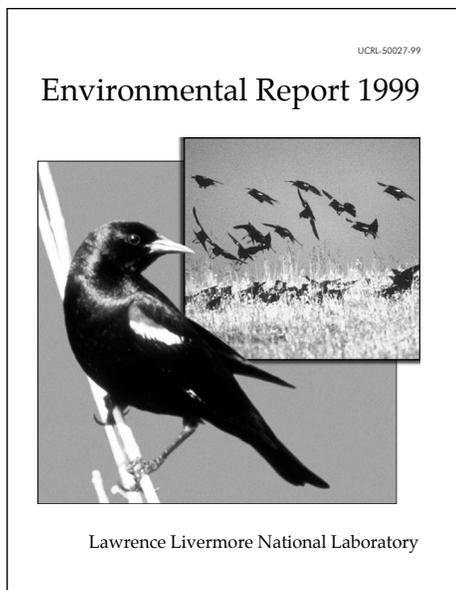


Environmental Report 1999



Tricolored Blackbird
Agelaius tricolor

Lawrence Livermore National Laboratory



Cover

The Tricolored Blackbird (*Agelaius tricolor*), which has state and federal status as a species of Special Concern, is endemic only to California and is largely restricted to the San Joaquin Valley where it is estimated that populations have declined by at least 50% in the last half-century. It roosts and nests in cattail or tule marshes in dense colonies that can number in the thousands of birds. The male Tricolored has a darker red patch than the Red-winged Blackbird and a conspicuous white margin that is identifiable even in flight.

Historically, Site 300 has had a small population nesting in the Elk Ravine wetland. This colony is considered unique because Tricoloreds typically do not inhabit foothill habitat areas like those at Site 300. When Tricoloreds are actively nesting, LLNL restricts traffic levels to protect the adult birds during their egg incubation period and rearing of young (roughly late March through May). LLNL wildlife biologists collect information on the density of nesting birds, productivity at the nest sites, and the areas used by the colony for foraging. This information is important to our understanding of the natural history and wildlife management aspects of the site as well as to state and federal resource agencies that track Tricolored population trends across California.

Cover photos provided by:

- flock—Jim S. Woollett, Jr., wildlife biologist, LLNL
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Environmental Report 1999

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Distribution:

Subject: 1999 Site Annual Environmental Report (SAER) for the
Lawrence Livermore National Laboratory (LLNL)

This report, prepared by LLNL for the Department of Energy, Oakland Operations Office (DOE-OAK), provides a comprehensive summary of the environmental program activities at LLNL for calendar year 1999. Site Annual Environmental Reports (SAERs) are prepared annually for all DOE sites with significant environmental activities, and distributed to relevant external regulatory agencies and other interested organizations or individuals.

To the best of my knowledge, this report accurately summarizes the results of the 1999 environmental monitoring, compliance, impacts assessment, and restoration program at LLNL. This assurance can be made based on DOE-OAK and LLNL review of the SAER, and quality assurance protocols applied to monitoring and data analyses at LLNL.

A reader survey form is provided with the SAER to provide comments or suggestions for future versions of the report. Your response is appreciated. Questions or comments regarding this report may also be made directly to DOE-OAK, by contacting Ron Sommer at (925) 422-3390.

Sincerely,

A handwritten signature in black ink that reads "Michael K. Hooper".

Michael K. Hooper
Assistant Manager for National Nuclear
Security Administration Operations

Preface

The *Environmental Report 1999* is prepared for the U.S. Department of Energy (DOE), as required by DOE Order 5400.1 and DOE Order 231.1, by the Environmental Protection Department at Lawrence Livermore National Laboratory (LLNL). The results of LLNL's environmental monitoring and compliance efforts and an assessment of the impact of LLNL operations on the public and the environment are presented in this publication.

One important change has been made to the 1999 report. A new Appendix C, Errata, has been added to notify holders of previous environmental reports that corrections to the bound, hard copies were necessary, what the corrections were, and that the corrections were made on the Internet versions. With the errata, the hard copy and Internet versions are equivalent documents. Environmental reports covering calendar years 1994 through 1999 can be accessed on the Internet at the address of the LLNL SAER homepage: <http://www.llnl.gov/saer>. Both the main volume and data supplement volume of each individual report can be viewed in its fully corrected, most up-to-date form.

To produce a more readable and useful document for our diverse readership, which includes regulators, scientists and engineers, educators, the media, public interest groups, and interested citizens, this report is divided into two volumes: main volume and Data Supplement. The main volume describes LLNL's environmental impact and compliance activities and features descriptive and explanatory text, summary data tables, and plots showing data trends. The summary data include measures of the central tendency of the data (i.e. mean and medium), their spread or variability, and their extreme values. The main volume contains the Executive Summary and the Compliance Summary; it features individual chapters on monitoring of air, sewage, surface water, ground water, soil and sediment, vegetation and foodstuff, and environmental radiation; and it contains chapters on site overview, environmental program information, ground water investigation and remediation, radiological dose assessment, and quality assurance. Information on both the Livermore site and Site 300 is presented in each chapter. The main volume contains the information of interest to most of our readers and will be distributed. The distribution list for the 1999 report can be accessed from the LLNL SAER homepage on the Internet at the address provided above. Requests for additions to or deletions from the list can be entered on the distribution list webpage.

The Data Supplement provides individual data points, where applicable, some summary data, and more detailed accounts of sample collection and analytical methods. The Data Supplement will be sent only upon request; a card for this purpose is included on the last page of this volume. Both the main volume and the Data Supplement are available on the Internet at the address provided above.

As in our previous annual reports, data are presented in Système International (SI) units. In particular, the primary units we use for radiological results are becquerels and sieverts for activity and dose, respectively, with curies and rem used secondarily ($1 \text{ Bq} = 2.7 \times 10^{-11} \text{ Ci}$; $1 \text{ Sv} = 100 \text{ rem}$). If the data are available, radioactivities are reported as the measured concentration with an uncertainty $\pm 2\sigma$ counting error); if not, they are reported as being less than a detection limit. If the concentration is less than the uncertainty, the result is considered to be indistinguishable from a zero concentration. Units are discussed in Supplement 13-1 of Chapter 13, Radiological Dose Assessment, and in Chapter 14, Quality Assurance, in the main volume.

This document is the responsibility of LLNL's Operations and Regulatory Affairs Division of the Environmental Protection Department. Monitoring data were obtained through the combined efforts of the Operations and Regulatory Affairs Division, Environmental Restoration Division, the Chemistry and Materials Science Environmental Services Laboratories, and the Hazards Control Department. Special recognition is deserved for the dedication and professionalism of the technicians who carried out environmental monitoring—Gary A. Bear, David J. Castro, Paul C. Dickinson, Keith Toon, David Macedo, Charles Hunt, Renee Needens, Terrance W. Poole, Donald G. Ramsey, Terri Crippen, and Robert Williams—and to the data management personnel—Jennifer Clark, Kimberly A. Stanford, Louise Morris, Beth Schad, Suzanne Chamberlain, Connie Wells, Della Burruss, and Susan Lambaren. Betty Cuevas provided secretarial support and collated and distributed drafts.

Special thanks go to Bill Hoppes for his strong support of the project and careful and timely reviews of all the drafts; C. Susi Jackson and Charlene Grandfield for reviewing the chapters; and Karen Folks and Paula Tate for their comments and help with chapters other than their own. In addition, the following people contributed significantly to this report: Janice Butler, Richard Crawford, Keith V. Gilbert, Albert L. Lamarre, Patricia L. Ottesen, Duane W. Rueppel, Jeffrey Sketchley, Brenda Staley, Judy Steenhoven, and Kim Heyward.

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Introduction

Lawrence Livermore National Laboratory (LLNL), a U.S. Department of Energy (DOE) facility operated by the University of California (UC), serves as a national resource of scientific, technical, and engineering capabilities. The Laboratory's mission focuses on nuclear weapons and national security, and over the years has been broadened to include areas such as strategic defense, energy, the environment, biomedicine, technology transfer, the economy, and education. The Laboratory carries out this mission in compliance with local, state, and federal environmental regulatory requirements. It does so with the support of the Environmental Protection Department, which is responsible for environmental monitoring and analysis, hazardous waste management, environmental restoration, and assisting Laboratory organizations in ensuring compliance with environmental laws and regulations.

LLNL comprises two sites: the Livermore site and Site 300. The Livermore site occupies an area of 3.28 square kilometers on the eastern edge of Livermore, California. Site 300, LLNL's experimental testing site, is located 24 kilometers to the east in the Altamont Hills and occupies an area of 30.3 square kilometers. Meteorological and environmental monitoring activities are conducted at both sites as well as in surrounding areas.

This summary provides an overview of LLNL's environmental activities in 1999, including radiological and nonradiological surveillance, effluent and compliance monitoring, remediation, assessment of radiological releases and doses, and determination of the impact of LLNL operations on the environment and public health.

Environmental Monitoring Results

During 1999, the Environmental Protection Department sampled air, sewerable water, surface water, ground water, soil and sediment, and vegetation and foodstuff. Samples were analyzed for radioactive and nonradioactive substances using (1) standard methods approved by the U.S. Environmental Protection Agency (EPA), (2) special systems such as the continuous monitoring system for Livermore site sewage, or (3) special analytical techniques designed to measure very low levels of radionuclides. Environmental



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radiation was also measured directly using dosimeters. More than 13,000 environmental samples were taken, and more than 250,000 analytical results were obtained.

Air Monitoring

Air was monitored for various airborne radionuclides (including particles and tritiated water vapor) and beryllium at the Livermore site, Site 300, and off-site locations throughout the Livermore Valley and Tracy areas. Concentrations of all monitored radionuclides and beryllium at all of these locations were well below levels that would endanger the environment or public health, according to current regulatory standards. For example, in 1999, the highest median plutonium concentration for samples collected at any air monitoring station was 0.0036% of the federal Derived Concentration Guide (DCG). The DCG specifies the concentration of radionuclides in air or water that could be inhaled or ingested continuously 365 days a year without exceeding the DOE radiation protection standard for the public. Median concentrations of tritiated water vapor collected at Livermore Valley sampling locations showed a highest median value of 0.001% of the DCG, while the highest median values on the Livermore site perimeter and within the site boundaries were, respectively, 0.004% and 0.1% of the DCG. The highest median concentrations of beryllium on the Livermore site and Site 300 were 0.11% and 0.13%, respectively, of the guideline level established by the Bay Area Air Quality Management District and the EPA and are representative of naturally occurring levels.

Stack Air Effluent Monitoring

In 1999, LLNL operated 101 samplers for measuring radioactivity in air effluent at eight facilities at the Livermore site. These samplers extracted a measured volume of air from the exhaust stack of a facility or process and collected particles or vapor in a collection medium. Measured radiological air emissions from Livermore site operations remained well below levels of health and environmental concern. Building 331 emissions accounted for 96% of the estimated total tritium emissions from the site in 1999; emissions from this facility remained at a level far below those of the 1980s and caused public dose impacts far below levels allowed by regulatory standards. Radionuclide emissions from the other monitored facilities were very low.

Nonradioactive air emissions from exempt and permitted sources at LLNL were quite small and typical of values in previous years. For example, total emission of nitrogen oxides from the Livermore site in 1999 was 81 kg per day, which is 0.06% of the quantity of this air pollutant released daily over the entire San Francisco Bay Area; corresponding



numbers for reactive organics were 24 kilograms per day and 0.02%. The total emission of criteria air pollutants (nitrogen oxides, volatile organics, sulfur oxides, particulate matter, carbon monoxide, and lead) was 140 kilograms per day for the Livermore site and about 6 kilograms per day for Site 300.

Sewerable Water Monitoring

Discharges of radioactive and hazardous material to the combined sanitary and industrial sewer at the Livermore site are controlled by use of administrative and engineering controls, including limiting the disposal of those materials and routing some discharged material to retention tanks for later characterization and treatment. Flow-proportional and instantaneous samples of the site's wastewater are regularly collected and analyzed (for metals, radioactivity, toxic chemicals, and water-quality parameters) to ensure that LLNL's sewage effluent meets the requirements of the permit granted by the City of Livermore. In addition, the site effluent is monitored continuously for pH, regulated metals, and radioactivity. If concentrations are detected above warning levels, an alarm sounds and the effluent is automatically contained by LLNL's sewer diversion system. The diversion system captures all but the initial minutes of wastewater flow that causes an alarm, thereby protecting the Livermore Water Reclamation Plant (LWRP) and minimizing any required cleanup. With the 1998 addition of a new monitoring and diversion capability for pH, even the initial minutes of a pH-related release are contained on site.

In 1999, the Livermore site discharged an average of 1.0 million liters per day of wastewater to the City of Livermore sewer system, an amount that constituted 4.4% of the total flow to the system (about 13% of the Livermore site effluent was generated by Sandia National Laboratories/California). The Livermore site's sanitary sewer effluent was monitored continuously and sampled daily, weekly, and monthly to satisfy various permit compliance requirements.

LLNL achieved 100% compliance during 1999 with LWRP wastewater discharge permit limits. Similarly, no sewer releases exceeded discharge limits for radioactive materials during 1999.

Surface Water Monitoring

Surface water sampling and analysis are a large part of the LLNL surveillance and compliance monitoring effort for the Livermore site, Site 300, and their surrounding areas. The waters monitored include storm water runoff, rainfall, water in the



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Livermore site Drainage Retention Basin, wastewater discharges from cooling towers at Site 300, and a variety of other water that includes off-site reservoirs and ponds, drinking water taps both on and off site, and the Livermore site swimming pool. Overall, the surface water monitoring data indicate compliance with established regulatory limits and negligible impact on the environment.

Radioactivity detected in the storm water was all at small percentages of the levels allowed in drinking water (referred to as the maximum contaminant level, or MCL). The maximum tritium concentration in storm water effluent at the Livermore site was 17% of the MCL. Plutonium was not detected in the liquid phase of any storm water samples. The sediment phase of one sample contained a low concentration of plutonium, which is consistent with worldwide fallout and naturally occurring concentrations.

Chemical monitoring of Livermore site storm water showed that concentrations of several metals were higher in effluent samples than influent samples. Acute and chronic fish toxicity tests conducted on Livermore site storm water demonstrated no toxicity to the test species. Allowable lead concentration was slightly exceeded in one release from the Drainage Retention Basin. Site 300 storm water contained levels of specific conductance and total suspended solids higher than comparison criteria; however, these effluent levels were lower than the off-site background levels. Sampling results from the Site 300 cooling towers effluent indicated compliance with all limits with the exception of one high flow measurement that was the result of a malfunctioning mechanical valve.

Tritium measurements in rain showed a slight increase in 1999 over the measurements in 1998. The maximum on-site measurement in 1999 was 73% of the MCL. In drinking water sources, the maximum tritium concentration was less than 0.05% of the MCL.

Ground Water Monitoring

Ground water in the Livermore Valley and the Altamont Hills is monitored to assess the progress of remediation efforts in areas of known contamination, to test the impact of LLNL operations on local water sources, and to comply with numerous federal, state, and local permits. Ground water samples are routinely measured for tritium, uranium, and other radioisotopes; gross radioactivity; toxic metals; a wide range of organic chemicals; and other general contaminant indicators. Special consideration is given to monitoring those dissolved elements and organic compounds that are known to be toxic in trace amounts.



The impact of Livermore site and Site 300 operations on off-site ground water continued to be minimal in 1999. In the Livermore Valley, no monitored radioactive or inorganic nonradioactive constituent was found to exceed primary drinking water MCLs in any off-site well. In on-site wells, chromium and nitrates have been detected above the primary MCLs, but these constituents have not migrated off site at levels above the primary MCL. The maximum tritium activity detected in any sample of ground water measured in the Livermore Valley was 1.4% of the MCL, as measured at an on-site location. At Site 300, tritiated water and depleted uranium have been released to ground water from landfills and firing tables, but the boundaries of the slowly moving ground water plumes lie entirely within site boundaries. The shallow ground water beneath Site 300 contains volatile organic compounds (VOCs), tritium, nitrate, Freon, perchlorate, and depleted uranium, but it presents no current health risks because this contaminated water is not used as a potable water supply for domestic, industrial, or agricultural use. LLNL works with the regulatory agencies to contain or clean up ground water contamination where needed.

Soil and Sediment Monitoring

The impact of Laboratory operations on soil and sediment at the Livermore site in 1999 was insignificant and unchanged from previous years. The highest level of plutonium (isotopes 239 and 240) measured at the LWRP represented 1.9% of the EPA preliminary remediation goal for commercial or industrial sites. Other constituents of concern were measured at background or trace concentrations or were below the limit of detection. At Site 300, the concentrations of radionuclides and beryllium in soil samples were generally representative of background or naturally occurring levels, as in previous years. Elevated concentrations of uranium-238 found in Site 300 soils in 1999 were attributed to contamination by debris from firing-table experiments.

Sampling of the vadose zone, carried out as part of the Livermore Ground Water Management Program, showed that ground water on the Livermore site is not being affected by contaminants carried in storm water.

Soil was sampled at Big Trees Park in Livermore during August and September of 1998 to provide information about the vertical and lateral distribution of plutonium in the soil, the pathway by which plutonium got to the park, and the distribution of plutonium in areas of public concern. All sample results indicated that plutonium concentrations were below the risk-based preliminary remediation goal for residential areas. In a January 2000 report, the Agency for Toxic Substances and Disease Registry (ATSDR) stated that the use of plutonium-contaminated sewage sludge as a soil amendment was the most credible pathway by which plutonium reached the park. The EPA, the



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California Department of Health Services, and ATSDR all concurred that there was no unacceptable risk to human health or the environment from the levels of plutonium present at Big Trees Park.

Vegetation and Foodstuff Monitoring

LLNL impacts on vegetation and food in the Livermore Valley remained minimal in 1999. Tritium, which is the only measurable radionuclide in the vegetation and foodstuff monitoring program, was estimated to be well below levels of concern, even when organically bound tritium was taken into account. In 1999, tritium concentrations in wines from the Livermore Valley, California, and Europe are within the range of those reported in previous years and remain low in wines from all areas. Even the highest detected tritium value in Livermore Valley wine represented only 1.1% of the amount of tritium that EPA allows in drinking water (no health standards exist for radionuclides in wine).

Radiological Dose Assessment

Radiological dose-assessment modeling—using conservative EPA-mandated computer models, actual LLNL meteorology, population distributions appropriate to the two sites, and 1999 radionuclide usage inventory and monitoring data—was conducted this past year for key facilities. Emissions from more than 200 points were reported in 1999. These sources were of several types: stacks and other exhaust pathways from buildings, diffuse area sources generally external to buildings, and open-air firing tables at Site 300 where explosives experiments were conducted.

LLNL reports public doses resulting from air releases of radionuclides during routine operations and from accidents. The principal exposure pathways taken into account are internal exposures from inhalation of air and ingestion of foodstuff and drinking water contaminated by the air releases. Releases of radioactivity from LLNL via water do not directly contribute to the public dose because this water is not used as a potable water supply for domestic, industrial, or agricultural use.

The most significant radiological effluent for the Livermore site from the standpoint of public dose continues to be tritium, the radioactive isotope of hydrogen. The calculated total potential dose for the sitewide maximally exposed individual (SW-MEI), (i.e., a hypothetical member of the public having the greatest possible exposure from Livermore site operations in 1999) was 1.0 microsievert (0.1 millirem). This result was calculated based on LLNL's standard assumptions regarding potential public dose



caused by tritium releases. In 1998, the EPA mandated that LLNL's compliance evaluations use a more conservative assumption, in which gaseous tritium must be treated as though it were tritiated water vapor. This translates to a higher calculated dose of 1.20 microsievert (0.12 millirem) to the SW-MEI. Trends in this SW-MEI dose for the Livermore site over the last eight years show levels in the range 1.0 to 0.4 microsievert per year (0.1 to 0.04 millirem per year), down from 2.40 microsievert per year (0.24 millirem per year) in 1990. These small radiation quantities exhibit large percentage but small absolute value fluctuations from year to year.

At Site 300, depleted uranium (containing isotopes with atomic weights 238, 235, and 234) remains by far the principal contributor to off-site dose. The calculated total potential dose to the SW-MEI during 1999 was 0.35 microsievert (0.035 millirem). This is well within the range of doses calculated over the past 10 years.

Conservatively calculated radiological doses to the maximally exposed public individuals from Livermore site and Site 300 emissions amounted to about 1.0% (1.2% using EPA assumptions) and 0.35%, respectively, of the EPA National Emission Standards for Hazardous Air Pollutants regulatory standard. These doses are a small fraction (about 1/2500) of the doses received by these populations from natural background radiation. Thus, the potential radiological doses from LLNL operations in 1999 were well within regulatory limits and were very small compared with doses from natural background radiation sources.

Environmental Compliance and Program Activities

LLNL works to ensure that its operations comply with all environmental laws and federal, state, and local regulatory guidelines. Many activities related to water, air, waste, waste reduction, community "right to know," and other environmental issues were addressed in 1999.

Ground Water Remediation

As a Superfund site, LLNL continued to treat ground water at both the Livermore site and Site 300 under the jurisdiction of the Comprehensive Environmental Response, Compensation and Liability Act. LLNL's primary treatment method to remediate contaminated ground water is pump-and-treat technology. In 1999, nearly 270 kilograms of VOCs were removed from 1.1 billion liters of ground water and 20,000 cubic meters of water vapor from soil at the Livermore site. These efforts at control and remediation have reduced VOC concentrations throughout the site and reduced plume sizes.



New treatment facilities were added to the Treatment Facility A (TFA) and TF5475 areas. TFA-East, which began operating in 1999, consists of one extraction well. A portable solar-powered unit treats the extracted ground water. Vapor Treatment Facility (VTF) 5475, which began operation in early 1999, extracts soil vapor from the vadose zone using a vapor extraction system. The soil vapor is processed using granulated activated carbon. Because of elevated tritium concentrations in the vadose zone, VTF5475 was designed as a closed-loop system. Following removal of VOCs from the process air stream, the tritiated vapor is reinjected into the subsurface at a soil vapor inlet well, and no effluent vapor is released to the atmosphere.

Significant progress was also made at Site 300, where 39 kilograms of VOCs were removed from soil and ground water. In addition to the three treatment facilities, which operated throughout the year, three new treatment facilities were constructed and began operation in 1999. In the Eastern General Services Area, the plume of high (>500 parts per billion) trichloroethene (TCE) concentrations has been restricted to the Site 300 property. It had previously extended more than 1600 m beyond the site boundary before the treatment facility started up in 1991. With only a few minor exceptions, treated ground water discharges and VOCs vented to air were within permit limits during 1999.

Waste Minimization and Pollution Prevention

LLNL continues to employ a weighted ranking system to prioritize and evaluate its waste streams. Cost, type of waste, and operational aspects are emphasized rather than simple considerations of total waste volume. Transuranic and transuranic-mixed and low-level wastes continue to be of highest priority for LLNL even though their relative quantities are low.

Comparing 1999 with the 1993 baseline, levels of waste in three of the four categories—radioactive, hazardous, and mixed—have decreased by more than the 50% specified in LLNL's contract with UC. The total waste diverted from landfills in 1999 was more than 47,000 tons, comparable to the 1998 total. Although LLNL has not yet achieved a 33% reduction goal for routine nonhazardous waste, its recycling percentage for nonhazardous waste was 89% in 1999.

The Laboratory has a Chemical Exchange Warehouse (CHEW) that enables employees to locate needed chemicals already on site. By reducing the need to buy new chemicals, production of waste is minimized. Employees can use ChemTrack, LLNL's computerized



chemical inventory system, to search for chemicals in CHEW. In 1999, ChemTrack tracked 176,000 chemicals through the use of bar codes, hand-held bar code laser scanners, and customized software.

Air, Wastewater, and Water Compliance

LLNL continued to perform all activities necessary to comply with clean air and clean water requirements. In 1999, the Bay Area Air Quality Management District issued or renewed 137 operating permits for the Livermore site. The San Joaquin Valley Unified Air Pollution Control District issued or renewed 47 permits for Site 300 operations. LLNL has permits for underground and aboveground storage tanks and for discharge of treated ground water, industrial and sanitary sewage, and storm water. Site 300 has additional permits for inactive landfills, cooling tower discharges, operation of the sewer lagoon, septic tanks, and leach fields. The Laboratory complies with all requirements for self-monitoring and inspections associated with these permits.

Endangered Species

LLNL meets the requirements of both the U.S. Endangered Species Act and the California Endangered Species Act as they pertain to endangered or threatened species and other species of special concern that may exist or are known to exist at the LLNL sites. In 1999, biological assessment surveys were performed for special-status species at 76 LLNL project construction (ground disturbance) areas. Although no active San Joaquin kit fox dens were discovered, 10 occupied American badger dens were found. In addition, 18 active burrowing owl dens were discovered at Site 300; the owls were marked with leg bands to initiate long-term studies, monitoring, and conservation of the species. A population of the federal candidate species California tiger salamander (*Ambystoma tigrinum*) was monitored, and a Livermore site population of the federally threatened red-legged frog (*Rana aurora draytonii*) was monitored and protected. Also at the Livermore site, three separate pairs of white-tailed kites (*Elanus leucurus*), a state-protected raptor, successfully nested and fledged 18 young.

Two of the three known natural populations of the large-flowered fiddleneck (*Amsinckia grandiflora*), a federally listed endangered plant species, occur at Site 300, where a portion of the site has been designated as critical habitat for the plant. In spite of attempts to reduce competing grass in 1998, the number of native plants continued to decline in 1999. Investigations into the use of controlled burns and rodent predation on seed population are currently planned.



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Monitoring of the big tarplant (*Blepharazonia plumosa*), a California Native Plant Society "rare" plant, and the Diamond-petaled poppy (*Eschscholzia rhombipetala*), a plant previously thought to be extinct, continued in 1999. The big tarplant continued to be widespread throughout Site 300, although the individual populations were reduced in size. A total of nine Diamond-petaled poppy plants were located; of these, six plants produced seed-bearing pods.

Environmental Occurrences

Notification of environmental occurrences at the Laboratory is required by a number of environmental laws, regulations, and DOE orders. LLNL responded to four incidents that required federal and/or state agency notification during 1999. None of these caused adverse impact to human health or the environment.

Work Smart Standards

In 1997, LLNL and DOE's Oakland Operations Office inaugurated a Work Smart Standard (WSS) process. As part of this process, safety and environmental professionals from both organizations identified environment, safety, and health hazards and established standards of operation to protect the public, workers, and the environment from these hazards. WSSs were implemented in 1999 and include more than 250 requirements directly related to the environment.

Conclusion

The current techniques LLNL uses for environmental monitoring are very sensitive, allowing detection of extremely low levels of constituents. The combination of surveillance and effluent monitoring, source characterization, and computer modeling shows that radiological doses to the public caused by LLNL operations are less than 1% of regulatory standards and are about 2500 times smaller than the doses received from natural background radiation. The analytical results and evaluations generally show continuing low contaminant levels, reflecting the responsiveness of the Laboratory in controlling pollutants.

In 1999, LLNL successfully engaged in environmental compliance activities related to water, air, waste, waste reduction, and other environmental issues. Some key examples include ground water remediation activities that restricted a high TCE plume at Site 300,



waste minimization efforts that reduced the amount of waste generated in LLNL operations, and recycling efforts that diminished the quantity of waste sent to landfills. Actions to protect endangered species at both LLNL sites continued on several fronts.

In summary, the results of the 1999 environmental programs demonstrate that LLNL is committed to protecting the environment and ensuring that its operations are conducted in accordance with applicable federal, state, and local laws and regulations. The environmental impacts of LLNL operations are minimal and pose no threat to the public or the environment.

Site Overview

Introduction

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

Operations

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

LLNL is a full-service research laboratory with the infrastructure—engineering, maintenance, and waste management activities, as well as security, fire, and medical departments—necessary to support its operations and about 8700 personnel.

Location

LLNL consists of two sites—the main laboratory site located in Livermore, California (Livermore site) in Alameda County, and the Experimental Test Site (Site 300) located near Tracy, California, in San Joaquin and Alameda counties (**Figure 1-1**). Each site is unique, requiring a different approach for environmental monitoring and protection.



1 Site Overview

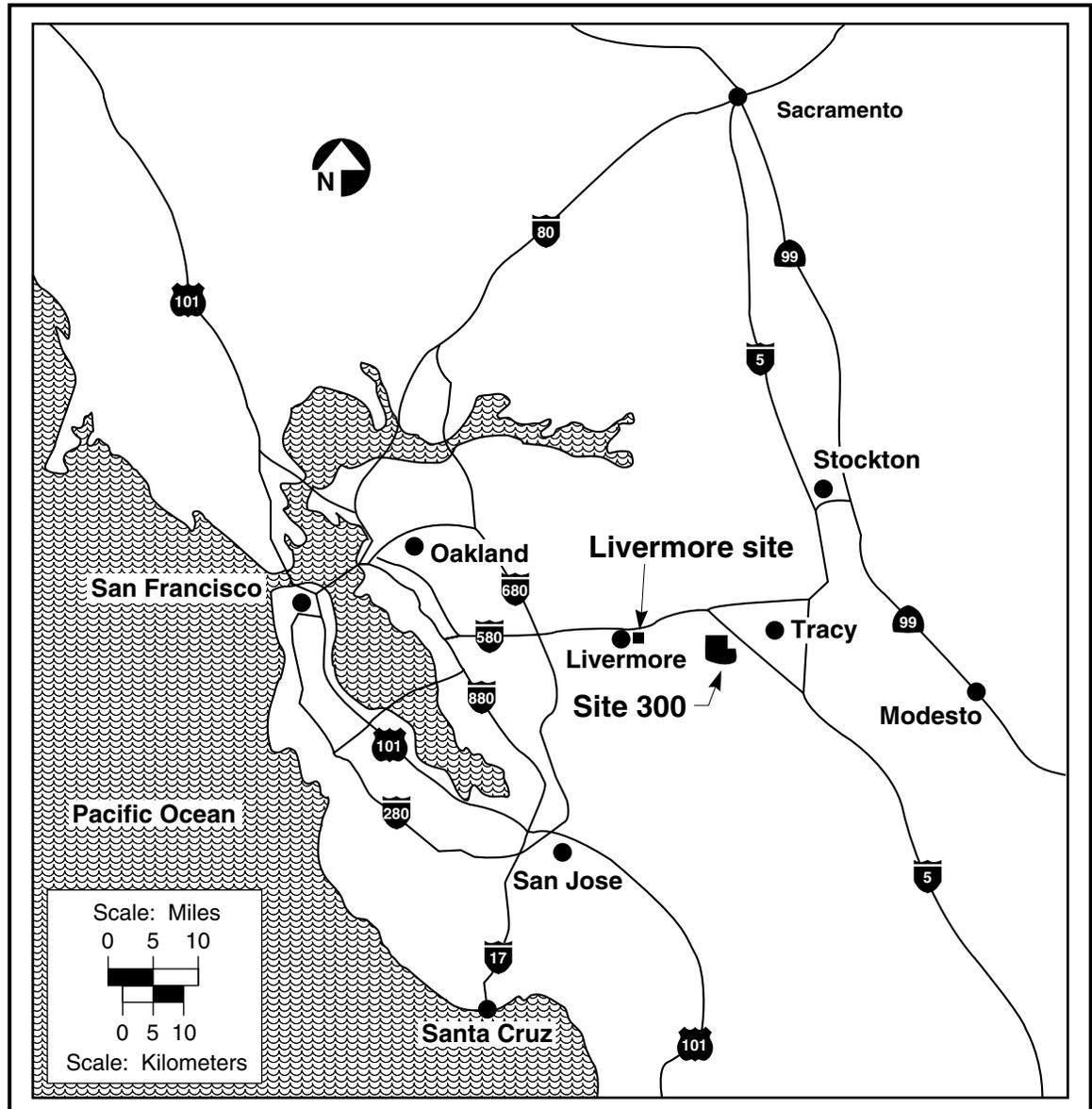


Figure 1-1. Locations of LLNL Livermore site and Site 300.

LLNL was founded at the Livermore site in 1952 at a former U.S. Navy training base. At that time the location was relatively isolated, being approximately 1.6 km from the Livermore city limits. Over time, Livermore evolved from a small town of fewer than 7000 people when the Laboratory began to its present population of about 74,300. The economy, which had been primarily agricultural, diversified to include light industry and business parks. Within the last few years, low-density, single-family



residential developments have begun to fill the formerly vacant fields. Livermore residences are now near LLNL's western boundary.

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

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

Site 300, LLNL's Experimental Test Facility, is located 20 km east of the Livermore site in San Joaquin and Alameda counties in the Altamont Hills of the Diablo Range; it occupies an area of 30.3 km². It is in close proximity to two other testing sites: PRIMEX/Physics International operates a testing site that is adjacent and to the east of Site 300, and SRI International operates another site, located approximately 1 km south of Site 300. 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 54,200), located 10 km to the northeast.

Meteorology

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



1 Site Overview

temperature for both sites in 1999 was 15°C. Temperatures range from 5°C during some predawn winter mornings to 40°C during some summer afternoons.

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

Annual wind data for the Livermore site are given in **Figure 1-2** and **Table 1-1**. These data show that greater than 50% of the wind comes from the south-southwest to westerly direction. Based on a ten-year record, the highest and lowest annual rainfalls were 541 and 211 mm, and the average annual rainfall was 360 mm. In 1999, the Livermore site received 245 mm of rain.

The meteorological conditions at Site 300, while generally similar to those at the Livermore site, are modified by higher elevation and more pronounced topological relief. The complex topography of the site significantly influences local wind and temperature patterns. Annual wind data are presented in **Figure 1-3** and **Table 1-2**. The data show that winds are more consistently from the west-southwest and reach greater speeds than at the Livermore site. The increased wind speed and elevation of much of Site 300 result in afternoon temperatures that are typically lower than those for the Livermore site. Rainfall for 1999 was 198 mm at Site 300.

Topography

The Livermore site is located in the southeastern portion of the Livermore Valley, a topographic and structural depression oriented east-west within the Diablo Range of the California Coast Range Province. The Livermore Valley, the most prominent valley in the Diablo Range, is an east-west trending structural and topographic trough that is bounded on the west by Pleasanton Ridge and on the east by the Altamont Hills. The valley floor is covered by alluvial, lake, and swamp deposits consisting of gravels, sands, silts, and clays, at an average thickness of about 100 m. The valley is approximately 25-km long and averages 11 km in width. The valley floor is at its highest elevation of 220 m above sea level along the eastern margin and gradually dips to 92 m at the southwest corner. The major streams passing through the Livermore Valley are Arroyo del Valle and Arroyo Mocho, which drain the southern highlands and flow intermittently. Major arroyos are depicted in Chapter 7 (**Figure 7-1**).

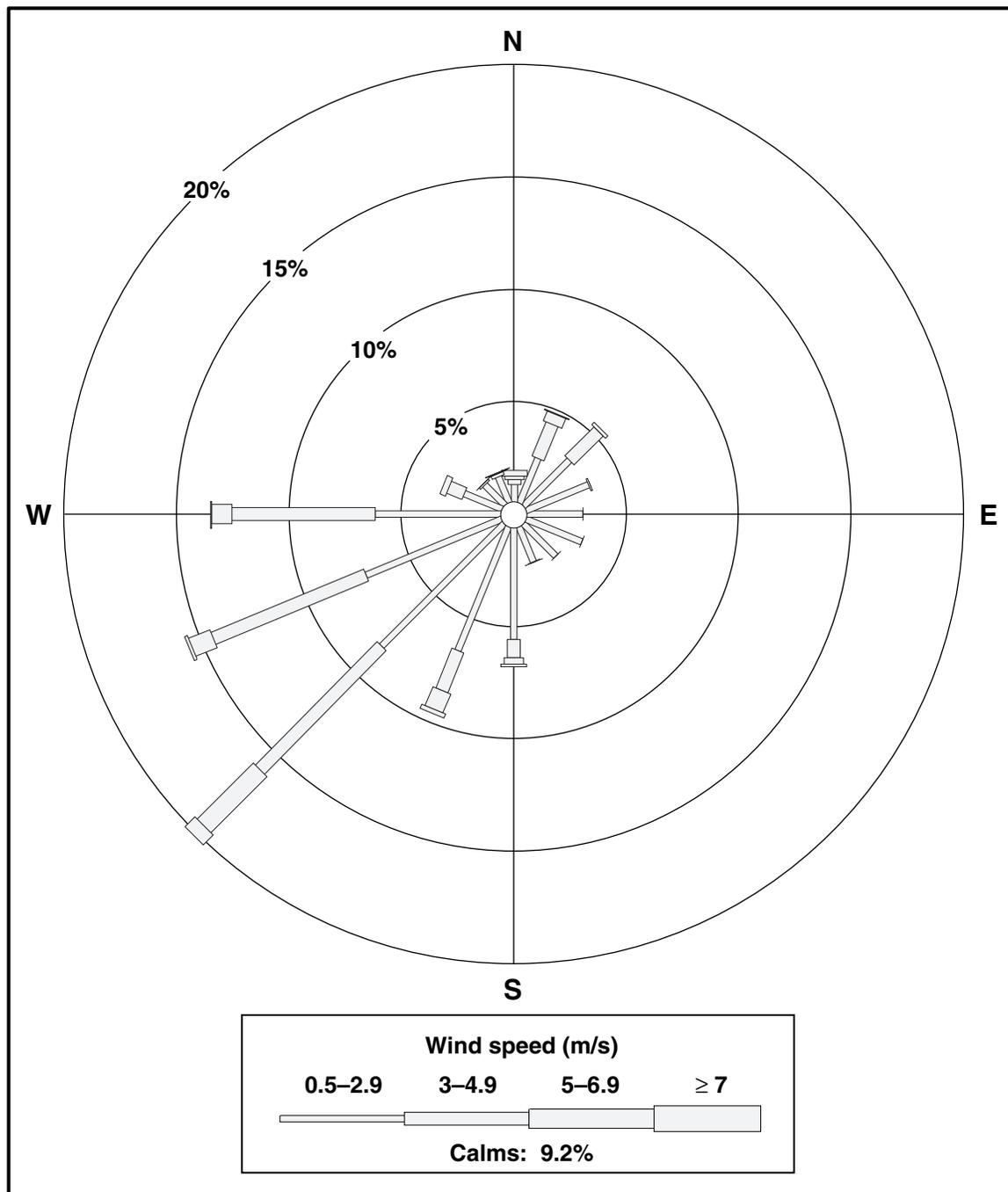


Figure 1-2. Wind rose showing the frequency of occurrence for wind speed and direction at the Livermore site, 1999.



1 Site Overview

Table 1-1. Wind rose data for LLNL's Livermore site at the 10-m level for 1999. Values are frequency of occurrence (in percent). Columns and rows may not exactly sum to the listed totals because of rounding.

Direction	Wind speed range (m/s)					Total
	0.0-0.4	0.5-2.9	3.0-4.9	5.0-6.9	≥7.0	
NNE	0.58	2.11	1.66	0.46	0.05	4.9
NE	0.58	2.84	1.83	0.14	0.00	5.4
ENE	0.58	2.92	0.08	0.00	0.00	3.6
E	0.58	2.41	0.03	0.00	0.00	3.0
ESE	0.58	2.61	0.02	0.00	0.00	3.2
SE	0.58	2.00	0.00	0.00	0.00	2.6
SSE	0.58	1.65	0.00	0.03	0.00	2.3
S	0.58	4.95	0.81	0.29	0.11	6.7
SSW	0.58	5.96	1.89	0.90	0.23	9.6
SW	0.58	7.71	7.72	3.51	0.65	20.2
WSW	0.58	8.44	5.48	0.97	0.16	15.6
W	0.58	5.43	6.52	0.96	0.05	13.5
WNW	0.58	1.86	0.74	0.26	0.00	3.4
NW	0.58	1.31	0.09	0.02	0.00	2.0
NNW	0.58	1.26	0.14	0.03	0.03	2.0
N	0.58	0.76	0.23	0.14	0.27	2.0
Total	9.3	54.2	27.2	7.7	1.6	100

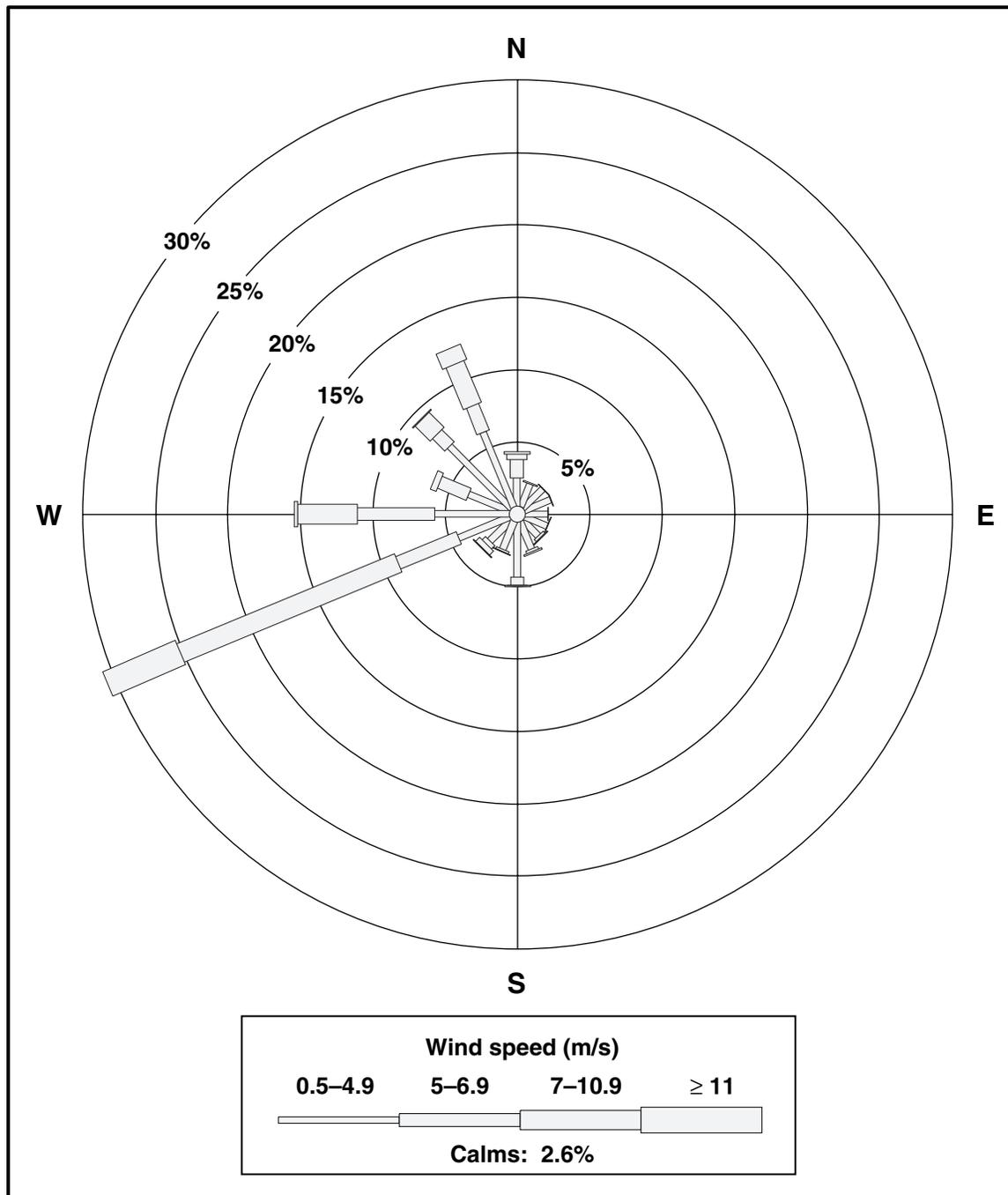


Figure 1-3. Wind rose showing the frequency of occurrence for wind speed and direction at Site 300, 1999.



1 Site Overview

Table 1-2. Wind rose data for LLNL's Site 300 at the 10-m level for 1999. Values are frequency of occurrence (in percent). Columns and rows may not exactly sum to the listed totals because of rounding.

Direction	Wind speed range (m/s)					Total
	0.0–0.4	0.5–4.9	5.0–6.9	7.0–10.9	≥11.0	
NNE	0.16	1.69	0.05	0.00	0.00	1.9
NE	0.16	1.91	0.03	0.00	0.00	2.1
ENE	0.16	1.91	0.00	0.00	0.00	2.1
E	0.16	1.53	0.05	0.00	0.00	1.7
ESE	0.16	1.62	0.03	0.03	0.00	1.8
SE	0.16	1.50	0.19	0.07	0.00	1.9
SSE	0.16	2.04	0.17	0.10	0.00	2.5
S	0.16	3.77	0.56	0.06	0.00	4.6
SSW	0.16	2.06	0.16	0.03	0.00	2.4
SW	0.16	2.09	0.33	0.38	0.05	3.0
WSW	0.16	3.78	4.56	16.2	5.46	30.2
W	0.16	5.20	5.33	4.09	0.25	15.0
WNW	0.16	4.04	1.21	0.45	0.00	5.9
NW	0.16	6.08	1.20	1.46	0.06	9.0
NNW	0.16	5.65	2.56	2.47	1.12	12.0
N	0.16	1.94	1.29	0.37	0.17	3.9
Total	2.6	46.8	17.7	25.8	7.1	100



The topography of Site 300 is much more irregular than that of the Livermore site; a series of steep hills and ridges is oriented along a generally northwest-southeast trend and is separated by intervening ravines. The Altamont Hills, where Site 300 is located, are part of the California Coast Range Province and separate the Livermore Valley to the west from the San Joaquin Valley to the east. The elevation ranges from approximately 538 m above sea level at the northwestern corner of the site to approximately 150 m in the southeast portion.

Hydrogeology

Livermore Site

The hydrogeology and movement of ground water 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; and Thorpe et al. 1990). This section has been summarized from the reports of these investigations and from data supplied by Alameda County Flood Control and Water Conservation District Zone 7, the agency responsible for ground water management in the Livermore Valley basin (San Francisco Bay Regional Water Quality Control Board 1982a and b).

The Livermore Formation (and overlying alluvial deposits) contains the aquifers of the Livermore Valley ground water basin, an important water-bearing formation. Natural recharge occurs primarily along the fringes of the basin and through the arroyos during periods of winter flow. Artificial recharge, if needed to maintain ground water levels, is accomplished by releasing water from Lake Del Valle or from the South Bay Aqueduct into arroyo channels in the east. Ground water flow in the valley generally moves toward the central east-west axis of the valley and then westward through the central basin. Ground water 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. **Figure 1-4** shows a contour map of water table elevations (meters above mean sea level) for the Livermore site area. Although water table elevations vary slightly with seasonal and year-to-year differences in both natural and artificial recharge, the qualitative patterns shown in **Figure 1-4** are generally maintained. At the eastern edge of the Livermore site, ground water 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.



1 Site Overview

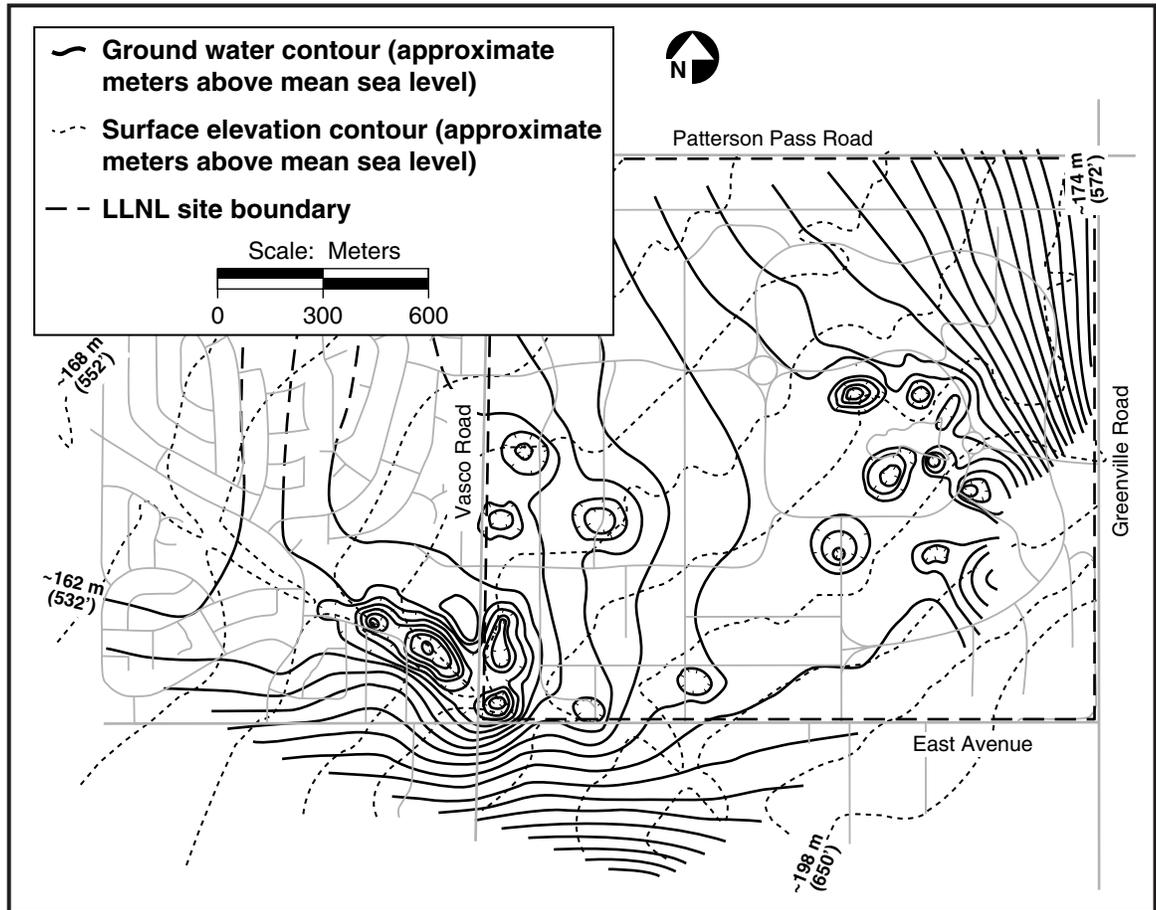


Figure 1-4. 1999 approximate ground water and surface elevation contours, Livermore site and vicinity.

Ground water flow under most of the site is southwesterly. This flow direction diverges from the generally westward regional flow and from flow patterns demonstrated for the site in the 1980s. This shift in flow direction is a consequence of ground water recovery and remediation in the southwest portion of the site and agricultural pumping. Aquifer tests on monitoring wells in the vicinity of the Livermore site indicate that the hydraulic conductivity (a measure of the rate of flow) of the permeable sediments ranges from 1 to 16 m/day (Isherwood et al. 1991). This, in combination with the observed water table gradients, yields an estimated average ground water velocity of 20 m/y (Thorpe et al. 1990). The range in these values reflects the heterogeneity typical of the more permeable alluvial sediments that underlie the area.



Site 300

Gently dipping sedimentary bedrock dissected by steep ravines generally underlies Site 300. The bedrock is made up primarily of interbedded sandstone, siltstone, and claystone. Most ground water occurs in the Neroly Formation upper and lower blue sandstone aquifers. Significant ground water is also locally present in permeable Quaternary alluvium valley fill. Much less ground water 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 ground water and act as aquitards, confining layers, or perching horizons. Ground water is present under confined conditions in parts of the deeper bedrock aquifers but is generally unconfined elsewhere.

Ground water flow in most aquifers follows the attitude of the bedrock. In the north-west part of Site 300, ground water 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, ground water in bedrock flows roughly south-southeast, approximately coincident with the attitude of bedrock strata.

The thick Neroly lower blue sandstone, stratigraphically near the base of the formation, generally contains confined water. Wells located in the western part of the General Services Area (GSA) (see **Figure 8-8**) are completed in this aquifer and are used to supply drinking and process water.

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

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



1 Site Overview

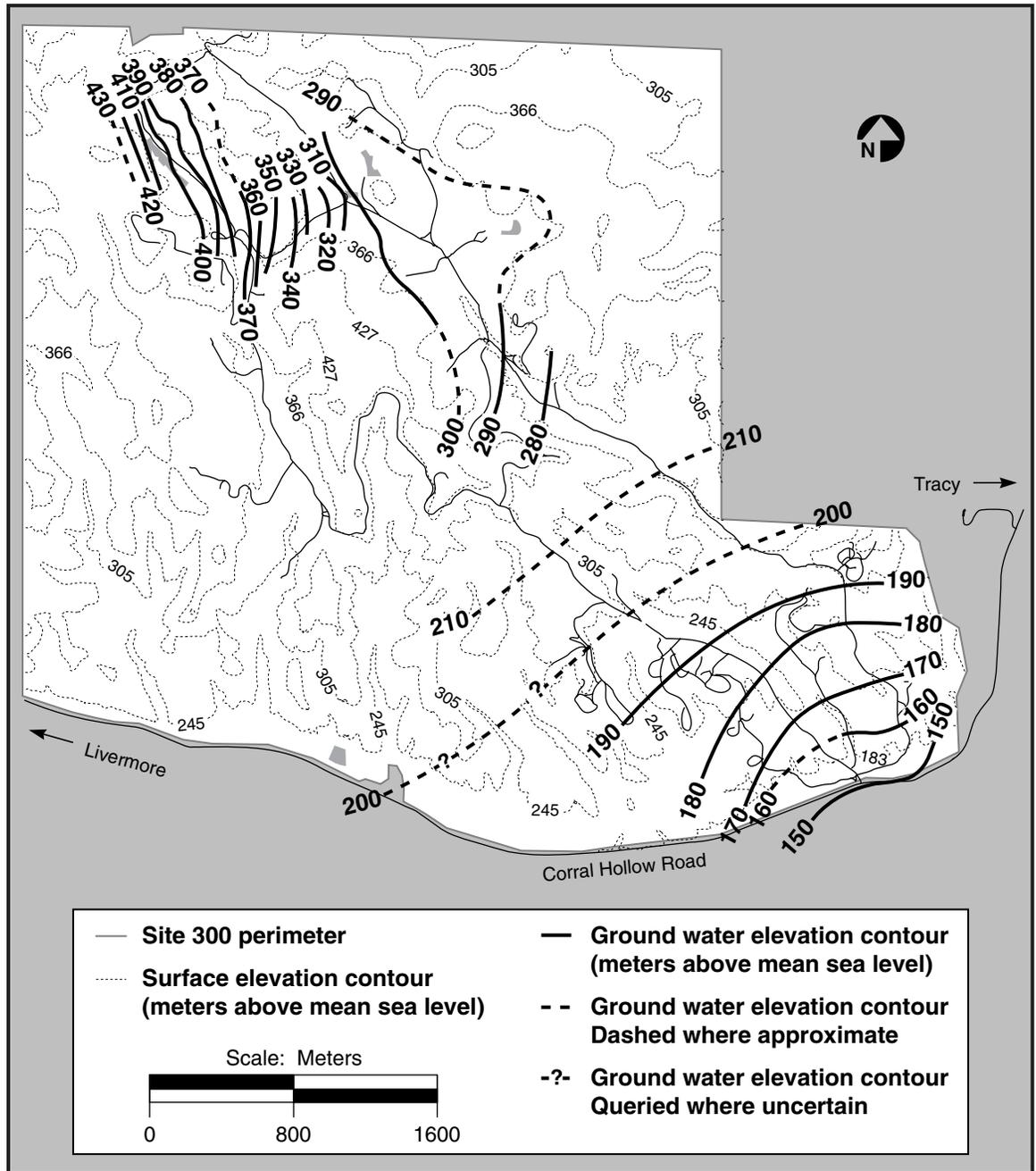


Figure 1-5. 1999 approximate ground water elevations in the principal continuous water-bearing zone at Site 300.

