, and T. Carlsen (2002), *Compliance Monitoring Plan/Contingency Plan for Interim Remedies at Lawrence Livermore National Laboratory Site 300,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-147570).

Gallegos, G. M. (1991), *Assessment of Sediment Monitoring at LLNL,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-121236).

Gallegos, G. M. (1993), "Surveillance Monitoring of Soils for Radioactivity: Lawrence Livermore National Laboratory 1976 to 1992," *Health Physics* **69** (4), 487–493.

Gallegos, G. M., B. K. Balke, K. A. Surano, W. G. Hoppes, P. J. Tate, J. C. Steenhoven, B. C. Fields, L. M. Garcia, K. C. Lamson (1992), *Environmental Report 1991,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-91).

Gallegos, G. M., D. MacQueen, and K. A. Surano (1999), *Livermore Big Trees Park: 1998 Summary Results,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-134581).

Gallegos, G. M., P. J. Tate, B. K. Balke, E. Christofferson, R. J. Harrach, W. G. Hoppes, R. A. Failor, S. Wander, B. C. Fields, L. M. Garcia, and A. R. Grayson (1994), *Environmental Report 1993,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-93).

Galles, H. L. (1997), Letter to J. Cho re: Lawrence Livermore National Laboratory Drainage Retention Basin Monitoring Plan Amendment (WGMG97-439, December 9, 1997).

GEMI (1996), ISO 14001 *Environmental Management System Self-Assessment Checklist*, Global Environmental Management Initiative, Washington, DC. Revised November 2000.

Goodrich, R., and R. Depue (2003), *LLNL Livermore Site and Site 300 Environmental Restoration Project Standard Operating Procedures,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-MA-109115, Rev. 11).

Gouveia, F., and K. R. Chapman (1989), *Climatology of Lawrence Livermore National Laboratory,* Lawrence Livermore National Laboratory, Livermore, CA (UCID-21686).

Grayson A., (2005), *Lawrence Livermore National Laboratory Livermore Site Semiannual Wastewater Point-Source Monitoring Report December 2003–May 2004,* Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10204-04-2).

Grayson A., (2005), *Lawrence Livermore National Laboratory Livermore Site Semiannual Wastewater Point-Source Monitoring Report June 2004–November 2004,* Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10204-05-1).

Gudiksen, P. H., C. L. Lindeken, C. Gatrousis, and L. R. Anspaugh (1972), *Environmental Levels of Radioactivity in the Vicinity of the Lawrence Livermore Laboratory, January through December 1971,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-51242).

Gudiksen, P. H., C. L. Lindeken, J. W. Meadows, and K. O. Hamby (1973), *Environmental Levels of Radioactivity in the Vicinity of the Lawrence Livermore Laboratory, 1972 Annual Report,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-51333).

Harrach, R. J., R. A. Failor, G. M. Gallegos, P. J. Tate, E. Christofferson, E. R. Brandstetter, J. M. Larson, A. H. Biermann, R. A. Brown, B. C. Fields, L. M. Garcia, and A. R. Grayson (1996), *Environmental Report 1995*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-95), http://www.llnl.gov/saer/.

Harrach, R. J., G. M. Gallegos, R. A. Failor, E. Christofferson, P. J. Tate, E. R. Brandstetter, J. M. Larson, J. McIntyre, B. C. Fields, R. A. Brown, L. M. Garcia, and A. R. Grayson (1995), *Environmental Report 1994*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-94), http://www.llnl.gov/saer/.

Harrach, R.J, G. M. Gallegos, S. R. Peterson, K. R. Wilson, P. E. Althouse, J. M. Larson, N. A. Bertoldo, P. J. Tate, and B. M. Bowen (2004). *LLNL NESHAPs 2003 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-113867-04).

Harrach, R.J, G. M. Gallegos, S. R. Peterson, and K. R. Wilson (2005). *LLNL NESHAPs 2004 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-113867-05).

Harrach, R. J., G. M. Gallegos, P. J. Tate, E. Christofferson, E. R. Brandstetter, J. M. Larson, A. H. Biermann, B. C. Fields, L. M. Garcia, and K. A Surano (1997), *Environmental Report 1996*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-96), http://www.llnl.gov/saer/.

Hoffman, F., R. G. Blake, Z. Demir, R. J. Gelinas, P. F. McKereghan, and C. D. Noyes (2003), A conceptual model and remediation strategy for volatile organic compounds in unconsolidated sediments: A Lawrence Livermore National Laboratory case study. *Environmental & Engineering Geoscience* 9 (February 2003), no. 1:83–94.

Howell, S. (2003), "Biodiesel Specifications and Life Cycle," presented at Alternative Diesel Fuels Symposium, Sacramento, California, August 19–20, 2003.

Huey, A. S. (1948), "Geology of the Tesla Quadrangle, California," *California Division of Mines and Geology*, Bulletin 140.

IAEA/WMO (2004). Global Network of Isotopes in Precipitation. The GNIP Database. Available at: http://isohis.iaea.org

Isherwood, W. F., C. H. Hall, M. D. Dresen, and A. J. Boegel (1991), *CERCLA Feasibility Study Report for the LLNL Livermore Site,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-104040).

Jackson, C. S. (1997), Letter to the San Francisco Bay Regional Water Quality Control Board re: Lawrence Livermore National Laboratory Building 253 Catch Basin Mercury Residue, May 23, 1997.

Jackson, C. S. (2002), *Drainage Retention Basin Monitoring Plan Change*, Letter to Ms. Naomi Feger, San Francisco Bay Regional Water Quality Control Board, Lawrence Livermore National Laboratory, Livermore, CA WGMG02:175: CSJ:RW:kh, (December 6, 2002).

Karachewski, J., M. Dresen, E. Folsom, L. Berg, and J. Coty (Eds.) (2004), LLNL *Ground Water Project 2003 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-126020-03).

Karachewski, J., M. Dresen, E. Folsom, L. Berg, and J. Coty (Eds.) (2005), *LLNL Ground Water Project 2004 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA. (UCRL-AR-126020-04).

Lamarre, A. L., and M. J. Taffet (1989), *Firing Table Gravel Cleanup at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10282).

LLNL (1992), *CERCLA Record of Decision for the Lawrence Livermore National Laboratory, Livermore Site,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-109105).

LLNL (1998) *Livermore Big Trees Park 1998 Sampling Plan*, Lawrence Livermore National Laboratory, Livermore, CA 94551 (UCRL-ID-130551).

LLNL (2001), *Radioactive Waste Management Basis for the Lawrence Livermore National Laboratory*, September 2001

LLNL (2002), Personal communication with Jim Woollett and Michael van Hattem, Wildlife Biologists, Lawrence Livermore National Laboratory, Livermore, California.

LLNL (2003a), *Integrated Safety Management System Description,* Version 6.0, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-132791).

LLNL (2003b), LLNL avian monitoring program variable circular plot point count and constant effort mist netting. Lawrence Livermore National Laboratory, Livermore, CA.

LRL (1959–1970), LRL Environmental Reports, Semiannual and annual summaries prepared by the Lawrence Radiation Laboratory for the U.S. Atomic Energy Commission and submitted to the California State Department of Public Health, Bureau of Radiological Health, Berkeley, CA. On file in California Department of Health Services public records section.

MacQueen, D. H. (1995), *Livermore Big Trees Park January 1995 Soil Survey Results,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-121045).

MacQueen, D. H., G. Gallegos, K. A. Surano (2002), *Livermore Big Trees Park:1998 Results*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-143311).

Mathews, S. (2000), *Lawrence Livermore National Laboratory Site 300 Water Suppliers' Pollution Prevention and Monitoring and Reporting Program*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-139704).

Mathews, S., and M. Taffet (1997), *Final Closure Plan for the High-Explosives Open Burn Facility at Lawrence Livermore National Laboratory Experimental Test Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-111753 Rev. 1).

Myers, D. S., W. J. Silver, D. G. Coles, K. C. Lamson, D. R. McIntyre, and B. Mendoza (1976), "Evaluation of the Use of Sludge Containing Plutonium as a Soil Conditioner for Food Crops," in *Transuranium Nuclides in the Environment,* International Atomic Energy Agency, IAEA-SM-199/42.

NAREL (1994), Confirmatory sampling of plutonium in soil from the southeast quadrant of the Lawrence Livermore National Laboratory, U. S. Environmental Protection Agency, National Air and Radiation Laboratory (WA No. 2-12), August,15, 1994.

NCRP (1987a), *Ionizing Radiation Exposure of the Population of the United States*, Report No. 93, National Council on Radiation Protection and Measurements, Washington, DC.

NCRP (1987b), *Recommendations on Limits of Exposure to Ionizing Radiation*, Report No. 91, National Council on Radiation Protection and Measurements, Washington, DC.

NCRP (1999), *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies*, National Council on Radiation Protection and Measurements, Bethesda, MD (NCRP Report No. 129).

Orloff, S. (1986), *Wildlife Studies of Site 300 Emphasizing Rare and Endangered Species: Lawrence Livermore National Laboratory, San Joaquin County, California*. BioSystems Analysis, Inc., Sausalito, CA. 46 pp.

Parks, B. S. (1992), *User's Guide for CAP88-PC, Version 1.0,* U.S. Environmental Protection Agency, Office of Radiation Programs, Las Vegas, NV (EPA 402-B-92-001).

Paterson, L. and E. Espeland (2005), *Rare Plant Restoration and Monitoring at Lawrence Livermore National Laboratory Site 300 Project Progress Report Fiscal Year 2004 October 2003 – September 2004.* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-142408-04).

Peterson, S-R., and P. A. Davis (2002), "Tritium Doses from Chronic Atmospheric Releases: A New Model Proposed for Regulatory Compliance." *Health Physics.* (UCRL-JC-141535).

Preston, R. E. (1997), *Delineation of Waters of the United States for Arroyo Las Positas, Lawrence Livermore National Laboratory, Alameda County, California,* Jones & Stokes Associates, Inc. Sacramento, CA.

Preston, R.E. (2002), *Special-status Plant Species Surveys and Vegetation Mapping at Lawrence Livermore National Laboratory,* Jones and Stokes, Sacramento, CA.