Further information on the hydrology of both the Livermore site and Site 300 can be found in the ground water protection information in Chapters 8 and 9.



Summary

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

We acknowledge the work of Frank Gouveia, Michael Taffet, Richard Blake, William Hoppes, and Janice Butler in preparing this chapter.

Compliance Summary

Introduction

During 1999, Lawrence Livermore National Laboratory (LLNL) participated in numerous activities to comply with federal, state, and local environmental regulations as well as internal requirements and Department of Energy (DOE) orders. This chapter, which is organized according to the various laws and regulations that drive LLNL's compliance activities, describes the activities the Laboratory carried out related to air, water, waste, waste reduction, community "right to know," protection of sensitive resources, and other environmental issues at the Livermore site and Site 300. A wide range of compliance activities is summarized in this chapter. Compliance activities specific to DOE Orders 5400.1 and 5400.5 are discussed in the chapters that follow. Many documents concerned with these activities and other environmental topics are available for public viewing at the LLNL Visitors Center and the Livermore and Tracy public libraries.

Comprehensive Environmental Response, Compensation and Liability Act

The Livermore Site Ground Water Project (GWP) and the Site 300 CERCLA Project are under the jurisdiction of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)/Superfund Amendment and Reauthorization Act, Title 1. As part of work on these projects, DOE and LLNL also continued with environmental restoration and community relations activities. These projects and activities are described in the following sections.

Livermore Site Ground Water Project

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



2 Compliance Summary

underground tank systems), continuous monitoring, and remediation of ground water. The ground water contaminants (constituents of concern) are volatile organic compounds (VOCs), primarily trichloroethene (TCE) and tetrachloroethene (PCE). For the most part, these contaminants are present within the site boundary and to some extent at the site boundary and beyond, mainly to the west and south of the site (see **Figures 8-3 to 8-7**, Chapter 8). In 1999, GWP activities included preparing the required CERCLA documents, meeting milestones, operating ground water treatment facilities, and maintaining liaison with community groups.

Documentation

As required by the Livermore site FFA, DOE and LLNL issued the *1999 Ground Water Project Annual Report* (Aarons et al. 2000) on March 23, 1999. DOE and LLNL also finalized and issued Remedial Project Manager (RPM) meeting summaries. Quarterly self-monitoring data were reported in letter reports (Bainer and Joma 2000a, 2000b). LLNL also issued an updated *Quality Assurance Project Plan* (Dibley 1999).

A draft explanation of significant differences, submitted on December 14, 1999, for regulatory review, described proposed changes to the planned ground water treatment system at Trailer 5475 to allow ground water containing both VOCs and tritium above their maximum contaminant levels (MCLs) to go through an aboveground treatment unit (Berg 1999).

DOE and LLNL began preparing a draft action memorandum (Berg and Bainer 2000) for a time-critical removal action for soil containing residual polychlorinated biphenyls (PCBs) in the East Traffic Circle. The document will be finalized in 2000.

Milestones and Activities

LLNL has completed all the *1999 Remedial Action Implementation Plan (RAIP)* milestones (Table 5 in Dresen et al. 1993) for the Livermore site ahead of schedule. For a detailed list of these milestones and corresponding dates, please see **Table 8-1** in Chapter 8. Details of 1999 environmental restoration activities are discussed in the *LLNL Ground Water Project 1999 Annual Report* (Aarons et al. 2000).

Treatment Facilities

In 1999, LLNL operated ground water treatment facilities in the TFA, TFB, TFC, TFD, TFE, TFG, TF406, TF518, and TF5475 areas (see **Figure 8-1** in Chapter 8). Sixty-nine ground water extraction wells operated at 20 separate locations, treating about 3,161,000 liters of ground water per day. The vapor treatment facilities VTF518 and



VTF5475 treated about 3000 m³ of vapor per day. Together, these treatment facilities removed approximately 269 kg of VOCs in 1999. Since remediation efforts began in 1989, more than 4.5 billion liters of ground water and approximately 477,480 m³ of vapor have been treated, and about 752 kg of VOCs have been removed. Remediation activities at the Livermore site are discussed in greater detail in Chapter 8.

Community Relations

The Community Work Group met once in 1999 to discuss the DOE budget, progress on the Livermore site cleanup, and the Livermore Site Priority List/Consensus Statement. LLNL continued to correspond and communicate with Community Work Group members throughout the year. DOE and LLNL met four times with members of Tri-Valley Communities Against a Radioactive Environment (CAREs) and its scientific advisor as part of the activities funded by an EPA technical assistance grant.

Other Livermore site community relations activities in 1999 included communications and meetings with neighbors; local, regional, and national interest groups; and other community organizations. LLNL also conducted public presentations, including those to local realtors and to national and northern California peace leaders; produced and distributed the Environmental Community Letter; maintained the information repositories and the administrative record; conducted tours of the site environmental activities; and responded to public and news media inquiries. In addition, LLNL now conducts some community relations activities electronically, answering questions and sending responses via electronic mail. LLNL also posts documents, letters, and public notices on the Internet at the following address: <http://www-envirinfo.llnl.gov/>

Site 300 CERCLA Project

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

During 1999, LLNL submitted all required regulatory documents (see Chapter 8) on or ahead of schedule, performed all actions stipulated in the FFA, and maintained liaison with community groups. Results and status for Site 300 environmental restoration study areas are discussed in Chapter 8. Background information for LLNL environmental



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characterization and restoration activities at Site 300 can be found in the *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300* (Webster-Scholten 1994).

Documentation

LLNL submitted the required documentation to oversight agencies on time in 1999. The *Draft Final* and *Final Site-Wide Feasibility Study* (Ferry et al. 1999a,b), *Draft Final Proposed Plan for Environmental Cleanup* (Dresen et al. 1999), quarterly reports, and work plans were among the documents submitted.

Milestones and Activities

LLNL has completed all the 1999 FFA milestones for Site 300 on or ahead of schedule. For a detailed list of these milestones and corresponding dates, please see **Table 8-2** in Chapter 8.

Treatment Facilities

VOCs (primarily TCE) are the main contaminants at Site 300. High explosives, tritium, depleted uranium, organosilicate oil, nitrates, and perchlorates are also found in ground water. Three treatment facilities that remove and treat VOCs operated throughout 1999. Additionally, three new treatment facilities were constructed and began operation at Site 300 during 1999. These facilities are discussed in more detail in Chapter 8. Eighteen wells that extract ground water only, and 17 wells that extract both ground water and soil vapor operated during 1999, treating about 84.5 million liters of ground water. The 17 wells that extract both vapor and ground water and three wells that extract vapor only, together removed 431,000 m³ of vapor. In 1999, the Site 300 treatment facilities removed approximately 39 kg of VOCs. Since remediation efforts began in 1990, more than 565 million liters of ground water and approximately 1.58 million m³ of vapor have been treated, to yield about 141 kg of removed VOCs. Chapter 8 also includes maps of the study areas and details of the distribution of contaminants in ground water at Site 300.

Community Relations

The Site 300 CERCLA project maintains proactive communication with the surrounding communities of Tracy and Livermore. Community relations activities in 1999 included maintenance of the information repositories and administrative records; Site 300 tours for scientists and students from universities and local public schools; off-site, private well-sampling activities; and preparation of a fourth Site 300 Environmental Restoration



fact sheet (Heffner 1999). Quarterly meetings were held with Tri-Valley CAREs, which receives an annual technical assistance grant from EPA to independently evaluate CERCLA activities at Site 300. A tour of Site 300 CERCLA activities was also conducted for Tri-Valley CAREs.

In March 1999, the remedial project managers held a public workshop to present the initial selection of remedial alternatives in the *Draft Site-Wide Feasibility Study* (Ferry et al. 1999a) to the community. In December 1999, a second public workshop was held to present the *Draft Final Proposed Plan for Environmental Cleanup* (Dresen et al. 2000).

Site Evaluations Prior to Construction

Before any construction begins, the CERCLA Record of Decision requires that the project site be evaluated to determine if soil or rubble (concrete and asphalt) is contaminated. Soil is sampled and analyzed for potential radioactive and/or hazardous contamination. Depending on the analytical results, soil may be reused on site or disposed of according to established procedures. Depending on the potential for radioactive contamination, rubble may be either surveyed or analyzed for radioactivity. During 1999, soil and rubble were evaluated at 75 construction sites.

Agency for Toxic Substances and Disease Registry Assessment

The Agency for Toxic Substances and Disease Registry (ATSDR) is a federal public health agency whose mission is to prevent exposure and adverse human health effects and diminished quality of life associated with exposure to hazardous substances from waste sites, unplanned releases, and other sources of pollution in the environment. As part of its mission, ATSDR is mandated by Congress to conduct Public Health Assessments (PHAs) at sites, such as LLNL, that appear on the National Priorities List.

In 1999, ATSDR worked with the California Department of Health Services (CDHS) to complete a health consultation related to Livermore site operations, which will most likely be part of the final PHA for LLNL. This health consultation report assessed concerns related to the discovery of plutonium at levels above background in Big Trees Park in the City of Livermore.

Big Trees Park has been the object of public scrutiny since 1993, when a single soil sample was found to contain plutonium at a concentration higher than would have been



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expected from global fallout alone. In 1998, LLNL resampled soil in the park to determine the vertical and lateral extent of plutonium contamination and the likelihood of possible pathways. LLNL and ATSDR, in August 1999 and January 2000, respectively, published reports concluding that there was no systematic distribution of plutonium at depth, that the horizontal distribution is consistent with the application of plutonium-contaminated sewage sludge as a soil amendment, and that the most credible pathway to the park was the application of plutonium-contaminated sewage sludge as a soil amendment. The plutonium at the park was found to be below levels of health concern and below the recommended levels requiring additional activities. (See Chapter 10 for more information on the sampling and analysis.)

The ATSDR report, LLNL sampling documents, and regulatory statements can be viewed at the following address: <http://www-envirinfo.llnl.gov>

Superfund Amendment and Reauthorization Act, Title III

Title III of the Superfund Amendment and Reauthorization Act (SARA) is known as the Emergency Planning and Community Right-to-Know Act (EPCRA). It requires owners or operators of facilities that handle certain hazardous chemicals on site to provide information on the release, storage, and use of those chemicals to organizations responsible for emergency response planning. Executive Order 12856 directs all federal agencies to comply with the requirements of EPCRA, including SARA 313, Toxic Release Inventory Program.

EPCRA requirements and LLNL compliance are summarized in **Table 2-1**. **Tables 2-2** and **2-3** identify those chemicals and their hazards reported during 1999 by LLNL for the Livermore site and Site 300, respectively, under Title III, Section 311.

Clean Air Act—Air Quality Management Activities

Air permits are obtained from the Bay Area Air Quality Management District (BAAQMD) for the Livermore site and from the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) for Site 300. In 1999, BAAQMD issued or renewed air permits for 128 air emission sources for the Livermore site. In 1999, SJVUAPCD issued or renewed air permits for 47 air emission sources for Site 300 (see **Table 2-4**). During 1999, BAAQMD inspectors found no deficiencies at the



Livermore site (see **Table 2-5a** for a summary of inspections in 1999). At Site 300 SJVUAPCD conducted an inspection of emission sources and observed the start-up of an internal combustion engine; no deficiencies were found (see **Table 2-5b**). On October 19, 1999, SJVUAPCD issued permits to operate the explosive waste treatment units.

Table 2-1. Summary of LLNL compliance with EPCRA in 1999.

EPCRA requirement	Brief description	Compliance
302 Planning Notification	Operator must notify SERC ^(a) of presence of extremely hazardous substances. In California, operator must notify CEPRC ^(b) of presence of extremely hazardous substances above threshold planning quantities.	Originally submitted May 1987.
303 Planning Notification	Operator must designate a facility representative to serve as emergency response coordinator.	Updates submitted February 10, 1999, and May 20, 1999.
304 Release Notification	Releases of certain hazardous substances must be reported to SERC and LEPC. ^(c)	No EPCRA-listed extremely hazardous substances were released above reportable quantities.
311 MSDS ^(d) /Chemical Inventory	Operator must submit MSDSs or chemical list to SERC, LEPC, and Fire Department.	Tables 2-2 and 2-3. Updated May 20, 1999.
312 MSDS/Chemical Inventory	Operator must submit hazardous chemical inventory to appropriate county.	Business plans and chemical inventory submitted to San Joaquin County (December 11, 1998) and Alameda County (January 20, 1999).
313 Toxic Release Inventory	Operator must submit Form R to U.S. EPA and California EPA for toxic chemicals released.	Form R for Freon 113 submitted June 24, 1999, to DOE; DOE forwarded it to U.S. EPA and California EPA on June 30, 1999.

^a SERC = State Emergency Response Commission.

^b CEPRC = Chemical Emergency Planning and Response Commission.

^c LEPC = Local Emergency Planning Committee.

^d MSDS = material safety data sheet.



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Table 2-2. Livermore site, SARA, Title III, Section 311, Chemical List, 1999.^(a)

Livermore site chemicals	Physical hazard			Health hazard	
	Fire	Pressure	Reactivity	Acute	Chronic
Acetylene	•	•		•	
Air		•			
Ammonia, anhydrous		•		•	
Ammonium hydroxide				•	
Argon		•		•	
Brayco 889, coolant	•				
Carbon, activated	•				
Carbon dioxide		•		•	
Chlorine		•	•	•	
Chromium(III) chloride				•	
Cobalt	•			•	•
Diesel fuel	•				
Ethyl alcohol	•			•	•
Freon 113				•	
Gasoline	•			•	•
Helium		•		•	
Hydrochloric acid				•	•
Hydrofluoric acid		• ^(b)	•	•	•
Hydrogen	•	•		•	
Hydrogen peroxide (<52%)			•		
Insulating oil, inhibiting	•				
Lead (bricks and ingots)				•	•
Methane	•	•		•	
Neon		•		•	
Nitric acid	•		•	•	•
Nitric oxide		•	•	•	
Nitrogen		•		•	
Oxygen		•	•		
Paint	•				
Potassium cyanide				•	



Table 2-2. Livermore site, SARA, Title III, Section 311, Chemical List, 1999 (concluded).^(a)

Livermore site chemicals	Physical hazard			Health hazard	
	Fire	Pressure	Reactivity	Acute	Chronic
Propane	•	•		•	
Sodium hydroxide			•	•	•
Sulfur hexafluoride			•	•	
Sulfuric acid			•	•	•

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

^b Some containers have a pressure hazard.

Table 2-3. Site 300, SARA, Title III, Section 311, Chemical List, 1999.^(a)

Site 300 chemicals	Physical hazard			Health hazard	
	Fire	Pressure	Reactivity	Acute	Chronic
Argon		•		•	
Carbon, activated	•				
Chlorine		•		•	
Bis(2,2-dinitro-2-fluoroethyl) formal in methylene chloride	— ^(b)		— ^(b)	•	•
Diesel fuel	•				
Gasoline	•			•	•
Helium		•		•	
High explosives			•		
Lead (bricks)				•	•
Nitrogen		•			
Oil, hydraulic	•				
Oil, inhibited insulating	•				
Oil, transformer	•				
Sulfuric acid			•	•	•

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

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



2 Compliance Summary

Table 2-4. Summary of permits active in 1999.(a,b)

Type of permit	Livermore site	Site 300
Air	<p>BAAQMD issued 128 permits for operation of various types of equipment, including boilers, emergency generators, cold cleaners, ultrasonic cleaners, degreasers, printing press operations, manual wipe-cleaning operations, metal machining and finishing operations, silk-screening operations, silk-screen washers, paint spray booths, adhesives operations, image tube fabrication, optic coating operations, storage tanks containing VOCs in excess of 1.0%, plating tanks, drum crusher, semiconductor operations, diesel air-compressor engines, ground water air strippers/dryers, ovens, material-handling equipment, sewer diversion system, wave soldering machine, oil and water separator, fire test cells, gasoline-dispensing operation, resin-mixing operation, paper-pulverizer system, and firing tanks.</p>	<p>SJVUAPCD issued 47 permits for operation of various types of equipment, including boilers, emergency generators, paint spray booth, ground water air strippers, soil vapor extraction units, woodworking cyclone, gasoline-dispensing operation, explosive waste treatment units, and drying ovens.</p>
Water	<p>WDR Order No. 88-075 for discharges of treated ground water from Treatment Facility A to percolation pits and recharge basin.</p> <p>WDR Order No. 95-174, NPDES Permit No. CA0030023 for discharges of storm water associated with industrial activities and low-threat nonstorm water discharges to surface waters.</p> <p>WDR Order No. 99-08-DWQ, NPDES California General Construction Activity Permit No. CAS000002, DWTF Site ID No. 201S305140, Soil Reuse Project ID No. 2015305529 and National Ignition Facility, Site ID No. 201S306762, for discharges of storm water associated with construction activities affecting two hectares or more.</p> <p>WDR Order No. 99-086 for the Arroyo Las Positas Maintenance Project.</p> <p>Two ongoing projects permitted under streambed alteration agreements.</p> <p>FFA for ground water investigation/remediation.</p>	<p>WDR Order No. 99-08-DWQ, NPDES California General Construction Activity Permit No. CAS000002, Contained Firing Facility/Chemistry Magazine Loop, Site ID No. 5B39S307131 for discharges of storm water associated with construction activities impacting two hectares or more.</p> <p>WDR Order No. 93-100 for post-closure monitoring requirements for two Class I landfills.</p> <p>WDR Order No. 94-131, NPDES Permit No. CA0081396 for discharges of storm water associated with industrial activities and from cooling towers.</p> <p>WDR Order No. 96-248 for operation of two Class II surface impoundments, a domestic sewage lagoon, and percolation pits.</p> <p>WDR Order No. 97-242, NPDES Permit No. CA0082651 for discharges of treated ground water from the eastern General Services Area treatment unit.</p> <p>One ongoing project permitted under a streambed alteration agreement.</p> <p>FFA for ground water investigation/remediation.</p> <p>52 registered Class V injection wells.</p>

**Table 2-4.** Summary of permits active in 1999 (concluded).^(a,b)

Type of permit	Livermore site	Site 300
Hazardous waste	<p>EPA ID No. CA2890012584.</p> <p>Authorization to mix resin in Units CE231-1 and CE443-1 under conditional exemption tiered permitting.</p> <p>Closure under interim status of the Building 419 size reduction unit and Building 419 solidification unit.</p> <p>Authorizations to construct the permitted units of Building 280, Building 695, and additions to Building 693.</p> <p>Authorization under hazardous waste permit to operate 18 waste storage units and 14 waste treatment units.</p> <p>Continued authorization to operate seven waste storage units and eight waste treatment units under interim status.</p>	<p>EPA ID No. CA2890090002.</p> <p>Part B Permit—Container Storage Area (Building 883) and Explosives Waste Storage Facility (issued May 23, 1996).</p> <p>Part B Permit—Explosives Waste Treatment Facility (issued October 9, 1997).</p> <p>Docket HWCA 92/93-031. Closure and Post-Closure Plans for Landfill Pit 6 and the Building 829 Open Burn Facility.</p>
Sanitary sewer	<p>Discharge Permit No. 1250 (99/00) for discharges of wastewater to the sanitary sewer.</p> <p>Permit 1510G (99) for discharges of sewerable ground water from CERCLA restoration activities.</p>	
Storage tanks	<p>Nine operating permits covering 13 underground petroleum product and hazardous waste storage tanks: 111-D1U2 Permit No. 6480; 113-D1U2 Permit No. 6482; 152-D1U2 Permit No. 6496; 271-D2U1 Permit No. 6501; 321-D1U2 Permit No. 6491; 322-R2U2 Permit No. 6504; 365-D1U2 Permit No. 6492; 490-R3U1 and 490-R3U2 Permit No. 6509; and 611-D1U1, 611-G1U1, 611-G2U1, and 611-O1U1 Permit No. 6505.</p>	<p>One operating permit covering five underground petroleum product tanks assigned individual permit numbers: 882-D1U1 Permit No. 006530; 875-D1U2 Permit No. 006549; 879-D1U1 Permit No. 006785; 879-G3U1 Permit No. 007967; and 871-D1U2 Permit No. 008013</p>

^a Permit numbers are based on actual permitted units or activities maintained and renewed by LLNL during 1999.

^b See Glossary for list of acronyms.



2 Compliance Summary

Table 2-5a. Inspections and tours of the Livermore site by external agencies in 1999.

Medium	Description	Agency ^(a)	Date	Finding
Air	Emission sources	BAAQMD	1/14 1/28 2/18 3/11 11/4 11/17 12/2	No violations
Water	Sandia Recharge Basin Tour of North and Southwest Buffer Zones, Drainage Retention Basin, Treatment Facility A recharge ponds	SFBRWQCB	1/11 11/2	No violations
Sanitary sewer	Annual compliance sampling Categorical sampling	LWRP	10/12–13 3/12 10/12 12/2 12/8	No violations
Waste	Hazardous waste facilities	DTSC	6/28–6/29, 7/12, 7/13, 7/15, 7/16, and 8/12	16 alleged violations ^(b)
	Medical waste	ACDEH	9/14	No violations
Storage tanks	Compliance with underground storage tank upgrade requirements and operating permits.	ACHCS	3/11 9/20	No violations

^a See Glossary for list of acronyms.

^b LLNL disputes some of these alleged violations in the final Summary of Violation (SOV) dated on 12/22/99, and responded to DTSC on 2/15/00.

Table 2-5b. Inspections and tours of Site 300 by external agencies in 1999.^(a)

Medium	Description	Agency ^(b)	Date	Finding
Air	Emission sources	SJVUAPCD	4/14	No violations
	Review for internal combustion engine start-up		12/16	
Water	Permitted operations	CVRWQCB	4/13	No violations
Waste	Various facilities	DTSC	6/17, 7/9, and 7/13	One violation ^(c)

^a There were no inspections of the sanitary sewer or storage tanks at Site 300 in 1999.

^b See Glossary for complete list of acronyms.

^c DTSC determined that Site 300 returned to compliance on 9/16/99.



National Emission Standards for Hazardous Air Pollutants

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

The *LLNL NESHAPs 1999 Annual Report* (Gallegos et al. 2000), submitted to DOE and EPA, reported that the estimated total site-wide maximally exposed individual radiological doses for the Livermore site and Site 300 were 1.0 $\mu\text{Sv}/\text{y}$ (0.1 mrem/y) and 0.35 $\mu\text{Sv}/\text{y}$ (0.035 mrem/y), respectively, for 1999. Using the EPA-mandated assumption that gaseous tritium be treated as though it were tritiated water yielded a slightly higher dose of 1.2 μSv (0.12 mrem) for Livermore site operations.

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

In 1999, LLNL continuously monitored radionuclide emissions from Building 331 (the Tritium Facility), Building 332 (the Plutonium Building), the seismically strengthened portion of Building 251, and five other buildings (see Chapter 4). During 1999, some sampling systems were deactivated (see Chapter 4). There were no unplanned atmospheric releases at the Livermore site or at Site 300 in 1999.

Clean Water Act and Related State Programs

Preserving clean water is one objective of local, state, and federal regulations. The National Pollutant Discharge Elimination System (NPDES) under the Federal Clean Water Act establishes permit requirements for discharges into waters of the U.S. In addition, the State of California, under the Porter Cologne Water Quality Control Act, requires permits, known as Waste Discharge Requirements (WDRs), for any waste discharges affecting the beneficial uses of waters of the state. The regional water quality control boards are responsible for issuing and enforcing both permits.



2 Compliance Summary

Several agencies issue other water-related permits. The Livermore Water Reclamation Plant (LWRP) requires permits for discharges of sewerable water to the city sanitary sewer system. The Army Corps of Engineers (ACOE) issues permits for work in navigable waterways below the ordinary high-water mark and for controlling fill operations in waters of the United States. The State Water Resources Control Board (SWRCB) can issue water quality certifications or WDRs. The California Department of Fish and Game (CDFG) under the Fish and Game Code Section 1601 et seq. requires streambed alteration agreements for any work that may disturb or impact rivers, streams, or lakes. The Safe Drinking Water Act requires registration with the EPA and management of injection wells to protect underground sources of drinking water. The Clean Water Act also requires facilities meeting specific storage requirements to have and implement Spill Prevention Control and Countermeasure (SPCC) plans for oil-containing equipment and tanks. Finally, Alameda County Health Services (ACHS) and San Joaquin County Environmental Health Services issue permits for operating underground storage tanks containing hazardous materials or hazardous waste as required under the California Health and Safety Code. Water-related permits are summarized in **Table 2-4** and discussed in detail in Chapters 6, 7, and 9.

In December 1998, LLNL performed the triennial review and evaluation of the SPCC plans for Site 300 and the Livermore site. Based on this review, the Site 300 SPCC plan was amended in December 1999, and the Livermore site SPCC plan will be amended in 2000. No significant changes were made to the technology or practices documented in the *Spill Prevention Control and Countermeasures Plan* (Campbell 1995). The changes noted in the review reflect a reduction in the number of oil-containing tanks and equipment managed at the Livermore site and Site 300.

Ground Water and Surface Water

Discharges of treated ground water to surface water drainage courses and percolation ponds at LLNL are governed by NPDES permits, WDRs, and CERCLA Records of Decision (see **Table 2-4**). The CVRWQCB is currently in the process of reissuing WDR 94-131. The SFBRWQCB is in the process of reissuing WDR 95-174. Details about surface water discharges are found in Chapter 7 of this report. Details about ground water monitoring are found in Chapters 8 and 9 of this report, the *LLNL Ground Water Project 1999 Annual Report* (Aarons et al. 2000), and the LLNL Remedial Program Manager's quarterly reports (Littlejohn and Lamarre 1999, and Bainer and Littlejohn 1999a,b).



LLNL discharges storm water associated with industrial activities, low-threat nonstorm water, various process waters, and domestic wastewater to surface waters, percolation pits, surface impoundments, and a sewage lagoon under four NPDES permits and four WDRs (see Chapters 7 and 9). LLNL received no Notices of Violation (NOVs) in 1999 from the regional water quality control boards that issued the NPDES and WDR permits; however, LLNL identified nonconformance with two of the four NPDES permits (see **Table 2-6**). In addition, LLNL was unable to comply with prohibitions in WDR 96-248 on three occasions in 1999, where wastewater was released to the ground from containment or disposal systems. These discharges were reported by phone and in writing to the CVRWQCB and are discussed further in Chapter 9.

Table 2-6. Summary of NPDES permit nonconformance.

Permit No.	Outfall	Nonconformance	Date(s) of nonconformance	Description—solution
CAS000002	Arroyo Las Positas (Livermore site)	National Ignition Facility—Failure to repair BMPs ^(a) within the SWPPP ^(b) -specified 48-hour period.	6/98–5/99 ^(c)	Delayed repair did not result in BMP failures or releases to the storm drainage system. Contractors and construction staff were reminded of maintenance requirements.
		National Ignition Facility—Failure to perform and document inspections for laydown areas.	6/98–5/99	Revised SWPPP compliance strategy for laydown areas to place them under industrial SWPPP program.
		Soil Reuse Project—Failure to update SWPPP to incorporate the more protective BMPs being implemented.	9/98	Updated the SWPPP.
	Elk Ravine (Site 300)	Contained Firing Facility/Chemistry Magazine Loop Project—Failure to update SWPPP to incorporate a new project area.	6/98–5/99	Wrote SWPPP amendment.
		Contained Firing Facility/Chemistry Magazine Loop Project—Failure to update SWPPP at the start of a new construction project.	4/99	Updated the SWPPP.
CA0081396	Corral Hollow Creek (Site 300)	Failure to collect required quarterly cooling tower monitoring samples.	10–12/99	Issued an internal nonconformance report and established a system to remind technologists to collect required samples.

^a BMP = Best management practice.

^b SWPPP = Storm Water Pollution Prevention Plan.

^c These dates reflect the construction reporting period of June 1998 through May 1999. The actual nonconformance may not have occurred over the entire time; however, specific nonconformance dates cannot be determined.



2 Compliance Summary

LLNL continued construction operations on four projects during 1999. These activities are covered by the California General Construction Activity permit (see **Table 2-4**). Continuing operations included construction of the Decontamination and Waste Treatment Facility (DWTF), the Soil Reuse Project, and the National Ignition Facility (NIF) at the Livermore site and the Contained Firing Facility/Chemistry Magazine Loop Project at Site 300.

The SFBRWQCB visited the Livermore site to observe the Sandia Recharge Basin associated with the pending reissuance of WDR 88-075, and visited the North and Southwest Buffer Zones and the Drainage Retention Basin after a staff change at the regional water quality control board. The CVRWQCB inspected the Site 300 permitted facilities in April 1999. No violations were found at either site (see **Tables 2-5a** and **2-5b**).

Sewerable Water

The Livermore site's sanitary sewer discharges are sampled continuously, daily, weekly, and monthly to satisfy various permit requirements. The monitoring results for the LLNL effluent were reported monthly to the LWRP. In 1999, LLNL had no discharges in violation of the LWRP permit covering wastewater discharges to the sanitary sewer. Self-monitoring of categorical processes continued during 1999, as required in the permit; results were reported semiannually. In 1999, there were no compliance issues related to categorical processes.

Discharges from ground water treatment facilities to sanitary sewer under Permit 1510G (1999) are monitored as they occur and reported annually to the LWRP. In 1999, LLNL complied with all the terms and conditions of Permit 1510G. Chapter 6 discusses these self-monitoring programs for the site effluent, categorical processes, and discharges from ground water treatment facilities. The analytical results that document permit compliance with the self-monitoring provisions of the permits are discussed in Chapter 6.

LWRP collected split samples of site effluent as part of the annual compliance sampling. LLNL and LWRP also inspected and sampled identified federally regulated processes. No deficiencies or violations were noted during any of the inspections (**Table 2-5a**).



Streambed Alteration Agreements and Nationwide Permits

CDFG, SFBRWQCB, and ACOE all issue permits for work in streambeds. CDFG issued one five-year streambed alteration agreement for maintenance within Arroyo Seco (see **Table 2-7**). LLNL continued operations allowed under a five-year streambed alteration agreement issued for the Arroyo Las Positas Maintenance Project, and the SFBRWQCB issued a WDR for this project in October 1999. At Site 300, LLNL continued to operate under a five-year CDFG streambed alteration agreement issued in 1995 for maintenance of drainage channels. No projects at Site 300 or the Livermore site required permits from ACOE during 1999.

Table 2-7. Summary of streambed alteration agreements, 404 nationwide permits, and 401 waivers or WDRs^(a).

Project	Location	Agency/ type of permit	Year submitted
Storm-generated debris removal and vegetation management (five-year agreement)	Arroyo Seco	CDFG/SAA ^(b)	1999
Arroyo Las Positas Maintenance Project (five-year agreement)	Arroyo Las Positas	CDFG/SAA SFBRWQCB/ WDR	1998 1998
Maintenance (five-year agreement)	Site 300 drainage culverts	CDFG, SAA	1995

^a WDR = Waste discharge requirements.

^b SAA = Streambed Alteration Agreement.

Tank Management

LLNL manages its underground and aboveground storage tanks through the use of underground tank permits, monitoring programs, operational plans, closure plans and reports, leak reports and follow-up documentation, and inspections. At LLNL, underground storage tanks contain diesel fuel, gasoline, waste oil, and process wastewater; aboveground storage tanks contain diesel fuel, insulating oil, and process wastewater. Some wastewater systems are a combination of underground storage tanks and aboveground storage tanks. **Table 2-8** shows the status of tanks at the Livermore site and Site 300 as of December 31, 1999. All regulated underground storage tanks at the Livermore site were inspected in 1999, and no violations were found (see **Table 2-5a**).



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Resource Conservation and Recovery Act and Related State Laws

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

Table 2-8. Summary of in-service tanks, December 31, 1999.

Tank type	Livermore site			Site 300		
	Permitted	Permits not required	Total	Permitted	Permits not required	Total
Underground storage tanks						
Diesel fuel	7	0	7	4	0	4
Gasoline	2	0	2	1	0	1
Waste oil	1	0	1	0	0	0
Process wastewater	3	31	34	0	7	7
Subtotal	13	31	44	5	7	12
Aboveground storage tanks						
Diesel fuel	0	25	25	0	6	6
Insulating oil	0	1	1	0	3	3
Process wastewater	10 ^(a)	56	66	0	12	12
Subtotal	10	82	92	0	21	21
TOTAL	23	113	136	5	28	33

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



Hazardous Waste Permits

Livermore Site

The hazardous waste management facilities at the Livermore site consist of permitted units (located in Area 612, Building 280, and Buildings 695 and 693 of the DWTF) and units that operate under interim status (Area 514 Facility and the Building 233 Container Storage Facility). Two units formerly under interim status reverted to generator status under a delayed closure provision in the hazardous waste permit. These units are the Area 612-4 Container Storage Unit and Building 612 Laboratory Packing/Packaging Container Storage Unit. Permitted and interim status waste management units include container storage, tank storage, and various treatment processes (e.g., wastewater filtration, blending, and size reduction).

In accordance with the document, *Transition Plan, Transfer of Existing Waste Treatment Units to the Decontamination and Waste Treatment Facility* (Van Warmerdam and Finley 1997), operations in the Area 514 Facility will eventually be replaced by those in the new DWTF, and the Building 233 Container Storage Facility operations will be replaced by the Building 280 Facility.

On May 27, 1999, DTSC signed the hazardous waste permit and issued a Notice of Final Permit Decision for DWTF. On July 2, 1999, Tri-Valley CAREs et al. filed a petition for review to appeal the permit decision. On July 29, 1999, DTSC issued a notice of the permit decision appeal, staying the effective date of the hazardous waste permit, which was scheduled to become effective on July 9, 1999. On November 19, 1999, DTSC issued an order denying the permit appeal, and the permit immediately became effective. On December 23, 1999, a California Environmental Quality Act (CEQA) lawsuit was filed by Tri-Valley CAREs et al. This lawsuit challenges many of the environmental impact evaluations made in the DTSC initial study, which formed the basis of the CEQA Negative Declaration determination. The lawsuit is currently in litigation.

As reported in previous SAERs, the Building 513 shredder incident on July 2, 1997, resulted in DOE and DTSC investigations. The DOE/Oakland Operations Office (OAK) Type B Accident Investigation Committee issued its report on October 31, 1997, which included several Judgments of Need (JONs). LLNL, in turn, submitted an action plan in response to the JONs, and on March 11, 1999, DOE validated the completion of corrective actions derived from the JONs. DTSC representatives visited LLNL on November 12, 1997, and February 5, 1998. Their investigation of the shredder incident resulted in a Summary of Violations (SOV) dated February 9, 1998. LLNL, DOE, and DTSC are still developing an agreement regarding these issues, but continued delays caused by higher priority actions effectively closes our reporting of the Building 513



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incident in this report. The shredder unit involved in the incident has undergone RCRA closure, the shredder equipment has been removed from service, and the building has been released for normal use.

On May 26 and 27, 1998, DTSC conducted a compliance evaluation inspection of the hazardous waste storage and treatment facilities at the Livermore site. LLNL did not receive the final inspection report in 1999.

On June 28 and 29; July 12, 13, 15, and 16; and August 12, 1999, DTSC conducted a compliance evaluation inspection of the hazardous waste storage and treatment facilities at the Livermore site (see **Table 2-5a**). On August 12, 1999, LLNL received a SOV listing four alleged violations. LLNL responded to DTSC's SOV on August 19, 1999. On December 22, 1999, LLNL received the final inspection report and SOV. The final SOV listed 16 alleged violations, incorporating some of the previous alleged violations listed in the August SOV, dismissing others that were previously listed, and adding new alleged violations. The final inspection report also requested 41 items of additional information. On February 15, 2000, LLNL responded to DTSC regarding the alleged violations and information request. LLNL has not yet received a response from DTSC.

Site 300

The Explosives Waste Treatment Facility (EWTF), which replaced the closed Building 829 Open Burn Facility, became operational in March 1999. Upon receiving DTSC approval, closure operations for the Building 829 Open Burn Facility began in October 1997. The facility was closed in accordance with the *Final Closure Plan for the High-Explosives Open Burn Facility at Lawrence Livermore National Laboratory Experimental Test Site 300* (Mathews and Taffet 1997). The closure report, *Construction Quality Assurance for the RCRA Closure of Building 829 High Explosives Open Burn Treatment Facility* (Golder Construction Services 1998), was submitted to DTSC in February 1999.

On June 17, July 9, and July 13, 1999, DTSC conducted a compliance evaluation inspection of Site 300 hazardous waste generator areas, the Building 883 Container Storage Area, Explosives Waste Storage Facility (EWSF), and EWTF. As a result of the inspection, on July 13, 1999, DTSC issued a SOV under the category of "Minor Violations/Notice to Comply" for failing to provide annual refresher self-contained breathing apparatus training for one Building 883 Container Storage Area Hazardous Waste Management technician (see **Table 2-5b**). LLNL provided the required training on July 27, 1999, and submitted a certification of course completion to DTSC on August 2, 1999. After reviewing the submittal, DTSC issued a letter, dated September 16, 1999, stating that Site 300 is again in compliance.



Hazardous Waste Reports

LLNL completed two annual hazardous waste reports, one for the Livermore site and the other for Site 300, which address the 1999 transportation, storage, disposal, and recycling of hazardous wastes. The annual reports, required under 22 CCR 66262.41, were completed and submitted to meet DTSC's April 1, 2000, deadline. These same reports, *1999 Hazardous Waste Report—Mainsite* and *1999 Hazardous Waste Report—Site 300* (Galles and Gilbert 2000a, b), were submitted to the EPA under Sections 3002 and 3004 of RCRA, which requires a biennial reporting of hazardous wastes. DTSC is authorized to receive the reports for EPA.

Hazardous Waste Transport Registration

Transportation of hazardous waste over public roads (e.g., from one LLNL site to another) requires DTSC registration (22 CCR 66263.10). Conditions for registration may include annual inspections of transport vehicles and trailers by the California Highway Patrol (CHP), biennial terminal inspections, and special training and annual physical examinations for drivers. DTSC renewed LLNL's registration in November 1999. The CHP opted not to conduct inspections of LLNL vehicles in 1999.

Waste Accumulation Areas

In January 1999, there were 20 Waste Accumulation Areas (WAAs) at the Livermore site. Consolidation efforts resulted in the closure of one WAA; additionally, five temporary WAAs were put into service, and four temporary WAAs were taken out of service. Program representatives conducted formal inspections at least weekly at all WAAs to ensure that they were operated in compliance with regulatory requirements. Approximately 1107 formal WAA inspections were conducted at the Livermore site.

In January 1999, there were two WAAs at Site 300. One WAA was closed in 1999, leaving one WAA at Site 300. Program representatives conducted 92 formal inspections of the WAAs at Site 300.



2 Compliance Summary

California Medical Waste Management Act

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

LLNL is registered with the ACDEH as a generator of medical waste and has a treatment permit. The ACDEH inspection of buildings at Health Services, the Biology and Biotechnology Research Program, and the Medical Photonics Laboratory did not result in any compliance issues or violations (see **Table 2-5a**).

Federal Facility Compliance Act

LLNL is continuing to work with DOE to maintain compliance with the Site Treatment Plan (STP) that was signed in February 1997. All milestones for 1999 were completed on time. Reports and certification letters were submitted to DOE as required. The use of commercial facilities has allowed and will continue to allow earlier disposal of some waste streams than the dates listed in the STP.

Toxic Substances Control Act

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

In 1999, LLNL generated TSCA PCB waste from CERCLA cleanup projects, PCB oil drained from electrical equipment, electrical equipment contaminated with PCBs, liquid PCBs used to calibrate analytical equipment, and TSCA-regulated asbestos from building demolition or renovation projects.



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

National Environmental Policy Act

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

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

In 1999, one FONSI for the EA of the Terascale Simulation Facility Project was issued by DOE. Preparation of another EA for the decommissioning and demolition of Buildings 222 and 412 began in 1999. Eighteen categorical exclusion applications were approved by DOE, and there were no proposed actions at LLNL that required separate DOE floodplain or wetlands assessments under DOE regulations in 10 CFR 1022. In March 1999, DOE issued a *Supplement Analysis* (U.S. Department of Energy 1999b) that concluded that the 1992 *Final Environmental Impact Statement and Environmental Impact Report for Continued Operation of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore (1992 EIS/EIR)* (U.S. Department of Energy and University of California 1992a and b) did not need to be supplemented and remained adequate.



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California Environmental Quality Act

In November 1992, the University of California (UC) and LLNL made a commitment to implement 67 mitigation measures identified by the 1992 *EIS/EIR* and to provide annual reports on their implementation. The measures are being implemented in accordance with the approved 1992 Mitigation Monitoring and Reporting Program associated with that joint DOE/UC *EIS/EIR*. The fiscal year 1997 annual report was published in 1999; the next annual report will cover fiscal year 1998 activities. One CEQA mitigated Negative Declaration was issued in 1999 for the Arroyo Las Positas Maintenance Project.

National Historic Preservation Act

The National Historic Preservation Act of 1966 (NHPA), as amended through 1992, requires federally operated and funded installations such as LLNL to balance agency missions with cultural values by integrating historic preservation into federal agency programs. Federal agencies must take into account the effects their projects may have on "historic properties" (cultural resources), and they must allow a reasonable time period for the Advisory Council on Historic Preservation (the Council) to comment. LLNL has three significant types of cultural resources: (1) prehistoric, (2) historic (turn-of-the-century homesteading, ranching, and industrial), and (3) historic (World War II and Cold War science and technology).

A draft Programmatic Agreement (PA) was developed by LLNL in 1997 in consultation with the DOE/OAK, the Council, and the California Office of Historic Preservation to help LLNL implement applicable federal and state cultural resource laws and regulations. Activities included cultural overviews, development of theme and context for significance evaluation, research designs, archaeological site identification and evaluation methods, and records and collection management. The activities will also generate needed data and methods in order to develop a Cultural Resource Management Plan (CRMP), the final objective of the PA.

As a result of consultation with the Council and SHPO during a joint meeting with DOE in December 1998, the 1997 Draft PA is being modified and finalized. During 1999, LLNL continued consulting with DOE/OAK, the Council, and SHPO to formulate the content of the revised PA. The Fire Trail Relocation Project at Site 300 cut a new section of fire trail outside the boundaries of a known historic archaeological site. This action served to protect and preserve the site from future impacts so that LLNL can evaluate it and assess its significance and eligibility for listing on the National Register of Historic Places.



Endangered Species Acts and Sensitive Natural Resources

LLNL must meet the requirements of the U.S. Endangered Species Act, the California Endangered Species Act, and the California Native Plant Protection Act as they pertain to endangered or threatened species and habitats and other species of special concern that may exist or are known to exist at the LLNL sites. For example, in implementing the 1992 Mitigation Monitoring and Reporting Program in 1999, biological assessment surveys were performed for special-status species at 76 LLNL project construction (ground-disturbing) areas. Presence data for the San Joaquin kit fox (*Vulpes macrotis mutica*), American badger (*Taxidea taxus*), and Western burrowing owl (*Speotyto cunicularia*) were collected at each Site 300 project location, and other applicable mitigation measures were implemented where appropriate.

During 1999, no active San Joaquin kit fox dens were discovered, but five potential dens were found. Ten occupied American badger dens were discovered, and 40 unoccupied dens were identified. Eighteen active burrowing owl dens were discovered and monitored throughout the breeding and wintering season. The owls were marked with aluminum leg bands to initiate long-term studies, monitoring, and conservation of the species in the rugged topography of Site 300. Livermore site populations of the federally threatened California red-legged frog (*Rana aurora draytonii*) were monitored and protected in accordance with the 1997 and 1998 amended U.S. Fish and Wildlife Service Biological Opinions. In addition, a Species of Special Concern and federal candidate, the California tiger salamander (*Ambystoma tigrinum*), was monitored at wetland locations at Site 300. At the Livermore site, three pairs of white-tailed kites (*Elanus leucurus*), a state-protected bird of prey, successfully fledged 18 young. The kites were marked with aluminum leg bands to initiate long-term studies of the species in a semiurban edge habitat.

Two of the three known natural populations of the large-flowered fiddleneck (*Amsinckia grandiflora*), a federally listed endangered plant species, occur at Site 300. A portion of Site 300 has been designated as federal critical habitat for the plant. In addition, LLNL has established an experimental population within the designated critical habitat. LLNL is working with the U.S. Fish and Wildlife Service on continued monitoring of native and experimental *Amsinckia* populations, and to further develop habitat restoration and maintenance techniques. A progress report was prepared and submitted to the U.S. Fish and Wildlife Service in October 1999 (Carlsen et al. 1999).

The smaller of the two on-site native populations of fiddleneck was extirpated in 1997 when the bank containing the population washed away. No plants have been observed at this site since 1998. The number of fiddleneck plants in the larger native population



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continued to decline (six plants remaining in 1999, down from 218 plants observed in 1998). The number of fiddleneck plants observed in the experimental population also declined (42 plants remaining in 1999, down from 64 plants observed in 1998).

These declines were observed even though both populations were treated in 1998 to reduce competing grass cover. The three-year decline has also been observed in other existing natural and experimental populations of fiddleneck. A dramatic increase in nutlet predation by small rodents has been observed in the Site 300 experimental population. It is likely that several years of heavy grass cover resulted in increased numbers of seed predators. A study to determine the effect of rodent removal on nutlet predation is planned. The experimental population will also be expanded with additional native grass and *Amsinckia* transplantation to investigate more fully the use of fire as a management tool.

Monitoring of the big tarplant (*Blepharazonia plumosa*, listed on the California Native Plant Society Rare Plant 1B List), and the diamond-petaled poppy (*Eschscholzia rhombipetala*, a plant thought to be extinct until rediscovered) continued in 1999. The big tarplant remained widespread throughout Site 300, although the individual populations were much reduced in size. A total of nine diamond-petaled poppy plants were located (down from the 26 observed in 1998). Of these, six plants produced seed-bearing pods.

Antiquities Act (of 1906): Paleontological Resources

During soil excavation for the National Ignition Facility at the Livermore site in 1997, a molar from a 14,000-year-old mammoth was found at a depth of about 10 m below the surface. After this discovery, LLNL obtained an excavation permit from the Department of Interior under the provisions of the Antiquities Act of 1906 and removed bones from the construction area in late 1997 and early 1998. The bones (including 11 ribs, three vertebrae, one humerus, one complete and one partial tusk, and a partial skull with palate, jawbone, and molars) were accessioned into the UC Berkeley Museum of Paleontology collection in 1999 and have been partially prepared for possible later presentation at LLNL.

Environmental Occurrences

Notification of environmental occurrences is required under a number of environmental laws and regulations as well as DOE Order 232.1, *Occurrence Reporting and Processing of*



Operations Information, and DOE Order 5484.1, *Environmental Protection, Safety, and Health Protection Information Reporting Requirements*. DOE Order 232.1 provides guidelines to contractor facilities regarding categorization and reporting of environmental occurrences to DOE and divides occurrences into three categories: emergency occurrences, unusual occurrences, and off-normal occurrences.

The Environmental Protection Department's response to environmental occurrences is part of the larger LLNL on-site emergency response organization that also includes representatives from Hazards Control (including the LLNL Fire Department), Health Services, Plant Engineering, Public Affairs, Safeguards and Security, and Site 300. In 1999, four environmental incidents were reportable under DOE Order 232.1 and were categorized as off-normal occurrences according to DOE Order 232.1.

None of the environmental occurrences, summarized in **Table 2-9**, caused any adverse impact to the public or the environment. Agencies notified of these incidents included DOE and DTSC.

Table 2-9. Tabulation of environmental occurrences reported under the Occurrence Reporting (OR) System, 1999.

Date ^(a)	Occurrence category	Description
Feb 2	Off-Normal	LLNL shipped two 50-lb containers of dry explosives from the Nevada Test Site to the Pantex facility in Texas by commercial carrier. A small amount of the dry explosives (approximately one teaspoon) was released from one of the containers to the bed of the truck carrying the containers. The material was properly cleaned up, and the vehicle was released. The loose explosive material was not capable of detonation but could have contributed to a fire. A release of a hazardous material meets the requirements of an Off-Normal Occurrence. OR 1999-0004.
July 13	Off-Normal	Following a regulatory inspection of Site 300 by the DTSC, LLNL was issued a SOV for a training violation. During a review of personnel training records, it was discovered that a HWM ^(b) field technician was two months overdue for SCBA refresher training. Receiving an SOV meets the requirements of an Off-Normal Occurrence. OR 1999-0026.
Aug 12	Off-Normal	As a result of a regulatory inspection by the DTSC, LLNL was issued a SOV on Aug. 12, 1999. The initial SOV identified four alleged violations. On Dec. 22, 1999, LLNL received a DTSC Inspection Report and NOV, adding 12 alleged violations to the previous four. The alleged violations involved administrative practices, operating record issues, and training deficiencies. No findings involved compromise of public protection. Receiving an SOV/NOV meets the requirements of an Off-Normal Occurrence. OR 1999-0037.



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Table 2-9. Tabulation of environmental occurrences reported under the Occurrence Reporting (OR) System, 1999 (concluded).

Date ^(a)	Occurrence category	Description
Sept 22	Off-Normal	On September 21, 1999, a Hazardous Waste Management contractor employee was preparing hazardous waste for off-site shipment. The contractor was packaging a bottle containing Raney nickel, a solid that is normally suspended in water. After observing that there was no water in the container, the contractor added water to the container, allowed time for gas generation, and then replaced the screw cap. The contents of the container over-pressurized, blowing off the plastic screw cap. Less than 2.5 ounces of the material was discharged to the ceiling of the room and to the contractor's hair and shirt collar. The contractor and the room were decontaminated. There was no release to the environment because all the contents of the bottle were contained in the room. No injuries occurred, and assistance from the Fire Department was not needed. It was determined that this near-miss occurrence resulted from a failure to communicate or follow instructions. A courtesy phone call was made to DTSC informing it that a DOE occurrence report was initiated. Having only one barrier to prevent the release of a hazardous material to the environment meets the requirements of a Near Miss Off-Normal Occurrence. OR 1999-0045.

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

^b See Glossary for list of acronyms.

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Environmental Program Information

Introduction

Lawrence Livermore National Laboratory is committed to operating in a manner that preserves the quality of the environment. The Environmental Protection Department (EPD) leads this effort in the areas of environmental compliance and accountability. This chapter begins with a brief description of LLNL's integrated Environment, Safety, and Health (ES&H) Management System and continues with discussions of Work Smart Standards (WSS), missions, and activities of EPD and its three divisions. Performance measures (PMs) used by the U.S. Department of Energy (DOE) to evaluate the Laboratory's environmental protection efforts are then summarized. The bulk of the chapter is devoted to an account of LLNL's activities and progress in waste minimization and pollution prevention in 1999. Following descriptions of current issues and actions in the environmental program arena, this chapter concludes with a brief discussion of spill response and EPD environmental training.

Integrated Environment, Safety, and Health Management System

In 1998, LLNL began the process of developing and implementing an Integrated Safety Management System (ISMS) in accordance with the requirements of the University of California's (UC's) Prime Contract W-7405-ENG-48, Clause 6.7. The LLNL ISMS is designed to ensure the systematic integration of ES&H considerations into management and work practices so that missions are accomplished while protecting the public, workers, and the environment. "Safety" used in this context is synonymous with environment, safety, and health to encompass protection of the public, workers, and the environment (including pollution prevention and waste minimization). The core requirements of ISMS are based on the DOE's Seven Guiding Principles and Five Core Functions.

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



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

The Five Core Functions that describe how LLNL shall manage and perform work are summarized as: (1) define the scope of work; (2) identify and analyze the hazards associated with the work; (3) develop and implement hazards controls; (4) perform work within the controls; and (5) provide feedback on the adequacy of the controls for continuous improvement.

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

On November 15, 1999, the Laboratory declared its readiness for the DOE Phase I Verification of the institutional ISMS. DOE initiated the verification on November 29, 1999, and the results of the verification were presented on December 9, 1999. DOE recommended approval of the LLNL ISMS description after the completion of several action items.

Work Smart Standards

In 1997, LLNL and DOE's Oakland Operations Office (DOE/OAK) inaugurated a WSS process (DOE M 450.3-1), whereby safety professionals from both organizations identified ES&H hazards and established standards of operation appropriate for the particular work environment.

The WSS process requires an understanding of the work, an analysis of the hazards associated with the work, and the selection of standards from which hazard controls are developed. LLNL has traditionally identified and controlled hazards to protect the LLNL staff, the public, and the environment, but the WSS process differs from the past



in that responsibility for selection of appropriate and necessary standards is in the hands of both the DOE field office and LLNL. This process empowers the Laboratory and local DOE staffs, through consensus, to focus on the work being performed and to select sitewide ES&H standards based on the actual work being conducted and its associated hazards and threats to the environment. In 1998, several hundred individuals participated in the WSS process, including more than 100 subject matter experts (SMEs) who identified standards based on the work and the hazards. In addition, requirements for managing processes were identified to better connect project planning and execution with the standards, thereby providing protection to workers, the public, and the environment. This process resulted in the identification of almost 700 individual requirements, of which more than 250 directly relate to environmental protection. The WSS process also identified the need to develop nine local standards to either fill gaps or enhance existing standards; these ranged from standards on ergonomics to high-efficiency particulate air (HEPA) filters. For example, radioactive waste storage facility and tank system design criteria standards (Wood et al. 1999) were developed to ensure that requirements for facility design protect the environment.