Raber, E. (2004), *Third Quarter 2004 Monitoring Report for Waste Discharge Requirements (WDR) 5-00-175*, October 25, 2004.

Raber, E., and D. W. Carpenter, eds. (1983), *An Evaluation of the Hydrogeology and Groundwater Chemistry Associated with Landfills at LLNL's Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-53416).

Rainey, B. (2003), Personal communication with Lisa Paterson, July 2003.

Revelli, M. A. (2004a), *Ground Water Discharge Annual Self-Monitoring Report for 2003*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-143911-03).

Revelli, M. A. (2004b), *Lawrence Livermore National Laboratory Site 300—Compliance Monitoring Program for the Closed Building 829 Facility—Annual Report 2003,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-143121-03).

Rogers/Pacific Corporation (1990), *Lawrence Livermore National Laboratory Site 300 Resource Conservation and Recovery Act Closure and Post-Closure Plans—Landfill Pits 1 and 7,* Vols. I and II, Van Nuys, CA (California EPA No. CA2890090002).

Sanchez, L. (2003), LLNL *Site 300 Annual Storm Water Monitoring Report for Waste Discharge Requirements 97-03-DWQ Annual Report 2002–2003,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-144362-03).

Sanchez, L., P. E. Althouse, N. A. Bertoldo, R. G. Blake, S. L. Brigdon, R. A, Brown, C. G. Campbell, T. Carlson, E. Christofferson, L. M. Clark, G. M. Gallegos, A. R. Grayson, R. J. Harrach, W. G. Hoppes, H. E. Jones, J. Larson, D. Laycak, D. H. MacQueen, S. Mathews, M. Nelson, L. Paterson, S. R. Peterson, M. A. Revelli, M. J. Taffet, P. J. Tate, R. Ward, R. A. Williams and K. Wilson (2003), *Environmental Report 2002,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-02).

SFBRWQCB (1982a), *Waste Discharge Requirements and National Pollutant Discharge Elimination System (NPDES) Storm Water Permit for: U.S. Department of Energy and Lawrence Livermore National Laboratory,* San Francisco Bay Regional Water Quality Control Board, Oakland, CA. (Order No. 95-174, NPDES No. CA030023).

SFBRWQCB (1982b), *Water Quality Control Plan, San Francisco Bay Basin*, State of California, San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

SFBRWQCB (1995), *Water Quality Control Plan, San Francisco Bay Basin*, State of California, San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

Shleien, B., and M. S. Terpilak (1984), *The Health Physics and Radiological Health Handbook,* Nucleon Lectern Associates, Inc., Olney, MD.

Silver, W. J., C. L. Lindeken, J. W. Meadows, W. H. Hutchin, and D. R. McIntyre (1974), *Environmental Levels of Radioactivity in the Vicinity of the Lawrence Livermore Laboratory, 1973 Annual Report,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-51547).

Silver, W. J., C. L. Lindeken, J. W. Meadows, W. H. Hutchin, and D. R. McIntyre (1975), *Environmental Monitoring at the Lawrence Livermore Laboratory, 1974 Annual Report,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-74).

Silver, W. J., C. L. Lindeken, K. M. Wong, E. H. Willes, and J. H. White (1978), *Environmental Monitoring at the Lawrence Livermore Laboratory, 1977 Annual Report,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-77).

Swaim, K. (2002), *Results of surveys for special status reptiles at the Site 300 facilities of Lawrence Livermore National Laboratory*, Swaim Biological Consulting, Livermore, CA.

SWRCB (1999), *Waste Discharge Requirements for Discharges of Storm Water Runoff Associated with Construction Activity.* NPDES General Permit No. CAS000002 (Order No. 99-08-DWQ).

Taffet, M. J., L. Green-Horner, L. C. Hall, T. M. Carlsen, and J. A. Orberdorfer (1996), *Addendum to Site-Wide Remedial Investigation Report, Building 850/Pit 7 Complex Operable Unit, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-108131, Add. 1).

Taffet, M.J., V. Dibley, L. Ferry, W. Daily, Z. Demir, V. Madrid, J. Valett, and S. Bilir (2004a) *Final Interim Remedial Design for the Building 850 Subarea at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-AR-201835).

Taffet, M.J., L. Ferry, V. Madrid, T. Carlsen, Z. Demir, J. Valett, M. Dresen, W. Daily, S. Coleman, and V. Dibley (2004b) *Draft Final Remedial Investigation/Feasibility Study for the Pit7 Complex Subarea at Lawrence Livermore National Laboratory Site 300, Lawrence Livermore National Laboratory*, Livermore, CA (UCAR-AR-202492).

Tamplin, B. R. (1980), Sanitation and Radiation Laboratory Section, California Department of Health Services, letter to C. L. Lindeken, Environmental Evaluations Group, Hazards Control Department, Lawrence Livermore Laboratory, October 31, 1980.

Thorpe, R. K., W. F. Isherwood, M. D. Dresen, and C. P. Webster-Scholten (1990), *CERCLA Remedial Investigation Report for the LLNL Livermore Site,* Vols. 1–5, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10299).