WSSs were approved at the management level closest to and with the most expertise in the work. The LLNL Director and DOE/OAK Manager approved the final set of sitewide standards on August 5, 1999, after they were confirmed by an independent panel of external experts in March 1999. The WSS set was essentially considered part of the UC contract once it was signed by the LLNL Director and the DOE/OAK Manager. Reaching these agreements with DOE on new work-based standards aligns the Laboratory with industry practice, establishes common ES&H expectations for DOE and UC, and facilitates the tailoring of requirements to streamline and increase the effectiveness of management at the Laboratory. The existing ES&H methodologies and documentation are being modified to incorporate the newly identified set of standards and to reflect the requirements of ISMS.

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

Environmental Protection Department

As the lead organization at LLNL for providing environmental expertise and guidance to operations at LLNL, EPD is responsible for environmental monitoring, environmental regulatory compliance, environmental restoration, environmental community relations,



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and hazardous waste management in support of the Laboratory's programs. EPD prepares and maintains environmental plans, reports, and permits; maintains the environmental portions of the *ES&H Manual*; informs management about pending changes in environmental regulations pertinent to LLNL; represents the Laboratory in day-to-day interactions with regulatory agencies and the public; and assesses the effectiveness of pollution control programs.

EPD monitors air, sewerable water, ground water, surface water, soil, sediments, vegetation, and foodstuff, as well as direct radiation; evaluates possible contaminant sources; and models the impact of LLNL operations on humans and the environment. In 1999, 13,372 samples were taken, and 252,469 analytes were tested. The type of samples collected at a specific location depends on the site and the potential pollutants to be monitored; see the specific chapters of this report for discussions of each environmental medium.

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

LLNL programs are supported by the Hazards Control Department's four ES&H teams and by EPD's four environmental support teams (ESTs). The ESTs are integrated into the ES&H teams at the Laboratory through the environmental analyst, who chairs the ESTs. Each EST includes representatives from environmental specialties within the Operations and Regulatory Affairs Division (ORAD), the ES&H teams, and a field technician from the Hazardous Waste Management (HWM) Division. Some ESTs also include a representative from the Environmental Restoration Division (ERD) or the organizations supported by the ESTs. These teams evaluate operations, determine potential environmental impacts, and provide guidance on environmental regulations and DOE orders for existing and proposed projects. ESTs assist programs in planning, implementing, and operating projects and in understanding and meeting their environmental obligations. When permits are obtained from regulatory agencies, ESTs aid the programs in evaluating the permit conditions and implementing recordkeeping requirements.



Operations and Regulatory Affairs Division

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

ORAD prepares the environmental permit applications and related documents for submittal to federal, state, and local agencies; provides the liaison between LLNL and regulatory agencies conducting inspections; tracks chemical inventories; prepares National Environmental Policy Act (NEPA) documents; conducts related field studies for DOE; 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; and provides environmental impact modeling and analysis, risk assessment, and reporting.

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

Hazardous Waste Management Division

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

As part of its waste management activities, HWM tracks and documents the movement of hazardous, mixed, and radioactive wastes from waste accumulation areas (WAAs) located near the waste generator to final disposition; develops and implements approved standard operating procedures; decontaminates LLNL equipment; ensures that containers for shipment of waste meet the specifications of the U.S. Department of Transportation (DOT) and other regulatory agencies; responds to emergencies; and participates in the cleanup of potential hazardous and radioactive spills at LLNL facilities. HWM prepares numerous reports, including the annual and biennial



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hazardous waste reports required by the state and federal environmental protection agencies (see Appendix B). HWM also prepares waste acceptance criteria documents, safety analysis reports, and various waste guidance and management plans.

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

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

Environmental Restoration Division

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

As part of its responsibility for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) compliance issues, ERD plans, directs, and conducts assessments to determine both the impact of past releases on the environment and the restoration activities needed to reduce contaminant concentrations to protect human health and the environment. ERD interacts with the community on these issues through Environmental Community Relations. Public meetings are held each year and information provided to the public as required in the ERD CERCLA Community Relations Plans. To comply with CERCLA ground water remedial actions at the Livermore site, ERD has to date designed, constructed, and operated five fixed ground water treatment facilities and associated pipeline networks and wells, 16 portable ground water treatment units, and two soil vapor extraction facilities (see Chapter 8). At Site 300, ERD has designed, constructed, and operated three soil vapor extraction facilities and seven ground water extraction and treatment facilities.



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

Performance Measures Summary

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

At the end of 1999, DOE gave LLNL an average score of excellent for its environmental performance in 1998. DOE scores for individual performance measures are shown in **Table 3-1**. As indicated in the table, performance details are described in the *Environmental Report 1998* (Larson et al. 1999). Performance measure data for 1999 will be included in the annual self-assessment and evaluation conducted in 2000.

DOE Pollution Prevention Goals

The Secretary of Energy committed DOE to the following Pollution Prevention (P2) goals to be achieved throughout the DOE complex by December 31, 1999, using 1993 as a baseline:

1. Reduce total releases and off-site transfers for treatment and disposal of Emergency Planning and Community Right-to-Know Act (EPCRA) Section 313 toxic chemicals from routine operations by 50%.
2. Reduce the generation of radioactive waste from routine operations by 50%.
3. Reduce the generation of low-level mixed waste from routine operations by 50%.
4. Reduce the generation of hazardous waste from routine operations by 50%.
5. Reduce the generation of sanitary waste (after recycling) from routine operations by 33%.
6. Divert 33% of sanitary waste from all operations for recycling.
7. Increase the affirmative procurement of EPA-designated recycled products to 100%.



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Table 3-1. UC Contract 48 environmental protection performance measures for environmental performance in 1998.

PM designator	Performance measure	Location in <i>Environmental Report 1998</i>	Score
1.4.b	Radiation dose to the public Public radiation doses to the maximally exposed individual from DOE operations will be measured or calculated and controlled to ensure that doses are kept as low as reasonably achievable (ALARA).	Chapter 13, Radiological Dose Assessment, section on Radiological Doses from 1998 Operations. Chapter 2, Compliance Summary, section on National Emission Standards for Hazardous Air Pollutants.	Outstanding
1.4.g	Process and solid waste generation (Waste reduction and recycling) The Laboratory continues to progress toward meeting the DOE's pollution prevention goals for the year 2000.	Chapter 3, section on Waste Minimization/Pollution Prevention.	Excellent
1.4.h	Environmental violations The rate of validated environmental violations from inspections and reporting requirements from regulatory agencies is kept low.	Chapter 2: Compliance Summary, Tables 2-5a, 2-5b, and 2-9.	Excellent
1.4.i	Environmental releases The Laboratory controls and reduces the number of occurrences of environmental releases and the number of releases that result in violations.	Chapter 2: Compliance Summary, Table 2-9.	Outstanding

Progress toward achieving these goals is reported annually to the Secretary of Energy in DOE's *Annual Report of Waste Generation and Pollution Prevention Progress* (U.S. Department of Energy 1994, 1996a, 1997, 1998c, and 1999a).

In November 1999, the Secretary of Energy issued a new set of pollution prevention and energy efficiency goals in response to the President's Executive Orders for Greening the Federal Government. These goals provide direction for continued promotion of pollution prevention and waste minimization beyond the year 2000. Additionally, they expand the scope of previous goals to consider the following: building and facility energy efficiency; reduction of releases of toxic chemicals, ozone-depleting substances, and greenhouse gases; increased vehicle fleet efficiency and use of alternative fuels; and the required purchasing of environmentally preferable products and services. The new goals will continue to use 1993 as a baseline and have interim measurement points in 2005 and 2010.



LLNL prepares a P2 Plan that meets the requirements of (1) DOE Orders 5820.2A and 5400.1; (2) Resource Conservation and Recovery Act of 1976 (RCRA) Sections 3002(b) and 3005(h); and (3) Title 22 of the California Code of Regulations. This plan is reviewed annually and is typically updated every three years. The plan reviews past and current pollution prevention activities and states the objectives of LLNL's waste minimization and pollution prevention efforts. It was last updated and submitted to DOE in May 1997 (Celeste 1997). The timeline for the expected 2000 update to the LLNL P2 Plan has been deferred per DOE guidance.

The P2 Program at LLNL is an organized, comprehensive, and continuing effort to systematically reduce solid, hazardous, radioactive, and mixed-waste generation. The P2 Program is designed to eliminate or minimize pollutant releases to all environmental media from all aspects of the site's operations. These efforts help protect public health and the environment by reducing or eliminating waste management and compliance costs, resource usage, inventories and releases of hazardous chemicals, and civil and criminal liabilities under environmental laws.

In accordance with EPA guidelines and DOE policy, a hierarchical approach to waste reduction (i.e., source elimination or reduction, material substitution, reuse and recycling, and treatment and disposal) has been adopted and is applied to all types of waste.

Waste Minimization/Pollution Prevention

LLNL is required by UC Contract performance measure 1.4.g to annually review its waste generation for pollution prevention opportunities and to propose implementation projects. Previously, waste streams at LLNL were evaluated in terms of the total quantities of waste generated. However, the waste streams of greatest concern are not necessarily those having the largest volume. Each process that generates waste must be considered, as well as the individual characteristics of the components within each waste stream.

LLNL continues to use a weighted system to better rank the waste streams and to improve the prioritization of waste minimization efforts. The methodology assigns to each waste stream three weighting factors plus a factor based on annual quantity of waste generated. The three weighting factors use the following criteria: cost, waste type (which includes compliance and liability considerations), and operational aspects (such as routine vs nonroutine) as discussed in *A Comprehensive Opportunity Assessment for Pollution Prevention at Lawrence Livermore National Laboratory* (Celeste et al. 1998). This weighting system was used to prioritize waste minimization efforts for waste streams



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identified in LLNL's input to the document *Source Reduction Evaluation and Plan, Hazardous Waste Management Performance Report, Summary Progress Report* (U.S. Department of Energy 1999c).

In general, the 20 waste stream components having the highest priority (ranked by summing the four weighting factors) are entirely different from the top 20 sources ranked by quantity only. For example, transuranic waste (TRU)/TRU mixed and low-level wastes, which are problematic at LLNL, are now ranked as having the highest priority, though their relative quantities are somewhat low.

The Environmental Protection Department's Pollution Prevention Team reviews HWM's Total Waste Management System (TWMS) database monthly. By reviewing this database, which tracks waste generation, the Pollution Prevention Team can identify waste streams with potential problems for each directorate and address issues in a timely manner. Routine waste generation by waste category, from 1993 through 1999, is shown in **Table 3-2**. The trend from 1993 on shows a dramatic reduction in all waste categories, which is the result of LLNL's proactive P2 program.

Table 3-2. Routine waste generation totals (tons), 1993–1999.

Waste category	1993 ^(a) (baseline)	1994	1995	1996	1997	1998	1999
Low-level radioactive	256	181	136	91	68	73	66
Low-level mixed	34	26	36	23	21	25	11
Hazardous	628	368	368	360	240	232	188
Sanitary	2600	2246	2246	2001	2017	2201	2210
LLNL totals	3518	2821	2786	2475	2346	2531	2475

^a Baseline values 1993 through 1997 adjusted per agreement between DOE/OAK and LLNL on Feb. 20, 1998.

Table 3-3 presents the percent reductions in routine waste generation for 1999 compared with the 1993 baseline. With the decreases in routine radioactive and hazardous waste generation, the Laboratory met the 50% reduction goal for the performance measure in 1997. The 50% reduction goal for low-level mixed waste was achieved in 1999, largely because of an improved treatment technology and a decrease in programmatic generation. Reduction of the sanitary waste stream from the baseline of 1993 is currently at 15%. Further discussion of the sanitary waste stream occurs in the following section.



Table 3-3. Routine waste reduction, 1999.

Waste category	Reduction 1999 vs 1993 (%)
Radioactive	75
Mixed	68
Hazardous	71
Sanitary	15

Nonhazardous Solid Waste Minimization

In 1999, LLNL sent 5684 tons of routine and nonroutine, nonhazardous waste (also designated as sanitary waste) to a landfill. The routine portion was 2210 tons (see **Table 3-2**), and the nonroutine portion was 3474 tons. The breakdown for routine and nonroutine waste is shown in **Table 3-4**.

Diverted Waste

The total waste diverted from landfills in 1999 was 47,161.5 tons. This year's total diversions, over two times that of 1996 (**Table 3-5**), reflects the continued success of LLNL's diversion programs.

The recycling rate for nonhazardous waste is calculated by dividing the total of diverted waste by the sum of the nonhazardous landfill total and the diverted waste total. For 1999, the total of diverted waste plus nonhazardous waste generated was 52,846 tons. This results in a recycling rate of 89% for nonhazardous waste in 1999.

Table 3-4. Nonhazardous landfill totals (tons), 1999.

Landfill	1999 total
Routine	
Compacted	2130
Industrial (TWMS) ^(a)	80
Routine subtotal	2210
Nonroutine	
Construction demonstration (noncompacted)	3363
Industrial (TWMS)	111
Nonroutine subtotal	3474
LLNL total	5684

^a TWMS = Total Waste Management System.



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Table 3-5. Diverted waste totals (tons), 1996–1999.

	1996	1997	1998	1999
Diverted waste totals	20,266	323,465 ^(a)	31,513	47,161.5

^a The 1997 solid waste diversion total of 323,465 reflects an increase in soil reuse, predominately driven by construction of the National Ignition Facility.

Table 3-6 shows a breakdown of waste diversion categories for 1999, reflecting the variety of diversion programs in place at LLNL. Soil, a major contributor to diversion totals, is reused both on site and at the landfill for daily cover. Asphalt and concrete are reused as road base material at the landfill. Wood waste, created by broken pallets, shipping crates, and demolition or construction scrap, cannot be cost-effectively reused on site, so it is gathered in a collection yard for recycling by a vendor at a cost lower than that of other disposal alternatives. Intact pallets and other reusable wood remain on site for internal reuse.

Table 3-6. Waste diversion summary table, 1999.

Description	Cumulative 1999 total (tons)
Asphalt/concrete	2,782
Batteries	25
Cardboard	172
Compost	336
Cooking grease/food	3
Diverted soil	40,877
HWM recycled materials	76
Magazines, newspapers, and phone books	33
Metals	2,028
Paper	309
Tires and scrap	64
Toner cartridges	3
Wood	453
Beverage containers	0.5
LLNL diversion total	47,161.5

Another waste reduction method converts landscape clippings from the site’s lawns, trees, shrubs, and annual plantings into compost. Once it is properly aged, the compost is used on site as a soil amendment. By generating its own soil builders, LLNL benefits



twice: by eliminating an organic waste stream (with no tipping fees or hauling required), and by saving the purchase cost of new material. Gardeners also create a bright and attractive mulch by chipping office Christmas trees at the end of the holiday season. This mulch is used year-round, reducing the amount of dry-season irrigation necessary in tree wells.

Another well-developed and highly visible component of the LLNL recycling effort is the office-paper collection and reclamation project. The Laboratory operates a full-site program, with more than 122 facility collection points. Unclassified paper is transported to a contract firm, where it is shredded and recycled into toilet paper and egg cartons. Classified paper is preprocessed at the Livermore site using a hammer mill destruction process. LLNL also collects and recycles external and internal phone books, newspapers, and magazines by placing recycling bins on site for pickup by a local vendor. These items would otherwise contribute to the solid waste stream. In 1999, LLNL expanded the program to allow employees who are located in areas where drop-off bins are not easily accessible to mail in these items.

LLNL continues to look for diversion opportunities. A new beverage container recycling program serving all three on-site cafeterias was initiated in late 1999. This program collects aluminum, glass, and plastic containers, which are picked up and taken off site for recycling by a local vendor. Preliminary data from the fourth quarter of 1999 show that a half ton of beverage containers was recycled.

LLNL's goal in its UC contract was to reduce the routine nonhazardous waste by 33% by December 31, 1999. As shown in **Table 3-4**, LLNL generated 2210 tons of routine nonhazardous waste in 1999, a reduction of 15% with respect to the baseline. Because the 33% reduction goal was not achieved, despite an impressive 89% recycling rate for nonhazardous waste, the Laboratory has a strong incentive to continue to identify new waste reduction measures.

Cities and counties have been required by California law to reduce nonhazardous solid waste by 25% and 50% between the baseline year of 1990, and 1995 and 2000, respectively. LLNL contributes to this effort by tracking and reporting its waste diversions to the County of Alameda. Significant reductions have already been achieved. Compared with the 1990 baseline, by 1995 LLNL reduced its nonhazardous waste by 46% (see **Table 3-7**), which compared favorably with unincorporated Alameda County (8.9%) and the City of Livermore (13.8%) for 1995. Additional details are discussed in *Assessing the Nonhazardous Solid Waste Stream at Lawrence Livermore National Laboratory* (Wilson 1999).



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Table 3-7. Nonhazardous solid waste summary table, 1990–2000.

	1990	1995
Nonhazardous solid waste (routine and nonroutine)	8332	4560
Percent reduction	NA	46%

Source Reduction and Pollution Prevention

In 1999, LLNL continued to survey on-site operations for opportunities to eliminate, reduce, recover, or recycle potential pollutants to all media, including air, water, soil, sediments, and biota.

Toxic Reporting Inventory Information

At LLNL only one chemical, Freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane, also known as CFC 113), was tracked and reported as part of the Toxic Release Inventory for 1999. This reporting is required by EPCRA. All other chemicals are present in quantities below the threshold reporting levels or are in a form that does not require reporting.

Freon 113, which is used in parts cleaning operations and as a coolant or refrigerant, is an ozone-depleting substance whose consumption and production are slated for elimination by the year 2000. For this reason, the replacement and recycling of Freon 113 is a high priority at LLNL.

Implementing Cost-Saving Pollution Prevention (P2) Projects

As previously reported (Celeste et al. 1998) Pollution Prevention Opportunity Assessments (PPOAs) are conducted before the implementation of P2 projects. The purpose of PPOAs is to characterize waste streams and identify those P2 options that can be implemented cost effectively.

The DOE funds P2 projects through the High-Return-on-Investment (ROI) P2 Program. To date, DOE has funded high ROI projects at LLNL worth over \$2.6 million. The annual savings attributed to the projects were reassessed in the fall of 1999. Revised estimates of annual savings from implemented ROI projects are \$1.5 million per year. LLNL additionally uses ROI calculations and estimates of project cost-effectiveness to prioritize P2 projects for resource allocation and implementation at the Laboratory.



Review of New Processes or Experiments

Many organizations at LLNL use a “front-end” review process that applies to new programs, projects, or experiments that could have a significant impact on the environment. In this review process, the initial hazardous materials projected to be used are identified, and concentrations of both the starting materials and the wastes produced are estimated. The possibility for chemical substitution, process changes, and recycling is then addressed. If an opportunity for P2 is identified, the Pollution Prevention Team assists the generator in evaluating the options. Researchers and project managers are encouraged to implement alternatives that are less hazardous or nonhazardous.

In general, P2 activities are covered by the *FY97 Pollution Prevention Plan* (Celeste 1997). New activities are reviewed to identify possible P2 techniques. All personnel are encouraged to implement reasonable P2 opportunities that have been identified.

Design for Environment

Design for environment is a concept that involves developing an understanding of potential environmental impacts over the lifetime of a project, with the goal of minimizing or mitigating those potential impacts through modifications to the project at the design stage. Federal facilities are now required, under Executive Order 12856, to apply life-cycle analysis and total cost accounting principles to the greatest extent practicable when estimating P2 opportunities. Both of these can be considered elements of a new federally funded facility. In addition, Executive Order 13101, which replaced Executive Order 12873 in September 1998, requires federal facilities to implement P2 by giving preference to the purchase of environmentally preferable products and requires that P2 and life-cycle analysis be considered when plans, drawings, work statements, and specifications are developed. Executive Order 13101 also allows the use of “multi-media” EPA inspections of federal facilities for compliance with this order.

In 1997, the Pollution Prevention Team and National Ignition Facility (NIF) project management completed a design-for-environment evaluation of the opportunities within the NIF project. The *NIF Pollution Prevention and Waste Minimization Plan* (NIF P2/WMin Plan) was completed in 1998 (Cantwell and Celeste 1998). Based on this evaluation, the laboratory implemented recycling programs during NIF construction, began a Pollution Prevention Plan for NIF, and implemented aqueous cleaning concepts in the design for parts and optics cleaning. The NIF P2/WMin Plan included PPOAs on the predicted waste streams identified in the preliminary environmental



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impact statement. The PPOAs were aimed at developing waste minimization options before NIF becomes operational.

Implementing P2 Employee Training and Awareness Programs

Pollution prevention awareness information, which covers all disciplines, is disseminated in documents such as the *Pollution Prevention Plan* (Celeste 1997) and *A Comprehensive Opportunity Assessment for Pollution Prevention at Lawrence Livermore National Laboratory* (Celeste et al. 1998); posters and videos at events such as Earth Day; training and orientation; conferences and workshops; membership on LLNL committees; and formal presentations to groups such as the ES&H Working Group's Environmental Subcommittee.

P2 awareness is promoted through new employee and awareness briefings as well as articles in *Newsline* (LLNL's weekly newspaper) and administrative memos. The Pollution Prevention Team developed a website to electronically distribute P2 information and prepared brochures that briefly describe the P2 program at LLNL. The Pollution Prevention Team also sponsors a yearly Earth Expo event open to employees, their families, and the local community to provide awareness of environmentally sound technologies and LLNL waste diversion initiatives.

Current Return-on-Investment Projects

LLNL prepared several high ROI P2 project proposals in 1999. Major high ROI projects that received funding and began in 1999 are listed in **Table 3-8**.

Table 3-8. Major high return-on-investment projects, 1999.

Operation	Project
Low-Hg fluorescent lighting pilot at LBNL and LLNL	Studies the benefits and drawbacks of converting to low-Hg fluorescent tubes in office and shop space
Executive Order 13101 specification upgrade	Updates the LLNL facilities specification masters to bring them into compliance with EPA comprehensive procurement guidelines



ChemTrack

ChemTrack, which is a computerized chemical inventory system, serves as an important tool for ensuring that LLNL complies with the Superfund Amendment and Reauthorization Act (SARA) Title III and California Business Plan reporting requirements and for improving the overall management of hazardous materials. ChemTrack enhances LLNL's ability to obtain the toxic release information necessary to complete SARA 313 submittals, to improve emergency response capabilities and management of material safety data sheets (MSDSs), to more closely track specific high-hazard chemicals and other regulated substances, and to screen selected LLNL facilities for preliminary hazard analyses. ChemTrack currently has an inventory of approximately 176,000 chemical containers ranging from 210-L drums to gram-quantity vials.

Current Issues and Actions

Many current issues and actions are described in this report according to chapter subjects. This section lists several not covered elsewhere.

Miniature Optical Lair Explorer

In 1994, ORAD developed and began using the Miniature Optical Lair Explorer (MOLE) to perform biological assessment studies at Site 300. The MOLE is a miniature tracked vehicle with a tiny camera that allows scientists to investigate subterranean tunnel systems of special-status wildlife species to determine their presence and numbers.

LLNL has used the MOLE successfully to survey for the presence of several special-status species with subterranean habitats (e.g., the San Joaquin kit fox, burrowing owl, American badger, California tiger salamander, and California red-legged frog) before starting ground-disturbing activities to ensure that, if they are present, they are protected. Further development and use of the MOLE will continue in 2000.

Leaking Underground Fuel Tank Studies

As part of continuing state-funded leaking underground fuel tank studies, LLNL completed an 18-month study evaluating impacts of the fuel oxygenate methyl tertiary-butyl ether (MTBE) and submitted it to the California State Water Resources Control



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Board (SWRCB). Conclusions of the study are found in *Environmental Report 1998* (Larson et al. 1998).

LLNL is continuing to work with the California SWRCB to identify groundwater resources that may be vulnerable to MTBE impacts.

Evaluation of the Use of Ethanol to Replace MTBE in Gasoline

On March 25, 1999, California Governor Gray Davis issued Executive Order D-5-99, calling for the removal of MTBE from gasoline at the earliest possible date but no later than December 31, 2002. Task 10 of the Executive Order states “the California Air Resources Board (ARB) and the SWRCB shall conduct an environmental fate and transport analysis of ethanol in air, surface water, and groundwater. The Office of Environmental Health Hazard Assessment (OEHHA) shall prepare an analysis of the health risks of ethanol in gasoline, the products of incomplete combustion of ethanol in gasoline, and any resulting secondary transformation products.”

To assist the SWRCB, LLNL has led a team of researchers in evaluating the potential ground and surface water impacts that may occur if ethanol is used to replace MTBE. These findings are reported in the document entitled *Health and Environmental Assessment of the Use of Ethanol as a Fuel Oxygenate* (Rice and Cannon 1999). This document has been presented to the California Environmental Policy Council and may be viewed at: <http://www-erd.llnl.gov/ethanol/>

Ethanol may be used in oxygenated and reformulated gasoline (8% in federal oxyfuel or 6% in federal reformulated gasoline [RFG], by volume). Oxygenated gasoline must contain at least 2.7% oxygen by weight unless a state obtains a waiver from the U.S. Environmental Protection Agency (EPA). Such oxygenated gasoline is used in federally designated carbon monoxide nonattainment zones. RFG contains a minimum average of 2% oxygen (by weight), no more than 1% benzene (by weight), and no heavy metals. RFG is used in locations that exceed the ozone standard. Currently, about 70% of gasoline used statewide is RFG. Ethanol is a renewable, biomass-based source of fuel with tax incentives. Initial studies indicate that its environmental impacts are less than those associated with the use of MTBE. Although California has implemented improved containment practices for its underground storage tanks, releases of gasoline that may impact surface water and groundwater resources can still be expected.

Several abiotic and biotic processes or mechanisms that affect the fate of ethanol and ethanol-gasolines in the subsurface have been identified. Ethanol in gasoline will affect



the concentrations of BTEX that dissolve into groundwater and the residence time of fuel hydrocarbons in contact with the water table (saturated zone). The presence of ethanol in groundwater may alter microbially mediated BTEX fate and transport processes and could contribute to increased benzene plume lengths. Biodegradation of fuel alcohols contributes to the depletion of electron-acceptor pools, and this depletion is likely to affect temporal and spatial transitions in electron-acceptor conditions during natural attenuation of petroleum-product releases. Several modeling efforts evaluating the behavior of benzene groundwater plumes in the presence of ethanol indicate that benzene plumes are likely to increase in length, but the amount of this increase is not well known. A number of recommendations have been made to address knowledge gaps in the potential ground- and surface-water impacts associated with using ethanol to replace MTBE.

During evaluation of ground- and surface-water impacts, LLNL began to develop a comprehensive life-cycle model. This life-cycle model systematically addresses impacts from fugitive and accidental releases associated with the production, distribution, and use of ethanol-containing gasoline. LLNL also examined the salient environmental properties of alkylates, which are nonoxygenated compounds likely to be used in greater amounts in gasoline after an MTBE phaseout.

Initiative to Improve Volatile Organic Compound Cleanup Process by Using Historical Case Analysis

The goal of this initiative is to evaluate a large number of nationwide historical cases to identify common VOC release conditions that pose low risks and can be managed with minimal effort and cost, versus release conditions that pose higher risks and warrant larger expenditures. The key to this initiative is a cross-cutting evaluation of the large amount of VOC case data that is available.

This study is ongoing, and LLNL is continuing to gather chlorinated VOC historical case data to improve the evaluation of the behavior of chlorinated VOC plumes. A Phase 1 final report, entitled, *Historical Case Analysis of Chlorinated Volatile Organic Compound Plumes* (McNab et al. 1999), has been completed and can be viewed on the Internet at: <http://www-erd.llnl.gov/library/AR-133361.html>



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Response to Spills and Other Environmental Emergencies

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

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

During normal work hours, Laboratory employees report all environmental incidents to the Environmental Operations Group (EOG) environmental analyst assigned to support their program area. The EOG environmental analyst then notifies the on-duty EDO of the incident, and together they determine applicable reporting requirements to local, state, and federal regulatory agencies and to DOE. The EDO and the EOG environmental analyst also notify and consult with program management and have 7-day-a-week, 24-hour-a-day access to the office of Laboratory Counsel for questions concerning regulatory reporting requirements.

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

Environmental Training

Major efforts are ongoing to provide LLNL employees with training on environmental topics aimed at improved compliance. Training tasks address both specialized training for environmental professionals and training in a variety of environmental topics for



employees at all levels throughout LLNL. Courses presented by EPD's Training Section are listed in **Table 3-9**.

Table 3-9. EPD training courses.

Air Source Management	Packaging and Shipping Operations
Drills and Exercises for HWM	Petroleum Product Storage Tank Management
Emergency Response for Environmental Duty Officers	RCRA ^(b) for EWSF/EWTF ^(c)
Environmental Duty Officer Briefings	RCRA Facility Management
Field Fingerprint Verification Analyses	SARA/OSHA ^(d) Field Experience
Hazardous Waste Generation and Certification	SARA/OSHA Refresher Training
Hazardous Waste Generation and Certification Review	Spill Prevention, Control, and Countermeasure Training
Hazardous Waste Sampling	Storm Water Pollution Prevention
Hazardous Waste Transportation	TRU ^(e) Waste Generation and Certification
Identification of Hazardous Material	Waste Accumulation Area Operations
Legacy Waste Process Knowledge Evaluation	Waste Characterization Approval
Low-Level Waste Generation and Certification	Waste Management Unit OJT ^(f)
NEPA ^(a) Compliance	Waste Process and Matrix Identification
New Hire Orientation	Waste Retention Tank Management

^a NEPA = National Environmental Policy Act.

^b RCRA = Resource Conservation and Recovery Act.

^c EWSF/EWTF = Explosive Waste Storage Facility/Explosive Waste Treatment Facility.

^d SARA/OSHA = Superfund Amendment and Reauthorization Act/Occupational Safety and Health Administration.

^e TRU = Transuranic.

^f OJT = On-the-job training.

LLNL's Other Environmental Programs

While EPD plays a central role, every directorate at LLNL is responsible for environmental compliance and minimizing the impacts of its operations. Several directorates have taken particularly noteworthy steps in this direction. Some examples include the plans for Defense Nuclear Technologies Program's Contained Firing Facility at Site 300 that will move explosive tests inside a facility where the debris is contained, the Laser Program's efforts to design the National Ignition Facility to have minimal environmental impact, Engineering's Metal Finishing Group's efforts to reduce waste and substitute



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

Integral to LLNL's environmental research is the Environmental Programs Directorate that conducts multidisciplinary research to assess and mitigate environmental and human risk from natural and man-made hazards and to develop and demonstrate new tools and technologies for environmental restoration. This work includes studies in the design, analysis, and testing of advanced waste-treatment technologies; in situ environmental remediation using natural and engineered processes; pathway, dosimetry, and risk analysis of radioactive and toxic substances; atmospheric dynamics; subsurface imaging and characterization; and seismic processes.

Contributing Authors Acknowledgment

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Air Effluent Monitoring

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Introduction

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

Air Quality Laws

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

Enforcement authority of the Clean Air Act regulations for nonradiological air emissions have been delegated to the local air districts: the Bay Area Air Quality Management District (BAAQMD) for the Livermore site and the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) for Site 300. Applicable regulations and permitting requirements are contained in the BAAQMD Regulations 1-12 for the Livermore site and the SJVUAPCD Regulations Rules 1010-9120 for Site 300.



4 Air Effluent Monitoring

Monitored Emissions

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

Assessment of air effluent emissions and resulting dose to the public is performed by monitoring emissions and/or evaluating potential emissions. Currently, the air effluent sampling program measures only radiological emissions. LLNL has operations with nonradiological discharges; however, permits for these operations are obtained through local agencies, BAAQMD, and SJVUAPCD, and monitoring of the effluent is not required. The California Air Toxics “Hot Spots” legislation requires facilities to prepare an air toxics emissions inventory and risk assessment, which LLNL has completed. Based on the assessment, BAAQMD and SJVUAPCD have ranked LLNL as a low-risk facility for nonradiological air emissions.

Historically, monitoring of radionuclide air effluents at LLNL has been implemented according to the DOE as low as reasonably achievable (ALARA) policy. This policy is meant to ensure that DOE facilities are capable of monitoring routine and nonroutine radiological releases, so that the dose to members of the public can be assessed, and so that doses are ALARA. In addition, the NESHAPs 40 CFR 61, Subpart H, regulations require that facility radiological air effluents must be continuously monitored if the potential off-site dose equivalent is greater than $1 \mu\text{Sv}/\text{y}$ ($0.1 \text{ mrem}/\text{y}$), as calculated using the EPA-mandated air dispersion dose model and assuming that there are no emission control devices. The results from monitoring the air discharge points provide the actual emission source information for modeling, which is used to ensure that the NESHAPs standard, $100 \mu\text{Sv}/\text{y}$ ($10 \text{ mrem}/\text{y}$) total site effective dose equivalent, is not exceeded. Discharges from operations that have the potential to release radionuclides but that are not monitored are also evaluated according to the NESHAPs regulations, and the corresponding doses are added to those obtained by modeling monitored emissions to determine radiological NESHAPs compliance.



Operation of Monitoring Systems

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

Methods

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

At the beginning of 1999, LLNL operated 101 sampling systems for radioactivity from air exhausts at eight facilities at the Livermore site (see **Figure 4-1**). These systems are listed in **Table 4-1** along with the analytes of interest, the type of sampler, and the number of samplers. LLNL reassesses the need for continuous monitoring on an annual basis and more often if warranted by new operations or changes in operations. From NESHAPs assessments of operations during 1999, no additional discharge points were found to require continuous sampling.

In 1999, sampling at several air effluent locations was terminated. In the past, sampling operations performed in Buildings 175, 177, 490, and 491 have supported research and development for the separation of uranium isotopes under the Advanced Vapor Laser Isotope Separation (AVLIS) Program. In 1999, the AVLIS Program was shut down, and samplers on a Building 490 exhaust system were deactivated because the operation of the ventilation system was stopped. Air effluent sampling systems at Buildings 175, 177, and 491 continue to operate as part of the maintenance and surveillance shutdown plan for AVLIS facilities. At the Heavy Element Facility (Building 251), 20 samplers were deactivated. This facility has been in a standby mode of operation for some time, and activities involving the use radiological materials are not expected to resume in the areas previously monitored by the deactivated samplers. Finally, a sampling system located at the Expedited Technology of Molten Salt Oxidation project in Building 292 was removed because the project was completed. At the end of 1999, LLNL was operating 76 air effluent sampling systems at six facilities.



4 Air Effluent Monitoring

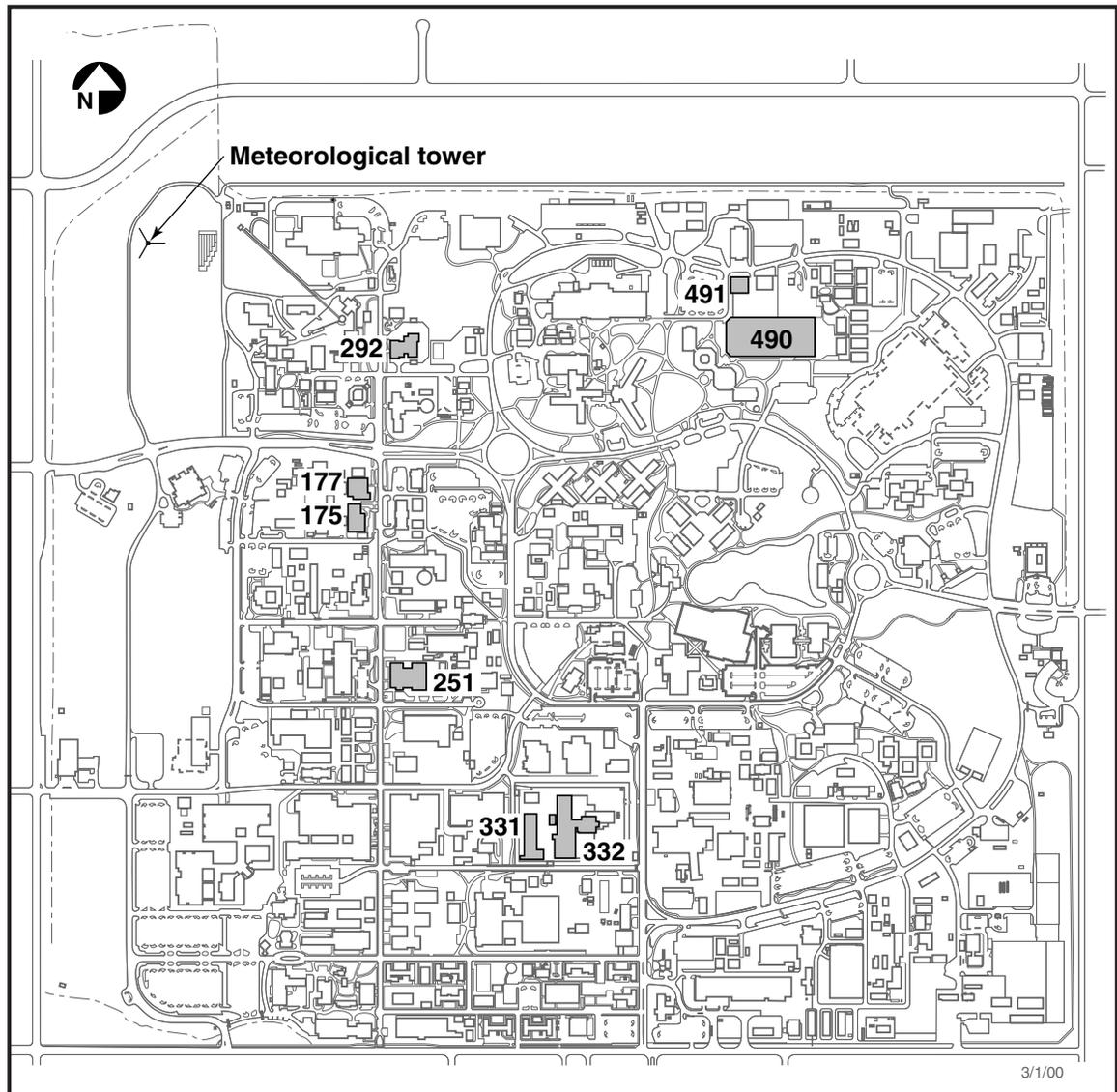


Figure 4-1. Facilities at the Livermore site with air monitoring systems for effluent gas streams during all or part of 1999.

Sampling for particles containing radioactivity was conducted in seven of the facilities; 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 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 is collected using molecular sieves. In addition to sample collection



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

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

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

Building	Facility	Analytes	Sampler type	Number of samplers
175	MARS	Gross α , β on particles	Filter	6
177	Extractor Test Facility	Gross α , β on particles	Filter	1
251	Heavy elements			
	Unhardened area	Gross α , β on particles	Filter	44 ^(a)
	Hardened area	Gross α , β on particles	Filter	4
	Hardened area	Gross α , β on particles	CAM ^(b,c)	4 ^(d)
292	Molten salt oxidation	Gross α , β on particles	Filter	1 ^(d)
331	Tritium	Tritium	Ionization chamber ^(c)	4
		Gaseous tritium and tritiated water vapor	Molecular sieves	4
332	Plutonium	Gross α , β on particles	CAM ^(b,c)	12
		Gross α , β on particles	Filter	16
490	Laser isotope separation	Gross α , β on particles	Filter	4 ^(d)
491	Laser isotope separation	Gross α , β on particles	Filter	1

^a Sixteen of these sampling systems were deactivated in 1999.

^b CAM = Eberline continuous air monitors.

^c Alarmed systems.

^d Sampling at these locations was terminated in 1999.

Measured Radioactive Air Emissions

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

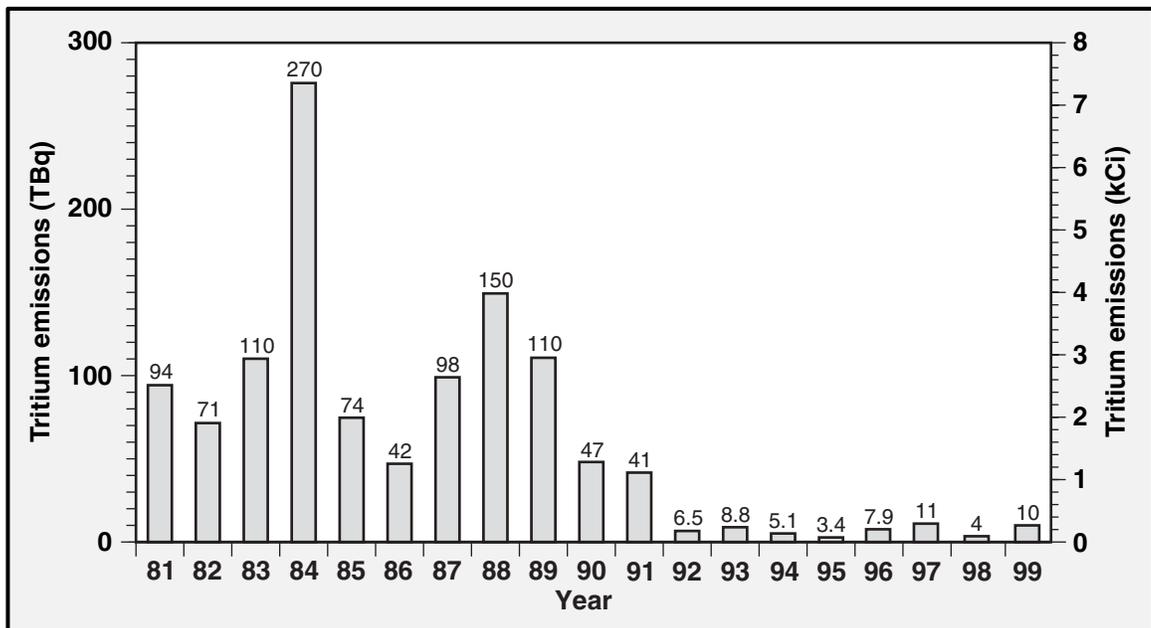


4 Air Effluent Monitoring

Livermore Site

In 1999, a total of 10.4 TBq (281 Ci) of tritium was released from the Tritium Facility (Building 331). Of this, approximately 7.9 TBq (214 Ci) were released as tritiated water vapor (HTO). The remaining tritium released, 2.5 TBq (67 Ci), was elemental tritium gas (HT). HTO emissions from the facility ranged from 26 Bq/m³ (7.0×10^{-10} Ci/m³) to 1.6×10^5 Bq/m³ (4.2×10^{-6} Ci/m³), while HT emissions ranged from 6.8 Bq/m³ (1.8×10^{-10} Ci/m³) to 1.3×10^5 Bq/m³ (3.5×10^{-6} Ci/m³). The highest single weekly stack emission from the facility was 1.5 TBq (41 Ci), of which 0.54 TBq (15 Ci) was HTO. The emissions from Building 331 accounted for 96% of the estimated potential tritium emissions from the Livermore site.

Emissions from Building 331 for 1999 continued to remain considerably lower than those during the 1980s. **Figure 4-2** illustrates the HTO and HT emissions from the facility since 1981. The tritium emissions for 1999 were greater than 1998 emissions because of programmatic activities and an equipment malfunction that occurred in the facility. The tritium air surveillance sample results (see Data Supplement, Chapter 5) accurately confirmed the facility emissions, including a slightly elevated release period from January to March.



Note: The plot of Tritium Facility emissions differs in this report as compared with similar plots in previous reports, in which the Tritium Facility emissions were overstated for the years 1981–1987. The previous reports contained the total LLNL emissions of HTO and HT, not just Tritium Facility emissions.

Figure 4-2. Tritium Facility HTO and HT emissions between 1981 and 1999.



In 1999, most sample results from the continuously sampled discharge points that have the potential for releasing particulate radionuclides were below the MDC of the analysis. This was the case for all of the sampled discharge points at Buildings 175, 177, 332, 490, and 491 and for sampled discharge points at Building 251 except for the one discussed below. Sometimes as few as one to four samples (out of 25 to 50 samples per year) exhibited concentrations greater than the MDC. Generally, these few samples with results above the MDC were only marginally above the MDC. In addition, because of the way some exhaust systems were configured, the monitoring systems sometimes sampled air from the ambient atmosphere and HEPA-filtered air from facility operations, which means that background atmospheric radioactivity was also collected. 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.

At Building 251 (in the unhardened area), one discharge point had a significant number of samples collected throughout the year with gross alpha results greater than the MDC. We use gross alpha as the primary indicator of potential emissions for operations, such as those at Building 251 that involve the use of uranium and transuranic materials. We use gross beta results to further corroborate those gross alpha results with concentrations above the MDC. The gross alpha and gross beta activity emissions for Building 251 were 1.4×10^2 Bq/y (3.7×10^{-9} Ci/y) and 2.5×10^3 Bq/y (6.8×10^{-8} Ci/y). Because of the number of samples with values above the MDC, we have taken a conservative approach and are reporting gross alpha and gross beta measurements as actual emissions.

The gross alpha monitoring concentrations for Building 251 ranged from -7.8×10^{-5} Bq/m³ (-2.1×10^{-15} Ci/m³) to 5.7×10^{-4} Bq/m³ (1.5×10^{-14} Ci/m³). The Building 251 facility was in a standby, limited mode of operation throughout 1999, so emissions were not anticipated. Also, the gross alpha and gross beta average activity concentrations do not significantly differ from those of the low-volume air particulate surveillance samplers (see Chapter 5). Therefore, it is likely that Building 251 measurements were caused by naturally occurring or background radioactivity and by the facility exhaust configuration, as previously mentioned. In any case, the gross alpha and gross beta emissions from operations did not significantly contribute to the radiological dose to the public.



4 Air Effluent Monitoring

Table 4-2 lists total radiological emissions as determined from the continuous sampling of facility exhausts for 1999. Radioactive effluent concentrations from individual discharge points at all monitored facilities are reported in Chapter 4, Data Supplement.

Table 4-2. Measured radiological air effluent emissions for the Livermore site, 1999.

Tritium			
Building	Facility	Elemental, HT (Bq)	Tritiated water, HTO (Bq)
331	Tritium	2.5×10^{12}	7.9×10^{12}
Gross alpha and gross beta			
Building	Facility	Gross alpha (Bq)	Gross beta (Bq)
251	Heavy element	1.4×10^2	2.5×10^3

Site 300

Currently, there is no requirement for air effluent monitoring of facilities at Site 300. Air surveillance monitoring is performed for Site 300, and results are reported in Chapter 5, Air Monitoring.

All Potential Sources of Radioactive Air Emissions

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

For 1999, LLNL evaluated potential emissions of radionuclides from approximately 50 facilities to determine their contribution of dose to a member of the public. Potential emissions were estimated based on radionuclide usage inventories specific to individual discharge points, physical state of the materials involved in the processes, and reductions caused by emission control systems. The effective dose equivalent (EDE) to a



member of the public from specific operations at the Livermore site and Site 300 were published in *LLNL NESHAPs 1999 Annual Report* (Gallegos et al. 2000) and are summarized in Chapter 13 of this report.

The radionuclide isotope responsible for the majority of the 1999 EDE was tritium. Emissions from the Tritium Facility in the form of HTO accounted for 56% of the potential EDE to the maximally exposed member of the public from the Livermore site. Emissions from the facility in the form of HT, when modeled as HTO emissions as mandated by EPA, accounted for 18% of the potential EDE. A discussion of the relative dose impacts from HTO and HT is given in Chapter 13 in the section entitled "Assessment Assumptions Regarding Tritium." The other measured emissions shown in **Table 4-2** (Building 251) contributed negligibly to the EDE for the maximally exposed member of the public.

When determining if continuous sampling is needed at a discharge point, LLNL evaluates operations to determine if the potential dose to the maximally exposed member of the public will exceed 0.1 mrem for the calendar year. This evaluation is similar to the evaluation of EDE previously described except no credit is allowed for emission control systems (according to the regulations). For 1999, LLNL reported more than 200 potential discharge points and/or discharges at the Livermore site and Site 300. As a result of the evaluation, no additional discharge points other than those already being continuously sampled were found to require continuous sampling.

Nonradioactive Air Emissions

The Livermore site currently emits approximately 140 kg/day of criteria air pollutants (e.g., nitrogen oxides, sulfur oxides, particulate matter [PM-10], carbon monoxide, and lead, as defined by the Clean Air Act). The largest sources of criteria pollutants from the Livermore site are surface-coating operations, internal combustion engines, solvent operations, and, when grouped together, boilers (oil and natural gas fired). **Table 4-3** lists the estimated Livermore site 1999 total airborne releases for criteria pollutants.

When comparing the estimated releases from exempt and permitted sources of air pollutants at the Livermore site with daily releases of air pollutants for the entire Bay Area, LLNL emissions are very low. For example, the total emissions of nitrogen oxides released in the Bay Area for 1997 were approximately 1.4×10^5 kg/day compared with an estimate for LLNL releases of 81 kg/day for the Livermore site (0.06% of total Bay



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Table 4-3. Nonradioactive air emissions, Livermore site and Site 300, 1999.

Pollutant	Estimated releases (kg/day)	
	Livermore site	Site 300
Organics/volatile organics	24	1.2
Nitrogen oxides	81	3.2
Carbon monoxide ^(a)	24	0.71
Particulates (PM-10)	8.6	0.33
Oxides of sulfur	0.98	0.28

^a In 1999 the emission factor used to calculate carbon monoxide was 0.035lb/1000 ft³ for large boilers and 0.021 lb/ft³ for small boilers. In previous years the emission factor used was 0.017 lb/ft³ for both large and small boilers. This resulted in a significant change in monoxide emissions reported for 1999.

Area emissions). The BAAQMD estimate for reactive organic emissions was 1.3×10^5 kg/day for 1997, versus the Livermore site's estimated releases of 24 kg/day (0.02% of total Bay Area emissions) in 1999.

Certain operations at Site 300 require permits from SJVUAPCD. The total estimated air emissions during 1999 from operations (permitted and exempt air sources) at Site 300 are given in **Table 4-3**. The largest sources of criteria pollutants at Site 300 include internal combustion engines, boilers, a gasoline-dispensing operation, open burning, paint spray booths, drying ovens, and soil vapor extraction operations.

Environmental Impact

Measured radiological air emissions from the Livermore site operations for 1999 are well below levels that should cause concern for public health according to existing regulatory standards for radioactive dose. The dose to the hypothetical maximally exposed member of the public caused by the measured air emissions reported here (that is, caused by emissions from monitored stacks) is 0.67 μ Sv/y (0.067 mrem/y). Including the measured HT emissions (with HT emissions modeled as HTO emissions as mandated by EPA), the dose to the hypothetical maximally exposed member of the public is 0.88 μ Sv/y (0.088 mrem/y). In either case, the dose is far below the NESHAPs standard of 100 μ Sv/y (10 mrem/y) and doses from naturally occurring radiation. Thus, the estimated radiological dose caused by measured air emissions from LLNL operations is minimal. See **Table 13-2** in Chapter 13 for a summary of all doses, monitored or otherwise. Nonradioactive air effluents, which are also very small compared with emissions in surrounding areas, are well below standards and are not a threat to the environment or public health.

Air Surveillance Monitoring

Paris E. Althouse
Paula J. Tate

Introduction

Lawrence Livermore National Laboratory performs air surveillance monitoring to evaluate its compliance with local, state, and federal laws and regulations and to ensure that human health and the environment are protected from hazardous and radioactive air emissions. Federal environmental air quality laws and U.S. Department of Energy (DOE) regulations include Title 40 of the *Code of Federal Regulations* (CFR) Part 61; the National Emissions Standards for Hazardous Air Pollutants (NESHAPs) section of the Clean Air Act; DOE Order 5400.1, *General Environmental Protection Program* Chapter IV, paragraph 1.a. and paragraph 5; and DOE Order 5400.5, *Radiation Protection of the Public and the Environment*, Change 2, Chapter II, Paragraph 1 (except 1.a.3.c. and 1.c), and Chapter III. The *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. Department of Energy 1991) provides the guidance for implementing DOE Orders 5400.1 and 5400.5. In general, the constituents for which LLNL monitors are at levels far below the regulatory standards.

LLNL conducts surveillance monitoring of ambient air to determine if airborne radionuclides or hazardous materials are being released by Laboratory operations, what the concentrations are, and what the trends are in the LLNL environs. In the air monitoring program, LLNL collects particles on filters and chemically traps vapors on a collection medium. Concentrations of various airborne radionuclides (including particles and tritiated water vapor) and beryllium are measured at the Livermore site, Site 300, and at off-site locations throughout the Livermore Valley and in the City of Tracy. In addition, some point sources and diffuse, or nonpoint sources, are monitored to fulfill NESHAPs requirements (Gallegos et al. 2000).

Methods

Several monitoring networks were established for surveillance of air particulates and tritium in the environs of LLNL and Site 300, as well as in the surrounding Livermore Valley and in the City of Tracy. The sampling locations for each monitoring network are listed in **Table 5-1** and shown on **Figures 5-1, 5-2, and 5-3**. All monitoring networks use



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continuously operating samplers. The radiological high-volume sampling networks use glass-fiber filters; the beryllium high-volume networks use cellulose filters; and the low-volume network uses Millipore AW-19 filters. The collection medium for tritium is silica gel.

Table 5-1. Air sampling locations listed by monitoring network.

High-volume radiological (glass fiber filters)	High-volume beryllium (cellulose filters)	Low-volume gross alpha and beta (millipore filters)	Tritium (silica gel)
Livermore site sampling locations			
B531 ^(a) CAFE COW CRED ^(a) MESQ MET SALV VIS	CAFE COW MESQ MET SALV VIS		B292 ^(a) B331 ^(a) B514 ^(a) B624 ^(a) CAFE COW MESQ MET POOL SALV VIS
Livermore Valley sampling locations			
AMON CHUR FCC FIRE HOSP LWRP PATT TANK ZON7		FCC HOSP	AMON FIRE HOSP VET XRDS ZON7
Site 300 sampling locations			
801E ECP EOBS GOLF NPS WCP WOBS	801E EOBS GOLF		
Site 300 off-site sampling locations			
PRIM TFIR	TFIR		PRIM

^a These locations are in areas of diffuse sources and are monitored to fulfill NESHAPs requirements.