Toy, A. J., C. L. Lindeken, K. S. Griggs, and R. W. Buddemeier (1981), *Environmental Monitoring at the Lawrence Livermore National Laboratory, 1980 Annual Report,* Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-80).

U.S. DOE (1991), *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance,* U.S. Department of Energy, Washington, DC (DOE/EH-0173T).

U.S. DOE (1993), *Record of Decision for the Lawrence Livermore National Laboratory Livermore Site,* U.S. Department of Energy, Washington, DC (UCRL-AR-109105).

U.S. DOE (2002), *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*, U.S. Department of Energy, Washington, DC, (DOE-STD-1153-2002).

U.S. DOE and UC (1992a), *Final Environmental Impact Statement and Environmental Impact Report for Continued Operation of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore,* Lawrence Livermore National Laboratory, Livermore, CA (DOE/EIS-0157, SCH90030847).

U.S. DOE and UC (1992b), *Final Environmental Impact Statement and Environmental Impact Report Executive Summary,* Lawrence Livermore National Laboratory, Livermore, CA (DOE/EIS-0157).

U.S. EPA (1987), *Data Quality Objectives for Remedial Response Activities: Development Process*, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC (EPA 540/G-87/003, OSWER Directive 9355-0).

U.S. EPA (1995), Lawrence Livermore National Laboratory Plutonium Fact Sheet, U.S. EPA Region 9, September 1995.

U.S. EPA (2000), "Notice: Final Reissuance of National Pollutant Discharge Elimination System (NPDES) Storm Water Multi-Sector General Permit for Industrial Activities," Environmental Protection Agency, Federal Register, Volume 65, No. 210 (October 30, 2000).

U.S. NRC (1977), *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluent for the Purpose of Evaluation Compliance with 10 Code of Federal Regulations, Part 50, Appendix 1, U.S.* Nuclear Regulatory Commission, Washington, DC (Regulatory Guide 1.109).

USFWS (1998), *Recovery Plan for Upland Species of the San Joaquin Valley, California,* U.S. Department of the Interior, Fish and Wildlife Service, Region 1, Portland Oregon, 319 pp.

USFWS (2000), "Endangered and threatened wildlife and plants; final determination of critical habitat for the Alameda whipsnake (*Masticophis lateralis euryxanthus*)," Federal Register 65(192) 58933-58962.

USFWS (2001), "Final determination of critical habitat for the California red-legged frog," Federal Register 66(49) 14626-14758.

USFWS (2004a), "Endangered and threatened wildlife and plants; proposed designation of critical habitat for the California red-legged frog (*Rana aurora draytonii*)," Federal Register 69(71) 19620–19642.

USFWS (2004b), "Endangered and threatened wildlife and plants; designation of critical habitat for the California tiger salamander, central population; proposed rule," Federal Register 69(153) 48570–48649.

Weber, W. (2002), *2001-2002 Wet Season Branchiopod Survey Report*, University of California, Lawrence Livermore National Laboratory, Site 300, Alameda and San Joaquin Counties. Condor Country Consulting, Hayward, CA.

Webster-Scholten, C. P., and C. H. Hall (1988), *Work Plan, Lawrence Livermore National Laboratory, Livermore Site: CERCLA/SARA Remedial Investigations/ Feasibility Studies,* Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10225).

Webster-Scholten, C. P., ed. (1994), *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-108131).

West, E. (2002), *2002 Small Mammal Inventory at Lawrence Livermore National Laboratory, Site 300*, Jones & Stokes, Sacramento, CA.

Woods, N., ed. (2005), *Environmental Monitoring Plan*, Operation and Regulatory Affairs Division, Environmental Protection Department, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-106132, Rev. 4).

World Energy, Biodiesel Background Sheet, available at www.worldenergy.net.

Yow, J.L., (2004a), *First Quarter 2004 Compliance Report for the Eastern General Services Area Soil Vapor and Ground Water Treatment Systems at Lawrence Livermore National Laboratory Site 300*, Livermore, CA, June 30, 2004.

Yow, J.L., (2004b), *Second Quarter 2004 Compliance Report for the Eastern General Services Area Soil Vapor and Ground Water Treatment Systems at Lawrence Livermore National Laboratory Site 300,* Livermore, CA, September 30, 2004.

Yow, J.L., (2004c), T*hird Quarter 2004 Compliance Report for the Eastern General Services Area Soil Vapor and Ground Water Treatment Systems at Lawrence Livermore National Laboratory Site 300*, Livermore, CA, December 30, 2004.

Yow, J.L., (2005), *Fourth Quarter 2004 Compliance Report for the Eastern General Services Area Soil Vapor and Ground Water Treatment Systems at Lawrence Livermore National Laboratory Site 300*, Livermore, CA, March 30, 2005.

Ziagos, J., and E. Reber-Cox (1998), *Ground Water Tritium Plume Characterization Summary Report for the Building 850/Pits 3 and 5 Operable Unit, Lawrence Livermore National Laboratory Site 300*, Livermore, CA, October 30, 1998.

Acronyms and Abbreviations

See also the Glossary for further definition of selected terms.