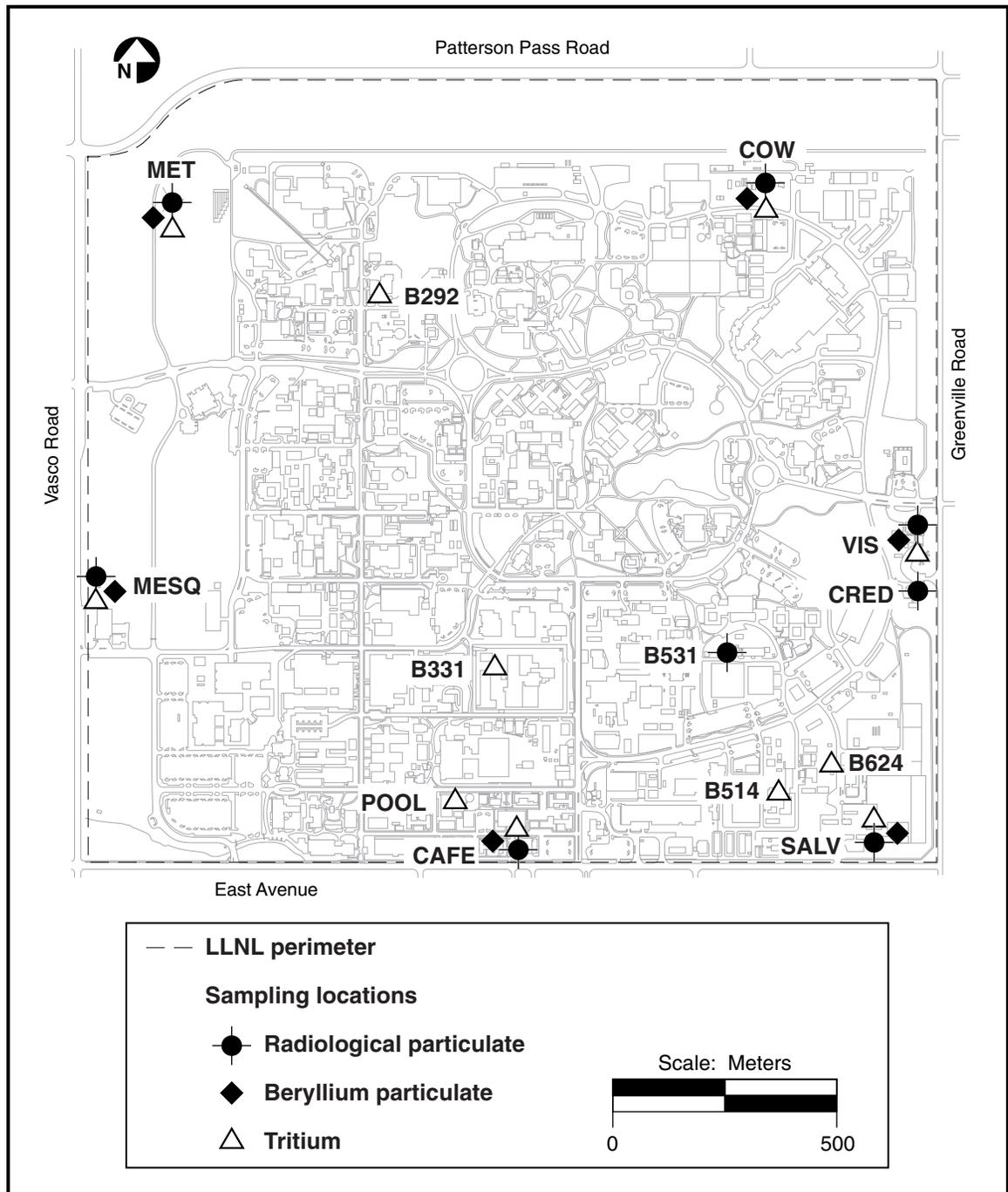


Figure 5-1. Air particulate and tritium sampling locations on the Livermore site, 1999.



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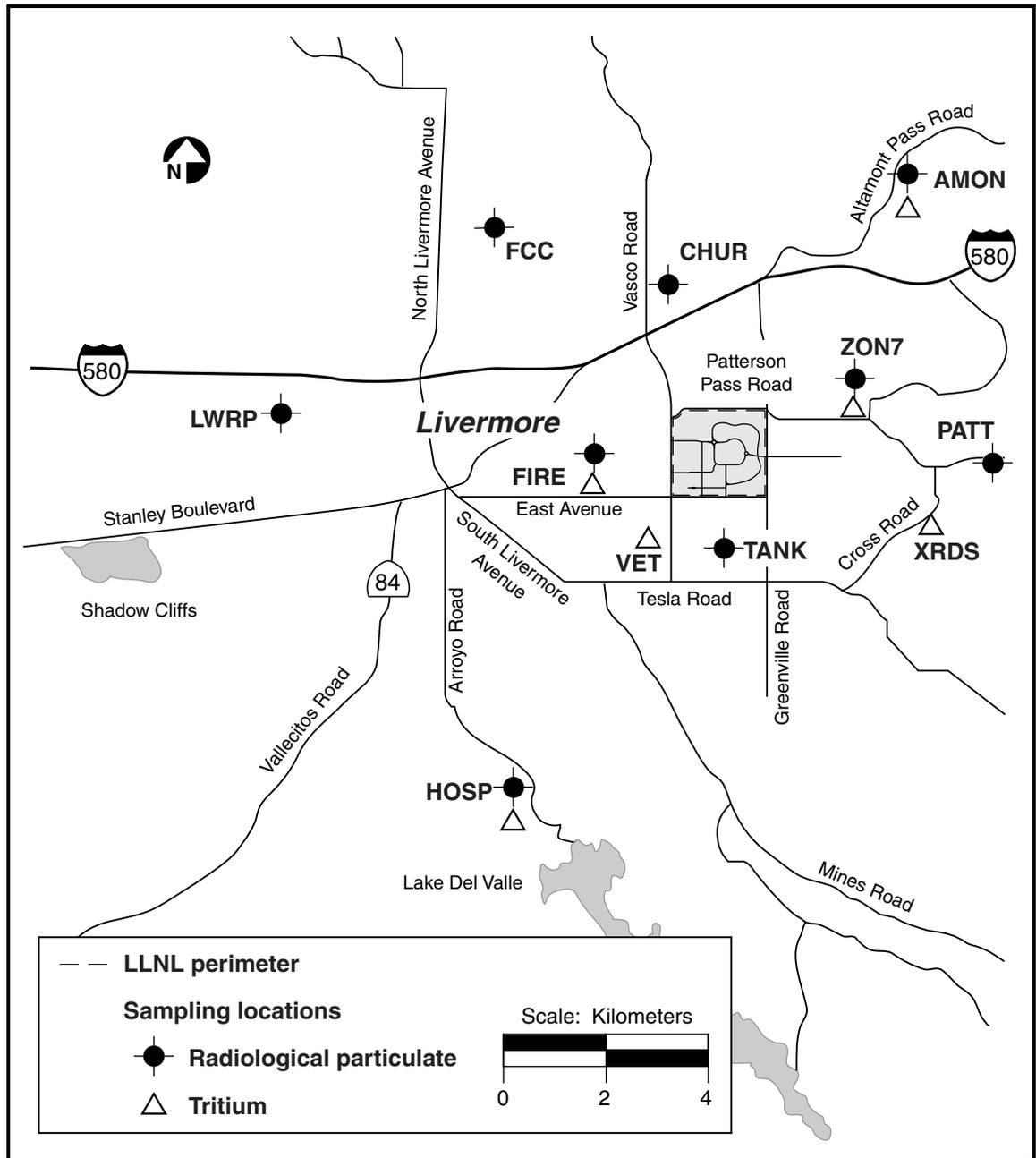


Figure 5-2. Air particulate and tritium sampling locations in the Livermore Valley, 1999.

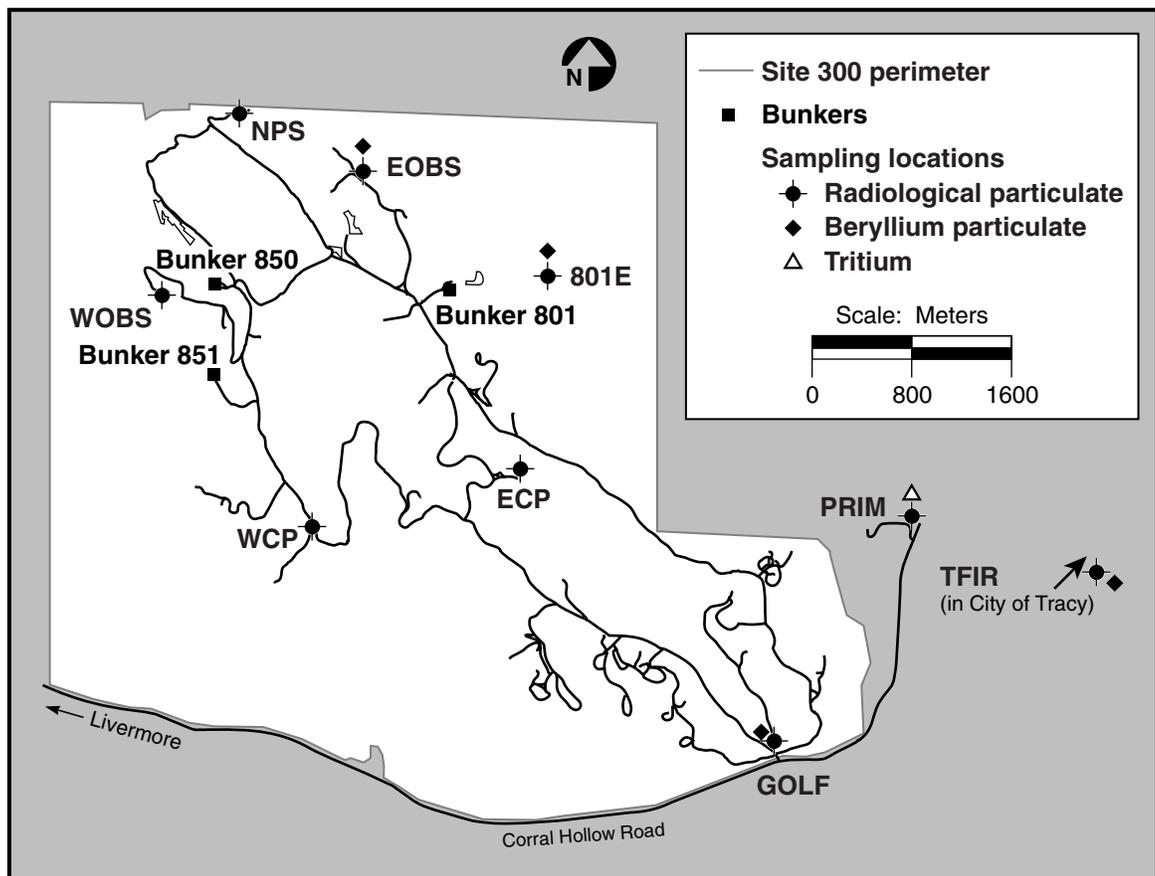


Figure 5-3. Air particulate and tritium sampling locations at Site 300 and off site, 1999.

All air samplers are positioned to provide reasonable probability that, if there were any significant concentration of radioactive or beryllium effluents from LLNL operations, it would be detected. The geographical details of the particulate sampling locations are described in the Environmental Protection Department's location database. Details for accessing the database are available in the Locations Database SOP Supplement EMP-QA-DM, *Sample and Data Management*.

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



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Air Particulate Sampling Locations

The Livermore site radiological air surveillance sampling network consists of six samplers at the perimeter; in addition, two areas of special interest (B531 and CRED shown in **Figure 5-1**) are monitored for plutonium only. These two locations in the southeast quadrant are areas of known plutonium contamination attributed to historic operations, which included the operation of solar evaporators for plutonium-containing liquid waste.

The Livermore Valley network (**Figure 5-2**) consists of air particulate samplers located in all compass directions from the Livermore site. For the purposes of data analysis, four samplers (FCC, FIRE, HOSP, and CHUR) located in the least prevalent wind directions are considered to be upwind or representative of background locations, and four samplers (PATT, ZON7, TANK, and AMON) located in the most prevalent downwind directions are considered most likely to be affected by Laboratory operations. An additional sampler is located in another area of special interest, the Livermore Water Reclamation Plant (LWRP), because of a 1967 and earlier plutonium releases to the sanitary sewer system with subsequent soil contamination and potential resuspension (see Chapter 10, Results, for a discussion of this).

Livermore site beryllium monitoring continued in 1999 at the six perimeter locations. To satisfy beryllium reporting requirements and determine the effects of the Laboratory's beryllium operations, LLNL conducted a technical assessment of the beryllium monitoring locations at Site 300 in 1997. Although there is no requirement to sample for beryllium at Site 300, as a best management practice, LLNL has decided to continue beryllium monitoring at three locations on site and at one location in the City of Tracy (TFIR).

Two sampling systems were added in July 1997 as part of the new low-volume radiological air surveillance sampling network. The samplers are situated at the FCC and HOSP locations, sites that are generally upwind of the Livermore site. The results are used to establish background levels of gross alpha and beta activity for direct comparison to results from the air effluent samplers (see Chapter 4). The sampling systems are very similar to the air-effluent samplers used in facilities, including sampling system design, sampler operation, filter media, sample tracking, sample analysis, and processing of results.



Tritium Sampling Locations

LLNL also maintains 11 continuously operating, airborne tritium samplers on the Livermore site (**Figure 5-1**), six samplers in the Livermore Valley (**Figure 5-2**), and one sampler near Site 300 (**Figure 5-3**) to assess historical and current activities that influence environmental impacts. Four of the Livermore site locations (B331, B292, B514, and B624) monitor diffuse tritium emissions.

Radiological Analysis

As outlined in *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. Department of Energy 1991), gross alpha and gross beta air filter results are used as trend indicators; specific radionuclide analysis is done for plutonium, uranium, and gamma emitters. Radiological analytical results are reported as a measured concentration per volume of air, or as less than the minimum detection concentration (MDC) when no activity is detected. In all cases, the MDC is adequate for demonstrating compliance with the pertinent regulatory requirements for radionuclides that may be or are present in the air sample and for evaluating LLNL-induced environmental impacts. Particle size distributions are not determined because the estimated effective dose equivalent to the maximally exposed individual is well below the 0.01-mSv (1-mrem) allowable limit as discussed in the above-mentioned environmental regulatory guide.

Gross alpha and gross beta activities are determined by gas-flow proportional counting, plutonium by alpha spectrometry, uranium by mass spectrometry, gamma emitters by gamma spectroscopy, and tritium by liquid scintillation. Further details of the surveillance monitoring methods are included in Chapter 5, Data Supplement.

Results

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

In April 1997, the radiological air particulate sampling filter media were changed from cellulose to glass fiber; however, blank glass-fiber filters contain detectable amounts of some naturally occurring radiological isotopes (Althouse 1998) including uranium-235, uranium-238, potassium-40, radium-226, radium-228 and thorium-228. LLNL adjusts



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the measured concentrations of these isotopes according to U.S. Environmental Protection Agency (EPA) procedures (Eadie and Bernhardt 1976) and subtracts the appropriate blank filter content from the gross analytical result to obtain a corrected net result.

Livermore Site

Airborne Radioactivity

Table 5-2 summarizes the monthly gross alpha and gross beta results for the LLNL perimeter, Livermore Valley, Site 300, and Site 300 off-site sampling locations. Detection frequencies, median concentrations, interquartile ranges (IQR), and maximum concentration values for each network are included. (See Data Supplement Tables 5-1, 5-2, and 5-3 for detailed location results for all high-volume networks for gross alpha and gross beta concentrations.)

Typical gross alpha activity (median value) for the LLNL perimeter is 4.5×10^{-5} Bq/m³ (1.2×10^{-15} Ci/m³); for the upwind Livermore Valley stations, the value is 3.8×10^{-5} Bq/m³ (1.0×10^{-15} Ci/m³); and for the downwind Livermore Valley stations, the value is 5.0×10^{-5} Bq/m³ (1.3×10^{-15} Ci/m³). Negative values occur when the activity of the analytical background filters is higher than the activity on the filters being analyzed. Typical gross beta activity (median value) for the LLNL perimeter is 3.2×10^{-4} Bq/m³ (8.7×10^{-15} Ci/m³); for the upwind Livermore Valley stations, the value is 3.0×10^{-4} Bq/m³ (8.1×10^{-15} Ci/m³); and for the downwind Livermore stations, the value is 3.4×10^{-4} Bq/m³ (9.1×10^{-15} Ci/m³). The primary sources of the alpha and beta activities are the naturally occurring radioisotopes of uranium and thorium, and any residual fallout from atmospheric weapons testing and the 1986 Chernobyl reactor accident. The values are slightly higher than those obtained from previous monitoring data during the past several years and are likely caused by a change in March in the analytical laboratory used to perform the gross alpha and gross beta analysis. Data were also elevated when the analytical laboratory was changed in 1993.

The monthly median gross alpha and gross beta concentrations are plotted in **Figures 5-4** and **5-5**, respectively. The gross beta results followed a pattern similar to previous years' data. The gradual increase in beta activity throughout the summer was most likely caused by an increase in resuspension of soils that occurs during the dry season.



Table 5-2. Gross alpha and gross beta concentration in air particulate samples summarized by month, 1999.

Month	Gross alpha (10^{-6} Bq/m ³)				Gross beta (10^{-6} Bq/m ³)			
	Detection frequency ^(a)	Median	IQR ^(b)	Maximum	Detection frequency	Median	IQR	Maximum
LLNL perimeter locations								
Jan	4/30	28.0	59.3	85.1	30/30	712	680	1460
Feb	1/24	9.78	21.8	68.0	20/24	203	100	478
Mar	21/24	45.9	20.9	72.9	24/24	230	72.8	327
Apr	22/29	50.3	49.3	98.8	29/29	269	148	844
May	7/24	18.6	18.1	74.4	24/24	315	90.1	394
Jun	11/23	27.3	37.0	130	23/23	185	116	525
Jul	22/30	43.1	39.9	125	30/30	245	108	659
Aug	13/24	35.1	64.6	96.9	24/24	331	357	696
Sep	23/23	71.4	36.4	120	23/23	648	179	932
Oct	28/30	228	168	385	30/30	1300	607	2660
Nov	20/24	115	77.2	214	24/24	882	276	1070
Dec	24/24	86.6	94.1	277	24/24	696	778	2530
Livermore Valley upwind locations								
Jan	2/20	16.1	64.8	84.6	20/20	651	822	1460
Feb	1/16	8.0	42.7	64.1	16/16	196	100	443
Mar	10/16	44.8	32.4	76.2	16/16	235	38.9	310
Apr	12/20	37.1	35.7	106	20/20	258	83.9	666
May	6/16	16.3	20.4	61.8	16/16	275	84.6	442
Jun	4/15	21.0	11.9	54.4	15/15	203	109	444
Jul	13/20	38.5	38.5	104	20/20	247	84.4	736
Aug	11/16	35.1	34.5	98.8	16/16	325	379	655
Sep	16/16	70.1	18.2	98.8	16/16	670	198	892
Oct	19/20	252	179	414	20/20	1270	566	2350
Nov	13/16	115	116	212	16/16	812	283	1120
Dec	15/16	90.8	87.0	259	16/16	605	832	2500



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Table 5-2. Gross alpha and gross beta concentration in air particulate samples summarized by month, 1999 (concluded).

Month	Gross alpha (10^{-6} Bq/m ³)				Gross beta (10^{-6} Bq/m ³)			
	Detection frequency ^(a)	Median	IQR ^(b)	Maximum	Detection frequency	Median	IQR	Maximum
Livermore Valley downwind locations								
Jan	3/25	11.3	50.9	101	25/25	717	696	1480
Feb	1/20	14.4	33.5	64.0	20/20	198	129	376
Mar	17/20	53.7	32.4	85.5	20/20	248	47.2	349
Apr	20/25	51.4	45.5	128	25/25	302	84.4	725
May	7/20	15.7	28.7	102	20/20	268	52.1	472
Jun	12/20	30.2	26.9	62.5	20/20	201	80.4	403
Jul	12/25	24.7	48.6	104	25/25	253	75.9	740
Aug	18/20	48.1	35.0	102	20/20	375	447	673
Sep	20/20	70.7	38.9	120	20/20	710	130	903
Oct	22/25	231	180	492	25/25	1210	648	2680
Nov	19/20	119	89.7	182	20/20	821	353	1080
Dec	18/20	92.9	129	302	20/20	677	895	2450
Site 300^(c) sampling locations								
Jan	2/35	20.8	42.2	110	34/35	551	651	1320
Feb	3/28	7.70	36.5	79.5	26/28	189	122	497
Mar	21/28	49.4	44.0	89.9	28/28	247	80	367
Apr	29/35	50.3	32.6	134	35/35	344	133	803
May	18/28	33.3	25.4	70.7	28/28	376	109	466
Jun	20/28	35.3	31.4	86.2	28/28	320	161	488
Jul	27/35	63.3	50.7	143	35/35	301	155	873
Aug	20/22	49.4	50.9	128	22/22	463	426	818
Sep	28/28	96.8	41.1	142	28/28	984	257	1210
Oct	32/35	221	152	352	35/35	1200	509	2330
Nov	26/28	116	93.8	214	28/28	849	369	1240
Dec	28/28	91.6	110	302	28/28	644	833	2510

^a Detection frequency is the number of samples with results above the detection limit divided by the number of samples.

^b IQR = Interquartile range.

^c Results for Site 300 off-site locations TFIR and PRIM are given in the Data Supplement Table 5-15.

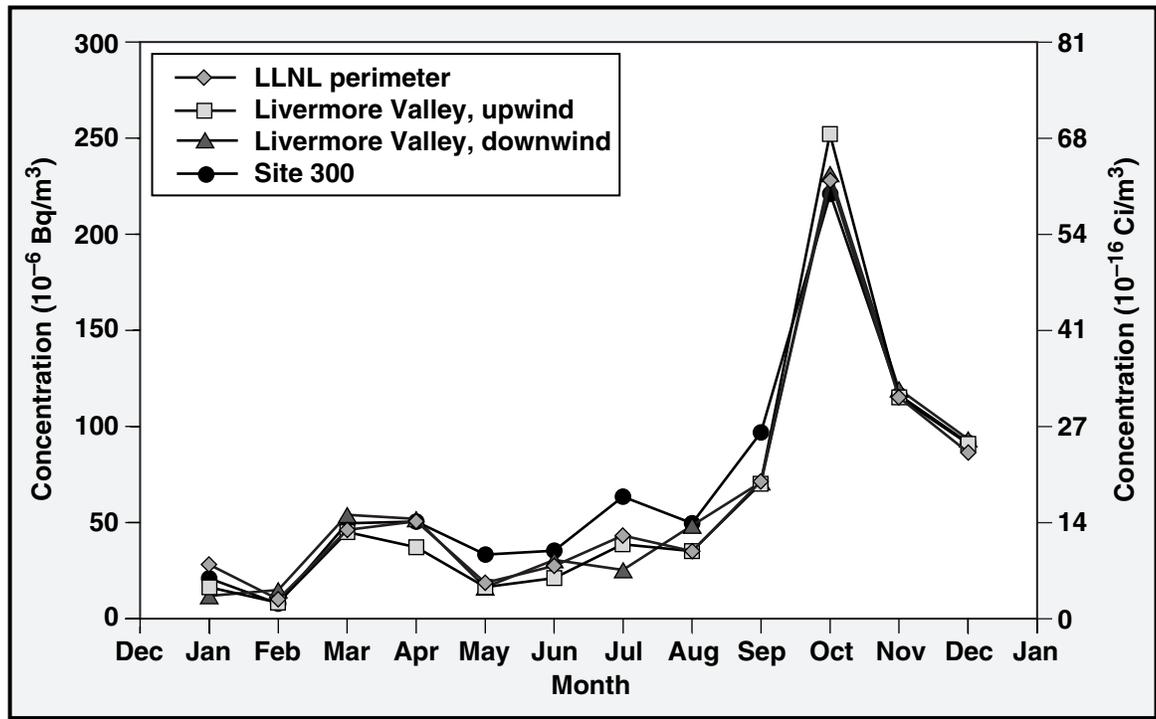


Figure 5-4. Monthly median gross alpha concentrations in particulate air samples from the LLNL perimeter, Livermore Valley, and Site 300 sampling locations, 1999.

Gamma-emitting radionuclide concentrations in air that contribute to the activity in the Livermore site perimeter samples are summarized in **Table 5-3**. (See Data Supplement Table 5-4 for monthly gamma activity data.) Of the nuclides identified, all were naturally occurring, with the exception of cesium-137. The primary source of cesium-137 is long-term global fallout and fallout resuspension.

By analyzing air samples for gamma-emitting radionuclides, LLNL verifies that there is no evidence of a release of the small inventories of mixed fission products and radiochemical tracers used at LLNL and also obtains baseline data on global fallout. The Derived Concentration Guides (DCGs) for these radionuclides are shown in **Table 5-3**. For air, DCGs specify the concentrations of radionuclides that could be inhaled continuously 365 days a year without exceeding the DOE primary radiation protection standard for the public, which is 1 mSv/y (100 mrem/y) effective dose equivalent (DOE Order 5400.5). (Chapter 13, Radiological Dose Assessment, provides an explanation of



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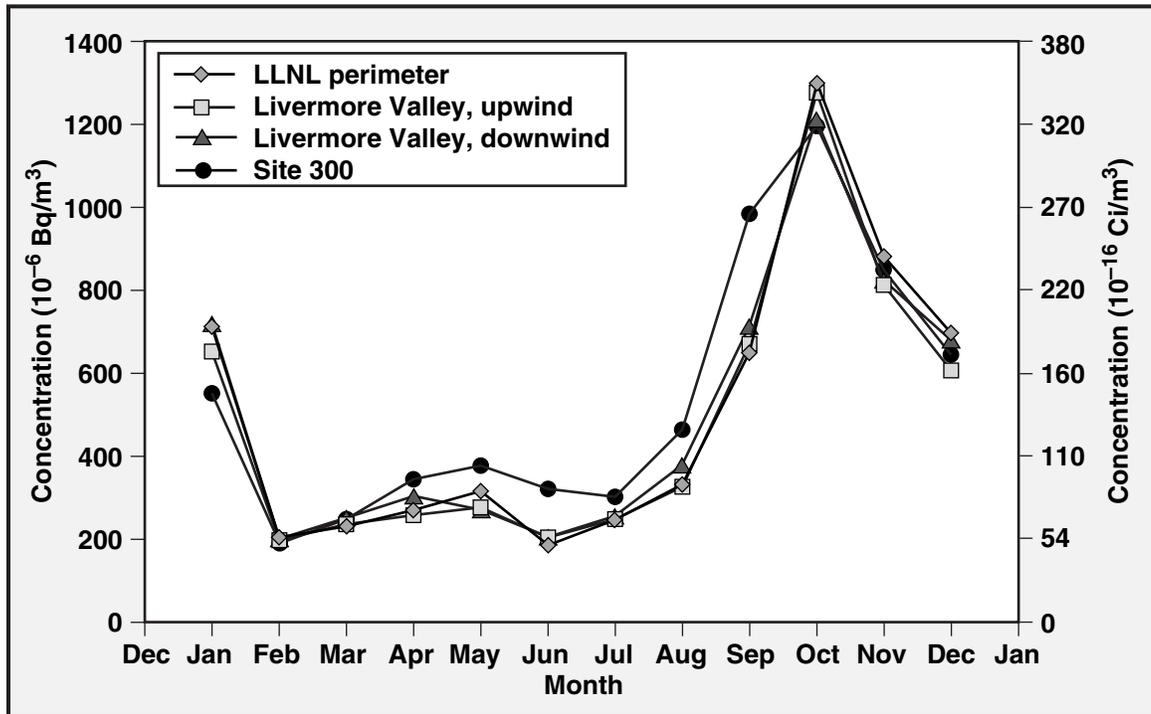


Figure 5-5. Monthly median gross beta concentrations in particulate air samples from the LLNL perimeter, Livermore Valley, and Site 300 sampling locations, 1999.

this and other units of dose.) **Table 5-3** also presents the percent of the DCGs, which demonstrates that the level of gamma activity present in air at the Livermore site perimeter was far below the DCGs.

Table 5-4 shows the concentrations of airborne plutonium-239+240 on air filters from the LLNL perimeter locations. (See Data Supplement Table 5-5 for the monthly data by location.) The highest concentration was registered at location VIS in May 1999; the concentration value is reported as 3.9×10^{-8} Bq/m³ (1.1×10^{-18} Ci/m³), which represents 0.005% of the DCG. The median concentration at location VIS is 1.3×10^{-8} Bq/m³ (3.5×10^{-19} Ci/m³), which is slightly lower than that for the previous year.

Table 5-4 also shows the detection frequency, median concentration, IQR, maximum concentration, and percent of DCG for the concentration of plutonium on air filter samples collected in the Livermore Valley. (See Data Supplement Table 5-6 for monthly data.) The highest off-site concentration of plutonium-239+240 occurred at PATT during October, which had a median observed value of 0.0004% of the DCG.

**Table 5-3.** Gamma activity in air particulate samples, Livermore site perimeter and Site 300, 1999.

	⁷ Be	⁴⁰ K	¹³⁷ Cs	²² Na	²²⁶ Ra	²²⁸ Ra	²²⁸ Th
	(10 ⁻³ Bq/m ³)	(10 ⁻⁶ Bq/m ³)					
Livermore perimeter locations							
Median	3.4	12	0.21	0.24	-0.011	0.33	0.29
Interquartile range	0.85	20	— ^(a)	— ^(a)	0.95	0.98	0.72
Maximum	7.8	40	0.57	0.57	0.96	3.7	1.8
Percent of DCG ^(b)	2.3 × 10 ⁻⁴	3.7 × 10 ⁻⁵	1.4 × 10 ⁻⁶	6.4 × 10 ⁻⁷	2.6 × 10 ^{-3(c)}	3.0 × 10 ⁻⁴	0.019
Site 300 locations							
Median	3.8	13	0.20	0.43	0.17	0.36	-0.31
Interquartile range	2.3	41	— ^(a)	— ^(a)	2.0	1.5	1.2
Maximum	7.2	61	0.62	0.71	1.8	5.4	3.3
Percent of DCG	2.5 × 10 ⁻⁴	3.8 × 10 ⁻⁵	1.3 × 10 ⁻⁶	1.1 × 10 ⁻⁶	4.6 × 10 ⁻⁴	3.2 × 10 ⁻⁴	0.22 ^(c)
DCG (Bq/m ³)	1.5 × 10 ³	33	15	37	0.037	0.11	1.5 × 10 ⁻³

^a No measure of dispersion calculated; see Chapter 14, Quality Assurance.

^b Derived Concentration Guide. Percent calculated from the median concentration.

^c Percent of DCG calculated with maximum value because the median is negative.

Table 5-4 shows the median concentrations of airborne plutonium-239+240 at the two diffuse source locations (B531 and CRED). (See Data Supplement Table 5-7 for monthly data.) The median concentration of 2.7×10^{-8} Bq/m³ (7.3×10^{-19} Ci/m³) at location B531 is higher than the median concentration for any of the other air particulate sampling locations, but it is still only 0.004% of the DCG. The higher concentrations are attributed to historic waste management operations, which included the operation of solar evaporators for plutonium-containing liquid waste (Silver et al. 1974).

In October, the plutonium concentrations reported were above the minimum detectible level for all locations. While this is unusual, none of these values exceeded the action levels identified in the *Environmental Monitoring Plan* (Tate et al. 1999). However, because the concentrations were unusual, they were investigated at the analytical laboratory. The analytical laboratory found no source of error or contamination. A similar increase was detected in nearly all other particulate surveillance data (including low-volume data) in October. This increase is likely the result of increased particulate resuspension and subsequent filter loading that occurs during dry months. This anomaly did not occur in any other months in 1999.



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Table 5-4. Plutonium-239+240 activity in air particulate samples (10^{-9} Bq/m³), 1999.

Sampling location ^(a)	Detection frequency ^(b)	Median	Interquartile range	Maximum	Percent of DCG ^(c)
Livermore Valley downwind locations					
AMON	4/12	3.58	4.16	16.1	4.84×10^{-4}
PATT	4/12	2.68	4.57	25.2	3.62×10^{-4}
TANK	2/12	2.01	1.99	8.66	2.71×10^{-4}
ZON7	2/12	1.87	2.65	23.1	2.52×10^{-4}
Livermore Valley upwind locations					
CHUR	3/12	1.37	5.78	23.8	1.84×10^{-4}
FCC	1/12	0.103	2.85	11.1	1.39×10^{-5}
FIRE	2/12	2.10	3.12	11.1	2.84×10^{-4}
HOSP	1/12	0.264	1.52	6.40	3.56×10^{-5}
LLNL perimeter locations					
CAFE	8/12	5.51	7.01	25.1	7.45×10^{-4}
COW	3/12	4.64	2.22	28.7	6.28×10^{-4}
MESQ	1/12	3.85	3.19	22.0	5.21×10^{-4}
MET	2/12	2.52	2.83	7.99	3.41×10^{-4}
SALV	3/12	3.88	2.43	18.0	5.25×10^{-4}
VIS	7/12	13.0	20.1	38.9	1.76×10^{-3}
Diffuse on-site sources locations					
B531	12/12	26.9	50.2	94.0	3.64×10^{-3}
CRED	7/12	6.05	4.29	33.5	8.18×10^{-4}
Special interest location					
LWRP	5/12	5.06	3.24	21.1	6.83×10^{-4}
Site 300 on-site locations					
S300 composite	4/12	1.79	2.52	8.7	2.41×10^{-4}
Site 300 off-site locations					
PRIM	2/12	1.91	3.78	11.3	2.58×10^{-4}
TFIR	3/11	2.43	5.67	12.6	3.29×10^{-4}

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

^b Detection frequency is the number of samples with results above the detection limit divided by the number of samples.

^c DCG = Derived Concentration Guide of 7.4×10^{-4} Bq/m³ (2×10^{-8} μ Ci/m³) for ²³⁹Pu activity in air. Percent calculated from the median concentration.



Figure 5-6 shows the annual median concentrations of plutonium-239+240 for locations SALV (on site) and FCC (off site) from 1982 to 1999. Location FCC represents a typical upwind background location, and SALV represents a typical perimeter location. The annual median concentration for FCC was 1.0×10^{-10} Bq/m³ (2.7×10^{-21} Ci/m³).

Figure 5-6 uses a log scale and, for the years in which a negative median concentration was calculated, the positive value closest to the median was plotted. The higher values in the past at SALV may be attributed to historical activities at LLNL. In 1993, clean top soil was laid over much of the area, reducing the potential for increased levels from soil resuspension. The sampler at SALV was moved to a nearby grassy knoll, possibly resulting in a decrease in the plutonium median for 1999. The downward trend at location FCC is the result of decreasing residual global fallout.

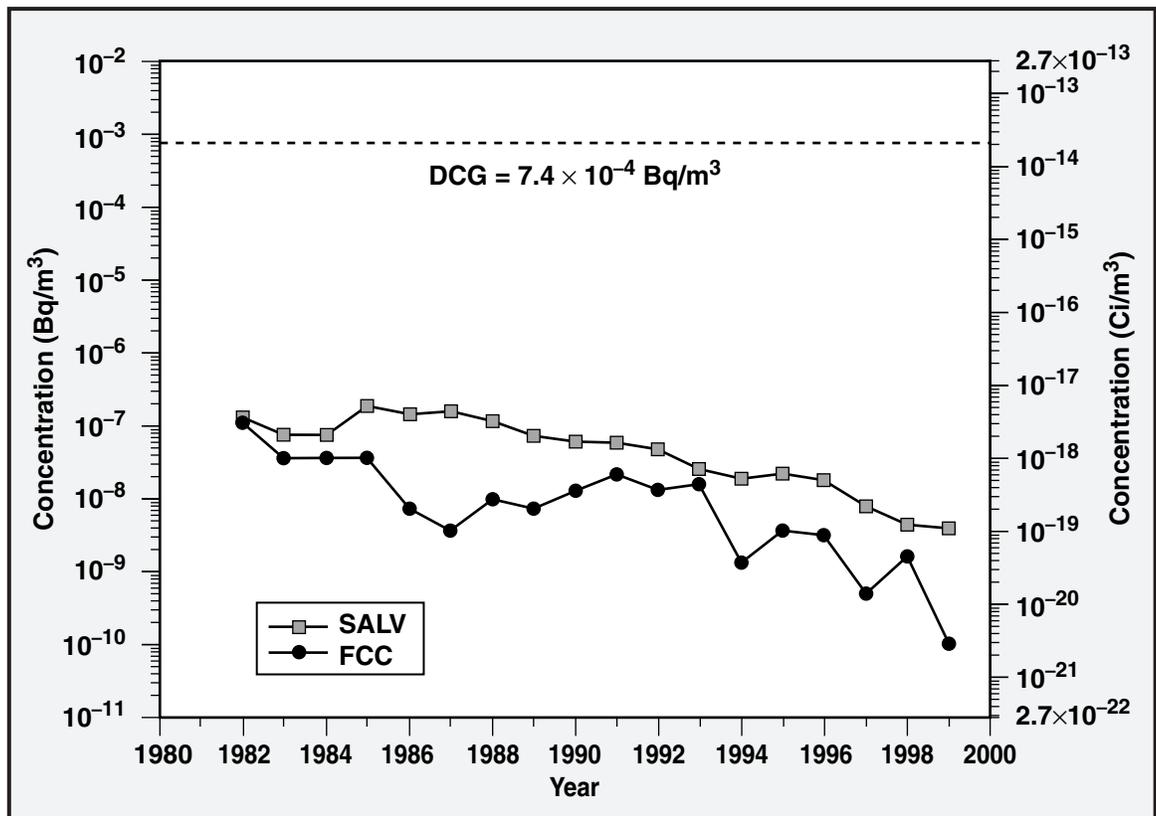


Figure 5-6. Annual median plutonium concentrations in air particulate samples at two locations, SALV and FCC, 1982–1999.



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The ratio of uranium-235 to uranium-238 can be used to identify the source of the uranium. Both uranium-235 and uranium-238 occur naturally in the area, but only 0.7% of the naturally occurring uranium is uranium-235, and the remainder is almost entirely uranium-238. The median uranium-235 and uranium-238 mass concentrations in air samples from the Livermore site perimeter are shown in **Table 5-5**. (See Data Supplement Table 5-8 for monthly data.) The maximum measured concentration of uranium-238 (at location SALV during October) is less than 0.2% of the DCG. All uranium-235/uranium-238 median ratios are generally as expected for naturally occurring uranium; however, September monthly data in the Data Supplement show some unexpected uranium-235/uranium-238 ratios. The cause for these anomalous data is unknown; however, these ratios may be the result of increased variability in measured concentrations near the detection limit. No significant environmental impact stems from the observed ratios.

The low-volume radiological air sampling locations HOSP and FCC have typical gross alpha and gross beta activity of $4.7 \times 10^{-5} \text{ Bq/m}^3$ ($1.3 \times 10^{-15} \text{ Ci/m}^3$) and $4.8 \times 10^{-4} \text{ Bq/m}^3$ ($1.3 \times 10^{-14} \text{ Ci/m}^3$), respectively. (See Data Supplement Tables 5-9 and 5-10 for monthly median data.) These gross alpha values are slightly higher than those reported from the high-volume sampling systems at the same locations. The difference is probably caused by differences in the filter type. LLNL is conducting a study to determine the cause of the differences.

Table 5-6 shows the median concentrations of tritiated water vapor for the Livermore Valley sampling locations. (See Data Supplement Table 5-11 for biweekly data for each location.) The highest annual median concentration was observed at location ZON7. At approximately $3.9 \times 10^{-2} \text{ Bq/m}^3$ ($1.1 \times 10^{-12} \text{ Ci/m}^3$), this concentration represents 0.001% of the DCG. The highest biweekly concentration was observed in February at ZON7. If it were a yearly average, this concentration, 0.27 Bq/m^3 ($7.3 \times 10^{-12} \text{ Ci/m}^3$), would be 0.007% of the DCG. The 1999 tritium values were slightly higher than those reported last year because of slightly elevated emissions from the Tritium Facility (Building 331) during January, February, and March.

Table 5-6 also shows the median concentrations of tritiated water vapor that were observed at the Livermore site perimeter sampling locations. (See Data Supplement Table 5-12 for biweekly data.) The highest annual median concentration was observed at location POOL, which was 0.14 Bq/m^3 ($3.8 \times 10^{-12} \text{ Ci/m}^3$), or 0.004% of the DCG.

**Table 5-5.** Uranium mass concentration in air particulate samples, 1999.

Sampling location ^(a)	²³⁵ U ^(b) (10 ⁻⁷ µg/m ³)	²³⁸ U ^(c) (10 ⁻⁵ µg/m ³)	²³⁵ U/ ²³⁸ U ^(d) (10 ⁻³)
LLNL perimeter locations			
CAFE			
Median	4.29	6.57	6.70
Interquartile range	2.54	5.32	0.335
Maximum	11.3	17.9	NA ^(e)
Percent of DCG ^(f)	9.13 × 10 ⁻⁴	2.19 × 10 ⁻²	NA
COW			
Median	4.96	7.13	6.88
Interquartile range	3.74	5.96	0.363
Maximum	10.9	15.7	NA
Percent of DCG	1.05 × 10 ⁻³	2.38 × 10 ⁻²	NA
MESQ			
Median	3.90	6.43	6.97
Interquartile range	3.07	4.41	0.549
Maximum	8.88	12.4	NA
Percent of DCG	8.30 × 10 ⁻⁴	2.14 × 10 ⁻²	NA
MET			
Median	2.66	3.80	6.85
Interquartile range	1.26	2.09	0.419
Maximum	9.32	13.5	NA
Percent of DCG	5.67 × 10 ⁻⁴	1.27 × 10 ⁻²	NA
SALV			
Median	2.34	3.77	6.88
Interquartile range	1.62	2.39	0.931
Maximum	10.3	14.8	NA
Percent of DCG	4.97 × 10 ⁻⁴	1.26 × 10 ⁻²	NA
VIS			
Median	3.25	4.76	6.85
Interquartile range	2.72	5.3	0.410
Maximum	11.4	17.1	NA
Percent of DCG	6.92 × 10 ⁻⁴	1.59 × 10 ⁻²	NA



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Table 5-5. Uranium mass concentration in air particulate samples, 1999 (concluded).

Sampling location ^(a)	²³⁵ U ^(b) (10 ⁻⁷ µg/m ³)	²³⁸ U ^(c) (10 ⁻⁵ µg/m ³)	²³⁵ U/ ²³⁸ U ^(d) (10 ⁻³)
Site 300 on-site locations			
Site 300 composite			
Median	2.91	4.55	6.29
Interquartile range	3.73	6.16	0.919
Maximum	9.06	18.6	NA
Percent of DCG	6.20	1.52	NA
Site 300 off-site location			
PRIM			
Median	4.01	5.70	6.98
Interquartile range	4.01	5.56	0.604
Maximum	14.7	18.2	NA
Percent of DCG	8.53	1.90	NA

^a See **Figures 5-1** and **5-3** for sampling locations.

^b Derived Concentration Guide = 0.047 µg/m³ for uranium-235 activity in air. Uranium-235 activities in Bq/m³ can be determined by dividing the weight in µg/m³ by 12.5, and pCi m³ can be determined by dividing by 0.463.

^c Derived Concentration Guide = 0.3 µg/m³ for uranium-238 activity in air. Uranium-238 activities in Bq/m³ can be determined by dividing the weight in µg/m³ by 80.3, and pCi m³ can be determined by dividing by 2.97.

^d Naturally occurring uranium has a uranium-235/uranium-238 ratio of 7.1 × 10⁻³.

^e NA = Not applicable.

^f DCG = Derived Concentration Guide. Percent calculated from the median concentration.

Diffuse sources of tritium on the Livermore site are monitored at air tritium sampling locations B292, B331, B514, and B624. **Table 5-6** shows the median concentrations of tritiated water vapor for these sampling locations. (See Data Supplement Table 5-13 for biweekly data.) The highest median concentration was observed at location B624. This concentration was 4.5 Bq/m³ (1.2 × 10⁻¹⁰ Ci/m³) and represents 0.1% of the DCG. The highest biweekly tritium concentration, 13.8 Bq/m³ (3.7 × 10⁻¹⁰ Ci/m³), was observed in April at location B331. If it were a yearly average, this concentration would represent 0.4% of the DCG.

The B331 location is near the Tritium Facility (Building 331), where LLNL personnel have reduced operations in recent years and performed significant inventory reduction and cleanup activities. During this process, tritium-contaminated equipment slated for disposal is stored in an area outside B331 before being sent to Hazardous Waste Management facilities. During 1999, outgassing from such waste processing released an estimated 2.7 × 10¹¹ Bq (7.3 Ci) of tritium to the atmosphere outside Building 331.

**Table 5-6.** Tritium in air samples (10^{-3} Bq/m³), 1999.

Sampling location ^(a)	Detection frequency ^(b)	Median	IQR ^(c)	Maximum	Percent of DCG ^(d)	Median dose (mSv) ^(e)
Livermore Valley locations						
AMON	13/25	20.0	25.6	175	5.4×10^{-4}	4.2×10^{-6}
FIRE	10/24	13.7	24.2	147	3.7×10^{-4}	2.8×10^{-6}
HOSP	5/23	3.27	10.7	87.0	8.8×10^{-5}	6.8×10^{-7}
VET	10/24	15.3	34.2	242	4.1×10^{-4}	3.2×10^{-6}
XRDS	9/25	10.2	24.9	93.2	2.8×10^{-4}	2.1×10^{-6}
ZON7	19/25	39.2	44.4	268	1.1×10^{-3}	8.1×10^{-6}
Livermore perimeter locations						
CAFE	23/26	65.0	85.5	1,890	1.8×10^{-3}	1.3×10^{-5}
COW	25/25	52.5	95.8	688	1.4×10^{-3}	1.1×10^{-5}
MESQ	16/25	45.9	68.1	357	1.2×10^{-3}	9.5×10^{-6}
MET	19/26	35.8	48.6	236	9.7×10^{-4}	7.4×10^{-6}
POOL	25/26	139	269	1,400	3.8×10^{-3}	2.9×10^{-5}
SALV	20/25	50.7	71.3	485	1.4×10^{-3}	1.1×10^{-5}
VIS	25/25	89.9	84.3	622	2.4×10^{-3}	1.9×10^{-5}
Diffuse on-site sources locations						
B292	26/26	182	228	540	4.9×10^{-3}	3.8×10^{-5}
B331	22/22	2,530	7,930	13,800	6.8×10^{-2}	5.2×10^{-4}
B514	26/26	1,650	1,230	2,950	4.5×10^{-2}	3.4×10^{-4}
B624	26/26	4,520	2,410	9,180	1.2×10^{-1}	9.4×10^{-4}
Site 300 off site location						
PRIM	2/25	4.11	15.0	27.4	1.1×10^{-4}	8.5×10^{-7}

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

^b Detection frequency is the number of samples with results above the detection limit divided by the number of samples.

^c IQR = Interquartile range.

^d DCG = Derived Concentration Guide of 3.7×10^3 Bq/m³. Percent calculated from the median concentration.

^e 1 mSv = 100 mrem.

The B624 location is situated in the Building 612 yard, which is dedicated to hazardous waste, radioactive waste, and mixed-waste management activities. The yard has several areas where waste containers that are outgassing tritium are stored outdoors.



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The B514 sampling location is in a hazardous waste management area where tritium-contaminated waste is treated, and the B292 location is near an underground retention tank that had previously leaked. The concentrations in air at the B514 sampling location are variable because of the changing concentrations of tritium in the waste stream. The 1999 median concentrations at B292 and B514 are similar to the median concentrations in 1998.

Beryllium in Air

The median concentrations of airborne beryllium for the Livermore site perimeter sampling locations are shown in **Table 5-7**. (See Data Supplement Table 5-14 for monthly data.) The highest value of 37.8 pg/m³ was found in the October composite at location COW and was most likely attributed to resuspension and mass loading of particulates containing naturally occurring beryllium from construction activities and a lack of rainfall. The median concentration for this location is 0.11% of the monthly ambient concentration limit (ACL) of 10,000 pg/m³ established by the Bay Area Air Quality Management District (BAAQMD) and the EPA.

Table 5-7. Beryllium^(a) in air particulate samples (pg/m³), Livermore site perimeter and Site 300 locations, 1999.

Sampling location ^(b)	Detection frequency ^(c)	Median	Interquartile range	Maximum
Livermore perimeter locations				
CAFE	11/12	11.1	7.40	23.8
COW	12/12	10.8	9.10	37.8
MESQ	11/12	11.0	7.50	36.4
MET	11/12	7.83	4.28	23.9
SALV	10/12	7.47	6.31	25.7
VIS	12/12	10.3	8.02	33.2
Site 300 locations				
801E	12/12	11.8	9.32	30.9
EOBS	10/12	5.53	4.77	18.2
GOLF	12/12	10.2	14.3	26.4
TFIR	11/11	13.4	6.24	32.3

^a The state ambient concentration limit is 10,000 pg/m³.

^b See **Figures 5-1** and **5-3** for sampling locations.

^c Detection frequency is the number of samples with results above the detection limit divided by the number of samples.



Figure 5-7 is a plot of the median beryllium concentration at the Livermore site perimeter from 1974 through 1999. The decrease in median concentration in 1993 and the increase in 1999 were the result of a change in the analytical laboratory used to perform the analysis. The overall median concentration from 1974 through 1999 was calculated to be 0.2% of the ACL. Unless there is a change in LLNL's operations, the beryllium levels are expected to remain unchanged.

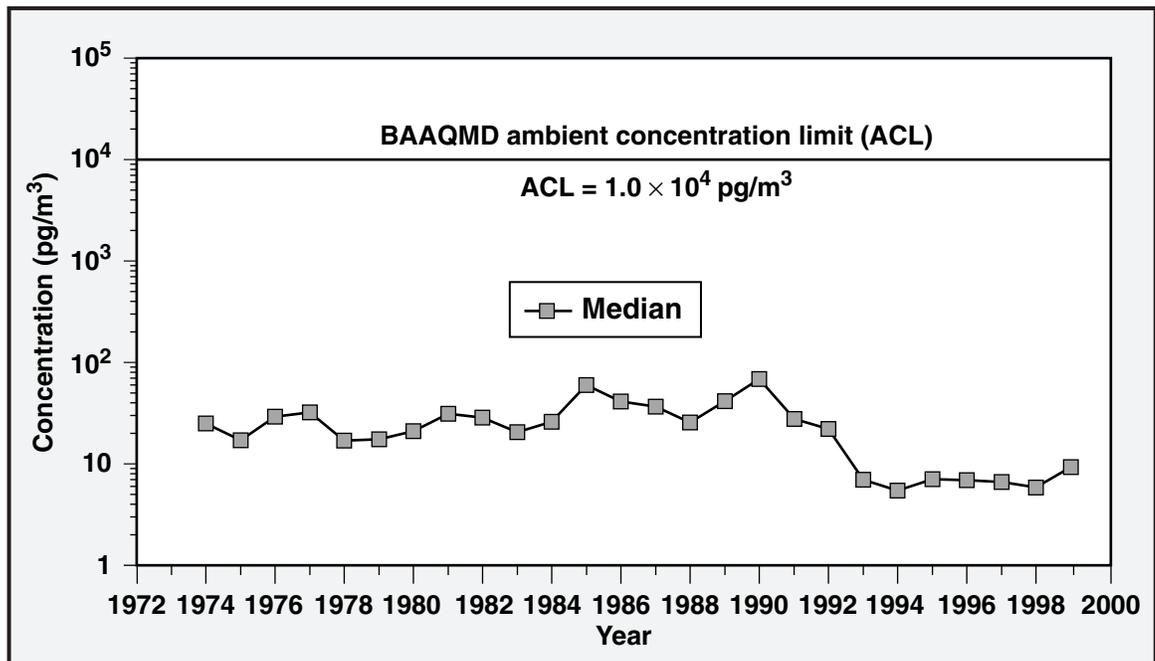


Figure 5-7. Median concentration of beryllium in air particulate samples taken at the Livermore site perimeter, 1974–1999.

Site 300

Airborne Radioactivity

Table 5-2 shows the detection frequency and the monthly gross alpha and gross beta median, IQR, and maximum for sampling locations at Site 300. (See Data Supplement Table 5-15 for monthly data.) The monthly median gross alpha and gross beta concentrations are shown in **Figures 5-4** and **5-5**. The Site 300 gross alpha and gross beta results show a similar pattern to those found at the Livermore site. Typical gross alpha activity is 5.0×10^{-5} Bq/m³ (1.3×10^{-15} Ci/m³). Typical gross beta activity is



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$4.2 \times 10^{-4} \text{ Bq/m}^3$ ($1.1 \times 10^{-14} \text{ Ci/m}^3$). These values are slightly higher than those obtained from previous monitoring data during the past several years and were likely caused by the variations in how the different analytical laboratories performed the analyses. (As mentioned above, LLNL selected a new analytical laboratory to perform gross alpha and gross beta analysis in March 1999).

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

Table 5-3 lists the annual median activities, detection frequencies, IQR, maximum, the percent of the DCG, as well as the DCG, of gamma-emitting radionuclides in samples from Site 300. (See Data Supplement Table 5-16 for monthly data.) All these radionuclides were measured at concentrations significantly below the DCGs. Of the nuclides identified, all are naturally occurring, with the exception of cesium-137. The primary source of ^{137}Cs normally is long-term global fallout and resuspension.

Table 5-4 shows the median concentration of plutonium-239+240 on air-filter samples collected from Site 300. (See Data Supplement Table 5-17 for monthly data.) The highest concentration of plutonium-239 was recorded in the September composite at a level of $8.7 \times 10^{-9} \text{ Bq/m}^3$ ($2.3 \times 10^{-19} \text{ Ci/m}^3$), or 0.001% of the DCG.

Table 5-5 shows the median concentration of uranium-235, uranium-238, and the uranium-235/uranium-238 ratio on air samples from Site 300 and vicinity. (See Data Supplement Table 5-18 for monthly data.) The highest concentration of uranium-238 was observed in the September composite at a level of $1.9 \times 10^{-4} \mu\text{g/m}^3$. The highest uranium-235 concentration was recorded at PRIM during March at a level of $1.5 \times 10^{-6} \mu\text{g/m}^3$.

As previously discussed in the Livermore Site Results section, the ratio of uranium-235 to uranium-238 is used to identify the source of the uranium. Because Site 300 operations use depleted uranium that contains very little uranium-235, it follows that if the ratio remains constant and near 0.7% (within the limit of sampling and analytical error), then the uranium-238 measured is from natural sources. The uranium-235/uranium-238 ratios in the September and October Site 300 composite (and in August and September at location PRIM) are less than expected for natural sources, which indicates some impact from operations at Site 300. These data are supported by Site 300 activities from B851 published in the NESHAPs Report (Gallegos et al. 2000). The median concentration of uranium-238 for 1999, however, is only 0.02% of the DCG.



The uranium-235/uranium-238 median ratios for PRIM (off site) are generally as expected for naturally occurring uranium; however, because of the higher value recorded for the uranium-235 during March, this ratio of 2.21×10^{-2} indicates other than natural uranium at this site. This sample was recounted at the analytical laboratory, and the values were consistent with the original sample. While no significant environmental impact stems from the observed uranium-235 value (0.003% of the DCG), it is highly unusual and is not corroborated with the Site 300 composite sample or seen in other months. Its cause is unknown; however, similar anomalous data have appeared in the past. The overall levels were essentially the same as those reported in previous years.

Table 5-6 shows the median concentration of tritiated water vapor that was observed at the new sampling location (PRIM) near Site 300. (See Data Supplement Table 5-19 for biweekly data.) The annual median concentration is 4.1×10^{-3} Bq/m³ (1.1×10^{-13} Ci/m³), or 0.0001% of the DCG.

Beryllium in Air

The detection frequency, median concentration, IQR, and maximum concentrations of airborne beryllium for the Site 300 sampling locations are shown in **Table 5-7**. (See Data Supplement Table 5-20 for monthly data.) The highest beryllium concentration of 32.3 pg/m³ occurred in October at location TFIR. The median concentration for this location is 0.13% of the federal and state ambient concentration limit, which is 10,000 pg/m³.

Environmental Impact

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

Radioactive Materials

LLNL operations involving radioactive materials had little impact on radionuclide concentrations in ambient air during 1999. Radionuclide concentrations in air at the Livermore site and in the Livermore Valley were well below the levels that would cause concern to the environment or public health according to existing regulatory standards.



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The diffuse tritium sources at B292, B331, B514, and B624 had a localized effect; typically, tritium concentrations detected at the site perimeter or off site were not from diffuse sources.

The concentrations of radionuclides measured around Site 300 and in the City of Tracy were well below all standards and, except for uranium isotopes, reflected background or naturally occurring levels of these materials. (See Chapter 13, Radiological Dose Assessment, for a discussion of estimated dose from these data.) The uranium-235/uranium-238 ratios in August and September were less than the ratio of naturally occurring concentrations of these isotopes, which suggested the presence of depleted uranium in those Site 300 air samples. This depleted uranium resulted from current testing as substantiated by Site 300 explosive experiments during those months (Gallegos et al. 2000). Nevertheless, the detected levels remain far below regulatory standards.

Nonradioactive Materials

The concentrations of beryllium at both sites can be attributed to resuspension of surface soil containing naturally occurring beryllium. Local soils contain approximately 1 ppm of beryllium, and the air of the Livermore area and the Central Valley typically contains 10 to 100 $\mu\text{g}/\text{m}^3$ of particulates. Using a value of 50 $\mu\text{g}/\text{m}^3$ for an average dust load and 1 ppm for beryllium content of dust, a conservative airborne beryllium concentration of 50 pg/m^3 can be predicted. The overall annual medians for the Livermore site and Site 300 are 9.3 pg/m^3 and 8.6 pg/m^3 , respectively. These data are lower than predicted, well below standards, and do not indicate the presence of a threat to the environment or public health.

Sewerable Water Monitoring

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Introduction

In 1999, the Livermore site discharged an average of 1.0 million liters (ML) per day of wastewater to the City of Livermore sewer system, an amount that constitutes 4.4% of the total flow to the system. This volume includes wastewater generated by Sandia National Laboratories/California, which is discharged to the LLNL collection system and combines with LLNL sewage before it is released at a single point to the municipal collection system (**Figure 6-1**). In 1999, Sandia/California generated approximately 13% of the total effluent discharged from the Livermore site. LLNL's wastewater contains sanitary sewage and industrial wastewater and is discharged in accordance with permit requirements and the City of Livermore Municipal Code, as discussed below in the Pretreatment Discharges and Categorical Discharges sections.

The effluent is treated at the Livermore Water Reclamation Plant (LWRP). As part of the Livermore-Amador Valley Wastewater Management Program, the treated sanitary wastewater is transported out of the valley through a pipeline and discharged into San Francisco Bay. A small portion of this treated wastewater is used for summer irrigation of the adjacent municipal golf course. Sludge from the treatment process is disposed of in sanitary landfills.

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



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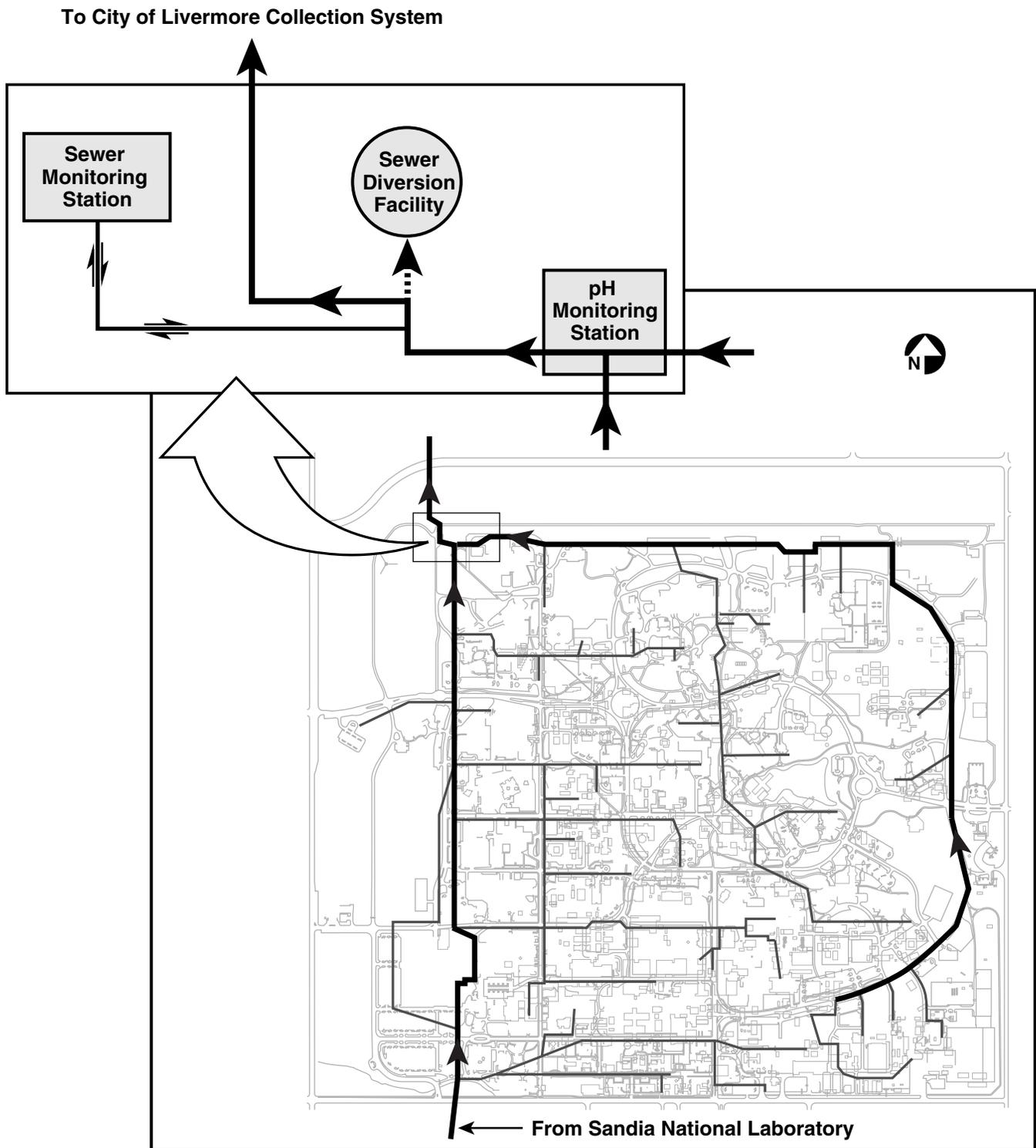


Figure 6-1. LLNL sanitary sewer system, monitoring stations, and diversion facility.



Preventive Measures

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

For facilities with installed retention tank systems, collected wastewater is discharged to the sanitary sewer only if analytical laboratory results show that pollutant levels are within allowable limits (Grandfield 1989). LLNL developed internal discharge guidelines for specific sources and operations to ensure that sewer effluent for the entire site complies with LLNL's wastewater discharge permit.

Table 6-1 shows LLNL's internal discharge guidelines for wastewater discharged to the sewer. Any processes that discharge to the sanitary sewer are subject to the general pretreatment self-monitoring program specified in the Wastewater Discharge Permit issued by the LWRP, and, as such, are managed by LLNL using these internal discharge guidelines as applied at the point of discharge into the LLNL sewer.

If pollutant levels exceed internal permissible concentrations, the wastewater is treated to reduce pollutants to the lowest levels practical and below LLNL guidelines, or it is shipped to an off-site treatment or disposal facility. Liquids containing radioactivity are handled on site and may be treated using processes that reduce the activity to levels well below those required by DOE Order 5400.5 or they are shipped to an off-site treatment or disposal facility. Internal guidelines for retention tank systems and specific sources and operations are discussed later in the Pretreatment Discharges section. Process wastewater generation and discharge frequency from retention tanks vary from monthly to yearly, depending upon the process. During 1999, there were approximately 31 retention tank



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systems in use at the Livermore site, with an average of 14 wastewater retention tanks discharged each month, averaging a volume of 8000 liters per tank.

Table 6-1. LLNL's internal discharge guidelines for pollutants in wastewaters.

Nonradioactive pollutants in wastewaters	
Constituent	Discharge guidelines
Metals (mg/L)	
Arsenic	0.06 ^(a)
Cadmium	0.9
Copper	10
Chromium (total)	4.9
Lead	4.9
Mercury	0.05
Nickel	5
Silver	1
Zinc	15
Cyanide (mg/L) ^(b)	5
Oil and grease (mg/L)	500
Total toxic organics (TTO) (mg/L) ^(c)	4.57
pH (pH units)	5–10

Radioisotopes in wastewaters ^(d)		
Parameter	Individual discharge	Total daily limit for site
Gross alpha	11.1 Bq/L (300 pCi/L)	185 kBq (5.0 µCi)
Gross beta	111 Bq/L (3000 pCi/L)	1.85 MBq (50.0 µCi)
Tritium	185 kBq/L (5.0 µCi/L)	3.7 GBq (100.0 mCi)

^a No specific internal discharge limit was developed for this constituent; therefore, the discharge limit in LLNL's wastewater discharge permit is used as a guideline for this parameter.

^b Limits apply to cyanide discharges other than cyanide salts. Cyanide salts are classified by the State of California as "extremely hazardous waste" and cannot be discharged to the sewer.

^c Total toxic organics is defined by the Livermore Municipal Code as the sum total of all detectable organic compounds that are on the Environmental Protection Agency's current priority pollutant list and that are present in concentrations of 0.01 mg/L or greater. Analysis of samples using EPA Methods 624 and 625 satisfy this requirement. A listing of the specific compounds included may be found in the Data Supplement, Chapter 6.

^d There is no gross gamma limit; DOE Order 5400.5 isotope-specific limits apply.



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

Monitoring

Monitoring at the Sewer Monitoring Station

LLNL's sanitary sewer discharge permit requires continuous monitoring of the effluent flow rate and pH. Samplers collect flow-proportional composite samples and instantaneous grab samples that are analyzed for metals, radioactivity, toxic chemicals, and water-quality parameters. In addition, as a best management practice, the outflow to the municipal collection system is sampled continuously and analyzed in real time for conditions that might upset the LWRP treatment process or otherwise impact the public welfare. The effluent is continuously analyzed for pH, regulated metals, and radioactivity. If concentrations above warning levels are detected, an alarm is registered at the LLNL Fire Dispatcher's Station, which is attended 24 hours a day, and the site effluent is diverted to the Sewer Diversion Facility (SDF). The monitoring system provides a continuous check on sewage control, and the LWRP is notified of contaminant alarms. Trained staff respond to all alarms to evaluate the cause and take appropriate action.

Monitoring at the Upstream pH Monitoring Station

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

Diversion System

LLNL operates and maintains a diversion system that activates automatically when either the SMS continuous monitoring system or the pHMS sounds an alarm. For SMS activated alarms, the SDF ensures that all but the first few minutes of the potentially



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affected wastewater flow is retained at LLNL, thereby protecting the LWRP and minimizing any required cleanup. During pH excursions activated by the pHMS, even the first few minutes of affected wastewater flow is retained. Up to 775,000 L of potentially contaminated sewage can be held pending analysis to determine the appropriate handling method. The diverted effluent may be returned to the sanitary sewer (if it meets LLNL's wastewater discharge permit limits), shipped for off-site disposal, or treated at LLNL's Hazardous Waste Management (HWM) Facility. All diverted sewage in 1999 was returned to the sanitary sewer.

Pretreatment Discharges

The general pretreatment regulations establish both general and specific standards for the discharge of prohibited substances (40 CFR 403.5) that apply to all industrial users. These regulations apply even if LLNL is subject to other federal, state, or local pretreatment standards. The pretreatment standards contain prohibitions intended to protect the LWRP and its operations from interference with its treatment processes or pass-through that would cause the LWRP to violate its own effluent limitations. The LWRP, under the authorization of the San Francisco Bay Regional Water Quality Control Board, requires self-monitored pretreatment programs at both the Livermore site and Site 300. The sampling and monitoring of nondomestic, industrial sources covered by pretreatment standards defined in 40 CFR 403 is required in the 1999-2000 Wastewater Discharge Permit No. 1250 issued for the discharge of wastewater from LLNL into the City of Livermore sewer system. Permit 1250 lists all the self-monitoring parameters that are applied at the SMS before wastewater enters the municipal collection system at LLNL's effluent outfall (see **Figure 6-1**). Parameters with numerical limits are listed in **Table 6-2**. The additional discharge limits shown in **Table 6-2** are discussed below in the Categorical Discharges and Discharges of Treated Ground Water sections. Other required parameters such as flow rate, biological oxygen demand, total dissolved solids, total suspended solids, and tributyltin are also monitored at the SMS but have no specific numerical limits. In 1999, no exceedances of the pollutant limitations in the discharge permit were observed.

**Table 6-2.** Permit discharge limits for nonradioactive pollutants in LLNL wastewaters.

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

^a These standards apply at the SMS (the point of discharge to the municipal sewer). All other standards in this table apply at the point of discharge into LLNL's sanitary sewer system.

^b These categorical standards were specified by EPA. By regulation, the EPA or City of Livermore limit is used, whichever is lower. The internal limits in **Table 6-1** are applied by LLNL where no other standard is specified.

^c There is no specific categorical limit for this parameter; therefore, the **Table 6-1** internal discharge limits apply.

^d Total toxic organics is defined by the Livermore Municipal Code as the sum total of all detectable organic compounds that are on the Environmental Protection Agency's current priority pollutant list and that are present in concentrations of 0.01 mg/L or greater. EPA Methods 624 and 625 analysis satisfies this requirement. A listing of the specific compounds included may be found in the Data Supplement, Chapter 6.

^e Limits apply to cyanide discharges other than cyanide salts. Cyanide salts are classified by the State of California as "extremely hazardous waste" and cannot be discharged to the sewer.

^f Although Permit 1510G lists a discharge limit for cyanide, sample collection is not required by the self-monitoring program.

Categorical Discharges

The Environmental Protection Agency (EPA) publishes categorical standards as regulations separate from the general pretreatment regulations and developed for broad categories of specific industrial processes determined to be the most significant contributors



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to point source water pollution. These standards contain specific numerical limits for the discharge of industry-specific pollutants from individual processes. The number of processes at LLNL using these pollutants is subject to rapid and frequent change as programmatic requirements dictate. During 1999, the LWRP identified 17 specific LLNL wastewater generating processes that fall under the definition of two categorical standards: Electrical and Electronic Components (40 CFR 469), and Metal Finishing (40 CFR 433). The discharge limits for these standards are shown in **Table 6-2**. Under the terms in Permit 1250, only those processes that discharge to the sanitary sewer require sampling, inspection, and reporting. Three of the 17 identified processes meet these criteria. In 1999, LLNL analyzed samples for all regulated parameters from these three processes and the results showed that LLNL complied with all federal categorical discharge limits.

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

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

Discharges of Treated Ground Water

LLNL's ground water discharge permit (1510G, 1999) allows treated ground water from site-wide Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 cleanup activities to be discharged in the City of Livermore sanitary

sewer in compliance with **Table 6-2** effluent limitations taken from the Livermore Municipal Code.

During 1999, the volume of ground water discharged to the sanitary sewer was approximately 386,000 liters. Water discharges during this period were related to start-up operations associated with new portable treatment units being built and installed throughout the site, testing of an experimental nitrate removal treatment system, and maintenance of existing ground water treatment facilities. Twelve separate discharges were sampled and discharged to the sewer during this period, all in compliance with self-monitoring permit provisions of Permit 1510G. Concentrations of regulated compounds were all below discharge limits. Monitoring data are presented in the Data Supplement, Chapter 6.

Radioactive Pollutants in Sewage

Monitoring Results

LLNL determines the total radioactivity released from tritium, alpha emitters, and beta emitters based either on the measured radioactivity in the effluent or on the limit of sensitivity, whichever is higher (see **Table 6-3**). The 1999 combined releases of alpha and beta sources was 0.32 GBq (0.0086 Ci). The combined total is based on the results shown in **Table 6-3**. The tritium total was 7.1 GBq (0.19 Ci), and the annual mean concentration of tritium in LLNL sanitary sewer effluent was 0.019 Bq/mL (0.51 pCi/mL).

Table 6-3. Estimated total radioactivity in LLNL sanitary sewer effluent, 1999.

Radioactive emitter	Estimate based on effluent activity (GBq) ^(a)	Limit of sensitivity (GBq)
Tritium	7.1	4.2
Alpha sources	0.043	0.034
Beta sources	0.28	0.046

^a 37 Gbq = 3.7×10^{10} Bq = 1 Ci.

Summary results for tritium measured in the sanitary sewer effluent from LLNL and LWRP are presented in **Table 6-4**. The monthly tritium numbers are based on the flow-weighted average of the individual daily sample results for a given month. The total annual result is based on the multiplication of each daily sample result or the limit of sensitivity, whichever is greater, by the total flow volume over which the sample was



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

Table 6-4. Tritium in sanitary sewer effluents (Bq/mL), LLNL and LWRP, 1999.

Monitoring results			
	LLNL		LWRP
	Daily	Monthly average	Weekly
Maximum	0.929 ± 0.018 ^(a)	0.045 ^(b)	0.017 ± 0.007 ^(c)
Median	0.003	0.006	0.001
IQR ^(d)	0.008	0.013	0.006
LLNL annual total (GBq)	7.1		

Discharge limits			
	Discharge limit	Fraction of discharge limit	
		LLNL maximum	LLNL median
LWRP permit daily	12	0.075	2.5×10^{-4}
DOE annualized discharge limit for application of BAT ^(e) (Bq/mL)	370	$1.2 \times 10^{-4(f)}$	$1.7 \times 10^{-5(f)}$
10 CFR 20 annual total (GBq)	185	0.038	

- ^a The daily result is for an October sample; the detection limit for the analysis was 0.011 Bq/mL. See the Data Supplement, Chapter 6, for all daily results.
- ^b This is the monthly average for October. All monthly averages are plotted in **Figure 6-2**.
- ^c This is a weekly result for a January sample. This result was the only weekly value above a detection limit; detection limits ranged from 0.005 to 0.013 Bq/mL. See the Data Supplement, Chapter 6, for all weekly results.
- ^d IQR = Interquartile range.
- ^e 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.
- ^f Monitoring results as a fraction of limit are calculated using LLNL monthly average results and the DOE annualized discharge limit.

The historical trend in the monthly average concentration of tritium is shown in **Figure 6-2**. Also included in the figure is the DOE tritium limit (370 Bq/mL), discussed in the Environmental Impact section of this chapter. The trend indicates a well-controlled tritium discharge, orders of magnitude below the DOE tritium limit.

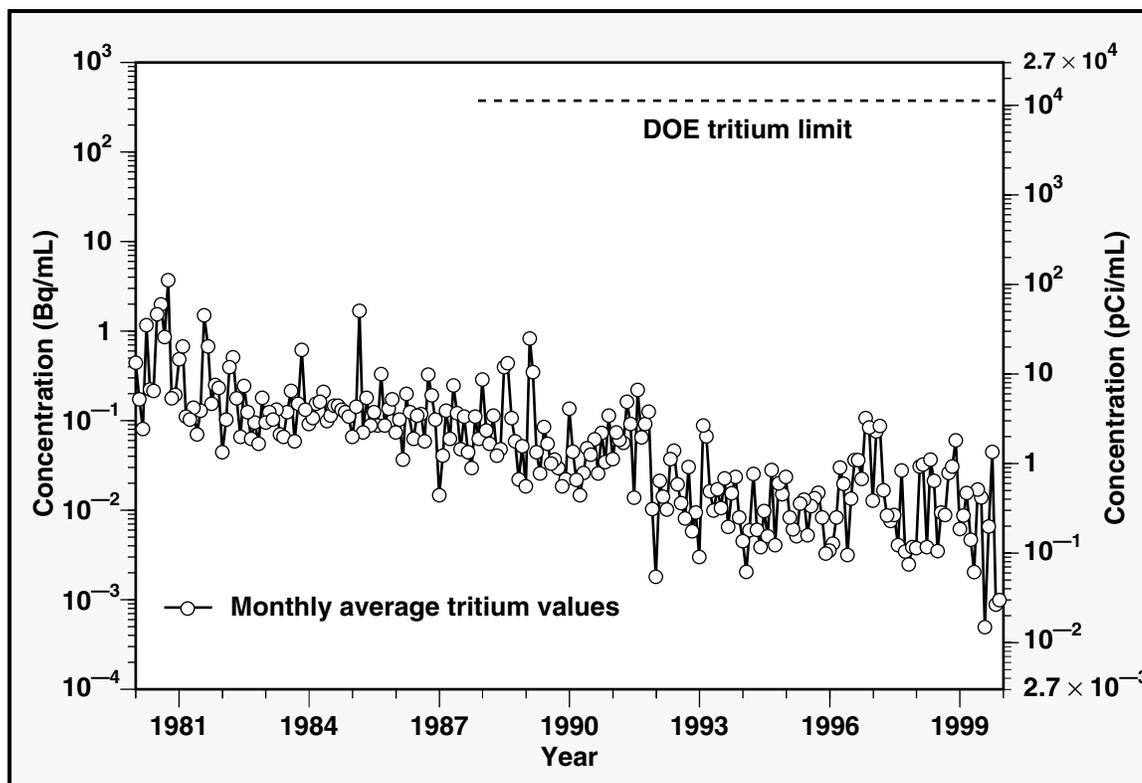


Figure 6-2. Historical trend in tritium concentration in LLNL sewage.

The concentrations of ^{239}Pu and ^{137}Cs measured in the sanitary sewer effluent from LLNL and LWRP are presented in **Table 6-5**. The plutonium and cesium numbers are the direct results for analyses of monthly composite samples of LLNL and LWRP effluent, and quarterly composites of LWRP sludge. At the bottom of the table, the total annual activity released is given by radioisotope. Also included in the table are fractions of DOE limits, discussed in the Environmental Impact section.

Figure 6-3 shows the average monthly plutonium and cesium concentrations in sewage since 1990. For 1999, the annual mean concentration of ^{137}Cs was 3.2×10^{-6} Bq/mL (8.6×10^{-5} pCi/mL); the annual mean concentration of ^{239}Pu was 1.8×10^{-7} Bq/mL (4.9×10^{-6} pCi/mL).



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Table 6-5. Cesium and plutonium in sanitary sewer effluents, LLNL and LWRP, 1999.

Month	¹³⁷ Cs (μBq/mL)				²³⁹ Pu (nBq/mL)				²³⁹ Pu (mBq/dry g)	
	LLNL		LWRP		LLNL		LWRP		LWRP sludge ^(a)	
	Radioactivity	MDC ^(b)	Radioactivity ^(c)	MDC ^(b)	Radioactivity	MDC	Radioactivity	MDC	Radioactivity	MDC
Jan	1.2 ± 0.6	0.4	<0.42	0.42	54.8 ± 19.4	10.1	6.5 ± 10.9	17.1		
Feb	0.73 ± 1.00	0.58	<0.40	0.40	155 ± 39	13	-4.9 ± 14.4	25.8		
Mar	0.81 ± 0.74	0.48	<0.36	0.36	76.6 ± 34.0	25.2	5.1 ± 19.1	44.4	0.12 ± 0.02	0.00
Apr	1.0 ± 0.9	0.5	<0.37	0.37	160 ± 83	64	17.9 ± 20.5	25.2		
May	0.42 ± 5.96	5.33	-1.7 ± 8.3	7.2	67.3 ± 28.9	10.1	9.0 ± 38.1	75.9		
Jun	1.2 ± 6.6	6.0	— ^(d)	— ^(d)	108 ± 38	16	— ^(d)	— ^(d)	0.094 ± 0.031	0.014
Jul	3.4 ± 3.2	3.1	2.6 ± 2.7	2.5	124 ± 41	24	-1.8 ± 12.6	27.4		
Aug	1.1 ± 7.0	6.2	-2.6 ± 3.7	2.9	71.0 ± 25.3	13.3	-0.71 ± 1.41	8.55		
Sep	2.5 ± 3.3	2.1	0.68 ± 3.89	3.46	844 ± 76	9	10.3 ± 19.2	31.4	0.18 ± 0.05	0.01
Oct	-0.92 ± 5.03	4.29	-0.78 ± 3.12	2.64	264 ± 36	7	1.35 ± 2.20	6.66		
Nov	2.0 ± 3.0	2.8	-0.07 ± 3.44	2.99	128 ± 28	7	0.10 ± 3.40	7.33		
Dec	3.2 ± 3.6	3.4	-1.2 ± 4.0	3.4	58.5 ± 19.9	9.3	6.1 ± 15.1	22.6	0.38 ± 0.04	0.01
Median	1.1		0.4		116		5.1		0.15	
IQR ^(e)	1.4		1.4		86		8.0		0.12	
	pCi/mL^(f)								pCi/dry g^(f)	
Median	3.0 × 10 ⁻⁵		9.7 × 10 ⁻⁶		3.1 × 10 ⁻⁶		1.4 × 10 ⁻⁷		0.0040	
IQR ^(e)	3.7 × 10 ⁻⁵		3.8 × 10 ⁻⁵		2.3 × 10 ⁻⁶		2.2 × 10 ⁻⁷		0.0033	
	Annual total discharges by radioisotope									
		¹³⁷Cs			²³⁹Pu			Total^(g)		
Bq/y		1.2 × 10 ⁶			6.8 × 10 ⁴			1.3 × 10 ⁶		
Ci/y		3.3 × 10 ⁻⁵			1.8 × 10 ⁻⁶			3.5 × 10 ⁻⁵		
	Fraction of limit^(h)									
DOE annualized discharge limit for application of BAT ⁽ⁱ⁾		5.7 × 10 ⁻⁶			4.8 × 10 ⁻⁷			3.6 × 10 ⁻⁶		

Note: Radioactivities are reported as the measured concentration and either an uncertainty ($\pm 2\sigma$ counting error) or as being less than or equal to the detection limit or minimum detectable concentration (MDC). If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection. See Main Volume, Chapter 14, Quality Assurance.

- ^a Sludge from LWRP digesters is dried before analysis. The resulting data indicate the plutonium concentration of the sludge prepared by LWRP workers for disposal at the Vasco Road Landfill in Alameda County.
- ^b For May through December data, decreased sample count times, lower efficiency detectors and new computer software contributed to greater MDCs than those shown for January through April. Other factors also contributed to the high MDCs shown for LLNL May and June and LWRP May analyses (smaller sample volumes), LLNL August analysis (low chemical recovery), and LLNL October analysis (shorter sample count time than the norm of May through December data).
- ^c The analytical laboratory provided measured concentrations and uncertainties for only the last eight months of 1999.
- ^d No data available because of analytical laboratory error in the analysis of the sample.
- ^e IQR = Interquartile range.
- ^f 1 Ci = 3.7×10^{10} Bq.
- ^g Does not include gross alpha and beta results shown in **Table 6-3** or the tritium results shown in **Tables 6-4** and **6-6**.
- ^h 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 ¹³⁷Cs and ²³⁹Pu, respectively) multiplied by the annual volume of Livermore site effluent.
- ⁱ 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.

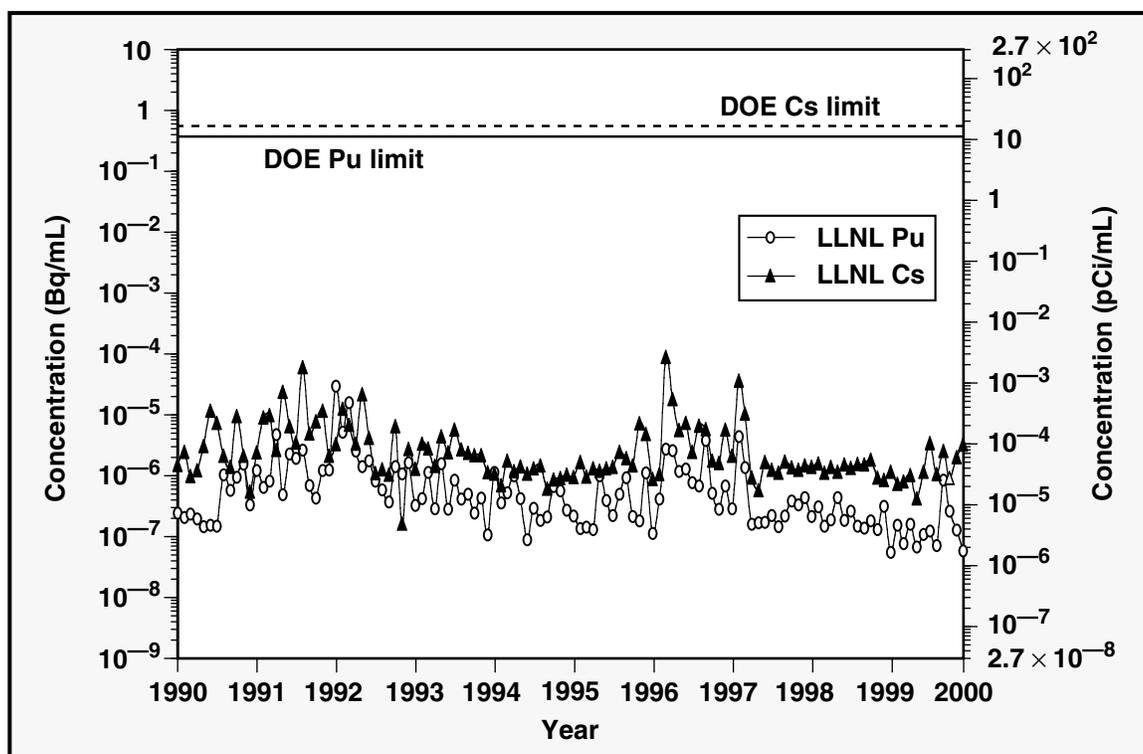
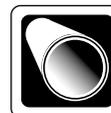


Figure 6-3. Historical trends in average monthly plutonium and cesium concentrations in LLNL sewage.

Environmental Impact

During 1999, no inadvertent discharges exceeded any discharge limits for release of radioactive materials to the sanitary sewer system.

In August 1999, the Work Smart Standards (WSSs) developed for LLNL became effective, as discussed in Chapter 3. As part of the WSS process, standards were selected for sanitary sewer discharges. For radioactive material releases, complementary (rather than redundant) sections from DOE Order 5400.5, Radiation Protection of the Public and Environment, and Title 10 of the Code of Federal Regulations, Part 20, were chosen as standards.

Prior to August 1999, DOE Order 5400.5 established DOE policy requiring that radiological releases to the sanitary sewer comply with legally applicable local and state regulations and that LLNL implement standards generally consistent with those of the Nuclear Regulatory Commission. The most stringent of these limits was adopted in Title 17 of the California Code of Regulations. As a federal facility, LLNL is formally



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exempt from the requirements of state regulations but followed those requirements under the guidance of DOE. In 1994, the discharge requirements previously found in Title 17 were removed, and the requirements in Title 10 of the Code of Federal Regulations, Part 20, were incorporated by reference.

As selected from DOE Order 5400.5, the WSS for sanitary sewer discharges includes 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 exceeded its specific concentration limit, LLNL would be required to improve discharge control measures until concentrations were again below the DOE limits. **Tables 6-4** and **6-5** include the DCGs for the specific radioisotopes of most interest at LLNL.

The median monthly average concentration of tritium in LLNL sanitary sewer effluent was 1.7×10^{-5} , that is, 0.0017% of the DOE DCG, and the maximum monthly average concentration of tritium was 1.2×10^{-4} , 0.012% of the DCG (see **Table 6-4**). The annual average concentration of ^{137}Cs was 5.7×10^{-6} (0.00057%) of the DOE DCG; and the annual average ^{239}Pu concentration was 4.8×10^{-7} (0.000048%) of the ^{239}Pu DOE DCG. These results are shown at the end of **Table 6-5**.

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

The 10 CFR 20 limit on total tritium activity (185 GBq) dischargeable during a single year overrides the DOE Order 5400.5 concentration-based limit for tritium for facilities such as LLNL that generate wastewater in large volumes. In 1999, the total LLNL tritium release was 3.8% of this Title 10 limit. Total LLNL releases (see **Table 6-3**), in the form of alpha and beta emitters (excluding tritium), were 0.86% of the corresponding Title 10 limit.

In addition to the DOE concentration discharge limit for tritium and the 10 CFR 20 annual total discharge limit for tritium, the LWRP established in the 1999-2000 Wastewater Discharge Permit an effluent concentration discharge limit for LLNL daily releases of tritium. This new limit is more stringent than the DOE discharge limit: it is a factor of 30 smaller and it applies to daily rather than an annualized concentration. The maximum daily concentration for tritium in 1999 was 7.5% of the permit discharge limit. **Table 6-4** shows this result and the daily effluent discharge limit for tritium. The LWRP

established the limit to preserve opportunities for an expanded recycling program for the plant's treated wastewater.

LLNL also compares annual discharges with historical values to evaluate the effectiveness of ongoing discharge control programs. **Table 6-6** summarizes the radioactivity in liquid effluent released over the past 10 years. During 1999, a total of 7.1 GBq (0.19 Ci), of tritium was discharged to the sanitary sewer, an amount that is well within environmental protection standards and is comparable to the amounts reported for the previous seven years. Moreover, the total tritium released by LLNL in 1999 continues the 1992 to 1998 trend of significantly smaller releases than those in the years prior to 1992.

Table 6-6. Radioactive liquid effluent releases from the Livermore site, 1990–1999.

Year	Liquid effluent (GBq)	
	^3H	^{239}Pu
1990	25	2.3×10^{-4}
1991	32	6.1×10^{-4}
1992	8	1.9×10^{-3}
1993	13	2.6×10^{-4}
1994	6.9	1.9×10^{-4}
1995	6.0	1.2×10^{-4}
1996	12 ^(a)	4.2×10^{-4}
1997	9.1	2.1×10^{-4}
1998	10	7.7×10^{-5}
1999	7.1	6.8×10^{-5}

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

Figure 6-3 summarizes the ^{239}Pu monitoring data over the past 10 years. The historical levels observed since 1990 average $1 \mu\text{Bq}/\text{mL}$ ($3 \times 10^{-5} \text{ pCi}/\text{mL}$). These historical levels generally are three-millionths (0.000003) of the DOE DCG for the ^{239}Pu . The greatest part of the plutonium discharged in LLNL effluent is ultimately concentrated in LWRP sludge, which is dried and disposed of at a landfill. The median plutonium concentration observed in 1999 sludge (**Table 6-5**), $0.15 \text{ mBq}/\text{dry g}$ is 620 times lower than the EPA preliminary remediation goal for residential soil ($93 \text{ mBq}/\text{dry g}$) and is nearly 2500-times lower than the remediation goal for industrial or commercial soil ($370 \text{ mBq}/\text{dry g}$).



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As first discussed in the *Environmental Report 1991* (Gallegos et al. 1992), plutonium and cesium concentrations were slightly elevated during 1991 and 1992 over the lowest values seen historically. As was established in 1991, the overall upward trend was related to sewer cleaning with new, more-effective equipment. The concentrations in 1996 and the first quarter of 1997 were also slightly higher than the lowest values seen historically, although slightly lower than those of 1990 through 1992. In fact, the cyclic nature of the data points in **Figure 6-3** suggests that built-up radionuclides in sewer lines are liberated by line cleaning. The higher plutonium and cesium concentrations are all well below applicable DOE DCGs. In general, the plutonium and cesium concentrations for 1999 are comparable to the lowest values seen historically, and are well below the applicable DOE DCGs. (Note that the open triangle in the figure indicates that the data point was negative; because negative data points cannot be plotted directly against a log scale, its absolute value has been plotted. Also, MDC values for cesium increased in May 1999, so most of the results plotted for the last two-thirds of the year are below their respective MDCs.)

Nonradioactive Pollutants in Sewage Monitoring Results

Table 6-7 presents monthly average concentrations for all regulated metals in LLNL's sanitary sewer effluent for 1999. The averages were obtained by a flow-proportional weighting of the analytical results for the weekly composite samples collected each month. Each result was weighted by the total flow volume for the period during which the sample was collected. The results are generally typical of the values seen during previous years, 1994–1998. **Figure 6-4** presents historical trends for the average monthly results from 1994 through 1999 for eight of the nine regulated metals; cadmium is not presented because this metal is typically not detected. Trends for chromium, mercury, nickel, and zinc show that average monthly concentrations are slightly elevated overall for mid-1996 through 1999, as compared with the previous two and a half years. The other four metals have no discernible trends in their concentrations, although copper concentrations are noticeably elevated in the latter part of 1999. During the period of January through early September, weekly composite sample were also analyzed for three non/regulated metals (aluminum, beryllium, and iron). Refer to the Data Supplement, Chapter 6, for the analytical results, which were typical of values in previous years.

Table 6-7. Average monthly results for regulated metals in LLNL sanitary sewer effluent (mg/L), 1999.

Month	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Jan	<0.010	0.0036	<0.0050	0.013	0.095	0.00053	0.012	0.011	0.19
Feb	<0.010	<0.0020	<0.0050	<0.010	0.062	0.00035	0.0091	0.010	0.20
Mar	0.012	0.0037	<0.0050	0.024	0.16	0.0017	0.014	0.025	0.35
Apr	0.012	0.0026	<0.0050	0.037	0.18	0.00078	0.011	0.021	0.45
May	<0.010	0.0023	<0.0050	0.012	0.085	0.00039	0.0062	0.0074	0.17
Jun	0.011	0.0031	<0.0050	0.022	0.16	0.00053	0.0082	0.019	0.32
Jul	<0.010	0.0028	0.0051	0.014	0.11	0.00019	0.0057	0.011	0.21
Aug	<0.010	0.0027	<0.0050	0.020	0.19	0.00026	0.0061	0.022	0.19
Sep	0.011	0.0036	<0.0050	0.053	0.28	0.00081	0.010	0.033	0.42
Oct	<0.010	0.0042	<0.0050	0.045	0.25	0.00061	0.011	0.028	0.55
Nov	0.013	0.0034	<0.0050	0.036	0.26	0.00094	0.0082	0.022	0.46
Dec	<0.010	0.0038	<0.0050	0.037	0.16	0.00034	0.0066	0.025	0.48
Median	<0.010	0.0033	<0.0050	0.023	0.16	0.00053	0.0087	0.022	0.34
IQR(a)	0.001	0.0009	—(b)	0.023	0.099	0.00044	0.0045	0.014	0.26
EPL(c)	0.2	0.06	0.14	0.62	1	0.01	0.61	0.2	3.0
Median fraction of EPL	<0.05	0.054	<0.036	0.037	0.16	0.053	0.014	0.11	0.11

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

^a IQR = Interquartile range.

^b Because of the large number of nondetects, the interquartile range cannot be calculated for these metals. See Chapter 14, Quality Assurance.

^c EPL = Effluent pollutant limit (LLNL Wastewater Discharge Permit 1997–1998 and 1998–1999).

Weekly and 24-hour composite sample concentrations for eight of nine regulated metals in LLNL sewage are each presented as a percentage of the corresponding effluent pollutant limit (EPL) in **Figure 6-5**; cadmium is not present because it was detected in less than five percent of the samples, with a maximum detected value of no more than 7.1% of the discharge limit. The EPL is equal to the maximum pollutant concentration allowed per 24-hour composite sample, as specified by the LLNL wastewater discharge permit. When a weekly sample concentration is at or above 50% of its EPL, the corresponding daily (24-hour composite) samples collected in the SMS must be analyzed to determine if any of their concentrations are above the EPL. As discussed in the following Environmental Impact section, in 1999, only one weekly composite sample concentration met this 50% action level, and no 24-hour composite sample concentrations were greater than the EPL.



6 Sewerable Water Monitoring

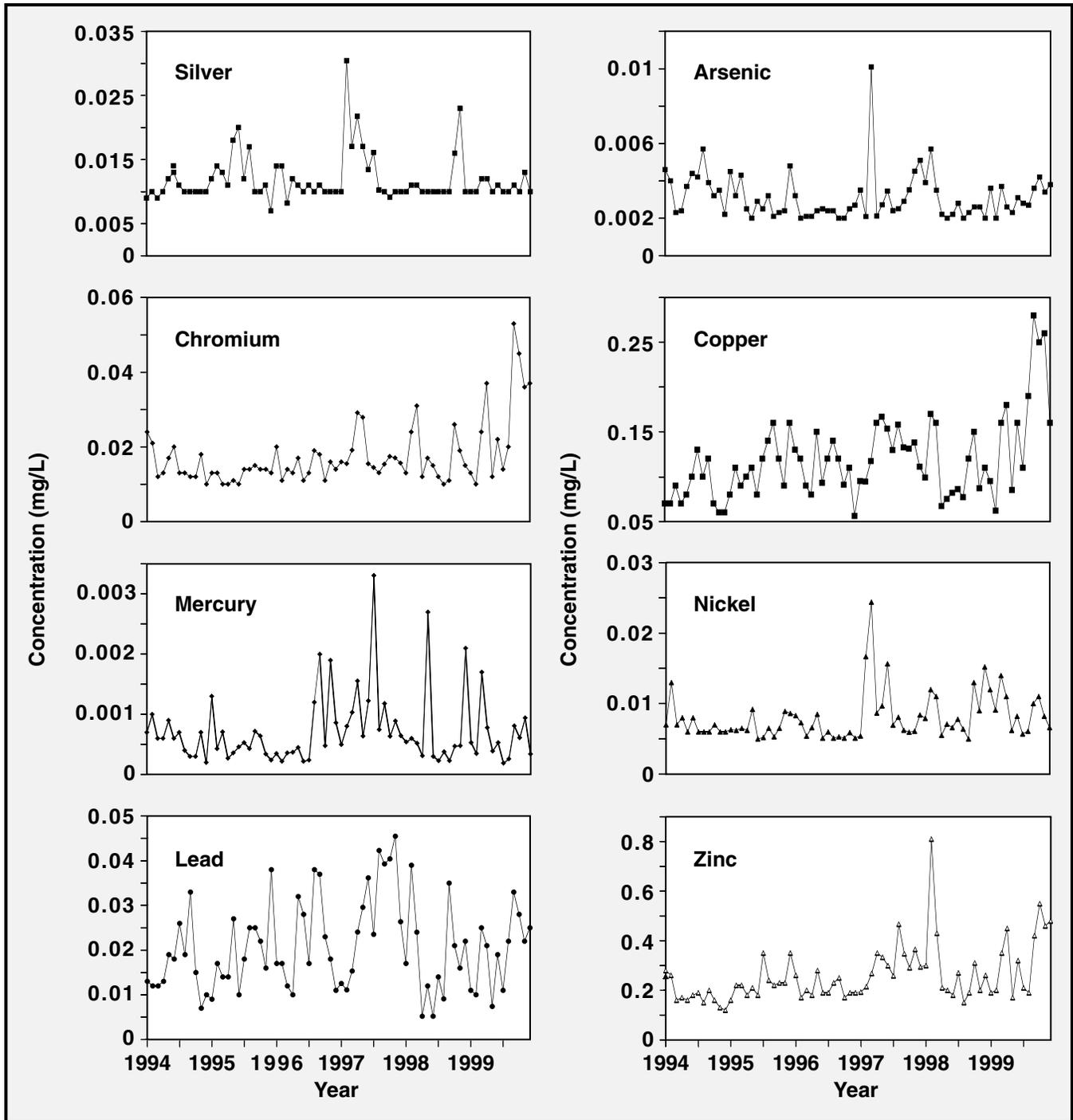


Figure 6-4. Average monthly concentrations for eight of the nine regulated metals in LLNL sanitary sewer effluent showing trends from 1994 to 1999.

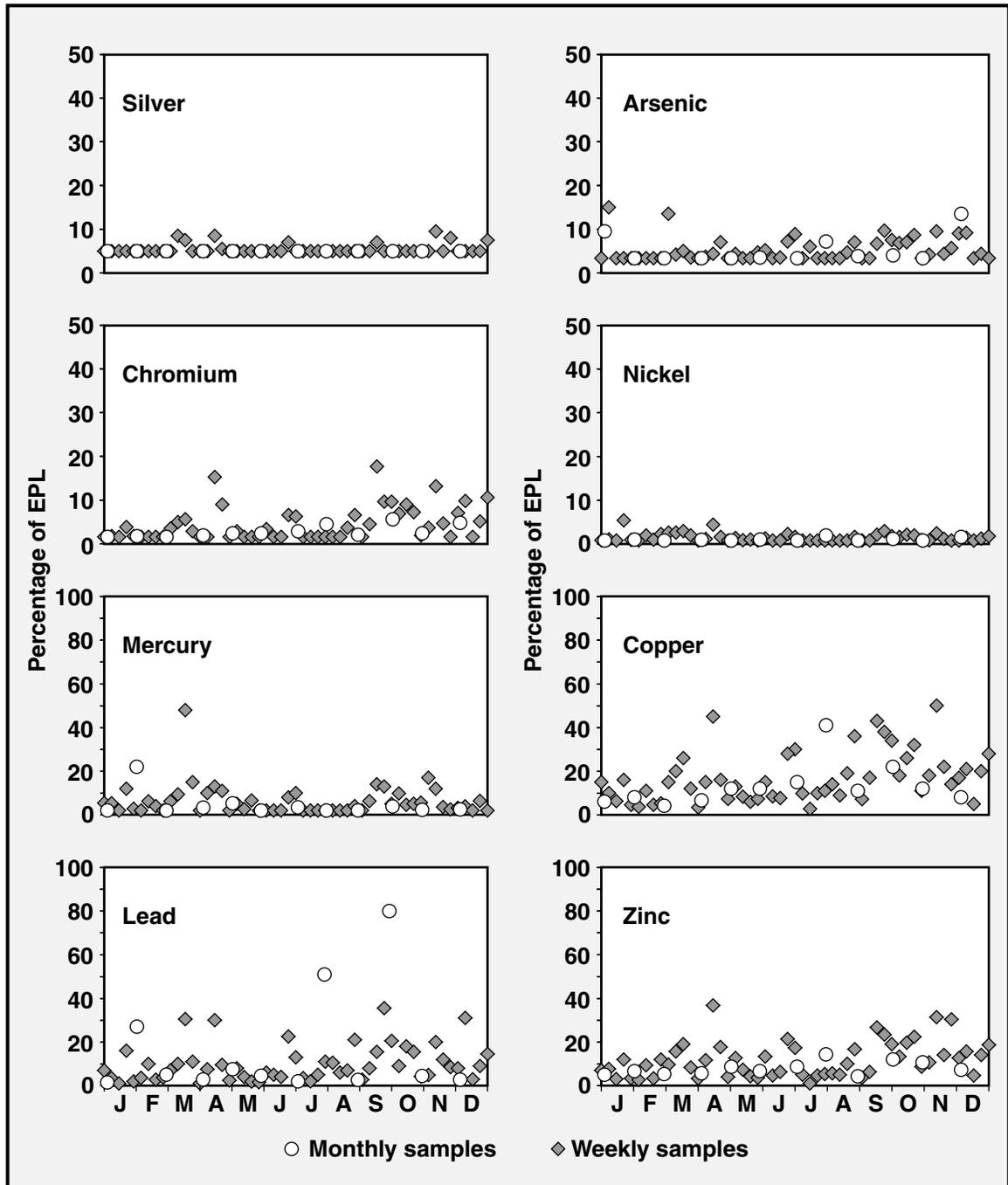


Figure 6-5. Results as percentages of effluent pollutant limits (EPLs) for eight of the nine regulated metals in LLNL sewage, 1999.



6 Sewerable Water Monitoring

Detections of anions, metals, and organic compounds and summary data concerning other physical and chemical characteristics of the sanitary sewer effluent are provided in **Table 6-8**. (All of the corresponding analytical results are provided in the Data Supplement Table 6-7.) Although samples were analyzed for bromide, nitrite (as N), carbonate alkalinity (as CaCO_3), hydroxide alkalinity (as CaCO_3), selenium, and cyanide, those analytes were not detected in any sample acquired during 1999, and so are not presented in the table. The results are quite typical of those seen in previous years except the sampling frequency for two regulated parameters was decreased. LLNL decreased the sampling frequency for oil and grease, and cyanide in response to changes in sampling requirements made by the LWRP, as discussed in detail in the Data Supplement Chapter 6.

Environmental Impact

Table 6-7 presents monthly average and summary statistics for all regulated metals concentrations in LLNL's sanitary sewer effluent. At the bottom of the table, the annual median concentration for each metal is compared with the discharge limit. In 1999, the metals that approached closest to the discharge limits were copper, lead, and zinc at 16%, 11%, and 11%, respectively.

Although average monthly concentrations for chromium, mercury, nickel, and zinc have generally been slightly elevated for the last several years (see **Figure 6-4**), all of the individual weekly and 24-hour composite results for 1999 were less than 50% of the corresponding discharge limits. In fact, only one metal result met the 50% action level in LLNL's Wastewater Discharge Permit. In November 1999, a weekly composite sample had a copper concentration of 0.50 mg/L, or 50% of the discharge limit of 1.0 mg/L (see **Figure 6-5**). The daily samples that correspond to the appropriate weekly composite sampling period of November 11–17 were submitted for copper analysis. All of the analytical results for the daily samples were less than the effluent pollutant limit; no sample had a measured copper concentration greater than 0.09 mg/L.

In 1999, the SMS continuous monitoring system detected four discharges outside of the permitted pH range of 5 to 10. Two of the discharges were below pH 5 and two were above pH 10: all four discharges were captured in the SDF. For comparison, 2, 13, and 1 such diversions occurred in 1998, 1997, and 1996, respectively.



Table 6-8. Monthly monitoring results for physical and chemical characteristics of the LLNL sanitary sewer effluent, 1999.^(a)

24-hour composite sample parameter (mg/L)	Detection frequency ^(b)	Minimum	Maximum	Median	IQR ^(c)
Alkalinity					
Bicarbonate alkalinity (as CaCO ₃)	11/11	130	221	185	24
Total alkalinity (as CaCO ₃)	11/11	130	221	185	23
Anions					
Bromide	2/12	<0.10	0.62	<0.11	— ^(d)
Chloride	10/12	22	63	44	12
Fluoride	10/12	<0.050	0.68	0.088	0.065
Nitrate (as NO ₃)	2/12	<0.40	1.6	<0.40	— ^(d)
Orthophosphate	12/12	12	198	18	5.3
Sulfate	12/12	4.0	44	9.7	8.7
Nutrients					
Ammonia nitrogen (as N)	12/12	28	53	40	9.3
Total Kjeldahl nitrogen	12/12	0.61	60	46	15
Oxygen demand					
Biochemical oxygen demand	11/12	<75	305	140	112
Chemical oxygen demand	12/12	130	664	302	293
Solids					
Solid settling rate (mL/L/h)	12/12	19	62	27	14
Total dissolved solids	12/12	120	510	233	92
Total suspended solids	12/12	84	398	123	235
Volatile solids	12/12	55	380	255	150
Total metals					
Aluminum ^(e)	11/12	<0.20	1.2	0.49	0.29
Beryllium ^(e)	0/12	<0.00020	<0.0010	<0.00050	— ^(d)
Calcium	12/12	11	19	14	2.8
Iron ^(e)	12/12	0.55	3.2	1.7	0.94
Magnesium	12/12	1.9	4.6	2.8	0.68
Potassium	12/12	13	99	18	4.3
Sodium	12/12	21	64	36	11
Total organic carbon	12/12	31	94	47	18
Tributyltin (ng/L)	2/2	7.0	33	20	13



6 Sewerable Water Monitoring

Table 6-8. Monthly monitoring results for physical and chemical characteristics of the LLNL sanitary sewer effluent, 1999 (concluded).^(a)

Grab sample parameter	Detection frequency ^(b)	Minimum	Maximum	Median	IQR ^(c)
Semivolatile organic compounds (µg/L)					
Benzoic acid	3/12	<10	<300	<44	— ^(d)
Benzyl alcohol	5/12	<2.0	<100	<10	— ^(d)
Bis(2-ethylhexyl)phthalate ^(f)	6/12	<5.0	<200	<17	— ^(d)
Butyl benzyl phthalate ^(f)	1/12	<2.0	55	<5.0	— ^(d)
Diethylphthalate	6/12	4.9	<50	<10	— ^(d)
m- and p- Cresol	1/3	<5.0	<50	<19	— ^(d)
p- Cresol	3/9	<2.0	<50	<16	— ^(d)
Total cyanide (mg/L)	0/7	<0.02	<0.02	<0.02	— ^(d)
Oil and grease (mg/L)	4/4	14	23	20	3
Total recoverable phenolics (mg/L)	3/3	0.024	0.069	0.038	— ^(d)
Volatile organic compounds (µg/L)					
1,4-Dichlorobenzene	10/12	<0.50	3.6	1.5	0.73
Acetone	12/12	54	360	120	70
Benzene ^(f)	1/12	<0.50	<2.0	<0.50	— ^(d)
Chloroform ^(f)	12/12	8.5	23	14	5.8
Dichlorodifluoromethane	1/12	<0.50	<4.0	<0.50	— ^(d)
Methylene chloride ^(f)	2/12	<1.0	<2.0	<1.0	— ^(d)
Toluene ^(f)	7/12	<0.50	<2.0	0.71	0.67

^a The 24-hour composite sample results plotted in **Figure 6-5** and nondetected values reported in the Data Supplement, Chapter 6, are not reported in this table.