A	**ACDEH**	Alameda County Department of Environmental Health
	ACL	ambient concentration limit
	AFV	alternative fuel vehicles
	ALARA	as low as reasonably achievable
	ANSI	American National Standards Institute
	ASE	accelerated solvent extraction
	ATSDR	Agency for Toxic Substances and Disease Registry
	AVLIS	Advanced Vapor Laser Isotope Separation
	AWQC	ambient water quality criteria
B	**BA**	biological assessment
	BAAQMD	Bay Area Air Quality Management District
	BMP	best management practice
	Bq	becquerel
	BSA	Blanket Service Agreement
C	**CAM**	continuous air monitor
	CAMP	Corrective Action Monitoring Program
	CCB	Change Control Board
	CCR	California Code of Regulations Container Content Report
	CD	compact disc
	CDFG	California Department of Fish and Game
	CDHS	California Department of Health Services
	CDHS–RHB	California Department of Health Services, Radiation Health Bureau
	CDPH–BRH	California Department of Public Health, Bureau of Radiological Health
	CEI	Compliance Evaluation Inspection
	CEQA	California Environmental Quality Act of 1970
	CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
	CES	Chemistry and Materials Science Environmental Services
	CFR	Code of Federal Regulations

	Chromium(VI)	hexavalent chromium
	Ci	curie
	CMP	Compliance Monitoring Program
	CNPS	California Native Plant Society
	COC	constituent of concern
	COD	chemical oxygen demand
	CSA	container storage area
	CUPA	Certified Unified Program Agency
	CVRWQCB	Central Valley Regional Water Quality Control Board
	CWA	(Federal) Clean Water Act
D	**D&D**	decommissioning and decontamination
	DCG	Derived Concentration Guide
	DHS	Department of Health Services
	DMP	Detection Monitoring Program
	DMT	Data Management Team
	DOE	U.S. Department of Energy
	DRB	Drainage Retention Basin
	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
	EIS	environmental impact statement
	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
	ERD	Environmental Restoration Division (of the Environmental Protection Department at LLNL)

	ES&H	Environment, Safety, and Health
	ESB	East Settling Basin
	EWSF	Explosives Waste Storage Facility
	EWTF	Explosives Waste Treatment Facility
F	**FEC**	Federal Electronics Challenge
	FFA	federal facility agreement
	FY	fiscal year
G	**GBq**	gigabecquerel (10^9 Bq)
	GEM	Global Electric Motorcar
	GIS	Geographic Information System
	GPS	global positioning system
	GSA	General Services Area (LLNL Site 300)
	GWP	Ground Water Project
H	**HCAL**	Hazards Control Department's Analytical Laboratory
	HE	high explosives
	HEPA	high-efficiency particulate air (filter)
	HMX	cyclotetramethyltetramine (high explosive). 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	Hazardous Waste Control Act
	HWFP	Hazardous Waste Facility Permit
I	**IEEE**	Institute of Electrical and Electronics Engineers
	IQR	interquartile range
	ISMS	Integrated Safety Management System
	ISO	International Organization for Standardization
L	**LARPD**	Livermore Area Recreation & Park District
	LDR	Land Disposal Restriction
	LEPC	Local Emergency Planning Committee
	LLD	lower limit of detection
	LLL	Lawrence Livermore Laboratory

	LLNL	Lawrence Livermore National Laboratory
	LOS	limit of sensitivity
	LRL	Lawrence Radiation Laboratory
	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
	MNA	monitored natural attenuation
	MRP	Monitoring and Reporting Program
	MSDS	material safety data sheet
	mSv	millisievert (10^{-3} Sv)
N	**NAREL**	National Air and Radiation Environmental Laboratory=
	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
	NIF	National Ignition Facility
	NNSA	National Nuclear Security Administration
	NOD	notice of deficiency
	NOV	notice of violation
	NPDES	National Pollutant Discharge Elimination System
	NRC	Nuclear Regulatory Commission
	nSv	nanosievert (10^{-9} Sv)
O	**OBT**	organically bound tritium
	OR	occurrence report
	ORAD	Operations and Regulatory Affairs Division (of the Environmental Protection Department at LLNL)
	OU	operable unit
P	**P2**	pollution prevention

	PCB	polychlorinated biphenyl
	PCE	perchloroethylene (or perchloroethene). Also called tetrachloroethylene (or tetrachloroethene).
	PETN	pentaerythritol tetranitrate
	PHA	public health assessment
	pHMS	pH Monitoring Station
	PM-10	particulate matter
	ppb	parts per billion
	ppm	parts per million
	PQL	practical quantitation limit
Q	**QA**	quality assurance
	QC	quality control
R	**RCRA**	Resource Conservation and Recovery Act of 1976
	RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine (high explosive)
	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
	Sandia/California	Sandia National Laboratories/California
	SARA	Superfund Amendment and Reauthorization Act of 1986 (see also CERCLA/SARA)
	SDF	Sewer Diversion Facility
	SERC	State Emergency Response Commission
	SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
	SHPO	State Historic Preservation Officer
	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
	SJVAPCD	San Joaquin Valley Air Pollution Control District
	SMS	Sewer Monitoring Station

	SOP	standard operating procedure
	SOV	summary of violations
	STP	Site Treatment Plan
	Sv	sievert
	SW-MEI	site-wide maximally exposed individual member (of the public)
	SWPPP	Storm Water Pollution Prevention Plan
T	**TAG**	Technical Assistance Grant
	TBq	terabecquerel (10^{12} Bq)
	TCE	trichloroethene (or trichloroethylene)
	TDS	total dissolved solids
	TEF	toxicity equivalency factor
	TEQ	toxicity equivalency
	TF	treatment facility
	TLD	thermoluminescent dosimeter
	TNT	trinitrotoluene
	TOC	total organic carbon
	TOX	total organic halides
	TRI	Toxics Release Inventory
	Tri-Valley CAREs	Tri-Valley Communities Against a Radioactive Environment
	TRU	transuranic (waste)
	TSCA	Toxic Substances Control Act
	TSDF	treatment, storage, and disposal facility
	TSS	total suspended solids
	TTO	total toxic organics
	TWMS	Total Waste Management System
U	**UC**	University of California
	USAEC	United States Atomic Energy Commission
	USDHEW	United States Department of Health, Education, and Welfare
	USEPA	United States Environmental Protection Agency
	USFWS	U.S. Fish and Wildlife Service
V	**VOC**	volatile organic compound
	VTF	vapor treatment facility

W	**WAA**	waste accumulation area
	WDR	Waste Discharge Requirement
	WIPP	Waste Isolation Pilot Plant
	WMA	Waste Management Area
	WSS	Work Smart Standards
Z	**Zone 7**	Alameda County Flood Control and Conservation District, Zone 7

Glossary

A **Absorbed dose:** the amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material, in which the absorbed dose is expressed in units of rad or gray (1 rad = 0.01 gray)

Accuracy: the closeness of the result of a measurement to the true value of the quantity measured

Action level: defined by regulatory agencies, the level of pollutants which, if exceeded, requires regulatory action

Aerosol: a gaseous suspension of very small particles of liquid or solid

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

Anadromous: ascending rivers from the sea for breeding

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.

Congener: any particular member of a class of chemical substances, such as dioxins. A specific congener is denoted by a unique chemical structure, for example 2,3,7,8-TCDD.

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)

Dewatering: the lowering of the water table due to groundwater extraction during site cleanup. Overdrafting at the Livermore site aquifer occurs when the rate of groundwater extraction exceeds the natural rate of recharge, thus resulting in a net loss of groundwater in the subsurface.

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

Granivory: feeding on seeds or grain

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.

Herbivory: feeding on nonwoody vegetation

(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

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 gray (Gy)	100 rad	1 rad	0.01 gray (Gy)
Radiation dose equivalent			
1 sievert (Sv)	100 rem	1 rem	0.01 sievert (Sv)
Metric	**Temperature**	**U.S. Customary**	
°C = (°F–32)/1.8		°F = (°C x1.8) + 32	

N **National Emission Standards for Hazardous Air Pollutants (NESHAPs):** standards found in the Clean Air Act that set limits for hazardous air pollutants

National Environmental Policy Act (NEPA): federal legislation enacted in 1969 that requires all federal agencies to document and consider environmental impacts for federally funded or approved projects and the legislation under which DOE is responsible for NEPA compliance at LLNL

National Institute for Standards and Technology (NIST): the federal agency, formerly known as the National Bureau of Standards, responsible for reference materials against which laboratory materials are calibrated

National Pollutant Discharge Elimination System (NPDES): federal regulation under the Clean Water Act that requires permits for discharges into surface waterways

NEWTRIT: model used to calculate doses from environmental measurements

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)

Practical quantitation limit (PQL): level at which the laboratory can report a value with reasonably low uncertainty (typically 10–20% uncertainty)

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

External Distribution

Agency for Toxic Substances anDisease Registry
Mark Evans
Trent L'Coutre
1600 Clifton Road NE
Mailstop E-32
Atlanta, GA 30333

Air Resources Board
J. Morgester
Compliance Division
P.O. Box 2815
Sacramento, CA 95812

A.K.T.
Eleni Tsakopoulos
770 College Town Drive
Suite 101
Sacramento, CA 95826-2303

Alameda County Department of
Environmental Health
Robert Weston
Larry Seto
Environmental Protection Division
1131 Harbor Bay Parkway, 2nd Floor
Alameda, CA 94502

Alameda County Flood Control and
Water Conservation District, Zone 7
David Lunn
5997 Parkside Drive
Pleasanton, CA 94588-5127

Alameda County Water District
E. L. Lenahan
43885 S. Grimmer Blvd.
Fremont, CA 94537

Argonne National Laboratory
Norbert Golchert
9700 S. Cass Avenue
Building 200, Room B-117
Argonne, IL 60439

Argonne National Laboratory
Michael Lazaro
9700 S. Cass Avenue
Building 200, Room B-900
Argonne, IL 60439

Assistant Administrator for Air Radiation (ANR-443)
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

Bay Area Air Quality Management District
Jack Broadbent
Chief Executive Officer/Air Pollution Control Officer
939 Ellis Street
San Francisco, CA 94109

Bay Area Air Quality Management District
Kelly Wee
Director of Enforcement
939 Ellis Street
San Francisco, CA 94109