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

^c IQR = Interquartile range.

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

^e Weekly sampling results for these parameters are included Data Supplement Table 6-5.

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

Monitoring results for 1999 reflect an outstanding year for LLNL's sewerable water discharge control program and Livermore site personnel. LLNL achieved 100% compliance with the provisions of its wastewater discharge permit.

Surface Water

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Overview

Lawrence Livermore National Laboratory monitors surface water at the Livermore site, in surrounding regions of the Livermore Valley, and at Site 300 and vicinity in the nearby Altamont Hills. At the Livermore site and vicinity, LLNL monitors reservoirs and ponds, the Livermore site swimming pool, the Drainage Retention Basin (DRB), rainfall, tap water, and storm water runoff. At Site 300 and vicinity, surface water monitoring encompasses rainfall, cooling tower discharges, and storm water runoff.

The water samples are analyzed for radionuclides, high explosives, total organic carbon, total organic halides, total suspended solids, conductivity, pH, chemical oxygen demand, total dissolved solids, oil and grease, metals, minerals, anions, and a wide range of organic compounds. In addition, bioassays are performed annually on water entering and leaving the Livermore site via the Arroyo Las Positas pathway, discharges from the DRB, and water contained in the DRB.

Storm Water

This section discusses general storm water information (including permits, constituent criteria, inspections, and sampling), sampling methods, and results.

General Information

Permits

The goals of the storm water (runoff) monitoring program are to demonstrate compliance with permit requirements, aid in implementing the Storm Water Pollution Prevention Plans (SWPPPs) (Eccher et al. 1994a and b), and measure the effectiveness of the Best Management Practices (BMPs) in preventing contamination of storm water discharges.



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LLNL monitors storm water at the Livermore site in accordance with a Waste Discharge Requirements and National Pollutant Discharge Elimination System permit (WDR 95-174, NPDES Permit No. CA0030023) issued in 1995 (San Francisco Bay Regional Water Quality Control Board [SFBRWQCB] 1995). In 1994, the Central Valley Regional Water Quality Control Board (CVRWQCB) issued a Waste Discharge Requirements and National Pollutant Discharge Elimination System Permit (WDR 94-131, NPDES Permit No. CA0081396) for Site 300 (CVRWQCB 1994). These permits include specific monitoring and reporting requirements. In addition to the storm water constituents required by the permits, LLNL monitors other constituents to provide a more complete water quality profile. The current list of analyses provided for storm water samples is given in Table 7-1.

Table 7-1. Analyses conducted on storm water samples, 1999.

Livermore site	Site 300
Specific conductance	Specific conductance
Total suspended solids	Total dissolved solids
pH	Total suspended solids
Chemical oxygen demand	pH
Biochemical oxygen demand	Potassium
Fish bioassay (fathead minnow)	Beryllium
Anions	Mercury
General minerals	Volatile organic compounds
Metals	Semivolatile organic compounds
Volatile organic compounds	Pesticides
Pesticides	PCBs
Oil and grease	Total organic halides
PCBs	Total organic carbon
Total organic carbon	Dioxins
Semivolatile organic compounds	Explosives
Gross alpha and beta	Gross alpha and beta
Tritium	Tritium
Plutonium	Uranium

The NPDES permits for storm water require that LLNL sample effluent two times per year. In addition, LLNL is required to visually inspect the storm drainage system monthly during the wet season, whenever significant storms occur, and twice during the dry season to identify any dry weather flows. Influent sampling is also required at the



Livermore site. LLNL monitors up to two more storm events each year at the Livermore site (a total of four sampling events) in support of U.S. Department of Energy (DOE) Orders 5400.1 and 5400.5. In addition, annual facility inspections are required to ensure that the BMPs are adequate and implemented.

LLNL also meets the storm water compliance monitoring requirements of the Statewide General NPDES Permit for Storm Water Discharges Associated with Construction Activity (Order 92-08-DWQ, NPDES Permit No. CAS000002) for construction projects that disturb 2 hectares of land or more (State Water Resources Control Board [SWRCB] 1992). In August 1999, the SWRCB reissued Order 92-08-DWQ as Order 99-08-DWQ. The new requirements of the reissued permit were implemented by LLNL beginning in November 1999 as required by the permit's conditions (SWRCB 1999). These conditions apply to the 1999/2000 rainy season that will be discussed in the Environmental Report for 2000.

Storm water monitoring also follows the requirements in the *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. Department of Energy 1991) and meets the applicable requirement of DOE Order 5400.1, *General Environmental Protection Program*; DOE Order 5400.5, *Radiation Protection of the Public and the Environment*; and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) *Record of Decision for the Lawrence Livermore National Laboratory Livermore Site* (U.S. Department of Energy 1993).

Constituent Criteria

Currently, there are no numeric criteria that limit concentrations of specific constituents in LLNL's storm water effluent. The Environmental Protection Agency (EPA) established benchmark values for 41 parameters but stressed that these concentrations were not intended to be interpreted as effluent limits (U.S. Environmental Protection Agency 1995). 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, the use of a broad range of criteria can help evaluate LLNL's storm water management program and ensure high quality storm water effluent.

Storm water sample results for the Livermore site were also compared with criteria listed in the *Water Quality Control Plan, San Francisco Bay Basin* (San Francisco Bay Regional Water Quality Control Board 1995), and results for Site 300 were compared with criteria listed in *The Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board, Central Valley Region, Sacramento and San Joaquin River Basins* (Longley et al. 1994). Criteria in the basin plans include surface water quality objectives for the protection of aquatic life and water quality objectives for waters designated for



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use as domestic or municipal supply or agricultural supply. These criteria include, by reference, California Maximum Contaminant Levels (MCLs) for drinking water. In addition, LLNL compared results with EPA MCLs and ambient water quality criteria (AWQC) as well as California AWQC. Criteria not specifically listed in the basin plans were obtained from *A Compilation of Water Quality Goals* (Marshack 1998). Criteria are summarized in Table 7-1 in the Data Supplement, which lists Primary MCL/Secondary MCL (PMCL/SMCL), Ambient Water Quality Criteria/Criteria for Agricultural Use (AWQC/Ag), and the EPA benchmarks.

In addition to chemical-specific monitoring, LLNL is required by NPDES permit (WDR 95-174) to conduct acute and chronic fish toxicity testing in Arroyo Las Positas (Livermore Site) once per wet season (defined as October of one year through April of the following year). Currently, LLNL is not required to test for fish toxicity at Site 300.

Inspections

Each directorate at LLNL conducts an annual inspection of its facilities to verify implementation of the SWPPPs and to ensure that measures to reduce pollutant loadings to storm water runoff are implemented. The Laboratory's associate directors certify that their facilities comply with the provisions of WDR 94-131, WDR 95-174, and the SWPPPs. The deputy director for operations certifies the facilities directly reporting to the Director's Office, except those facilities in the Laboratory Site Operations organization, which are certified by the Laboratory site manager. LLNL submits annual storm water monitoring reports to the SFBRWQCB and to the CVRWQCB with the results of sampling, observations, and inspections.

Monitoring for construction projects permitted by Order 92-08-DWQ included visual observations of construction sites by the construction staff before and after storms to assess the effectiveness of implemented BMPs. Annual compliance certifications summarize these inspections.

As in past years, the SFBRWQCB requested submission of compliance status reports for the Livermore site projects. (The CVRWQCB has never requested compliance status reports for projects located at Site 300.) The 1999 compliance certifications (and compliance status reports) covered the period of June 1998 through May 1999. During this period, three Livermore site projects were inspected: the Decontamination and Waste Treatment Facility (DWTF), the National Ignition Facility (NIF), and the areas associated with the Soil Reuse Project. One Site 300 project, the Contained Firing Facility, was also inspected under this program.



Sampling

To evaluate the overall impact of Livermore site and Site 300 operations on storm water quality, storm water flows are sampled where they exit the sites and at upstream locations. Because of flow patterns at the Livermore site, storm water at sampling locations includes water runoff from other sources, such as neighboring agricultural land, parking lots, and landscaped areas. In contrast, storm water at Site 300 is sampled at locations that target specific industrial activities, with negligible run-on from other sources. These samples provide information used to evaluate the effectiveness of LLNL's storm water pollution control program.

Livermore Site

The natural drainage at the LLNL Livermore site was altered by construction activities several times up to 1966 (Thorpe et al. 1990) so that the current northwest flow of Arroyo Seco and the westward flow of Arroyo Las Positas do not represent historical flow paths. About 1.6 km to the west of the Livermore site, Arroyo Seco merges with Arroyo Las Positas, which continues to the west to eventually merge with Arroyo Mocho (see **Figure 7-1**).

The DRB was excavated and lined in 1992 to prevent infiltration of storm water that was dispersing ground water contaminants. It also serves storm water diversion and flood control purposes. The DRB collects about one-fourth of the surface water runoff from the site and a portion of the Arroyo Las Positas drainage (**Figure 7-2**).

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 sewers and ditches. Arroyo Seco cuts across the southwestern corner of the site. Arroyo Las Positas follows the northeastern and northern boundaries of the site and exits the site near the northwest corner.

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



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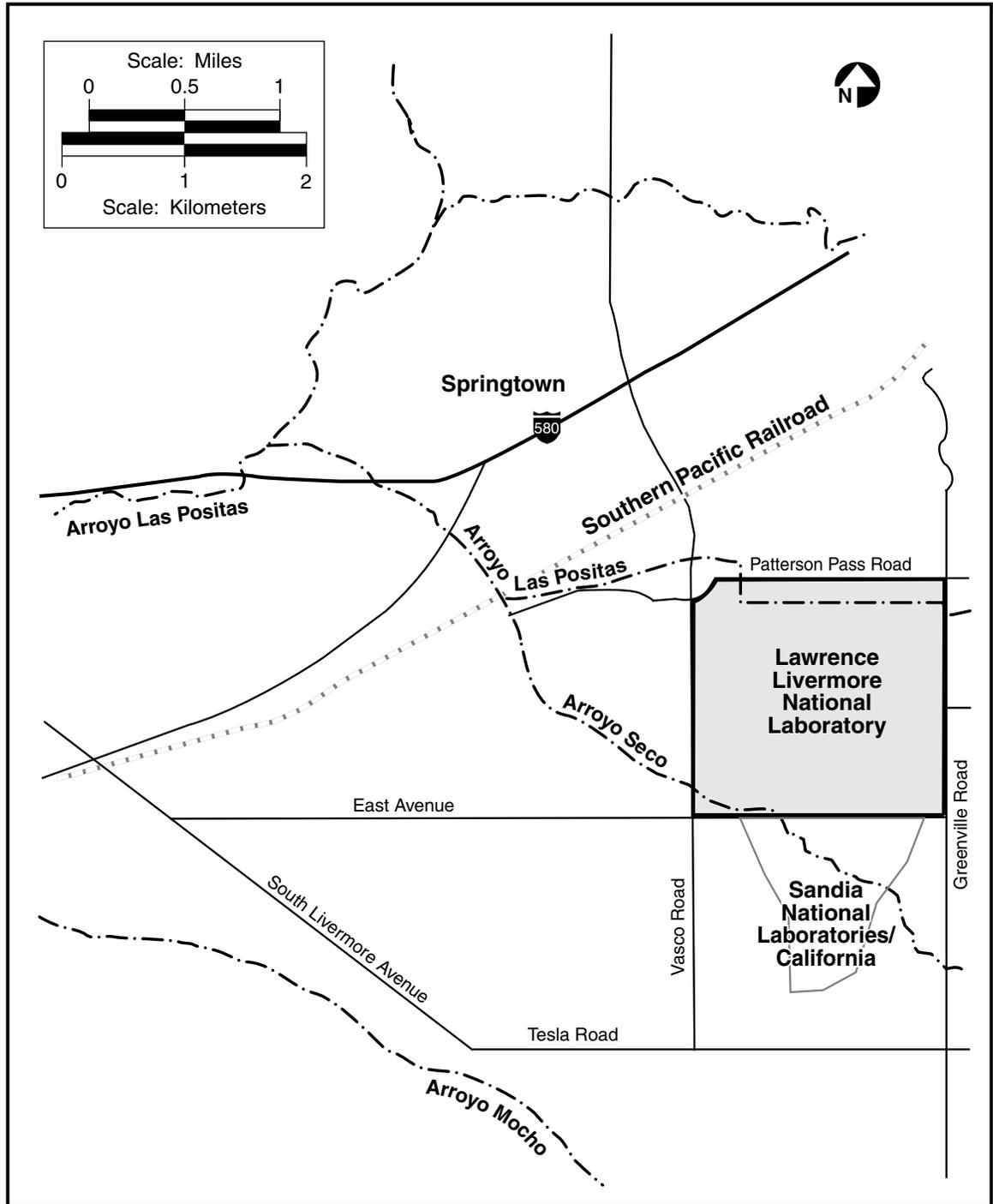


Figure 7-1. Surface water courses in the vicinity of the Livermore site.

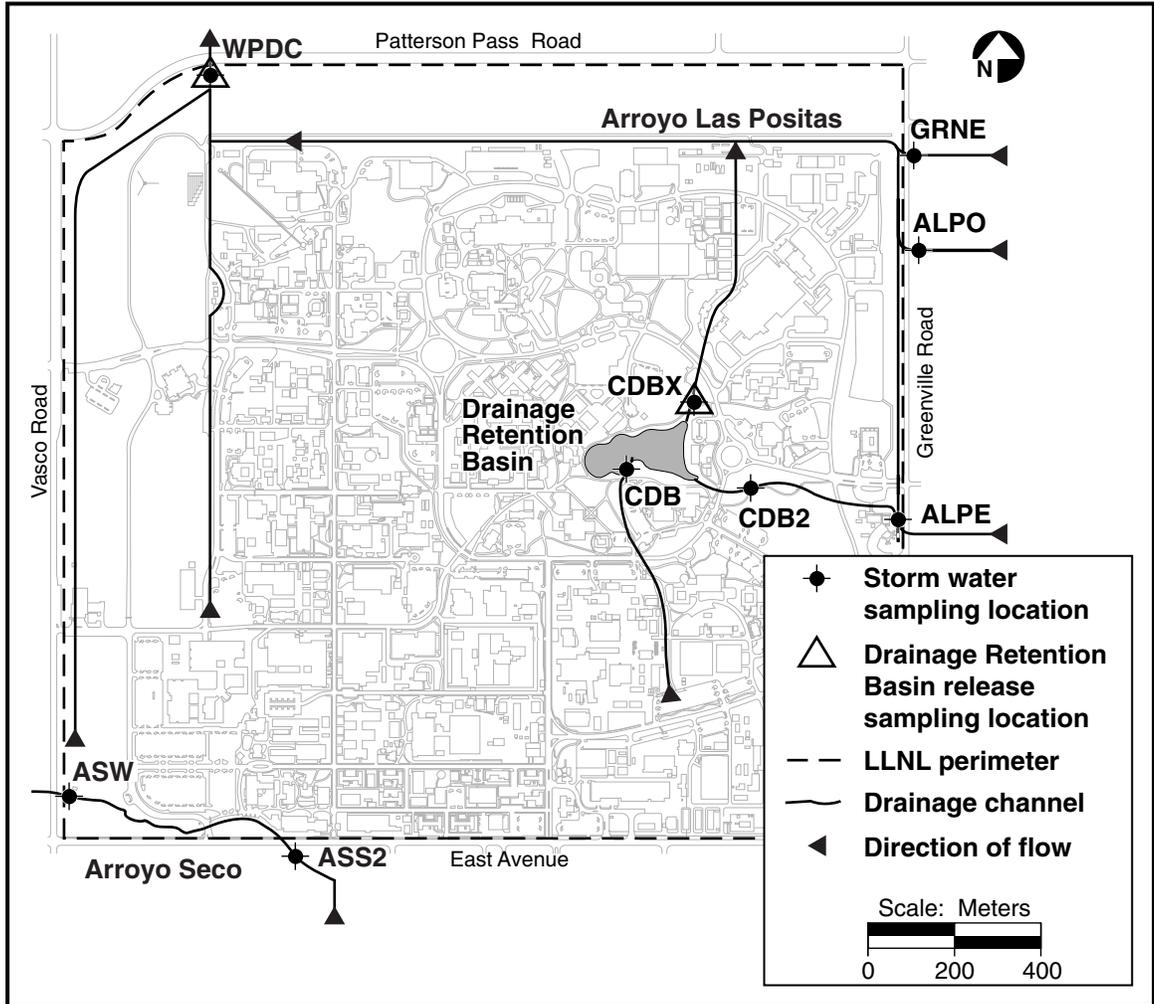


Figure 7-2. Storm water runoff and Drainage Retention Basin discharge sampling locations, Livermore site, 1999.

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 continuously flowing streams are present in the Site 300 area. Elk Ravine is the major drainage channel for most of Site 300; it extends from the northwest portion of the site to the east-central area (see **Figure 9-3**). Elk Ravine drains the center of the site into Corral Hollow Creek, which drains eastward to the San Joaquin River Basin. Some smaller canyons in the northeast portion of the site drain to the north and east toward Tracy.



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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. A number of artificial surface water bodies are present at Site 300. A sewage evaporation pond and a sewage percolation pond are located in the southeast corner of the site in the General Services Area (GSA), and two lined, high-explosives (HE) process water impoundments are located to the west in the Explosives Process Area. Monitoring results associated with these facilities are reported in Chapter 9.

Other surface water flow at Site 300 results from blowdown water from cooling towers in the Building 801 complex in the East/West Firing Area and Building 836A near the eastern site boundary. Additionally, three wetlands created by now-discontinued flows from cooling towers located at Buildings 827, 851, and 865 are currently maintained by discharges of potable water. Cooling tower discharges and their potential impact are discussed in the *Final Site-Wide Remedial Investigation Report* (Webster-Scholten 1994).

The Site 300 storm water sampling network began in 1994 with six locations and now consists of seven locations (**Figure 7-3**). Location CARW is used to characterize runoff in Corral Hollow Creek upgradient and therefore is unaffected by Site 300 activities. Location GEOCRK is used to characterize runoff in Corral Hollow Creek, downstream of Site 300. The remaining locations were selected to characterize storm water runoff at locations that could be affected by specific Site 300 activities.

Methods

Samples are collected by grab sampling from the runoff flow at specified locations. Sample bottle requirements, special sampling techniques, and preservation requirements for each analyte are specified in the *Environmental Monitoring Plan* (Tate et al. 1999) and summarized below.

If the water to be sampled is accessible to the technician, 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 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 water to minimize the collection of sediment with the sample matrix. Sample vials for volatile organics are filled first before sample vials for all other constituents and parameters.

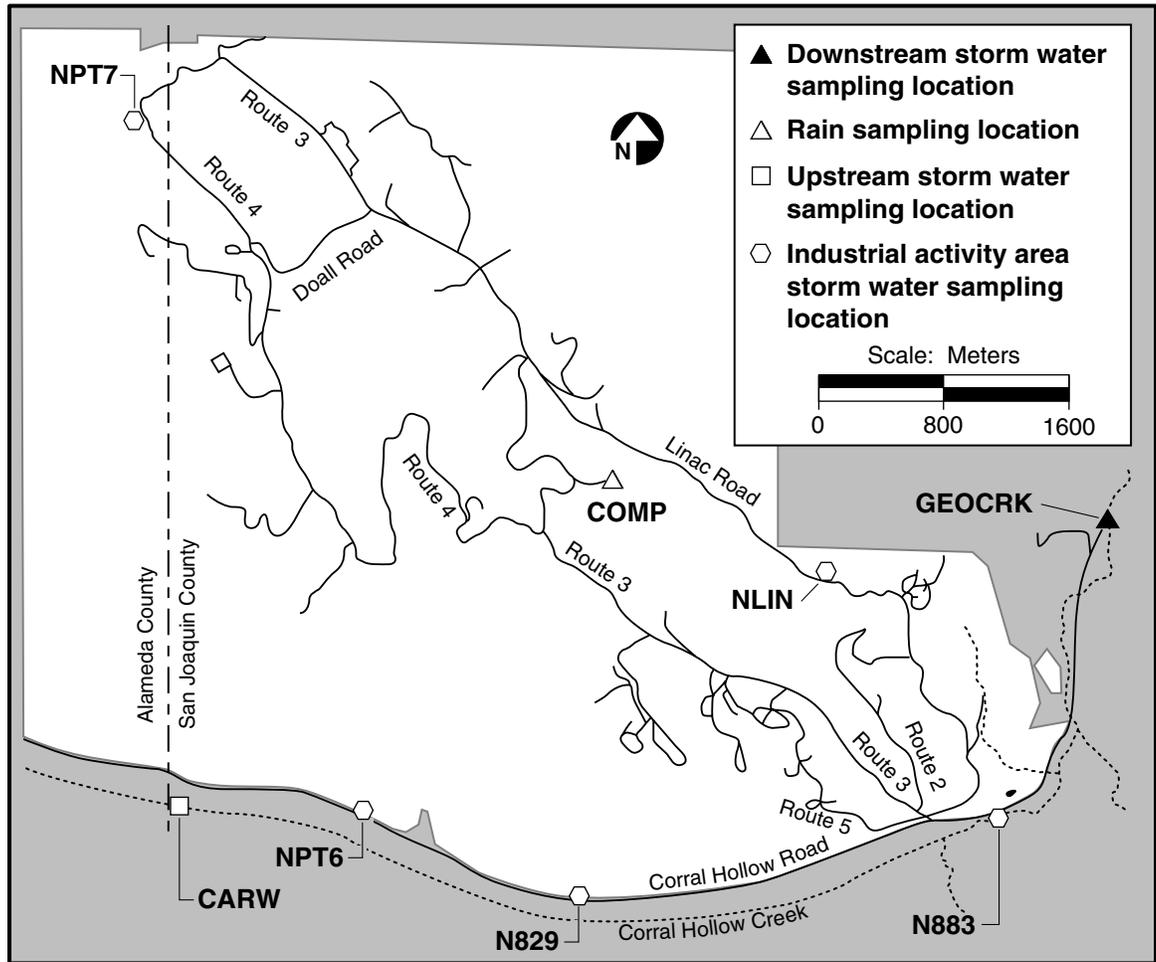


Figure 7-3. Surface water flow in the vicinity of Site 300.

Results

Inspections

All 12 directorate-level organizations at the Livermore site conducted the permit-required annual inspections during 1999. These inspections of more than 500 facilities indicated that all BMPs were in place, implemented, and adequate to protect storm water in all but five instances at the Livermore site. Three of the exceptions noted were the absence of BMPs for the outdoor storage of materials (paint cans, batteries, and drums). The paint cans and batteries were removed, and the drums are being evaluated to determine if secondary storage is necessary. In addition, there was one instance where dumpster covers were missing. The dumpster covers are being replaced. Finally,



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rainwater was observed in secondary containment pallets in one area. The rainwater was removed and disposed of properly. All Site 300 inspections of more than 100 facilities indicated that the applicable BMPs were in place, implemented, and adequate to protect storm water.

LLNL conducted the permit-required inspections before and after rain events at four permitted construction sites: three at the Livermore site and one at Site 300. The findings of these inspections indicated compliance with the permit and the construction site SWPPPs with these exceptions documented in the 1998/1999 annual compliance certifications:

- There were two instances on the Contained Firing Facility construction project where the SWPPP was not updated as required: (1) a new area of the project was not included, and (2) the SWPPP was not updated at the start of a new construction package.
- The Soil Reuse Project SWPPP was not updated as required to show the more protective BMPs being employed on the project.
- The NIF project did not perform inspections as required at some of the project's laydown areas, and on the main construction site some BMPs were not repaired within the 48-hour time period specified in the SWPPP.

Livermore Sampling

LLNL collected storm water samples at all nine Livermore site locations on February 8 and April 8, 1999. Samples were collected from six locations on January 20, 1999. Three locations did not produce flow on this date but were sampled during a later storm that occurred on January 26, 1999. Samples were collected from eight locations on November 8, 1999; no sample was collected at location ASS2 because there was no flow at this location. Fish toxicity analyses were conducted on the January 20, 1999, sample.

Toxicity Monitoring

As required by WDR 95-174, grab samples were collected and analyzed for acute and chronic toxicity using the fathead minnow (*Pimephales promelas*) as the test species. In the acute test, the 96-hour survival test was observed in undiluted storm water collected from location WPDC. The permit states that an acceptable survival rate is 20% lower than the control sample. The testing laboratory provides water for the quality control sample. As specified by the permit, upgradient water from influent locations ALPE, ALPO, and GRNE is used as an additional control. 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 additional toxicity testing during the next significant storm event. If two consecutive tests fail, LLNL must perform a toxicity reduction evaluation to identify the source of the toxicity. Survival in the acute test at WPDC and all corresponding influent locations (ALPE, ALPO, and GRNE) was 100% in 1999 (sampled January 20).

In the chronic test, storm water dilutions of 0 (lab control), 6.25, 12.5, 25, 50, and 100% (undiluted storm water) were used to determine a dose-response relationship, if any, for both survival and growth of the fathead minnow (see **Table 7-2**). No criteria are set for this test; it is performed for information purposes only. Also, because this test is only required at effluent location WPDC and not conducted with water from corresponding influent locations, there is no way to determine if any effect should be attributed to LLNL or to upgradient water quality. From the data collected for this test, no observed effect concentrations (NOECs) and lowest observed effect concentrations (LOECs) were calculated using *EPA/600/4-91-002*. The NOECs and LOECs for survival and growth were 100%. Thus, both the acute and chronic fish toxicity tests indicated that storm water had no effect on survival or growth of the fathead minnow.

Table 7-2. Fish chronic toxicity test results, Livermore site, 1999.

Sample concentration (%)	7-day survival		7-day weight ^(a)	
	Average (%)	Standard deviation	Average (mg)	Standard deviation
Lab control	100	0	0.64	0.060
6.25	95	5.8	0.53	0.058
12.5	98	5.0	0.44	0.221
25	95	5.8	0.52	0.084
50	95	10.0	0.58	0.056
100	98	5.0	0.56	0.100

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

Livermore Site Radioactive Constituents

Storm water tritium, gross alpha, and gross beta results are summarized in **Table 7-3**. Complete results are in the Data Supplement Tables 7-2, 7-3 and 7-4. Median activities at effluent locations were less than 10% of the respective MCLs. **Figures 7-4** and **7-5**, which show the historic trend in storm water gross alpha and gross beta, respectively, do not reveal a discernible trend. In these and other storm water historical trend figures, LLNL has aggregated all available data for the influent and effluent locations of the two runoff pathways through the Livermore site. Also, data have been aggregated on a wet



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season basis—that is, October of one year through May of the next—rather than on a calendar-year basis. The 1999 points represent a partial wet season, pending collection of year 2000 data, and are based on only one sampling event (November 8, 1999).

Table 7-3. Radioactivity in storm water runoff (Bq/L), Livermore site, 1999.

	Tritium	Gross alpha	Gross beta
All locations			
Median	17.4	0.0642	0.179
Minimum	-0.903	0	0.0351
Maximum	7215	0.477	0.655
Interquartile range	36.9	0.0773	0.120
Effluent locations			
Median	19.4	0.0381	0.184
Minimum	-0.703	0	0.109
Maximum	129	0.0681	0.237
Interquartile range	42.4	0.0445	0.0935
MCL ^(a)	740	0.555	1.85

^a MCL = Maximum contaminant level

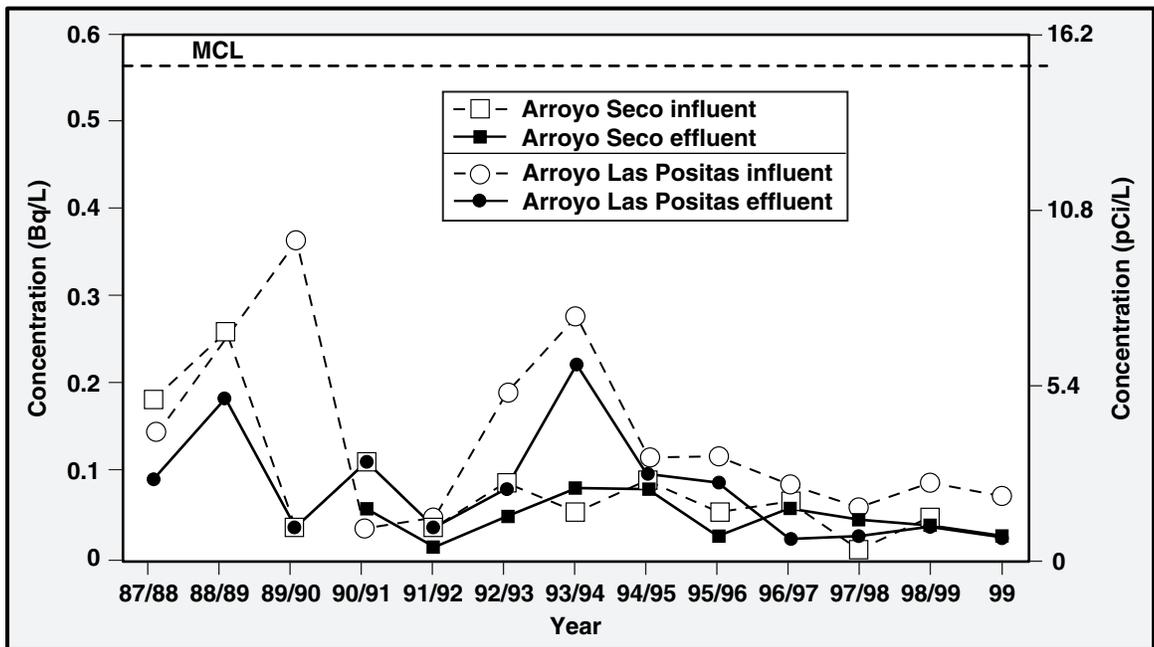


Figure 7-4. Annual median gross alpha concentrations in Livermore site storm water compared with the maximum contaminant level (MCL).

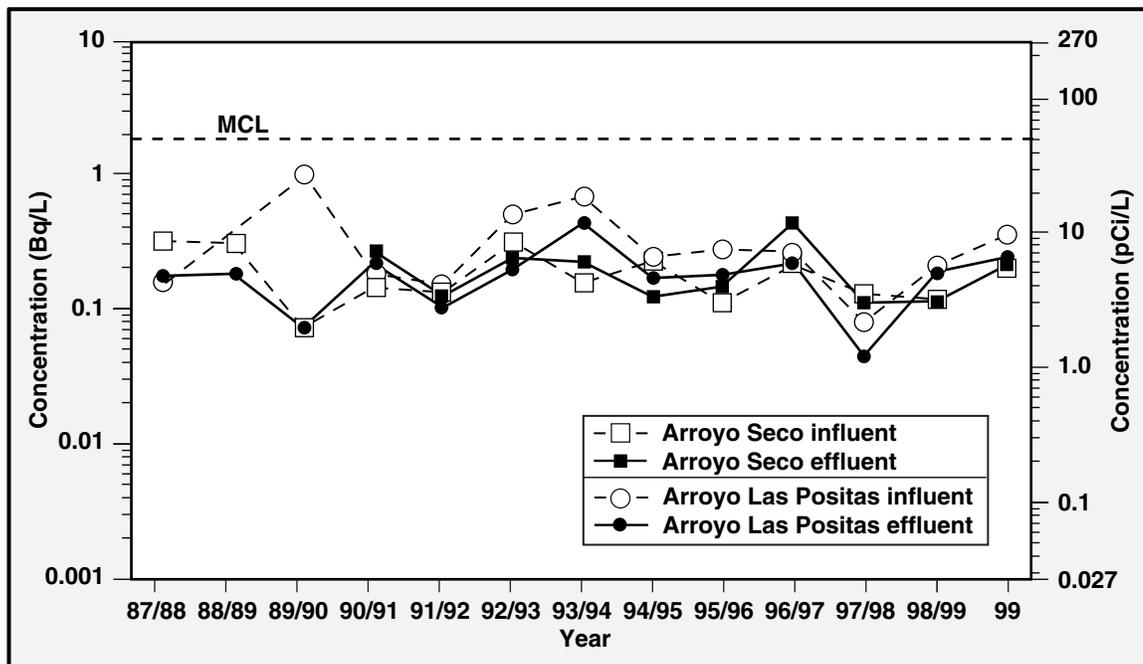


Figure 7-5. Annual median gross beta concentrations in Livermore site storm water compared with the maximum contaminant level (MCL).

The historical trend in tritium levels is presented in **Figure 7-6**. Prior to the 1998/1999 wet season, the analytical laboratory reported the minimum detectable level for non-detections, and these values were used in calculating medians for the plots. Beginning in the 1998/1999 wet season, changes in laboratory reporting procedures included reporting a “calculated value” for nondetections. The calculated value is an estimate of an unmeasurably low level. It is less than the minimum detectable level, and can even be negative (due to subtraction of background radiation). (See Chapter 14 for a complete explanation of calculated values.) Under the former reporting method, medians involving nondetections were biased high. This change in reporting procedures results in a better estimate, on average, of the true level. At some locations the decrease in tritium levels in the 1998/1999 wet season represented on **Figure 7-6** may be a result of the new reporting procedures. The historical trend in tritium levels generally correlates with decreased emissions (see Chapter 5), and indicates decreasing tritium levels in storm water from a peak in the 1988/1989 season.

Beginning with the 1996/1997 season, the tritium concentration in Arroyo Las Positas has been higher in storm water leaving the site than in storm water entering the site. On May 23, 1997, at location WPDC, where effluent is measured, a single higher-than-typical result for tritium in storm water (359 Bq/L) was measured.



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In response to the elevated effluent tritium concentrations, additional tritium investigations were initiated in the fall of 1998 to reconfirm the current evidence that effluent tritium concentration is greater than influent tritium concentration and to identify sources for the higher tritium concentrations. These investigations included:

- Review of air tritium sampling results (the air tritium data during and prior to 1998 did not indicate a source for the tritium).
- Increased frequency of rain sampling.
- Increased frequency and number of locations of storm water sampling.

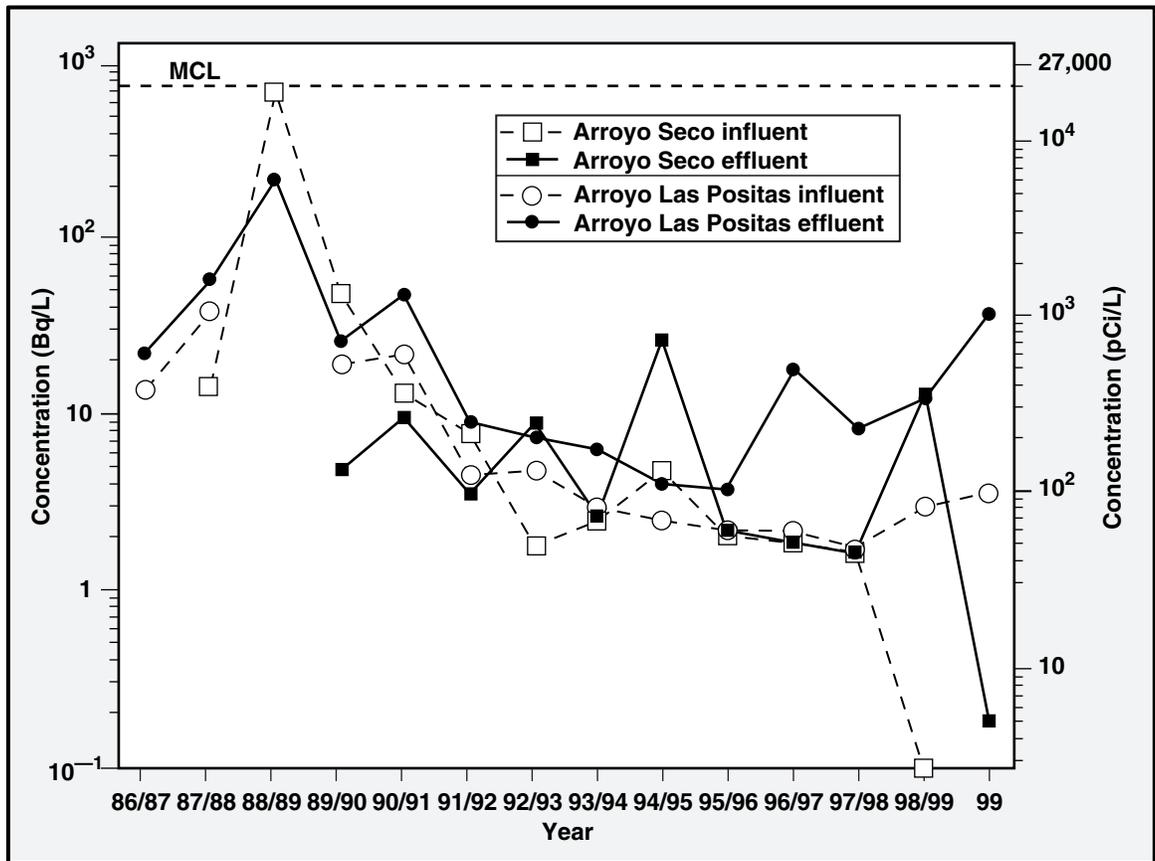


Figure 7-6. Annual median tritium concentrations in Livermore site storm water compared with the maximum contaminant level (MCL). Negative results were assigned a value of 10⁻¹ for plotting purposes



The initial approach taken to evaluate tritium flow patterns across the Livermore site was to evaluate two locations (WPDW and 196S in **Figure 7-7**) where the storm drainage channels join the main Arroyo Las Positas channel slightly upstream of where Arroyo Las Positas leaves the Livermore site effluent location (WPDC). Samples were collected at these junctures on November 30, 1998, and reported in the *Environmental Report 1998* (Larson et al. 1999). Tritium was not detected in the incoming channels (calculated values of 2.0 and 0.9 Bq/L at WPDW and 196S, respectively), but was detected at 31 Bq/L in the main Arroyo Las Positas channel at both WPDS and 196E. Additional locations were added in each subsequent sampling event during the spring of 1999 to further evaluate the tritium flow patterns (**Figure 7-7**). There was a general increase in runoff tritium detected at internal sampling locations during the course of the wet season (Data Supplement Tables 7-2 and 7-3). **Figure 7-7** demonstrates that the source was from the north-south channel, sampled at locations 3726 and 2582.

During this same time period (beginning in mid-January 1999), analytical results from molecular sieves that monitor stack effluent at Building 331 (the Tritium Facility) began to show evidence of above-normal releases of tritium (detected as both tritiated hydrogen and tritiated water, or HT and HTO). On March 28, facility staff located a glove box with a faulty pump that was causing the glove box contents to vent directly to the building stack. The pump/glove box was repaired on March 29, and storm water effluent tritium levels returned to levels seen in recent years. The highest site storm water effluent tritium level (58.5 Bq/L, or 1580 pCi/L) was collected February 8, compared to 11.1 Bq/L (301 pCi/L) collected on April 8.

Based on the sample results described above, the north-south channel containing locations 3726 and 2582 will be the focus of the tritium source investigation for year 2000. Additional storm water sampling locations will be added to this flow path to further investigate this source. LLNL will also evaluate sampling sediment for tritium in this area.

LLNL began analyzing for plutonium in storm water in 1998. Samples were analyzed from the Arroyo Seco and Arroyo Las Positas effluent locations (ASW and WPDC). When the samples were low in suspended sediments (January 26 and February 8), the unfiltered water was analyzed. At intermediate suspended sediment levels (April 8), the runoff was filtered, and the filtered water and filtrate were analyzed. When the laboratory determined that sufficient suspended sediment was present in the runoff (as in the November 8 sample), a portion of the runoff was analyzed unfiltered, and the remaining runoff was filtered. The filtrate and filtered water were analyzed (three analyses total from each location). Plutonium was never detected in the liquid portion



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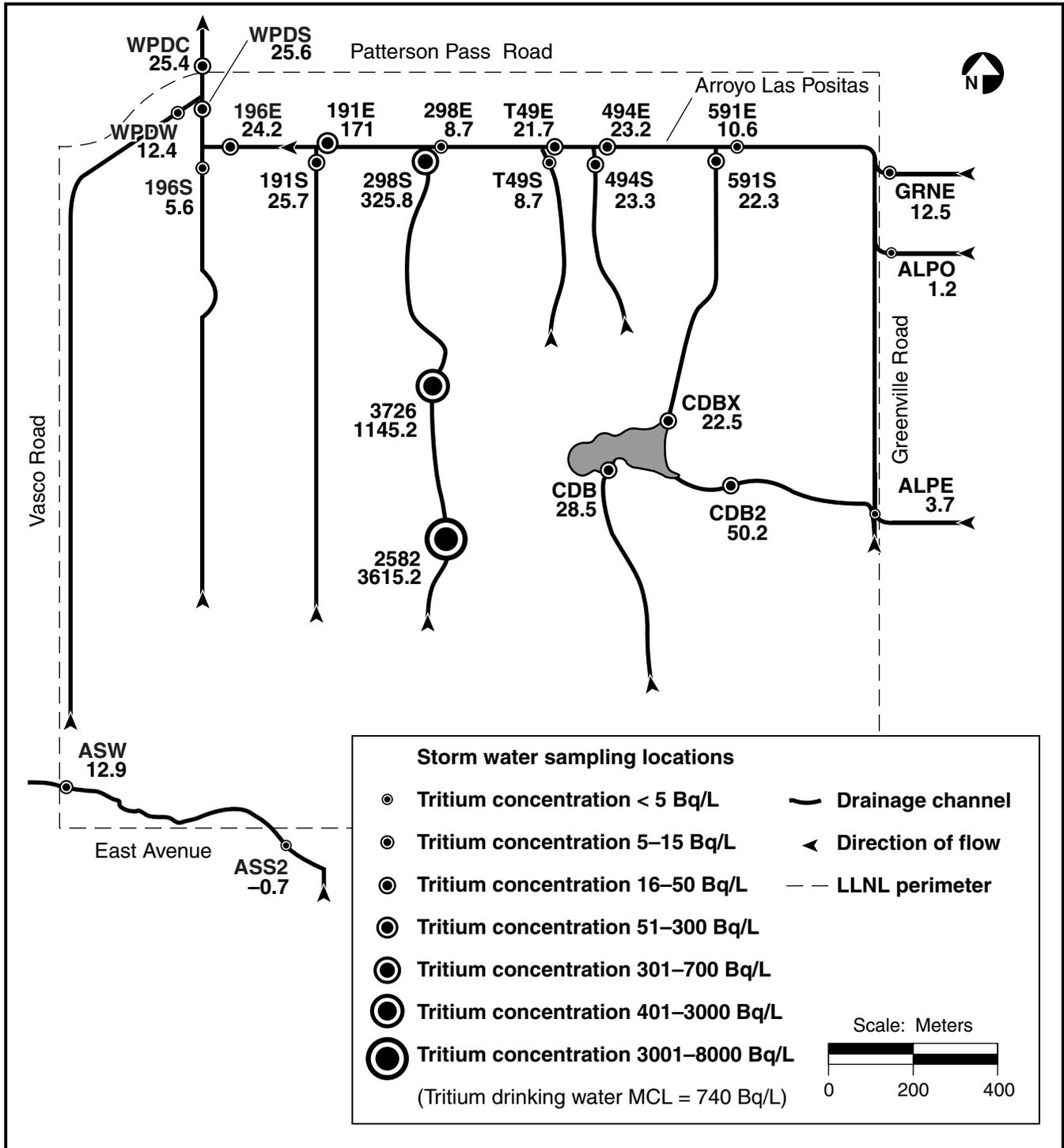


Figure 7-7. Median tritium concentrations in storm water runoff at the Livermore site, 1999.



of 1999 runoff. The only plutonium detected in 1999 was in the filtrate from the November 8 sample from location WPDC (4.22×10^{-4} Bq/g of plutonium-239+240). This value is comparable to plutonium-239+240 levels routinely seen in sediments at the location and is below the background level (4.44×10^{-4} Bq/g) for sediments. This background concentration reflects worldwide fallout and naturally occurring concentrations (see Chapter 10). Thus, there is no evidence in the data to indicate that LLNL has contributed plutonium to runoff. Complete plutonium results are found in Data Supplement Table 7-4.

Livermore Site Nonradioactive Constituents

Sample results were compared to the criteria in Table 7-1 of the Data Supplement. Of greatest concern are the constituents that exceeded 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, therefore, further investigation is not warranted. Constituents that exceeded comparison criteria, and for which effluent concentrations were higher than influent concentrations, are listed in **Table 7-4**. All the constituents identified by this screening process were metals, which were attributed to naturally occurring concentrations transported in sediments during a previous 2-year study (Brandstetter 1999). Furthermore, nearly half of the high effluent values occurred in Arroyo Seco on January 26; on this date, effluent total suspended solids (TSS) concentration was nearly three times higher than influent TSS concentration, indicating that the source is runoff-borne sediments. Under the requirements of WDR 99-086, LLNL will perform an analysis of Arroyo Seco and develop a management plan that includes a proposal to stabilize the channel and banks. Zinc was the only constituent identified by the screening process for other storm water sampling events. Complete storm water results for nonradioactive constituents are presented in Data Supplement Tables 7-5, 7-6, and 7-7.

Site 300 Sampling

LLNL procedures specify sampling of a minimum of two storms per rainy season from Site 300. Typically, a single storm will not produce runoff at all Site 300 locations because Site 300 receives relatively little rainfall and is largely undeveloped. Therefore, at many locations, a series of large storms is required to saturate the ground before runoff occurs. In 1999, samples were collected at locations with flow on February 9 and April 8. There was no detectable tritium in Site 300 storm water during 1999. The maximum of all effluent and downstream gross alpha and gross beta results were 0.37 and 0.48 Bq/L, respectively, approximately 65% and 25% of their MCLs (0.56 and 1.85 Bq/L). Upstream (location CARW) gross alpha and gross beta activities ranged as



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high as 3.7 and 5.1 Bq/L, respectively. A previous study (Harrach et al. 1996) demonstrated a relationship in Site 300 runoff between naturally occurring isotopes in suspended solids, and gross alpha and gross beta. TSS concentrations in the 1999 CARW samples are consistent with the results of that study, indicating that the high gross alpha and gross beta are from natural sources. Complete data results are in Data Supplement Table 7-8.

Table 7-4. Nonradioactive constituents above comparison criteria in storm water runoff, Livermore site, 1999.

Metal (mg/L)	Requested analysis	Storm date	Arroyo Seco			
			Influent ASS2		Effluent ASW	
			Dissolved	Total	Dissolved	Total
Aluminum	GENMIN	1/26		0.92	0.21	3.6
	NPDESMETAL			0.88	0.27	3.3
Iron	GENMIN	1/26		0.97		3.8
	NPDESMETAL			0.95		3.7
Manganese	GENMIN	1/26				0.074
	NPDESMETAL					0.073
Zinc	GENMIN	1/26		0.081		0.098
	NPDESMETAL			0.078		0.097
	GENMIN	2/8		0.077	0.042	0.085
	NPDESMETAL			0.074	0.04	0.08
	NPDESMETAL	4/8	0.058		0.062	

Metal (mg/L)	Requested analysis	Storm date	Arroyo Los Positas							
			Influent						Effluent	
			ALPE		ALPO		GRNE		WPDC	
			Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Zinc	GENMIN	1/20							0.055	
	NPDESMETAL								0.058	
	GENMIN	2/8				0.047		0.083		0.086
	GENMIN	4/8		0.033		0.096		0.07		0.013
	NPDESMETAL				0.088	0.034	0.079	0.046	0.097	



Tables 7-9, 7-10, and 7-11 in the Data Supplement list results for nonradioactive constituents in Site 300 storm water runoff. Because of a CERCLA remedial investigation finding of past releases of polychlorinated biphenyls (PCBs) and dioxins related to activities in the vicinity of Building 850, analysis for PCBs and dioxins was conducted at location NLIN, the storm water sampling location downstream of Building 850. The intent of the sampling was to determine whether these constituents are being released from the site in storm water runoff. PCBs, dioxins, and furans were detected at low levels (maximum of 2800 pg/L, or 2.8×10^{-6} mg/L); all concentrations were below MCLs and other comparison criteria.

Sampling at Pit 6 includes analyses required as part of the post-closure sampling (Table 7-11 in the Data Supplement). All post-closure sample results were below comparison criteria.

Specific conductance and TSS at Site 300 locations were at times above comparison criteria (see Table 7-1 in the Data Supplement); however, effluent levels were lower than levels at the upstream location (CARW), indicating that the levels observed in effluent are typical for the area. Results for pH were below the MCL and AWQC minimum (6.5) at location IV883 in both storm events sampled (6.04 and 6.1). All other Site 300 results were below comparison criteria.

Rainfall

This section discusses general information about rainfall in the Livermore site, Livermore Valley, and Site 300, as well as methods for sampling rainfall and the sampling results.

General Information

Livermore Site and Livermore Valley

Historically, the tritium activity measured in rainfall in the Livermore Valley resulted primarily from atmospheric emissions of HTO from stacks at LLNL's Tritium Facility (Building 331), and Sandia National Laboratories/California's (Sandia/California) former Tritium Research Laboratory. The Building 343 rain sampling location is near the Tritium Facility (Building 331). The total measured atmospheric emission of HTO from LLNL facilities in 1999 was 7.9 TBq, equal to 214 Ci (see Chapter 4).



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The rain sampling station locations are shown on **Figure 7-8**. The fixed stations are positioned to record the maximum activity expected down to background levels.

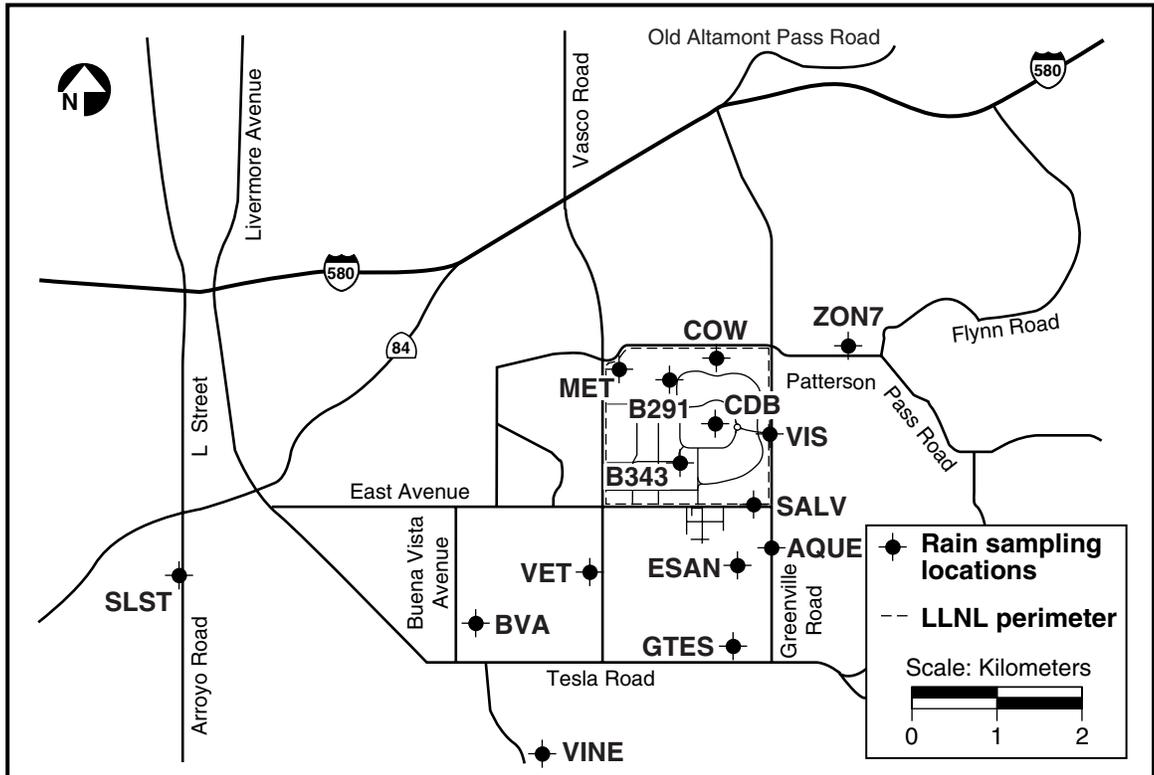


Figure 7-8. Rain sampling locations, Livermore site and Livermore Valley, 1999.

Site 300

One central location (COMP) is used to collect rainfall for tritium activity measurements at Site 300 (**Figure 7-3**). Rainfall is composited (i.e., added together) for each month and analyzed when there is sufficient volume.

Methods

Rainfall is sampled for tritium according to written procedures, described in Appendix B of the *Environmental Monitoring Plan* (Tate et al. 1999) and summarized here. Rainfall is collected in stainless steel buckets mounted about 1 m above the ground at specified



locations. Samples are decanted into 500-mL argon-flushed amber glass bottles with Teflon-lined lids and analyzed for tritium.

Results

Livermore Site and Livermore Valley

LLNL collected rainfall samples four times in 1999. Complete data are shown in Table 7-12 of the Data Supplement. The Livermore site rainfall has exhibited elevated tritium activities in the past (Gallegos et al. 1994). During 1999, measurements of tritium activity in rainfall were all below the 740 Bq/L MCL established by the EPA for drinking water. The highest overall activity was 540 Bq/L (see **Table 7-5**), measured on March 23, 1999, near Building 343, just to the north of the on-site Tritium Facility. This value is approximately 73% of the MCL for tritium. The highest off-site activity was 30.7 Bq/L, recorded in a sample collected from station ZON7 on February 10, 1999.

Table 7-5. Tritium activities in rainfall for the Livermore site and Livermore Valley, 1999.

	Livermore site (Bq/L)	Livermore Valley (Bq/L)
Maximum	540 ± 11	30.7 ± 3.2
Minimum	-5.11 ± 2.16	-7.33 ± 2.00
Median	19.0	2.53
Interquartile range	71.1	9.39
Number of samples	28	30

Similar to tritium concentrations in storm water, the concentrations of tritium in rain generally increased during the course of the wet season. The highest tritium concentration was measured in March. On March 29, when the Building 331 (the Tritium Facility) pump/glove box was repaired, the concentrations of tritium in rain were reduced. The highest tritium concentration (540 Bq/L) observed during 1999 was in a rain sample collected on March 23, compared to 154 Bq/L in a rain sample collected on April 9.

The median tritium activity measured in rainfall on site at LLNL increased from 5.59 Bq/L (151 pCi/L) in 1998 to 19.0 Bq/L (514 pCi/L) in 1999. However, median tritium activity measured in rainfall on site at LLNL remains decreased since 1990, down from 65.9 Bq/L (1780 pCi/L) to 19.0 Bq/L (514 pCi/L). This decrease mirrors the downward trend in total HTO emissions from LLNL's Tritium Facility and the closure of Sandia/California's former Tritium Research Laboratory. The increase in tritium activity



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in rainfall from 1998 to 1999 follows an increase in tritium emissions from LLNL's Tritium Facility from 4 TBq in 1998 to 10 TBq in 1999. These trends are shown in **Figure 7-9**. Rainfall will be sampled at additional locations and at an increased frequency in 2000 in order to understand the pattern of tritium activity in rainfall samples.

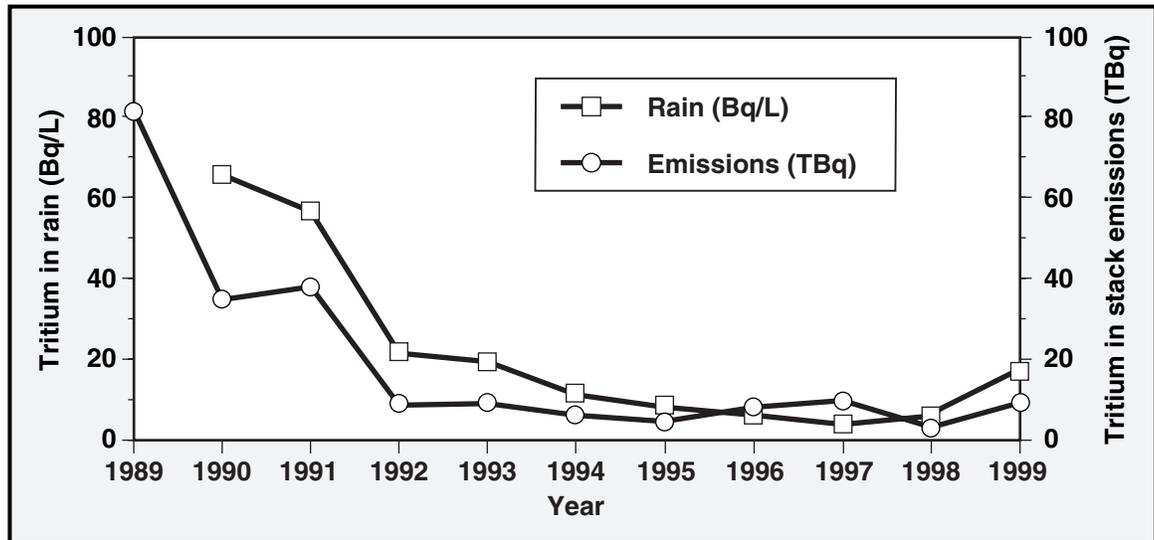


Figure 7-9. Trends of median tritium activity in rain and total stack emissions of HTO from the Livermore site and Sandia/California, 1989–1999. Emissions from 1996–1999 are from LLNL only.

Values for median tritium activity shown in **Figure 7-9** are derived from the six on-site rain sampling locations (Building 343, Building 291, CDB, SALV, VIS, and COW) that historically have given the highest activities. A decrease in total HTO emissions has occurred since 1990, down from 34.9 TBq (943 Ci) to 8.1 TBq (220 Ci).

Site 300

During 1999, Site 300 rain samples were analyzed for January, February, March, and April, with tritium activities of -5.74 ± 1.49 , 0.241 ± 1.88 , -1.45 ± 1.27 , and 1.01 ± 2.70 Bq/L, (-155 ± 40.4 , 6.52 ± 50.8 , -39.1 ± 34.3 , and 27.4 ± 73.1 pCi/L), respectively. These values are all below the minimum detectable activity.

Livermore Site Drainage Retention Basin

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



General Information

Previous environmental reports detail the history of the construction and management of the DRB (see Harrach et al. 1995–1997). In 1997, LLNL began to discharge treated ground water routinely to the DRB. In 1999, discharges from Treatment Facility D, Treatment Facility E, and related portable treatment units continued to be a year-round source of water entering the DRB. Wet weather flows into the DRB are still dominated by storm water runoff, but dry weather discharges from the treatment facilities now constitute a substantial portion of the total water entering and exiting the DRB.

The SFBRWQCB regulates discharges from the DRB within the context of the Livermore site CERCLA *Record of Decision* (U.S. Department of Energy 1993), as modified by the *Explanation of Significant Differences for Metals Discharge Limits at the Lawrence Livermore National Laboratory Livermore Site* (Berg 1997a). The CERCLA Record of Decision establishes discharge limits for all remedial activities at the Livermore site to meet applicable, relevant, and appropriate requirements derived from the Federal Clean Water Act, the Federal and State Safe Drinking Water Acts, and the California Porter-Cologne Water Quality Act.

The DRB sampling program implements requirements established by the SFBRWQCB and modified in 1997 (Galles 1997a). The program consists of monitoring wet and dry weather releases for compliance with discharge limits, and monitoring internal DRB water quality to support management actions, characterize water quality before its release, and perform routine reporting.

LLNL samples DRB discharges (at location CDBX) and the corresponding site outfall (at location WPDC) during the first release of the rainy season, and from a minimum of one additional storm (chosen in conjunction with storm water runoff sampling). During the dry season, samples are collected from each discrete discharge event. Discharge sampling locations CDBX and WPDC are shown in **Figure 7-2**. Samples are collected at CDBX to determine compliance with discharge limits. Sampling at WPDC is done to identify any change in water quality as DRB discharges travel through the LLNL storm water drainage system and leave the site. Sampling frequencies for CDBX and WPDC and effluent limits for discharges from the DRB, applied at CDBX, are found in Table 7-13 of the Data Supplement.

The routine management constituents, management action levels, and the monitoring frequency that apply to water contained in the DRB are identified in Data Supplement Table 7-14. Sampling to determine whether water quality management objectives are met is conducted at several points within the DRB. Dissolved oxygen content and temperature are measured at eight locations (**Figure 7-10**). Because of limited variability



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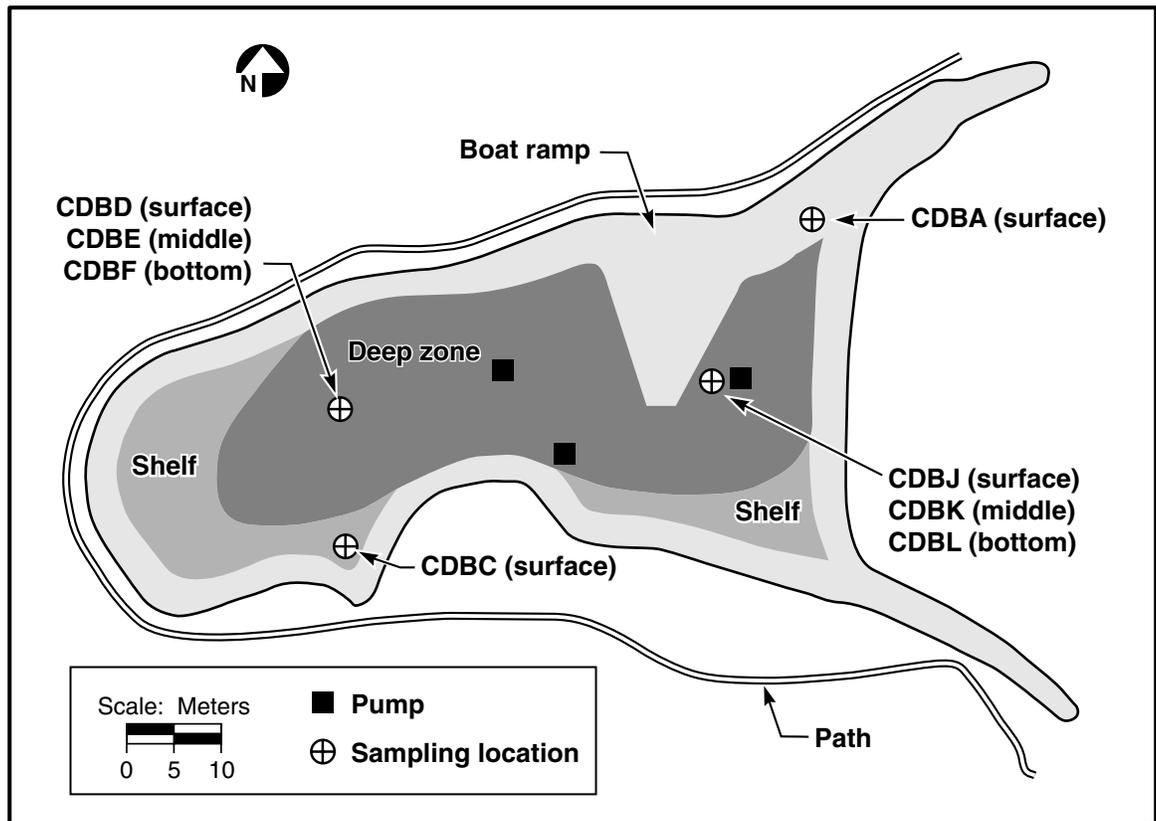


Figure 7-10. Sampling locations within the Drainage Retention Basin, 1999.

among sampling locations, all samples are routinely collected from sample location CDBE. CDBE is located at the middle depth of the DRB. 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 1997a). 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 1997a) (wet season December 1 through March 31, dry season April 1 through November 30).

Every quarter LLNL submits a report summarizing weekly, monthly, quarterly, semiannual, and annual monitoring of the basin to the SFBRWQCB. The *Drainage Retention Basin Management Plan* (DRB Management Plan) (Limnion Corporation 1991) identifies biological and microbiological surveys that are to be used as the primary means to assess the long-range environmental impact of the DRB. LLNL monitors plant and animal species at the DRB, the drainage channels discharging into the DRB, and downstream portions of Arroyo Las Positas. These surveys are conducted semiannually to identify the presence or absence of species. Surveys include amphibians, birds, fishes,



and mammals. Plant surveys are also done in the spring and the fall. During 1999, LLNL lacked resources to conduct the microbiological surveys but continued the biological surveys.

Methods

Sample collection procedures are discussed in Appendix B of the *Environmental Monitoring Plan* (Tate et al. 1999). All samples from the DRB are collected as grab samples. Field measurements for dissolved oxygen and temperature are made using a dissolved oxygen/temperature meter. Turbidity is measured using a Secchi disk. Certified laboratories analyze the collected samples. Flow measurements were not made during 1999.

Biological and microbiological methods are discussed in detail in the *Environmental Monitoring Plan* (Tate et al. 1999). Biological surveys are conducted by LLNL's biologist. Animal surveys follow standard survey protocols such as *Raptor Management Techniques Manual* (Pendleton 1987), *Inventory and Monitoring of Wildlife Habitat* (Cooperrider 1986), and *Wildlife Management Techniques Manual* (Schemnitz 1980). Vegetation surveys use protocols identified in the *U.S. Army Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987).

Results

Samples collected during 1999 within the DRB at CDBE did not meet the management action levels for dissolved oxygen concentration and saturation, temperature, turbidity, nitrate (as N), total dissolved solids (TDS), total phosphorus (as P), ammonia nitrogen (as N), chemical oxygen demand, pH, specific conductance, and lead (**Table 7-6**). No action was taken to adjust nutrient levels. LLNL continued to operate the DRB circulation pumps to increase the dissolved oxygen levels. No action was taken in response to the temperature changes because the low temperatures were consistent with normal seasonal patterns.

Releases were outside the allowable pH discharge range of 6.5 to 8.5 four times (January 20, 8.77; April 8, 8.75; June 28, 8.82; and November 8, 8.52). The February 8 DRB discharge exceeded the lead discharge limit of 6.4 µg/L (7.9 µg/L) (Data Supplement Table 7-15).



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Table 7-6. Summary of Drainage Retention Basin monitoring exceeding management action levels at sampling location CDBE.

Parameter	Management action level	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Field dissolved oxygen (mg/L) ^(a)	> 5	-	-	-	-	-	-	-	-	4.5	4.9	-	-
Oxygen saturation (%) ^(a)	< 80% saturation	-	78	-	-	70	72	-	64	52	51	66	65
Temperature (°C) ^(a)	<15.6 and >26.7	8.7	10.4	12.6	13	-	-	-	-	-	-	13.6	9.7
Turbidity (meters) ^(a)	<0.91	0.57	0.43	0.52	0.77	0.61	0.45	0.26	0.381	0.50	0.57	0.51	0.4826
Nitrate (as N)	> 0.2	1.7	1.2	0.57	-	0.33	0.77	1.2	0.59	0.49	1.2	2	1.9
pH	< 6.0 and > 9.0	9.09	-	9.24	9.08	9.13	9.06	-	-	-	-	-	-
Specific conductance (µmho/cm)	> 900	910	-	-	-	-	1000	1180	1160	1200	1210	1210	1100
Total dissolved solids (TDS) (mg/L)	> 360	510	457	372	414	435	600	745	680	695	700	735	653
Total phosphorus (as P) (mg/L)	> 0.02	0.08	0.12	0.17	0.1	0.21	0.21	0.21	0.12	0.14	0.14	0.13	0.1
Ammonia nitrogen (as N) (mg/L)	> 0.1	-	-	-	-	0.22	-	-	-	0.14	-	-	-
Chemical oxygen demand (mg/L)	> 20	-	-	-	46	-	-	-	27	-	-	-	-
Lead (mg/L) ^(b)	Wet season > 0.0064	-	0.0093	-	-	-	-	-	-	-	-	-	-

^a Monthly average

^b Wet-season management action level applies from April 1 through November 30.

Data for maintenance and release monitoring at sampling locations CDBA, CDBC, CDBD, CDBE, CDBF, CDBJ, CDBK, CDBL, CDBX, and WPDC and from the biological survey are presented in Tables 7-15 through 7-20 in the Data Supplement.

Chemical and Physical Monitoring

Surface water dissolved oxygen concentration monthly averages were at or above the management action level of at least 80% saturation of oxygen during all but 3 months. Middle depth samples monthly averages indicated that dissolved oxygen was below 80% saturation during 6 months, while the bottom depths samples were below 80% saturation in all but 2 months. (Figure 7-11). Dissolved oxygen concentrations can be manually increased using aeration pumps. These pumps are started whenever oxygen concentrations at any level of the DRB drop close to or below the critical management action level of 5 mg/L. In 1999, all three pumps operated continuously. During the colder

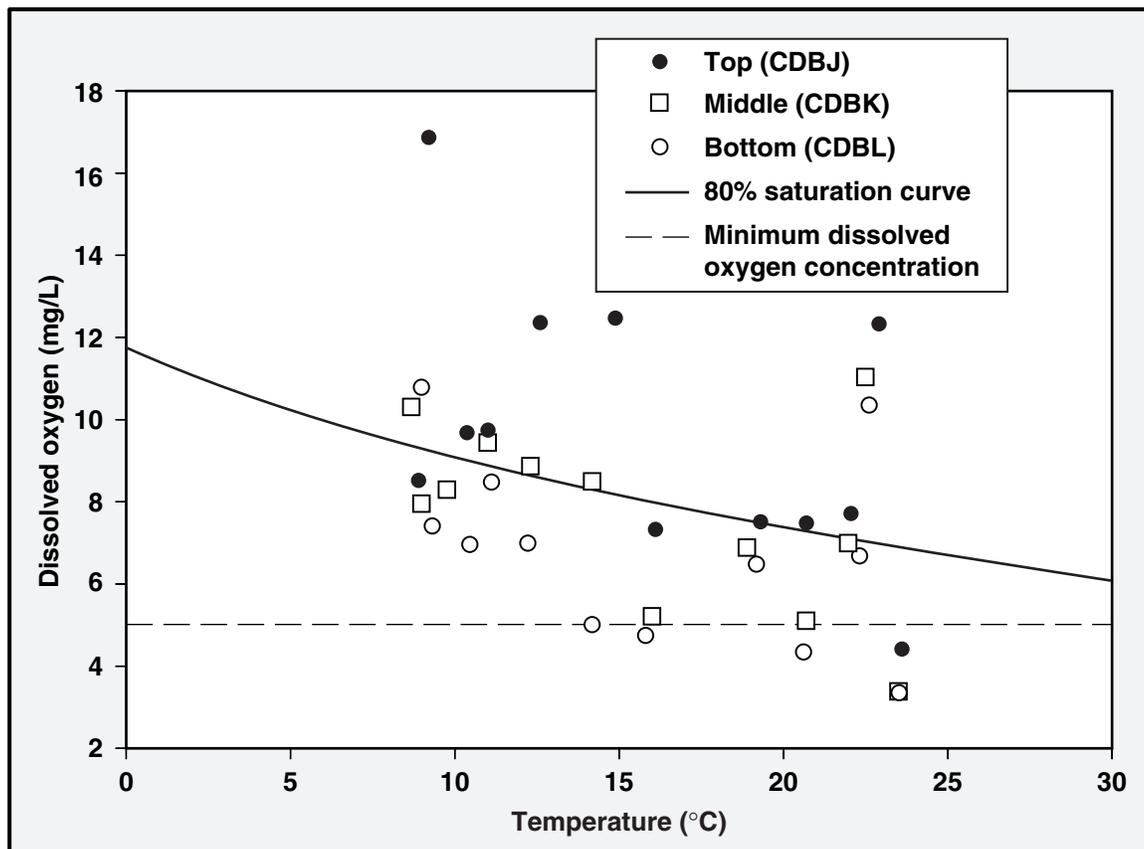


Figure 7-11. Monthly average dissolved oxygen vs temperature at each depth location in the Drainage Retention Basin, 1999.

winter months when the water has an increased capacity to contain oxygen, the dissolved oxygen levels were consistently above 5 mg/L. Dissolved oxygen concentrations at the surface, middle, and bottom elevations continued to differ during 1999 (**Figure 7-12**). Temperature, the other important parameter in determining how much oxygen is dissolved in water, showed characteristic seasonal trends (**Figure 7-13**). The uniform distribution of temperature in the top, middle, and bottom elevations reflects that the aerators were providing uniform physical mixing of the water.

Chemical oxygen demand was above management action levels during the second and third quarters of 1999. Chlorophyll-a had one winter and one summer peak. The elevated pH levels correspond to the period of the winter peak and may be associated with an occurrence of increased photosynthesis. The elevated pH within the DRB was reflected in the elevated pH during releases. The chlorophyll-a levels can be used as an indicator of alga population and of the duration and intensity of alga blooms.



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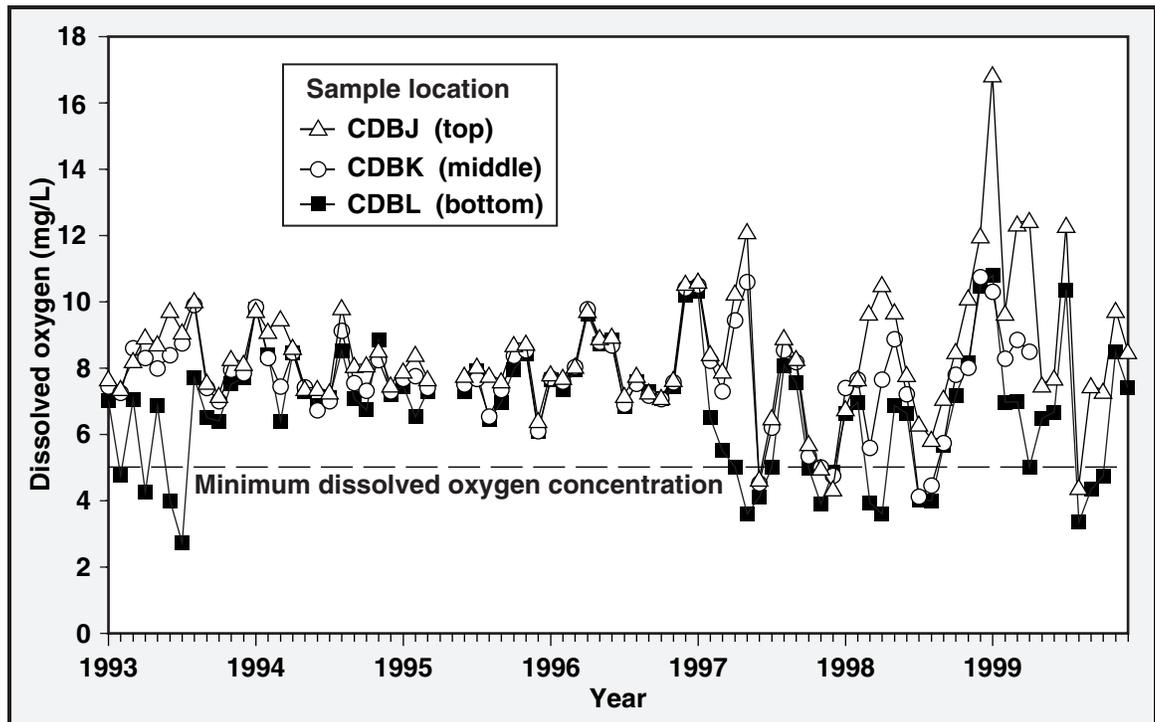


Figure 7-12. Monthly average dissolved oxygen concentration variations from the beginning of Drainage Retention Basin operations.

Turbidity rose above acceptable management levels during the 1993/1994 wet season and, through 1999, remained above the turbidity management action level. Wet season turbidity probably results from sediments that pass through the sediment traps discharging into the DRB. Turbidity seen during the warmer summer months is most likely the result of alga growth (Harrach et al. 1996). Turbidity is also caused by the operation of the aerators resuspending sediments and preventing smaller particles from settling. Lead exceeded the management action level at sample locations CDBE and CDBX during February.

Nutrient levels continued to be high during 1999. Nitrate and total phosphorous concentrations were well above management action levels throughout the year. Nitrate exceeded management action levels for all but one month of the year, while phosphorous exceeded management action levels every month. Sources of nitrate and phosphorous include storm water runoff and treated ground water discharges. In addition, ammonia exceeded the management action level during 2 months of the year. Ammonia formation is normally an indication of anoxic conditions. During 1999, total dissolved solids continued to exceed the management action levels with the concentration exceeding

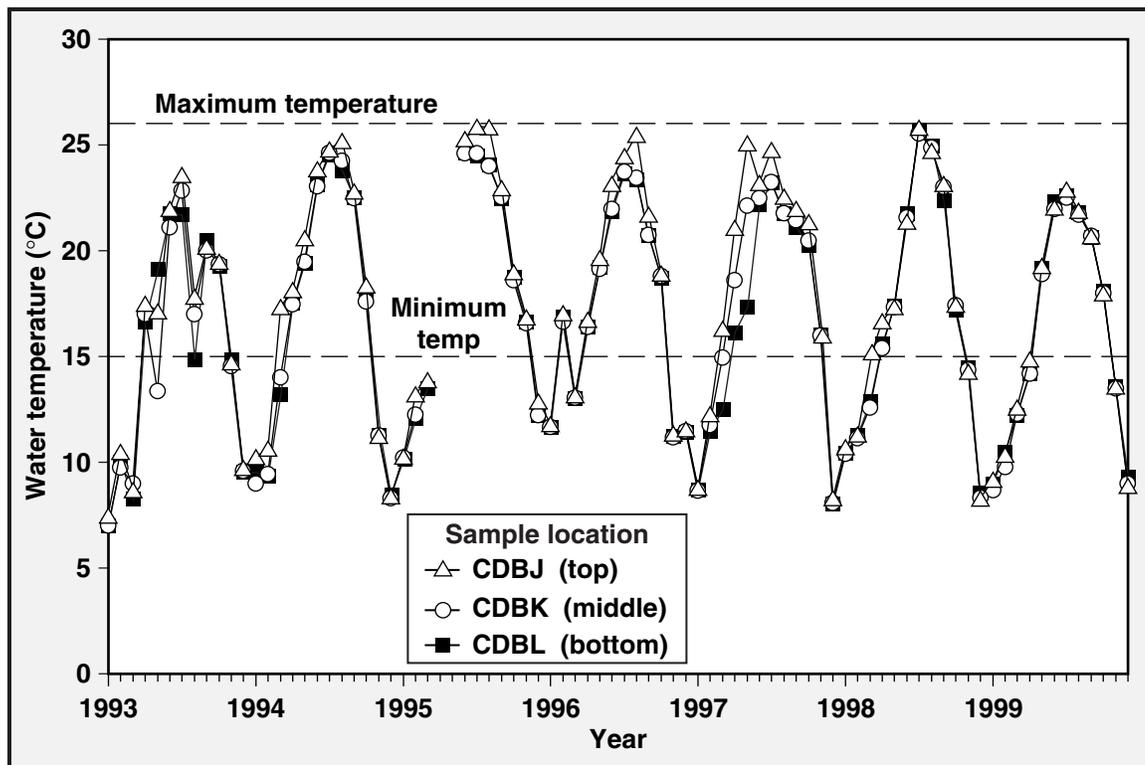


Figure 7-13. Monthly average seasonal temperature variation measured at sample top, middle, and bottom levels from the start of operations in 1993.

360 mg/L in all 12 months. Related to the increase in total dissolved solids is the increase seen in specific conductance. Specific conductance exceeded the management action level of 900 $\mu\text{mho}/\text{cm}$ for 8 months.

Biological Monitoring

Biological monitoring has not been conducted long enough to identify any trends resulting from operation of the DRB. However, biological monitoring has shown an expansion in the wetland areas in Arroyo Las Positas as a result of the continuous discharges of water from the DRB and other sources of treated ground water throughout the dry season. The California red-legged frog (*Rana aurora draytonii*), a federally listed threatened species, was found in Arroyo Las Positas, the DRB, and in the southwestern DRB tributary (upstream from sample location CDB). A number of other species routinely use the DRB and are listed in Data Supplement Table 7-20.



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Site 300 Cooling Towers

This section discusses general information about the Site 300 cooling towers, sampling methods, and sampling results.

General Information

LLNL samples cooling tower wastewater discharges as required by the Self-Monitoring Program of WDR 94-131, NPDES Permit No. CA0081396, and reports the results of the compliance sampling to the CVRWQCB quarterly.

Two primary cooling towers, located at Buildings 801 and 836A, regularly discharge to surface water drainage courses. The remaining 13 secondary cooling towers routinely discharge to percolation pits under a waiver of Waste Discharge Requirements from the CVRWQCB. Cooling tower locations are shown in **Figure 7-14**. (The Building 815 secondary cooling tower was removed from service in 1999.) The permit establishes separate effluent limits for the regular discharges from the primary cooling towers and secondary cooling towers that discharge only occasionally to surface water drainage courses. One secondary cooling tower discharged to a surface water drainage course in 1999.

Blowdown flow is monitored biweekly from the cooling towers located at Buildings 801 and 836A. TDS and pH are monitored quarterly at both locations.

Methods

Sample collection procedures are discussed in Appendix B of the *Environmental Monitoring Plan* (Tate et al. 1999) and summarized here. To determine the effects of the cooling tower blowdown on Corral Hollow Creek, the permit requires quarterly pH monitoring of the creek, both upstream (background) and downstream of the cooling tower discharges, whenever the creek is flowing. CARW is the upstream sampling location, and GEOCRK is the downstream sampling location (**Figure 7-14**). The GEOCRK sampling location is also fed by discharges of treated ground water from LLNL. Therefore, even when the upstream location is dry, there is often flow at GEOCRK. Field pH measurements, taken by LLNL technicians using calibrated meters, are used to monitor Corral Hollow Creek. These technicians also perform the required visual observations that are recorded on the field tracking forms along with the field pH measurements.

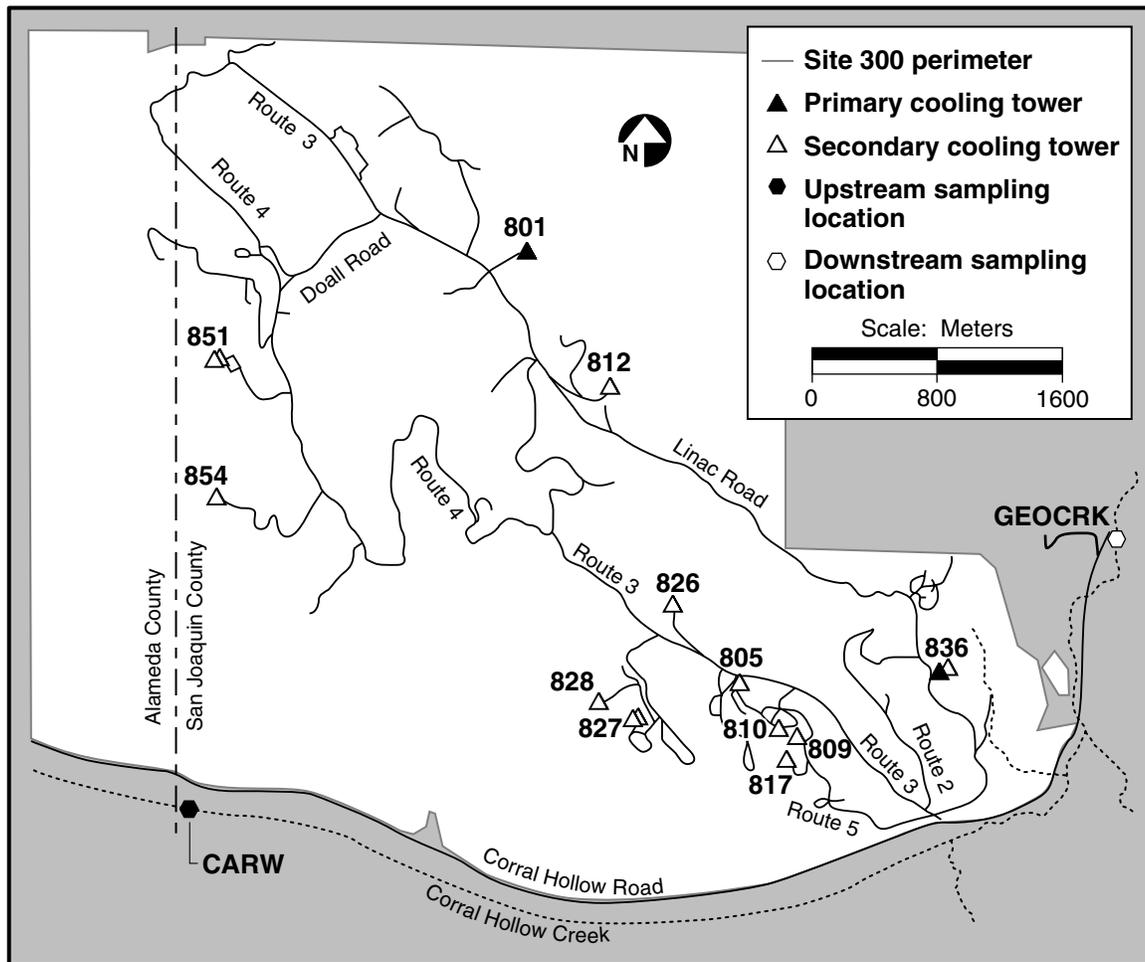


Figure 7-14. Cooling tower locations and receiving water monitoring locations, Site 300, 1999.

LLNL maintenance staff take operational TDS and pH measurements biweekly, using calibrated meters. LLNL reports these operational values at the request of CVRWQCB, but they are not used to determine compliance.

If the blowdown flow from one 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.



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Results

Biweekly and quarterly monitoring results are detailed in the quarterly self-monitoring report to the CVRWQCB. Summary data from primary cooling tower compliance monitoring and operational monitoring are found in **Tables 7-7** and **7-8**, respectively.

Table 7-7. Summary data from compliance monitoring of primary cooling towers, Site 300, 1999.

Test	Tower no.	Permitted maximum	Minimum	Maximum	Median	Interquartile range	Number of samples
Total dissolved solids (TDS) (mg/L) ^(a)	801	2,400	1,200	1,700	1,300	— ^(b)	3
	836A	2,400	1,200	1,500	1,200	— ^(b)	3
Flow (L/day)	801	16,276	1,802	9,886	6,227	2,981	26
	836A	8,138	0	29,166	1,464	1,968	26
pH (pH units)	801	10	8.5	9.0	8.6	— ^(b)	3
	836A	10	8.3	8.9	8.5	— ^(b)	3

^a Fourth quarter samples were inadvertently omitted. Samples collected 1/7/00 resulted in the following: 8.5 pH units, 1300 mg/L TDS at 801; 8.3 pH units, 1200 mg/L TDS at 836A.

^b Not enough data points to determine.

Table 7-8. Summary data from operational monitoring of primary cooling towers, Site 300, 1999.

Test	Tower no.	Permitted maximum	Minimum	Maximum	Median	Interquartile range	Number of samples
Total dissolved solids (TDS) (mg/L)	801	2400	1050	1450	1200	188	26
	836A	2400	700	2000	1100	150	26
pH (pH units)	801	10	8.8	9.1	9.0	0.1	26
	836A	10	8.6	9.1	9.0	0.1	26

All pH samples collected from the cooling tower discharges were below the permitted maximum of 10. All TDS concentrations were below both the daily maximum (2400 mg/L) and monthly average (2000 mg/L) limits. Fourth quarter samples were inadvertently omitted. Samples collected January 7, 2000, and the November 8, 1999, operational values, indicate fourth quarter compliance. These monitoring results demonstrate that cooling tower discharges were consistently in compliance with permitted limits (**Tables 7-7** and **7-8**).

Blowdown flow was below the maximum permitted design flow for 1999 with one exception. On July 7, 1999, blowdown from the Building 836A cooling tower exceeded the maximum permitted design flow of 8138 liters per day by 21,029 liters per day. By



the next scheduled measurement on July 21, blowdown flow was 1382 liters per day, well below permitted design flow. Operational flow measurements taken on July 5 (2593 liters per day) and July 19 (2120 liters per day) demonstrated normal blowdown flow. High blowdown flow was attributed to a stuck solenoid on the blowdown valve, which has since been replaced.

First quarter pH samples collected on February 3 measured a pH of 8.63 at CARW and 8.60 at the downstream GEOCRK location. Although these values are slightly over the 8.5 pH limit, biweekly flow monitoring data show that there was no discharge from the Building 836A cooling tower that day. Additionally, observations of the drainage courses leading from both the Building 801 and Building 836A cooling towers on February 3 were dry at approximately 500 yards downstream and 200 yards downstream, respectively. This indicates that the flow did not reach Corral Hollow Creek and, therefore, was not responsible for the elevated pH value in the creek.

Second quarter pH monitoring was done on April 28, 1999. The pH was 8.59 at CARW and 8.62 at GEOCRK. On May 25, flow was observed only at GEOCRK; the pH was 8.62. Although these values are slightly above the 8.5 pH limit, it is unlikely that the cooling tower blowdown caused the pH elevation in the receiving water because the flow can only reach Corral Hollow Creek if there is significant rain, and there was no significant rain during the second quarter. Previous studies have shown that the maximum blowdown rate from the cooling towers at Buildings 801 and 836A percolates into the ground before reaching Corral Hollow Creek (Fisher 1993 and Folks 1999).

During the third quarter, flow was observed only at GEOCRK. This downstream flow was sampled on August 4; the resulting pH was 8.56. As with the second quarter samples, this is slightly above the 8.5 pH limit; however, there was no rain during the third quarter.

During the fourth quarter, flow was observed only at GEOCRK, but samples were inadvertently omitted during this timeframe. As soon as the omission was noted, samples were collected even though the monitoring period had ended. The pH at GEOCRK was 8.8 on January 7, 2000. As with the second and third quarters, this is slightly above the 8.5 pH limit. However, there was no runoff at the time of the sampling event. (The most recent rain event preceding the sampling occurred on December 8, 1999.)

Visual observations of Corral Hollow Creek were performed each quarter as required in the permit. The ambient pH did not change by more than 0.5 units, and no visible oil, grease, scum, foam, or floating suspended material was noted in the creek during 1999.



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One discharge occurred from a secondary cooling tower in 1999. The Building 827 cooling tower percolation pit overflowed on August 20, 1999, because a coating of clay had sealed the gravel layer. The flow was diverted to the surface water drainage course until the pit was repaired (August 20–September 9, 1999). As required by the permit, monitoring samples were collected immediately from both cooling towers that discharge to that pit. Permit limits for the secondary cooling towers are as follows: TDS must not exceed a monthly average of 2000 mg/L or 5000 mg/L daily, pH must not exceed 10, and flow must not exceed the permitted design maximum. Analytical results (1820 mg/L TDS and 8.83 pH for cooling tower 827-1; 1440 mg/L TDS and 8.7 pH for cooling tower 827-2) were below the permit limits. The September 1, 1999, flow measurements were inadvertently omitted for this location. The operational flow values for this interval demonstrate compliance. For the period ending August 30, 1999, the operational values were 4088 liters per day for cooling tower 827-1 and 1968 liters per day for cooling tower 827-2. These values are below the 11,355 liters per day maximum permitted design flow.

Other Waters

Additional surface water monitoring is required by DOE Order 5400.1, *General Environmental Protection Program*, and DOE Order 5400.5, *Radiation Protection of the Public and the Environment*. Surface and drinking water near the LLNL Livermore site and in the Livermore Valley are sampled at locations shown in **Figure 7-15**. 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. Data from drinking water sources and drinking water outlets are used to calculate drinking water statistics (see **Table 7-9**) and doses.

Methods

Samples are analyzed for gross alpha, gross beta, and tritium, according to procedures set out in Appendix B of the *Environmental Monitoring Plan* (Tate et al. 1999). LLNL sampled these locations semiannually for gross alpha, gross beta, and tritium. The on-site swimming pool (POOL) was sampled semiannually for gross alpha and gross beta, and quarterly for tritium.

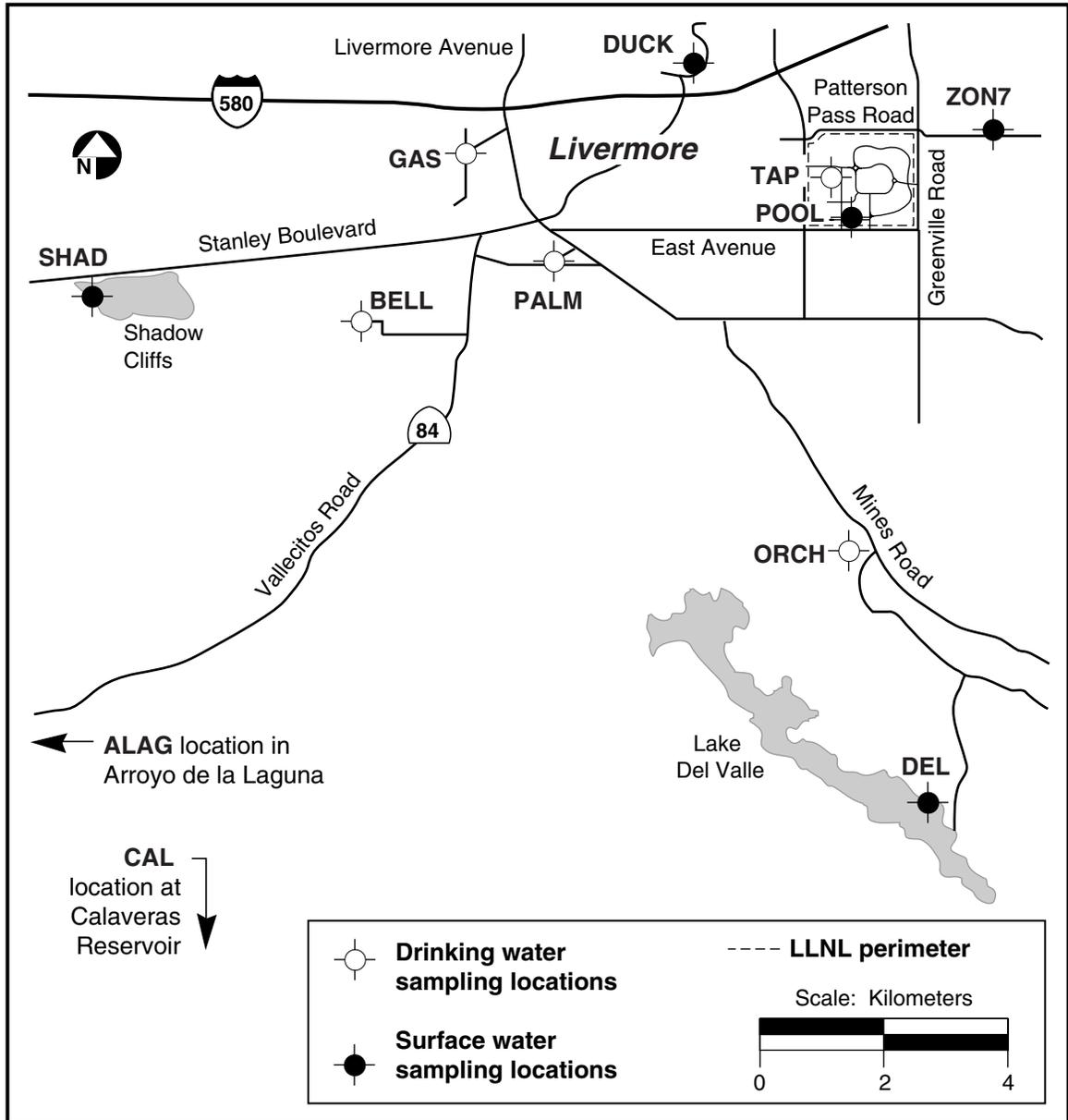


Figure 7-15. Surface and drinking water sampling locations, Livermore Valley, 1999.

Results

The median activity for tritium in surface waters was a result of nondetect; the maximum tritium activity was 1% of the MCL. Median activities for gross alpha and gross beta radiation in surface water samples were approximately 5% of the MCL.



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However, maximum activities detected for gross alpha and gross beta, respectively, were 0.374 Bq/L (10.1 pCi/L) and 0.18 Bq/L (4.9 pCi/L); both less than 10% of their respective MCLs (see **Table 7-9**). Detailed data are in Table 7-21 of the Data Supplement. Historically, gross alpha and gross beta radiation have fluctuated about the laboratory reporting limits. At these very low levels, the error measurements are nearly equal to the measured values so that no trends are apparent in the data.

Table 7-9. Radioactivity in surface and drinking water in the Livermore Valley, 1999

	Tritium (Bq/L)	Gross alpha (Bq/L)	Gross beta (Bq/L)
All locations			
Median	-1.34	0.0459	0.181
Minimum	-5.96	-0.00181	0.0353
Maximum	10.1	0.374	0.18
Interquartile range	4.84	0.0734	0.271
Drinking water locations			
Median	-3.12	0.0330	0.132
Minimum	-5.96	-0.00181	0.0353
Maximum	0.356	0.374	1.03
Interquartile range	4.55	0.0466	0.314

Environmental Impacts

This section discusses environmental impacts of storm water, rainfall, the DRB, cooling towers, and other waters.

Storm Water

The potential off-site impact of tritium was estimated by determining the effective dose equivalent (EDE). (See Appendix A for the method LLNL used to calculate dose.) Median tritium activity in storm water (runoff) effluent (location WPDC) was 19.4 Bq/L, about 3% of the MCL. The EDE to an adult who ingested 2 liters of water per day at the maximum storm water tritium concentration for 1 year would be less than 0.0003 mSv (0.03 mrem), or 0.03% of the 1 mSv DOE standard allowable dose for ingestion. Median effluent gross alpha and gross beta activities in storm water were 0.038 and 0.18 Bq/L, both less than 10% of their respective MCLs.

Concentrations of some metals were above comparison criteria; this was caused by metals associated with suspended solids in the storm water. Although some 1999 storm water



results were above criteria, there is no evidence that indicates any impact to off-site biota. The acute and chronic fish toxicity tests conducted during 1999 showed no toxicity in LLNL storm water runoff, further supporting the conclusion that LLNL storm water has no adverse effect on off-site biota.

Rainfall

Livermore Site and Livermore Valley

The environmental impact of tritium measured in rainfall samples from the Livermore site and the Livermore Valley was negligible. The median tritium activity measured in rainfall on site at LLNL increased from 5.59 Bq/L (151 pCi/L) in 1998 to 19.0 Bq/L (514 pCi/L) in 1999. However, median tritium activity measured in rainfall on site at LLNL has decreased since 1990: down from 65.9 Bq/L (1780 pCi/L) to 19.0 Bq/L (514 pCi/L). In 2000, rainfall samples will be collected at an increased frequency and at additional locations in an attempt to further understand the pattern of tritium activity observed in rainfall.

Site 300

The environmental impact of tritium measured in rainfall samples from Site 300 was negligible. The measured tritium activities of rainfall samples taken at Site 300 were all either less than the minimum detectable activity or less than the 2σ uncertainty. Over the past 27 years, 166 measurements of rainfall samples collected at this location give a maximum tritium activity of only 9.1 Bq/L. The tritium activity measured in rainfall at Site 300 has been indistinguishable from atmospheric background levels over the past 27 years.

Drainage Retention Basin

There is no evidence of adverse environmental impact resulting from releases from the DRB. Although mild toxicity was observed in the DRB and in water discharged from the DRB, there is no evidence that the discharge had an effect on the downstream receiving water. Because of the frequent dry season discharges that occurred from the DRB, discharges from ground water treatment facilities, and the wetter rainfall years that occurred from 1997 through 1999, wetland vegetation has increased both up- and downstream of the DRB. The federally listed threatened California red-legged frog has colonized these wetland areas.



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Cooling Towers

Both primary cooling towers that discharge to surface were within their permitted limits for pH and TDS. With one exception, flow from these cooling towers was below the maximum permitted design flow. Corral Hollow Creek was not flowing during the July 1999 flow excursion from the Building 836A cooling tower, and even with the higher flow, the blowdown is unlikely to have reached the creek during the hot dry weather typical of July. Thus, data indicate no negative impact to surface waters from these cooling towers. The secondary cooling tower percolation pit overflow at Building 827 was also within permitted limits, which indicates no negative impact to surface waters from this one-time event.

Because blowdown flow from the cooling towers does not reach Corral Hollow Creek, it is unlikely to have a negative impact on the receiving water. Run-off from livestock areas or natural pH variations may have a more significant impact than cooling tower blowdown.

Other Waters

The potential impact of tritium on drinking water supplies was estimated by determining the EDE (see Appendix A). Maximum tritium activity in drinking waters was 0.36 Bq/L (9.6 pCi/L). The EDE to an adult who ingested 2 liters of water per day at this maximum concentration for 1 year would be 0.000005 mSv (0.0005 mrem), or 0.013% of the DOE standard allowable dose of 0.04 mSv for drinking water systems. Gross alpha and gross beta activities were below their MCLs. The sample data indicate that the impact of LLNL Livermore site operations on surface and drinking waters is negligible.

Ground Water Investigation and Remediation

*Richard Blake
Michael Taffet*

Introduction

During 1999, ground water investigations and remediations under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) continued at both the Livermore site and Site 300. LLNL regularly samples and analyzes ground water from areas of known or suspected contamination. Portions of the two sites that contain ground water with concentrations of chemicals of concern are actively investigated to determine the magnitude of the contamination and its source. Remediation strategies are developed and evaluated in preparation for a CERCLA removal action or through the feasibility study process. An approved remedy for each study area is developed in consultation with the regulatory agencies and the community. This chapter reviews the distribution of contaminants in ground water, and the progress LLNL has made in removing contaminants from ground water and from the unsaturated zones (soil vapor) at the Livermore site and Site 300.

Livermore Site Ground Water Project

Physiographic Setting

The general topography of the Livermore site is described in Chapter 1. The Livermore Valley ground water system is a sequence of semiconfined aquifers in which ground water 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, ground water has historically flowed south into the Sunol Valley Ground Water Basin. The largest quantities of ground water are pumped from the central and western portions of the Livermore Valley, where the valley fill is thickest.

The valley fill sediments make up two aquifers: the Livermore Formation and its overlying alluvium. The Livermore Formation averages about 1000 m in thickness and occupies an area of approximately 250 km². The alluvium, which is about 100 m thick, is the principal water-producing formation within the valley.



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Hydrogeology

Sediment types at the Livermore site are grouped into four categories—clay, silt, sand, and gravel—based on dominant particle size. Ground water flow beneath the site is primarily in alluvial sand and gravel lenses and channels, bounded by the less permeable clays and silts. The alluvial sediments have been mapped into seven hydrostratigraphic units (HSUs) beneath the Livermore site using data collected over the years. HSUs can be defined as sedimentary sequences whose permeable layers show evidence of hydraulic connection. The HSUs of concern beneath the Livermore site are the Quaternary alluvial deposits of the upper Livermore member of the Livermore Formation (see **Figure 8-1**). HSUs 1B, 2, 3A, 3B, 4, and 5 contain contaminants that are primarily solvents (Blake et al. 1995 and Hoffman et al. 1998).

Remedial Activities

In 1999, the Livermore site Ground Water Project (GWP) treated more than 1100 ML of ground water, brought new treatment facilities on line, installed wells, conducted hydraulic tests, developed ground water models, published required documents, and maintained close contact with regulatory agencies and the community.

LLNL operated ground water treatment facilities and vapor treatment facilities (VTF) in the TFA, TFB, TFC, TFD, TFE, TFG, TF406, TF518, and TF5475 areas. A total of 69 ground water extraction wells operated at 20 separate locations at an average flow rate of 3.0 ML/day in 1999. A total of three vapor extraction wells operated at two separate locations at an average flow rate of 2846 m³/day. **Table 8-1** shows the volumes of ground water and soil vapor treated at the facilities and the estimated volatile organic compound (VOC) mass removed from the subsurface during 1999 and since the beginning of the remediation. A graph of VOC mass removal at the Livermore site since 1989 is presented in **Figure 8-2**. Concentrations of remaining VOCs in the fourth quarter of 1999 are depicted as concentration maps in the six HSUs in **Figures 8-3** through **8-8**.

Table 8-2 lists the extraction wells according to the hydrostratigraphic unit in which they are screened and the total flow rate for each treatment area. Together, the ground water and vapor treatment facilities removed approximately 267 kg of VOC mass in 1999. Since operations began, approximately 4247 ML of ground water and almost 0.48 million m³ of vapor have been treated, and more than 752 kg of VOCs have been removed. The VOC plumes in HSUs 1B, 2, 3A, 3B, 4, and 5 continue to be hydraulically controlled based on trends in ground water chemistry, capture zone analysis, and the total VOC isoconcentration maps (**Figures 8-3** through **8-8**) for each HSU.

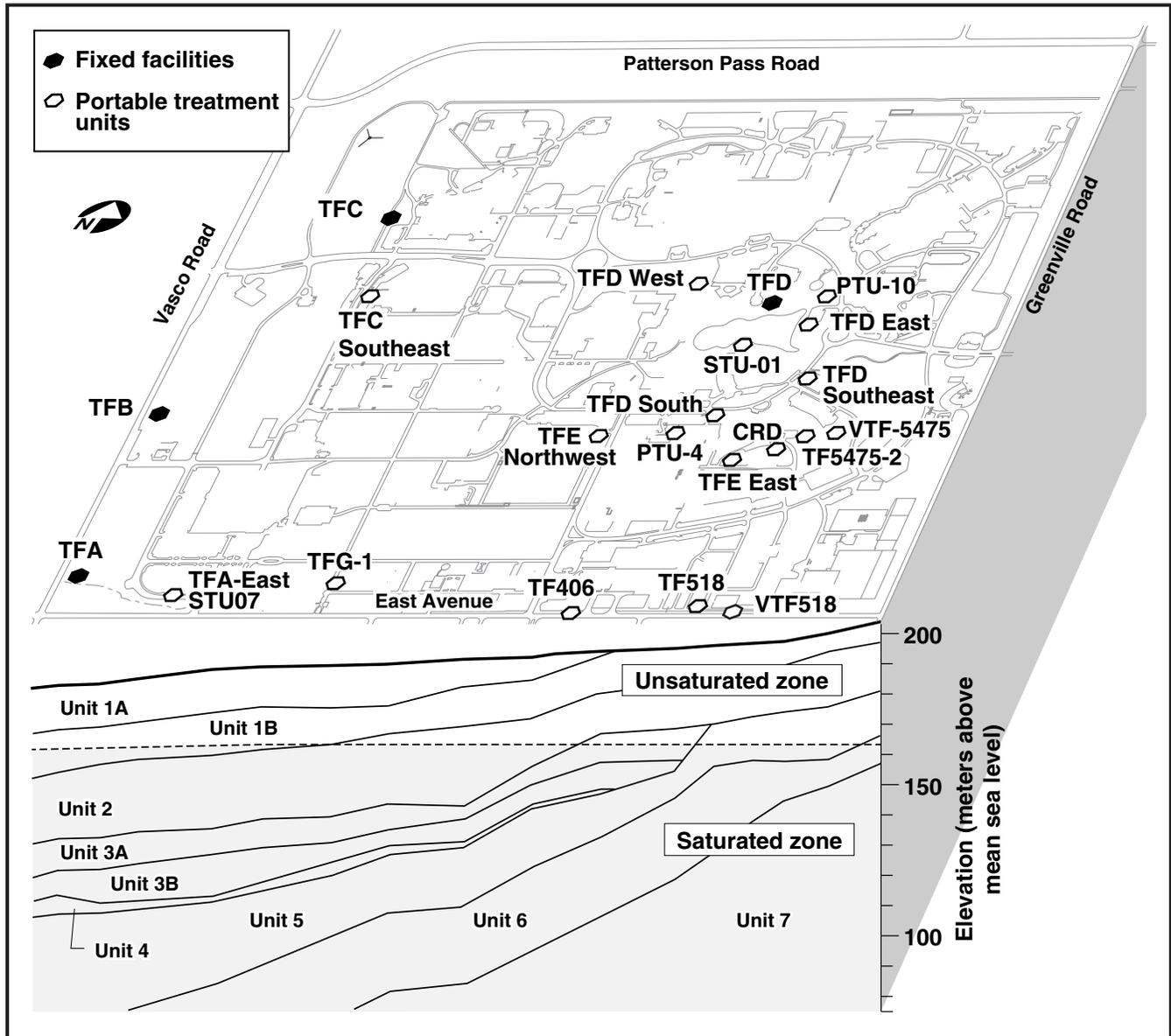


Figure 8-1. Map and cross section of the Livermore site showing hydrostratigraphic units and the locations of the treatment plants.