Biomedical & Environmental Sciences Lab
O. R. Lunt, Director
University of California
900 Veteran Avenue
Los Angeles, CA 90024

Brookhaven National Laboratory
Robert Miltenberger
G. L. Schroeder
Bldg. 535A
Upton, NY 11973

Brookhaven National Laboratory
J. Naidu
Safety & Environmental Protection
Bldg. 535A
Upton, NY 11973

California Department of Energy
Barbara J. Byron
Executive Office
1515 - 9th Street/MS-36
Sacramento, CA 95814

California Department of Health Services
Dorice Bailey
Edgar D. Bailey
K. Jackson
DHS/EMB, MS-396
601 N. 7th Street, Box 942732
Sacramento, CA 95814

California Department of Health Services
Jeff Wong
Radiological Health Branch
1625 Shattuck Avenue
Room 209
Berkeley, CA 94709

California Department of Health Services
Gary Bittner
Steve Shu
P.O Box 997414, MS 7610
Sacramento, CA 94105

California Department of Health Services
Marilyn Underwood
Environmental Health Investigation Branch
1515 Clay Street, Suite 1700
Oakland, CA 94611

California Environmental Protection Agency
Mark Piros
Northern California Coastal Cleanup
Operations Branch
700 Heinz Avenue, Suite 200
Berkeley, CA 94710-2737

California Environmental Protection Agency
Ted Park
Department of Toxic Substances Control
700 Heinz Avenue, Suite 300
Berkeley, CA 94710-2737

California Environmental Protection Agency
Mohinder Sandhu
Department of Toxic Substances Control
700 Heinz Avenue, Suite 300
Berkeley, CA 94710-2721

California Environmental Protection Agency
Charlene Williams
Department of Toxic Substances Control
700 Heinz Avenue, Suite 200
Berkeley, CA 94710-2721

California Regional Water Quality
Control Board
S. Timm
Central Valley Region
3443 Routier Road
Sacramento, CA 95827-3098

California Regional Water Quality Control Board
Naomi Feger
San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, CA 94612

California State Water Resources Control Board
Stan Martinson
Division of Water Quality
101 "I" Street
Sacramento, CA 95814

Continuous Electron Beam Accelerator Facility
Bob May
Radiation Control
12000 Jefferson Avenue
Newport News, VA 23606

County of San Joaquin
Office of Emergency Services
Mike Parissi
Room 610, Courthouse
222 East Weber Avenue
Stockton, CA 95202

Ernest Orlando Lawrence Berkeley
National Laboratory
Ron Pauer
Environmental Monitoring Group
MS75B-101
One Cyclotron Road
Berkeley, CA 94720

Ernest Orlando Lawrence Berkeley
National Laboratory
Henry Tran
MS75B-101
One Cyclotron Road
Berkeley, CA 94720

FERMCO
P. A. Kraps
Allan Lydic
Site Restoration Services
P.O. Box 538704
Cincinnati, OH 45253-8704

Fermilab
Sam Baker
Paul Kesich
P.O. Box 500, MS-119
Batavia, IL 60510

Hanford Environmental Health Foundation
Joseph K. Samuels
Environmental Health Services
P.O. Box 100, H1-78
Richland, WA 99352

Livermore Water Reclamation Plant
Darren Greenwood
Water Resources Manager
101 West Jack London Blvd.
Livermore, CA 94551

Livermore Water Reclamation Plant
Lynna Grijalva
Source Control Inspector
101 West Jack London Blvd.
Livermore, CA 94551

Lockheed Idaho Technologies Co.
Leah Street
Environmental Protection
P.O. Box 1625
Idaho Falls, ID 83415-4110

Los Alamos National Laboratory
Bruce Gallaher
Water Quality and Hydrology Group
MS-K497
P.O. Box 1663
Los Alamos, NM 87505

Los Alamos National Laboratory
Steven Rae
Ken Mullen
Water Quality and Hydrology Group
MS-K497, ESH-18
P.O. Box 1663
Los Alamos, NM 87505

Los Alamos National Laboratory
Lars Soholt
Environmental Surveillance Group
MS-M992E-ER
P.O. Box 1663
Los Alamos, NM 87505

Massachusetts Institute of Technology
Hugh Gusterson
STS Program
E51-296F
77 Massachusetts Avenue
Cambridge, MA 02139

Nevada Operations Office
Bruce W. Church
Asst. Manager for Environment,
Safety and Health
P.O. Box 98518
Las Vegas, NV 89193-8518

Oak Ridge National Laboratory
Laury Hamilton
Building 4500S, MS-6137
Oak Ridge, TN 37831-6137

Oak Ridge National Laboratory
John B. Murphy
Head, Environmental Surveillance
and Protection Section
Building 4500N, MS-6198
Oak Ridge, TN 37831-6198

Oak Ridge National Laboratory
Frank O'Donnell
Building 4500S, MS-6102
Oak Ridge, TN 37831-6102

Oak Ridge National Laboratory
Mark Tardiff
Office of Environmental Compliance
and Documentation
Building 4500N, MS-6198
Oak Ridge, TN 37831-6198

Pacific Northwest National Laboratory
P. Evan Dresel
Stuart Luttrell
Earth and Environmental Sciences
P.O. Box 999
Richland, WA 99352

Pacific Northwest National Laboratory
W. W. Laity, General Manager
Environmental Management Operations
Battelle Blvd.
P.O. Box 999
Richland, WA 99352

Questa Engineering Corporation
Jeff Peters
1220 Brickyard Cove Road
Point Richmond, CA 94807

Radiobiology & Environmental Health Laboratory
Sheldon Wolff, Director
University of California
Medical Center
San Francisco, CA 94143

San Francisco Public Utilities Commission
Water Quality Bureau
David Quinones
1000 El Camino Real
Millbrae, CA 94030

San Francisco Public Utilities Commission
Water Quality Bureau – Engineering
Raymond Mah
1000 El Camino Real
Millbrae, CA 94030

San Joaquin Valley Air Pollution Control District
Jim Swaney
Permit Services Manager
4230 Kiernan Avenue, Suite 130
Modesto, CA 95356

Sandia National Laboratories/California
Robert Holland
P.O. Box 969, MS-9221
Livermore, CA 94551-0969

Sandia National Laboratories/California
Barbara Larsen
P.O. Box 969, MS-9221
Livermore, CA 94551-0969

Sandia National Laboratories
H. S. Hwang
F. Ghanbari
Lih-Jenn Shyr
Dept. 7575
P.O. Box 5800, MS-0174
Albuquerque, NM 87185

Sandia National Laboratories
Marion McDonald
Dept. 6500, MS-1141
P.O. Box 5800
Albuquerque, NM 87185

Savannah River Plant
Tim Jannik
WSRC-Env. Analysis Section
Building 733-42A, Room 226
Aiken, SC 29808

Robert L. Schlegel
12321 Tampico Way
Silver Spring, MD 20904

Stanford Linear Accelerator Center
Trish Garriz
MS-77
2575 Sand Hill Road
Menlo Park, CA 94025-7015

Stanford Linear Accelerator Center
Michael P. Grissom
Environment, Safety, & Health, MS-84
2575 Sand Hill Road
Menlo Park, CA 94025-7015

William N. Taber
4211 S. Yuron Way
Lakewood, CO 80235

TetraTech, Inc.
John Nash
5203 Leesburg Pike, Suite 900
Falls Church, VA 22041

Tri-Valley CARES
Marylia Kelly
2582 Old First Street
Livermore, CA 94550

U.S. Department of Energy
Brookhaven Area Office
Gerald Granzen
Environmental Programs Division
Bldg. 464
Upton, NY 11973-5000

U.S. Department of Energy
Betsy Jonker
Idaho Operations Office
1955 Fremont Ave, MS-1216
Idaho Falls, ID 83402

U.S. Department of Energy
Stephen Chase
Office of Env. & Tech. Support
Defense Programs, DP-45
1000 Independence Avenue, S.W.
Washington, DC 20585

U.S. Department of Energy
Office of Scientific & Technical Information
P.O. Box 62
Oak Ridge, TN 37831

U.S. Department of Energy
Ross Natoli (3 copies)
Office of Air, Water & Radiation Protection
Policy and Guidance
EH-41/Forrestal Building
1000 Independence Avenue, S.W.
Washington, DC 20585

U.S. Department of Energy
Roy Hardwick
Office of Facility Safety
EH-2/270 Corporate Square Building
1000 Independence Avenue, S.W.
Washington, DC 20585-0270

U.S. Department of Energy
Glenn Podonsky
Office of Independent Oversight and
Performance Assurance
OA-1/Germantown Building
1000 Independence Avenue, S.W.
Washington, DC 20585-1290

U.S. Department of Energy
Steven Black
NNSA Service Center
Environmental, Safety and Health Department
P.O. Box 5400
Albuquerque, NM 87185-5400

U.S. Environmental Protection Agency
Federal Facilities Cleanup Office SFD8-1
Kathy Setian
Region IX
75 Hawthorne Street
San Francisco, CA 94105-3941

U.S. Environmental Protection Agency
Region IX
Deborah Jordan
75 Hawthorne Street
San Francisco, CA 94105-3941

U.S. Environmental Protection Agency
Region IX
D. Lessler
75 Hawthorne Street
San Francisco, CA 94105-3941

U.S. Environmental Protection Agency
Region IX
K. Silva, WTR-7
M. Gill, SFD-8
75 Hawthorne Street
San Francisco, CA 94105-3941

University of California Berkeley
James Hunt
Department of Civil and Environmental
Engineering
631 Davis Hall, MS-1710
Berkeley, CA 94720

West Valley Nuclear Services Co., Inc.
Anthony Nagel
Environmental, Safety, Health and
Quality Assurance
10282 Rock Springs Road
P.O. Box 191
West Valley, NY 14171-0191

Westinghouse Hanford Co.
Austin R. Johnson
P.O. Box 1970, H6-30
Richland, WA 99352

Westinghouse Savannah River Co.
James Heffner
Pete Fledderman
Environmental Protection
P.O. Box 616, Bldg. 735A
Aiken, SC 29802