The numbers and locations of new wells installed in 1999 are shown in **Table 8-3**. Well construction details, well closure data, and results of drawdown tests are provided in the *LLNL Ground Water Project 1999 Annual Report* (Aarons et al. 2000).



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Table 8-1. Volatile organic compounds (VOCs) removed from ground water and soil at the Livermore site.

Treatment facility ^(a)	Startup date	1999		Cumulative total	
		Water treated (ML) ^(b)	VOCs removed (kg)	Water treated (ML) ^(b)	VOCs removed (kg)
TFA	9/89	519	14	2,468	123
TFB	10/90	114	7.6	430	38
TFC	10/93	93	9.0	316	32
TFD	9/94	226	88	696	235
TFE	11/96	108	38	201	72
TFG	4/96	10	0.6	38	1.8
TF406	8/96	28	1.0	83	4.2
TF518	1/98	3.6	0.2	14	1.2
TF5475	9/97	0.64	0.4	0.76	2.3
Total		1,102	159	4,247	510
		Soil vapor treated (m ³)	VOCs removed (kg)	Soil vapor treated (m ³)	VOCs removed (kg)
VTF518 ^(c)	9/95	101,834	13.1	418,258	147
VTF5475 ^(c)	1/99	59,274	94.9	59,274	95
Total		161,108	108	477,531	242

^a Includes fixed and portable units.

^b ML = 1 million liters.

^c Vapor extraction facility.

Treatment Facility A

Treatment Facility A (TFA) is a fixed facility that is located in the southwestern quadrant of the Livermore site near Vasco Road and East Avenue (**Figure 8-1**). Ground water is treated using the large-capacity air-stripping system that was installed in June 1997. The VOCs are stripped from the ground water, and the effluent air from the stripper is passed through granular activated carbon (GAC) filters to remove the VOCs. The treated effluent air is then vented to the atmosphere. The California Regional Water Quality Control Board (RWQCB) permits LLNL to treat up to 500 gallons per minute (gpm) of ground water. Treated ground water from TFA is discharged to the Recharge Basin, located about 600 m southeast of TFA on Department of Energy (DOE) property administered by Sandia National Laboratories/California. Since startup of the new system, TFA has not exceeded the 5 parts per billion (ppb) total VOC discharge limit.



Wells at TFA pumped at a combined flow rate of about 1150 L/min and treated 519 ML of ground water containing an estimated 14 kg of VOCs.

Treatment Facility A—East (TFA-East) began operating in September 1999. This facility consists of one extraction well operating at a flow rate of 5.6 L/min. The water is treated at a portable solar-powered treatment unit that discharges its treated water to Arroyo Seco.

One monitor well was installed in the TFA area in 1999 (see **Table 8-3**). Two other piezometer wells were installed as a part of ongoing work at the infiltration study area.

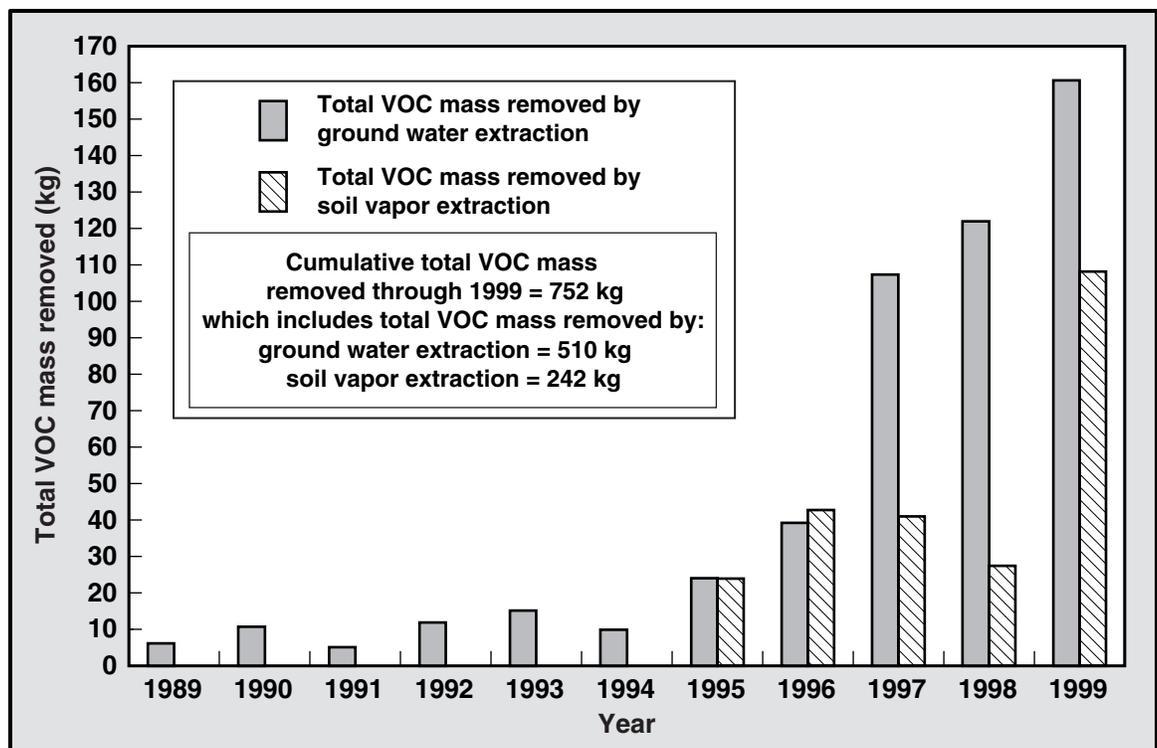


Figure 8-2. Total VOC mass removed from the subsurface of the Livermore site, 1989–1999.

Treatment Facility B

Treatment Facility B (TFB) is located in the west-central portion of the Livermore site. Ground water is treated using the large-capacity air-stripping system that was installed in October 1998. This unit replaced an ultraviolet/hydrogen peroxide (UV/H₂O₂) system that had been in use since 1990. Ground water is also treated for chromium(VI) in an ion-exchange unit during the winter months, based on the current RWQCB



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discharge substantive requirements. Wells at TFB pumped at a combined flow rate of about 287 L/min, and treated about 114 ML of ground water containing an estimated 7.6 kg of VOCs. Treated ground water from TFB is discharged into the north-flowing drainage ditch parallel to Vasco Road that empties into Arroyo Las Positas to the north. TFB was in compliance throughout 1999. No new wells were installed at TFB during 1999 (Table 8-3).

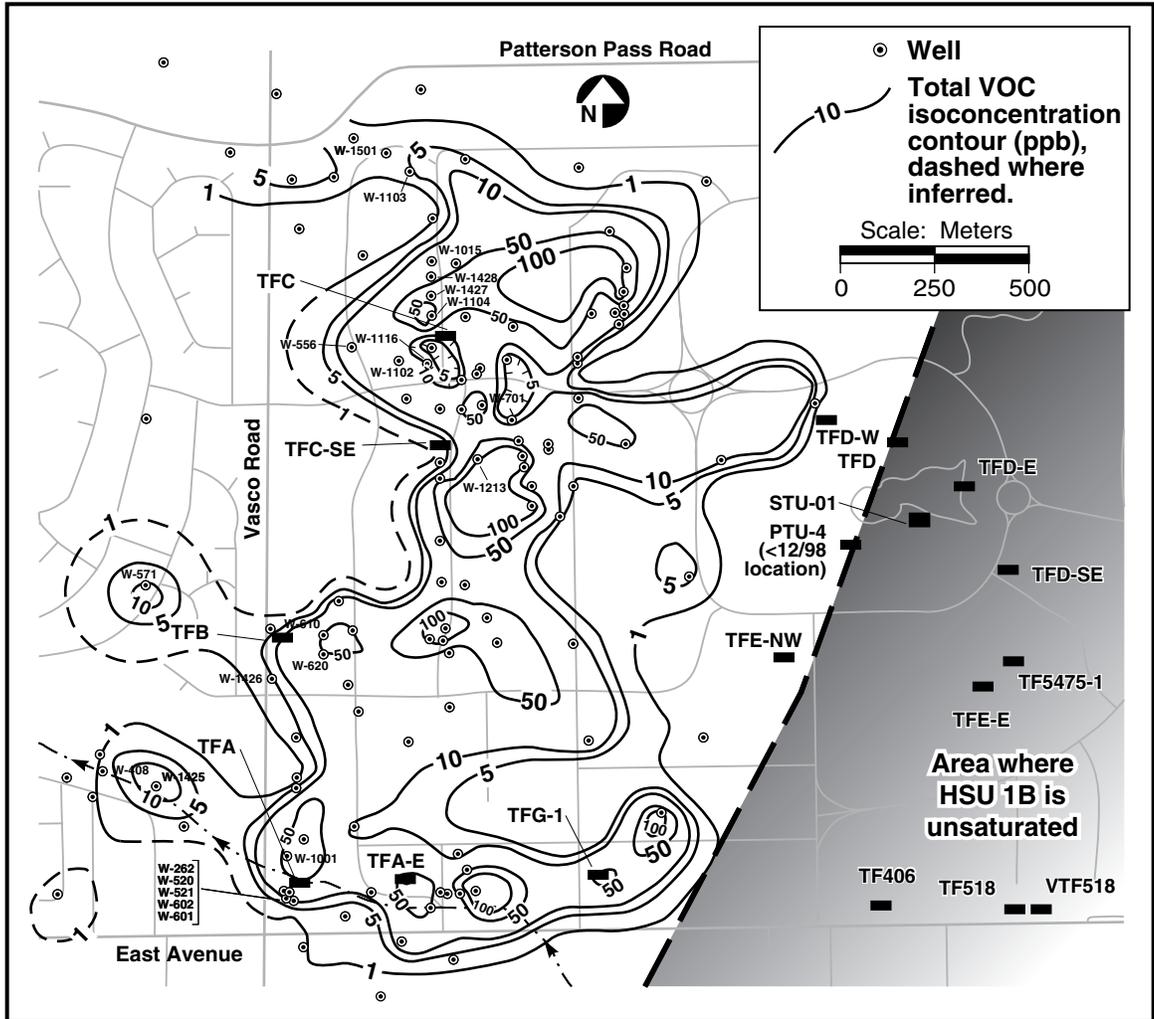


Figure 8-3. Isoconcentration contour map of total VOCs within HSU 1B.

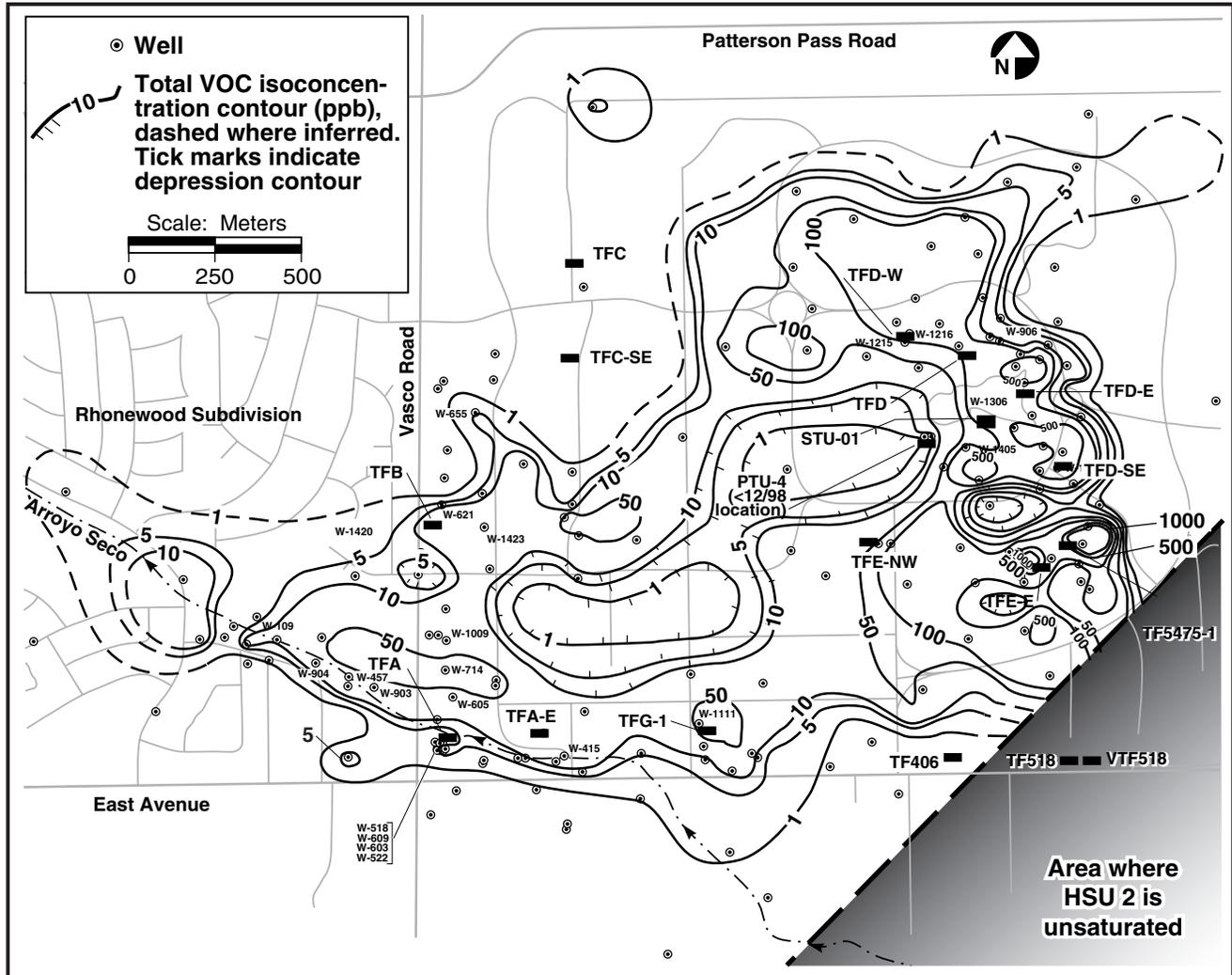


Figure 8-4. Isoconcentration contour map of total VOCs within HSU 2.

Treatment Facility C

Treatment Facility C (TFC) is located in the northwest quadrant of the Livermore site (Figure 8-1). Portable Treatment Unit (PTU) location TFC Southeast (TFC-SE), located near the intersection of Avenue A and Sixth Street in the northwest quadrant of the Livermore site, treats ground water from one HSU 1B well (W-1213). The combined TFC facilities operated at an average flow rate of 212 L/min in 1999. TFC and TFC-SE process VOCs in ground water using air stripping. The effluent air from the stripper is treated with granular activated carbon prior to discharge to the atmosphere. Ground water is treated for chromium(VI) in an ion-exchange unit during the winter months, in order to meet the current RWQCB discharge substantive requirements. Wells in the TFC



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area pumped at a combined flow rate of about 212 L/min and treated about 93 ML of ground water containing an estimated 9.0 kg of VOCs. Treated ground water from TFC is discharged into Arroyo Las Positas. Treated ground water from TFC-SE is discharged into a north-flowing drainage ditch that empties into Arroyo Las Positas to the north. The TFC effluent chromium(VI) concentration was 32 ppb in February 1999, above the wet season discharge limit of 22 ppb. The ion exchange unit was regenerated and subsequent samples were below the chromium(VI) discharge limit through the end of 1999. TFC-SE was in compliance with all permits throughout 1999. No new wells were installed at TFC during 1999 (Table 8-3).

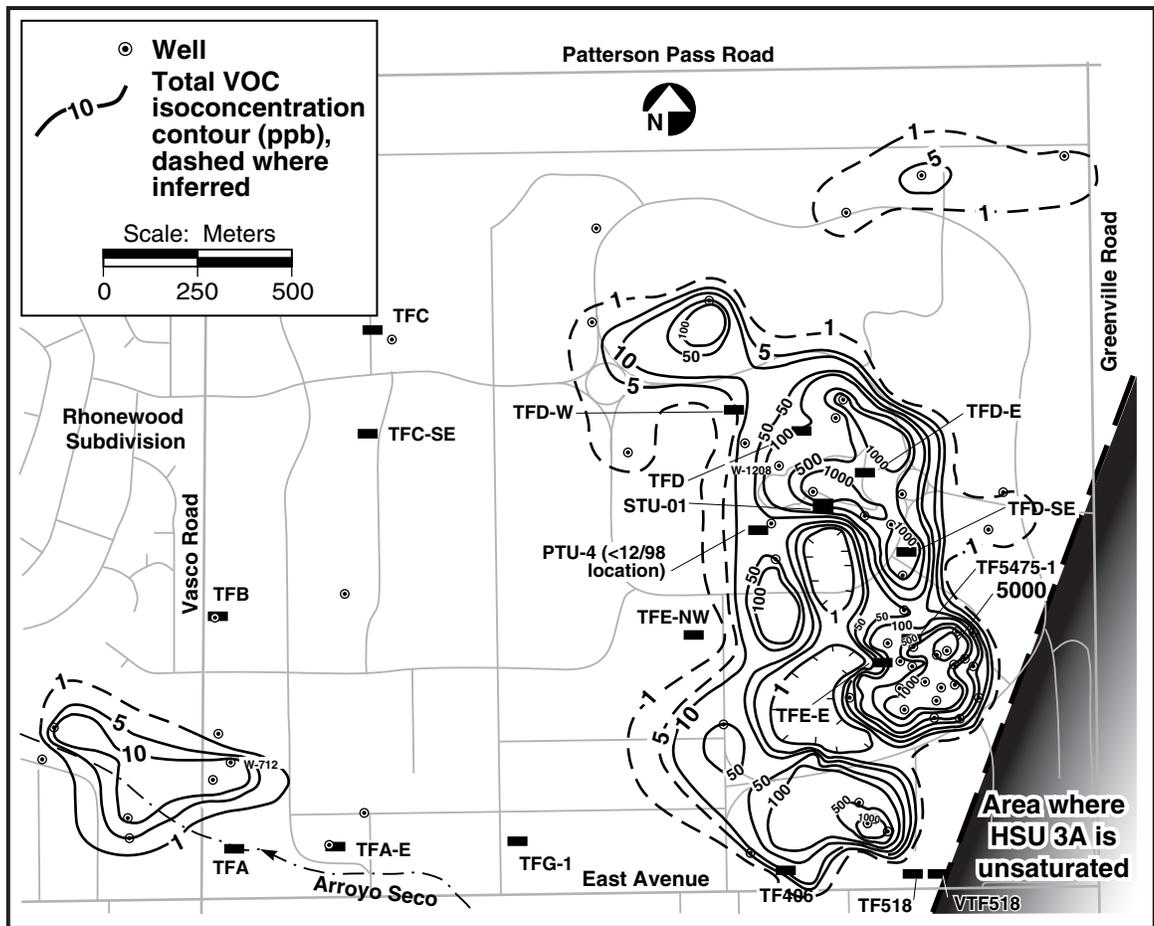


Figure 8-5. Isoconcentration contour map of total VOCs within HSU 3A.

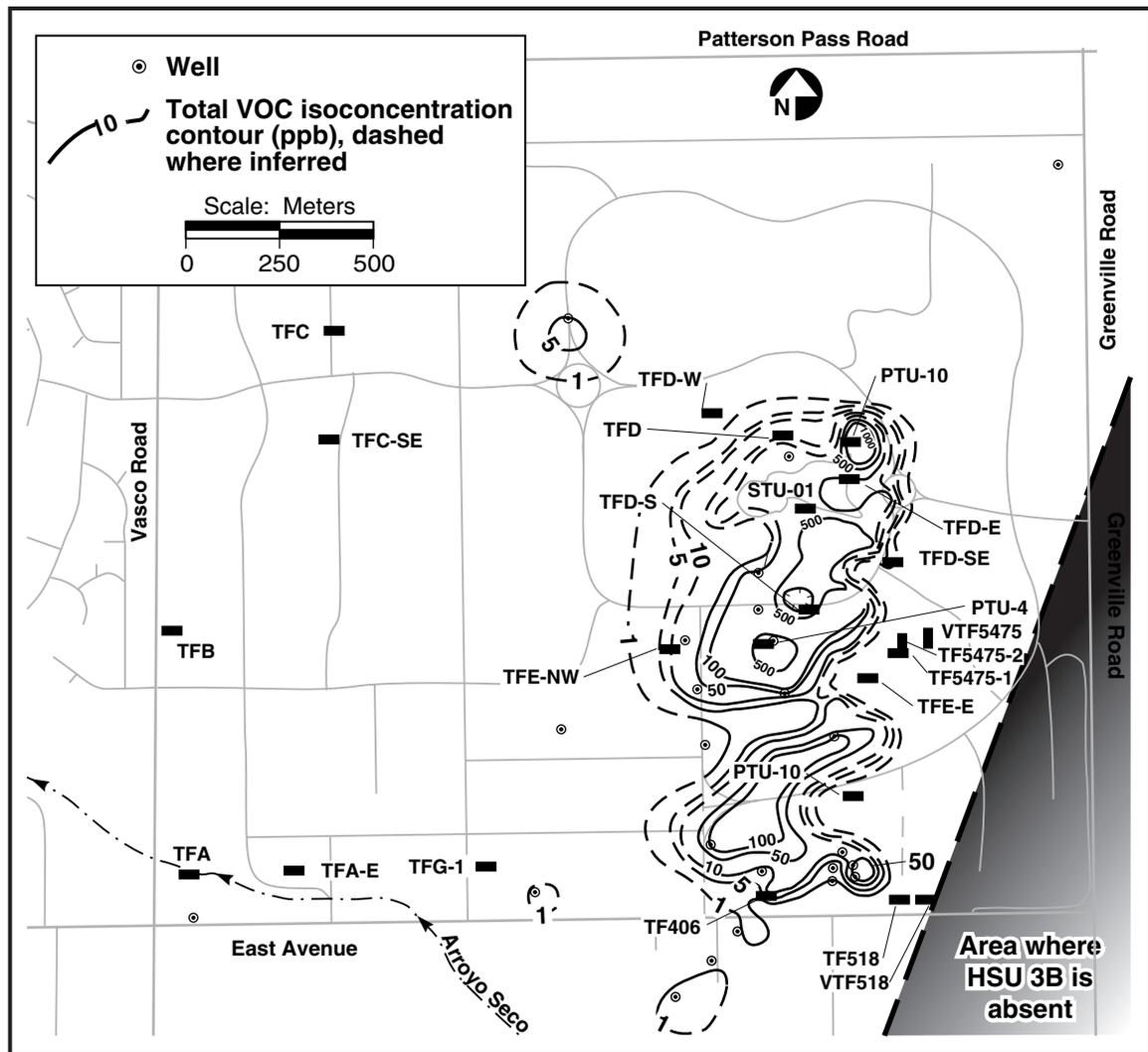


Figure 8-6. Isoconcentration contour map of total VOCs within HSU 3B.

Treatment Facility D

The Treatment Facility D (TFD) area is located in the northeast quadrant of the Livermore site (see **Figure 8-1**). Treatment facilities operating in this area include TFD; portable treatment units (PTUs) operating at TFD-East (TFD-E), TFD-West (TFD-W), TFD-South (TFD-S), TFD-Southeast (TFD-SE); and a solar-treatment unit (STU) operating along the south side of the Drainage Retention Basin (DRB). The combined TFD facilities operated at an average flow rate of 484–590 L/min in 1999. During 1999, these units treated about 226 ML of ground water containing an estimated 88 kg of VOCs. The STU contributed about 1.9 ML of ground water containing an estimated 2.5 kg of VOCs of that total.

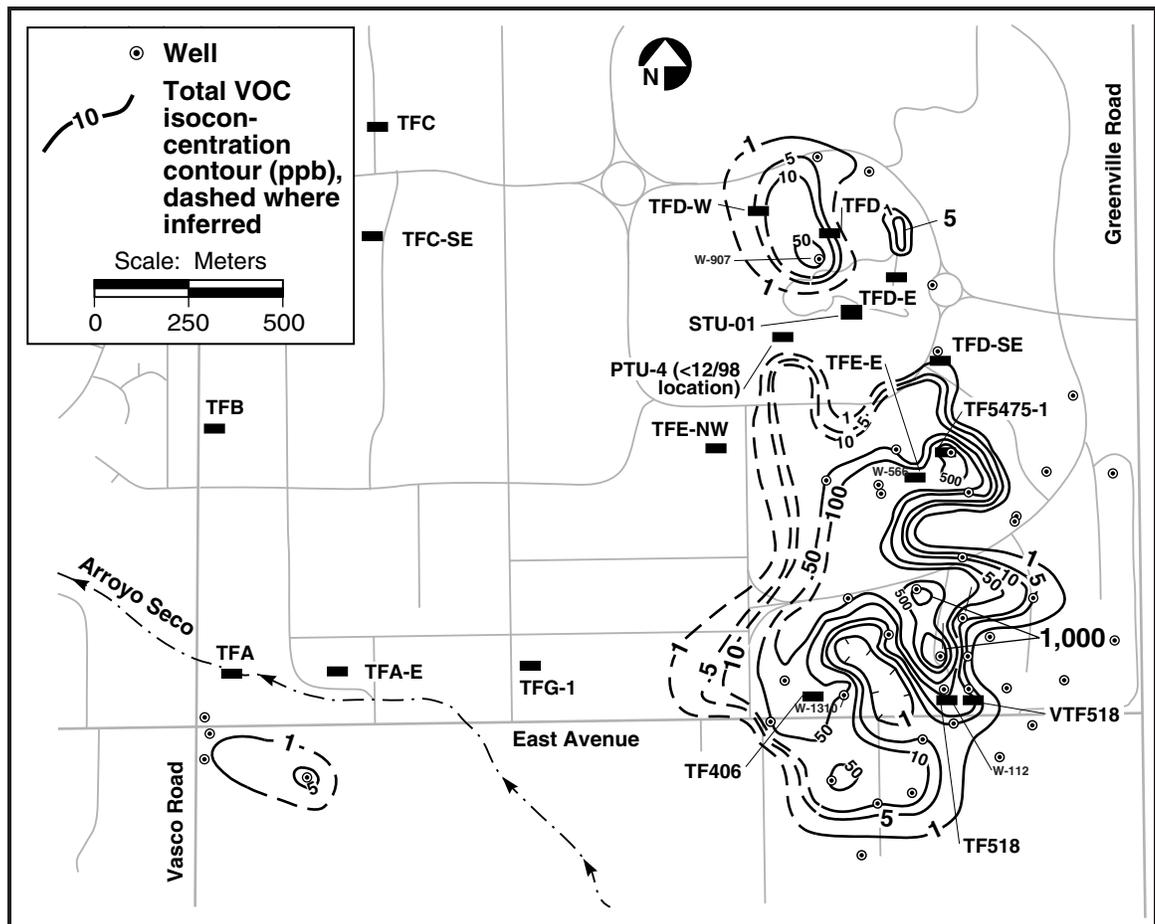


Figure 8-8. Isoconcentration contour map of total VOCs within HSU 5.

The TFD area extraction wells hydraulically control VOCs in HSUs 2, 3A, 3B, 4, and 5. Distal VOC plumes in the western TFD area should be hydraulically controlled once planned TFC-E and TFC-NE treatment facilities are operating, scheduled for June 2002 and May 2003, respectively.

Eleven new monitoring or remediation wells were installed and three new source investigation boreholes were drilled in the TFD area during 1999. Two of those three boreholes were completed as piezometer wells.

In 1999, one-hour drawdown tests were conducted on TFD area wells W-1502, W-1503, W-1504, W-1510, and W-1550 (Aarons 2000).



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Table 8-2. 1999 extraction wells and extraction rates.

Treatment facility area	Hydrostratigraphic unit	Extraction wells	Extraction rate (gpm) ^(a)
TFA	HSU 1B	W-262, W-408, W-520, W-601, W-602, W-1001, W-1004	220–312
	HSU 2	W-109, W-415, W-457, W-518, W-520, W-603, W-605, W-609, W-614, W-714, W-903, W-904, W-1009	
	HSU 3A	W-712	
TFB	HSU 1B	W-610, W-620, W-704	39–81
	HSU 2	W-357, W-621, W-655, W-1423	
TFC	HSU 1B	W-701, W-1015, W-1102, W-1103, W-1104, W-1116, W-1213	54–66
TFD	HSU 2	W-906, W-1215, W-1216, W-1303, W-1306, W-1308, W-1510	128–156
	HSU 3A	W-361, W-1208, W-1301	
	HSU3A/3B	W-1504, W-1551, W-1552	
	HSU 4	W-351, W-1206, W-1307, W-1503, W-314	
	HSU 5	W-907	
TFE	HSU 2	W-1109, W-1409	59–65
	HSU3	W-1422	
	HSU4	W-1211, W-1418	
	HSU 5	W-359, W-566	
TF406	HSU 4	GSW-445, W-1309	9–19
	HSU 5	W-1310	
TFG	HSU 2	W-1111	3.6–8
TF5475	HSU 2	W-1415	1–2.6
	HSU 3A	W-1302	
TF518	HSU 5	W-112	1–5
VTF518		SVI-518-201, SVI-518-303	18 –50 (scfm) ^(b)
VTF5475		SVI-ETS-504	20 (scfm)
	1999 Total		514-714 38-70 (scfm)

^a gpm = Gallons per minute.

^b scfm = Standard cubic feet per minute.

**Table 8-3.** Wells installed in 1999.

Treatment facility area	Hydrostratigraphic unit	Monitoring/extraction wells
TFA	HSU 1B	W-1509, SIP-INF-301, SIP-INF-302
TFB		None
TFC		None
TFD	HSU 2	SIP-ETC-301, SIP-ETC-303, W-1510, W-1512, W-1602
	HSU 3A	W-1603
	HSU 3B	W-1511, W-1601
	HSU 3A/3B	W-1550, W-1551, W-1552, W-1553
	HSU 4	W-1523
TFE	HSU 2	W-1506, W-1517, W-1518, SIP-ETS-601, W-1508
	HSU 3B	W-1522
	HSU 4	W-1505, W-1520
	HSU 5	W-1507, W-1516
TFG		None
TF406	HSU 3A/3B	W-1513, W-1514, W-1515
	HSU 5	W-1519
TF518		None
TF5475	HSU 4	W-1604

In 1999, wells at TFD pumped at a combined flow rate of about 518 L/min and treated about 226 ML of ground water containing an estimated 88 kg of VOCs. An additional PTU operated at wells W-1551 and W-1552 from September to December 1999 in the TFD-E area to expedite VOC mass removal and site cleanup near the TFD source area. Wells W-1551 and W-1552 pumped at a combined flow rate of about 17 L/min, and treated about 2.1 ML of ground water containing an estimated 14 kg of VOCs, which is included in the facility annual total.

Treatment Facility E

The Treatment Facility E (TFE) area is located in the southeastern quadrant of the Livermore site (**Figure 8-1**). In 1999, TFE East (TFE-E) continued treating ground water using a PTU. TFE-E is located in the east-central portion of the Livermore site. TFE-NW treats ground water from extraction wells in HSU 2 and HSU 4 and is located south of the Inner Loop Road, immediately west of Southgate Drive. TFE-E and TFE-NW



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process ground water for treatment of VOCs using an air stripper, and the effluent air is treated using granular activated carbon to remove VOCs before it is vented to the atmosphere. Treated ground water from TFE-E is discharged into a drainage ditch that flows north into the DRB. Treated ground water from TFE-NW is discharged into a storm drain that flows north into Arroyo Las Positas. TFE-E and TFE-NW were in compliance throughout 1999.

In the TFE area, the TFE-E extraction wells provide hydraulic containment of some portions of VOC plumes in HSUs 2, 4, and 5. The VOC plumes in HSUs 3A, 4, and 5, located in the western and southern TFE areas, should be hydraulically controlled once the TFE-SW, TFE-SE, and TFE-W treatment facilities are operating. The planned start-up dates for these treatment facilities are June 2000, and January and April 2001, respectively.

In 1999, wells at TFE pumped at a combined flow rate of about 227 L/min and treated about 108 ML of ground water containing an estimated 38 kg of VOCs. An additional PTU operated at wells W-1418 and W-1422 from January to December 1999 in the TFE area to expedite VOC mass removal and site cleanup. Wells W-1418 and W-1422 pumped at a combined flow rate of about 49 L/min and treated about 24.5 ML of ground water containing an estimated 13 kg of VOCs, which is included in the facility annual total.

Ten new wells were installed in the TFE area during 1999. Also, two additional PTUs operated in the TFE area during 1999. PTU-4 continued to operate at wells W-1418 (HSU 4) and W-1422 (HSU 3B) in the northern part of the TFE area to expedite VOC mass removal and site cleanup.

PTU-10 operated at TFE-SE extraction well W-359 (HSU 5) from March to June 1999. During 1999, well W-359 pumped at an average flow rate of about 37 L/min, and PTU-10 treated about 4.9 ML of ground water containing an estimated 2.9 kg of VOCs, which is included in the facility annual total.

Treatment Facility G

Treatment Facility G (TFG) is located in the south-central portion of the Livermore site (**Figure 8-1**). Treatment Facility G-1 (TFG-1) is located near Avenue B, about 90 m north of East Avenue. TFG-1 treats ground water for VOCs and chromium(VI). Under the current RWQCB discharge substantive requirements, water from TFG-1 requires treatment for chromium(VI) only during the winter months. Treated ground water from TFG-1 is discharged to a storm drain located about 50 ft north of TFG-1, which empties into Arroyo Seco. No boreholes or wells were drilled, and no hydraulic tests were conducted in the TFG area during 1999.



Before May 1999, TFG-1 processed ground water for VOC treatment using an air stripper, and the effluent air was treated using GAC to remove VOCs before they were vented to the atmosphere. In May 1999, the PTU at TFG-1 was replaced by a GAC treatment unit (GTU). A year-long treatability study conducted in 1998 and 1999 demonstrated that the GAC treatment was effective in the efficient removal of VOCs from TFG area ground water. Three 400-lb GAC canisters in series are used to process the water from well W-1111 from HSU 2 (**Figure 8-4**). Ground water is no longer treated for chromium(VI) because concentrations from March 1997 through November 1999 had consistently been below the discharge limit of 22 ppb.

TFG-1 was in compliance with all permits from January to October 1999. The TFG-1 effluent chloroform concentrations in November and December were 6.7 and 49 ppb, respectively, exceeding the discharge limit because the GAC filters exceeded their capacity to contain contaminants. The carbon in the unit was replaced and subsequent samples were nondetect for chloroform.

Treatment Facility 406

Treatment Facility 406 (TF406) is located east of Southgate Drive near East Avenue in the south-central part of the Livermore site. TF406 treats ground water to remove VOCs using an air stripper. The effluent air is passed over granular activated carbon to remove VOCs before it is vented to the atmosphere. All treated ground water was discharged to a storm drain that flows to Arroyo Las Positas. TF406 was in compliance throughout 1999.

TF406 processed ground water from extraction wells GSW-445, W-1309, and W-1310.

Passive bioremediation to remediate fuel hydrocarbons continued in the TF406 area during 1999 in HSUs 3A and 3B. Active ground water extraction and treatment for residual dissolved fuel hydrocarbons at Treatment Facility F was discontinued in 1996 with regulatory agency concurrence (San Francisco Bay Regional Water Quality Control Board 1996).

The TF406 extraction wells provide significant hydraulic control of VOC plumes in HSUs 4 and 5 near the TF406 facility. The VOC plumes in HSUs 3A, 4, and 5 should be hydraulically controlled throughout the TF406 area once treatment facilities at TF406-NW and TF518-N are installed in January 2000 and 2002, respectively. Four new wells were drilled and completed at TF406 during 1999 (**Table 8-3**).

During 1999, TF406 operated at an average flow rate of 60 L/min, treating more than 26 ML of ground water containing an estimated 1.0 kg of VOCs (see **Table 8-2**). Since



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system startup in 1996, TF406 has treated about 28 ML of ground water and removed about 1.0 kg of VOC mass from the subsurface (see **Table 8-1**).

During 1999, DOE/LLNL began evaluating electro-osmosis for remediating VOCs in fine-grained, low-permeability sediments. The TF406 area was chosen as a test location because prior characterization indicated the presence of good candidate lithologic sequences. Initial testing was conducted to determine design parameters (e.g., electrode spacing, voltage gradients), to evaluate operational issues (e.g., control of high pH and hydrogen gas at the cathode), and to measure electrochemical properties of the soil (e.g., electrical and electro-osmotic conductivity). The results of this work will be used for subsequent analysis and modeling necessary to evaluate electro-osmosis for potential deployment at LLNL. A report summarizing the results of the qualifications phase tests was issued in December 1999 (McNab 1999).

Ground Water Treatment Facility 518

Treatment Facility 518 (TF518) is located in the southeastern quadrant of the Livermore site, north of East Avenue and near Avenue H, adjacent to VTF518 (**Figure 8-1**). TF518 was constructed in 1997 and began operating in January 1998. In 1999, TF518 treated ground water from one extraction well, W-112 (HSU 5).

Sustainable flow rates from well W-112 have decreased steadily during 1999 from about 75 L/min to about 3.8 L/min in May 1999. TF518 periodically shut down during 1999 because of lack of sustainable flow and low water level conditions within well W-112. Hydraulic data indicate that the cumulative pumping from HSU 5 wells at TF406, TFE, and TF518 has significantly lowered ground water levels in the southeastern portion of the Livermore site and reduced yields observed in well W-112.

In July 1998, MTU-1 was activated in the TF518 area, replacing the PTU that had processed ground water there since January 1998. The MTU processes ground water for VOC treatment using an air stripper, and the effluent air is treated using GAC to remove VOCs prior to venting to the atmosphere. All treated ground water is discharged to a storm drain located about 250 ft north of TF518 that empties into Arroyo Las Positas. TF518 was in compliance with all permits throughout 1999.

During 1999, TF518 operated at an average flow rate of 7.6 L/min and treated about 3.6 ML of ground water from well W-112 containing an estimated 0.2 kg of VOCs (see **Table 8-2**). Since the facility started up in January 1998, TF518 has processed more than 14 ML of ground water containing an estimated 1.2 kg of VOCs (see **Table 8-1**). No boreholes or wells were drilled in the TF518 area during 1999. A step-drawdown test was conducted on proposed TF518-N extraction well W-1410.



A two-month recovery test was conducted on HSU 5 wells in the southwestern corner of the Livermore site to evaluate the effects of dewatering by extraction and recharge in this hydrostratigraphic unit. Between July 15 and September 7, 1999, the pumps in all HSU 5 extraction wells at the Livermore Site were shut off, and the rate of ground water recovery was observed in both the extraction wells and in surrounding HSU 5 monitor wells. While the rate of recovery at extraction wells W-1310 (TF406) and W-566 (TFE-E) and adjacent observation wells performed as expected by recovering at a relatively fast rate when pumping ceased, recovery in well W-112 (TF518) and surrounding monitor wells was very slow. The cause for this apparently was a lack of available ground water in the vicinity. The impact of the dewatering on the cleanup of the TF518 area is currently being evaluated.

PTU-10 was operated at proposed TF518-N extraction well W-1410 (HSU 3B) in September 1999. During this period, well W-1410 pumped at an average flow rate of about 44 L/min, and treated about 0.49 ML of ground water containing an estimated 0.1 kg of VOCs. These data are included in the TF518 volume and mass totals, as presented in **Table 8-1**.

Vapor Treatment Facility 518

Vapor Treatment Facility 518 (VTF518) is located in the southeastern quadrant of the Livermore site. Soil vapor is extracted from the vadose zone, and VOCs are removed from the vapor using granular activated carbon canisters. Following treatment, the effluent air is discharged to the atmosphere. VTF518 was in compliance with the Bay Area Air Quality Management District (BAAQMD) permit throughout 1999.

Two instrumented membrane system (IMS) sampling/monitoring wells, SEA-518-301 and SEA-518-304, continue to monitor vadose zone remediation in the VTF518 area. The IMS system is used to collect vapor pressure, soil temperature, soil moisture, and soil vapor concentration data at various discrete depths.

During 1999, VTF518 operated at an average flow rate of 1.4 m³/min, treating about 101,952 m³ of vapor containing an estimated 13.1 kg of VOCs (see **Table 8-2**). Since system startup in 1995, VTF518 has treated about 418,258 m³ of vapor and removed about 147 kg of VOC mass from the subsurface (see **Table 8-1**).

Treatment Facility 5475

The Treatment Facility 5475 (TF5475) area is located in the east-central portion of the Livermore site where tritium and VOCs are present in HSU 3A ground water in concentrations above the MCL. TF5475-1, which was activated in September 1998, uses down-hole, in situ catalytic reductive dehalogenation (CRD) to treat VOCs in ground water.



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This technology is based upon the reaction of dissolved hydrogen on a palladium-alumina catalyst to form ethane, methane, and chloride. Because of the high CRD reaction rates, water is treated in one pass through the unit, and the treatment unit can be placed in the well casing. This technology treats VOCs in ground water while keeping the tritium in the subsurface.

The CRD unit operates in extraction well W-1302, a dual-screened well in which the unit extracts ground water from the lower screened interval and injects treated ground water containing tritium into the upper screened interval. The required destruction efficiency is 90% or higher. The unit's destruction efficiency at TF5475-1 was 80% in April because of low hydrogen supply. The hydrogen supply cell was replaced and the unit's destruction efficiency improved. TF5475-2 was in compliance throughout 1999. One new well was drilled and completed at TF5475 during 1999 (see **Table 8-3**).

TF5475-2 employs an STU that uses a direct-current- (DC-) powered pump to extract ground water and a series of aqueous-phase GAC canisters for treatment. Treated ground water from TF5475-2 is discharged into a storm sewer that flows north into the DRB, and eventually into Arroyo Las Positas. TF5475-2 was in compliance throughout 1999 although anomalous data were reported in June and July that indicated breakthrough of VOCs from the carbon. Subsequent samples from the same carbon indicated no detectable VOCs. The effluent water was collected into a storage tank until the samples were analyzed and results indicated no detectable VOCs in the effluent.

Vapor Treatment Facility 5475

Vapor Treatment Facility 5475 (VTF5475) is located on the northern side of Trailer T5475 in the east-central portion of the Livermore site, and it treats soil vapor from vadose zone well SVI-ETS-504 (see **Figure 8-1**). VTF5475 began operation on January 21, 1999, ahead of the January 29, 1999, Remedial Action Implementation Plan (RAIP) milestone date.

Soil vapor is extracted from the vadose zone using a vapor extraction system and is processed using GAC. Because of elevated tritium concentrations in the vadose zone, VTF5475 has been designed as a closed-loop system. Following removal of VOCs from the process air stream, the tritiated vapor is reinjected into the subsurface at soil vapor inlet well SVI-ETS-505. Because no effluent vapor from VTF5475 is released to the atmosphere, BAAQMD has granted the facility a letter of exemption for 24-hour operation.

Since system startup in 1999, VTF5475 has operated at an average flow rate of 0.6 m³/min and treated about 59,472 m³ of vapor containing an estimated 95 kg of VOCs (see **Table 8-2**).



Two IMS sampling/monitoring wells, SEA-ETS-506 and SEA-ETS-507, are used to monitor vadose zone remediation in the VTF5475 area. The IMS system is used to collect vapor pressure, soil temperature, soil moisture, and soil vapor concentration data from various discrete depths.

Ground Water Flow and Transport Modeling

Ground water flow and transport models are used at the Livermore site to support remediation system design and performance evaluation; to support ongoing subsurface characterization activities; and to improve LLNL's ability to forecast, monitor, and interpret the progress of the ground water remediation program. In 1999, development continued on our three-dimensional ground water model for the Livermore site. The three-dimensional model builds vertical resolution into the two-dimensional model previously developed for the Livermore site (Tompson et al. 1995).

Treatment Facility A and B Model

In 1999, LLNL continued to use the three-dimensional ground water flow and contaminant transport model of HSUs 1B and 2 to evaluate perchloroethene (PCE) and trichloroethene (TCE) transport in the TFA, TFB, TFC, and TFG areas. The development of this model is described in detail in Demir et al. (1997) and Vogele et al. (1996). This model, developed using the CFEST (Coupled Flow, Energy and Solute Transport) computer code (Gupta et al. 1987), was calibrated to measured ground water elevation data collected from Livermore site monitoring wells.

Environmental Impact

Notable results of VOC analyses of ground water received from January through December 1999 are discussed below. **Figures 8-3 through 8-8** are isoconcentration maps for total VOCs underlying the Livermore site and vicinity within HSU 1B, HSU 2, HSU 3A, HSU 3B, HSU 4, and HSU 5, respectively.

The HSU 1B off-site VOC plume contours greater than the MCL of 5 ppb cover an area of approximately 20 acres. This is approximately one-third of its size in 1989 when our first ground water treatment facility began operating. The size of the HSU 2 off-site VOC plume over the MCL shows a reduction of 40 percent since 1989 and currently covers an area of about 62 acres.



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During the most recent sampling events, the highest VOC concentration in an HSU 1B off-site well was 15.4 ppb in November 1999 at well W-1425. The highest VOC concentration in an HSU 2 off-site well was 40.4 ppb in well W-903 in October 1999.

Overall, the Livermore site VOC plumes have remained relatively stable with respect to size in 1999, and changes in VOC concentrations are mostly observed in response to active ground water extraction. Concentrations in the HSU 1B, 2, and 3A VOC plumes along the western margin of the Livermore site in the TFA, TFB, and TFC areas continued to decline in response to ground water extraction. VOC concentrations near the source area east of TFA continue to decline. Total VOC concentrations at extraction well W-254 declined from 195 ppb in January 1998 to 125 ppb in October 1999. At TFA, off-site VOC plume contours greater than the MCL of 5 ppb are estimated to cover an area of approximately 7 acres in HSU 1B and 42 acres in HSU 2.

In the TFD area, VOC concentrations in parts of HSU 2 continue to decline in response to pumping the TFD extraction wells. VOC concentrations in HSU 2 extraction well W-906 have decreased from 789 ppb in 1995 to 104 ppb in October 1999. In HSU 2 monitor well W-355, VOC concentrations have decreased from concentrations that were consistently above 1000 ppb prior to pumping at well W-906 to 58 ppb in November 1999.

Prior to pumping in the TFD-E area, high VOC concentrations (in the 5000 to 7000 ppb range) were observed in HSU 3A/3B wells W-1551 and W-1552. After three months of ground water extraction from these two wells, VOC concentrations have remained consistently above 5000 ppb. Well W-1551 has the highest VOC mass removal rate, accounting for 7.7% of the total VOC mass removed from the entire site by ground water extraction.

In the TF518 area, the off-site HSU 5 VOC plume has shown significant decreases in VOC concentrations since pumping started at the TF406 and TF518 facilities in August 1996 and January 1998, respectively. Total VOC concentrations in off-site monitor well W-219 declined from 114 ppb in October 1997 to 3 ppb in October 1999.

In the TFE-SE area, LLNL conducted a pilot long-term pumping test for distal plume capture and VOC mass removal at proposed TFE-SE extraction well W-359 between March and June 1999. VOC concentrations in well W-359 increased from 326 ppb in March to 1395 ppb in October 1999. These data indicate that well W-359 is well positioned to capture VOCs from source areas to the south.

In the TFE-E area, VOC concentrations in well W-1109 decreased from 1744 ppb in January 1998 to 787 ppb in October 1999. Ground water extraction rates from well W-1109 increased from 2.5 to 8.8 gpm in 1999 in response to well redevelopment.



In the TFE-SE area, the initial total VOC concentration in newly installed HSU 2 piezometer SIP-ETS-601 was 1874 ppb. This high concentration confirms the presence of a source area that had been indicated on isoconcentration maps.

Site 300 CERCLA Project

Environmental investigations and cleanup activities at Site 300 began in 1981. Site 300 became a CERCLA/Superfund site in 1991, when it was placed on the National Priorities List (NPL). The CERCLA environmental restoration study areas are shown in Figure 8-9. The major contaminants of concern are listed in Table 8-4.

Table 8-4. Major contaminants of concern found in soil, rock, and ground water at Site 300.

Study area	Contaminant of concern
General Services Area (GSA)	VOCs (primarily TCE)
Building 834 Complex	VOCs (primarily TCE), organosilicate oil, nitrate
High Explosives Process Area	VOCs (primarily TCE) HE ^(a) (primarily HMX ^[b]) Nitrate, perchlorate
East and West Firing Areas (EFA/WFA)	Tritium Depleted uranium VOCs (primarily TCE and Freon-113) Nitrate, perchlorate
Building 854	VOCs (primarily TCE) Nitrate, perchlorate
Pit 6	VOCs (primarily TCE) Tritium, nitrate, perchlorate
Building 832 Canyon	VOCs (primarily TCE) Nitrate, perchlorate

^a HE = high explosives.

^b HMX = octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine.



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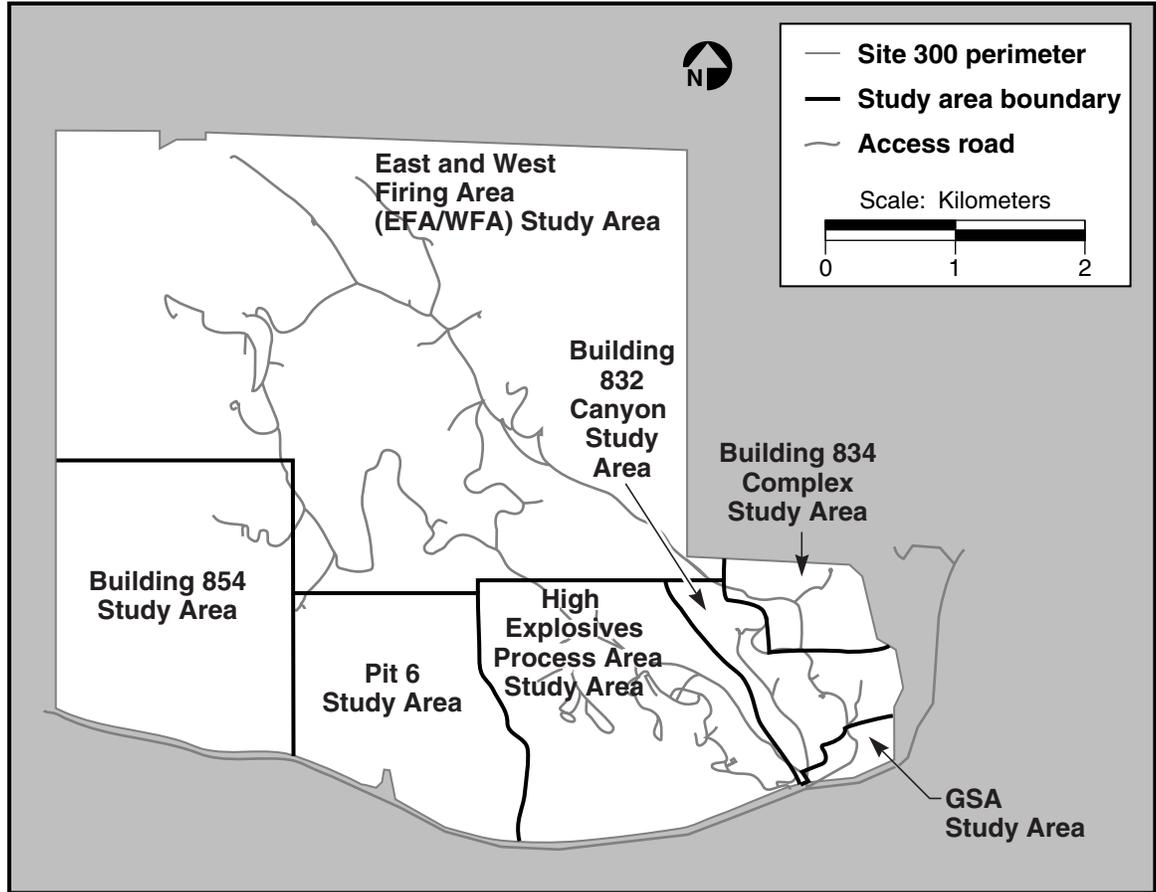


Figure 8-9. Environmental restoration study areas at Site 300.

Geology of Site 300

Site 300 is located in the sparsely populated Altamont Hills, which are part of the Coast Ranges Physiographic Province and separate the Livermore Valley to the west from the San Joaquin Valley to the east. Site 300 stratigraphy is shown in **Figure 8-10**. Rocks exposed in the region are classified into three groups:

- Late Tertiary-Quaternary (0–5 million years ago)—alluvium and semilithified sediments, mainly of continental origin.
- Early to late Tertiary (5–65 million years ago)—shallow marine and continental sedimentary and volcanoclastic rocks.



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

Distinctive blue-gray to brown weathering volcanoclastic sandstone and sandy siltstone, interbedded with light gray weathering tuffaceous claystone and conglomerate, are exposed extensively within Site 300. These rocks are mapped as the late Miocene Neroly Formation (Huey 1948; Dibblee 1980). The Neroly Formation is also present in the subsurface beneath the southeastern portion of Site 300.

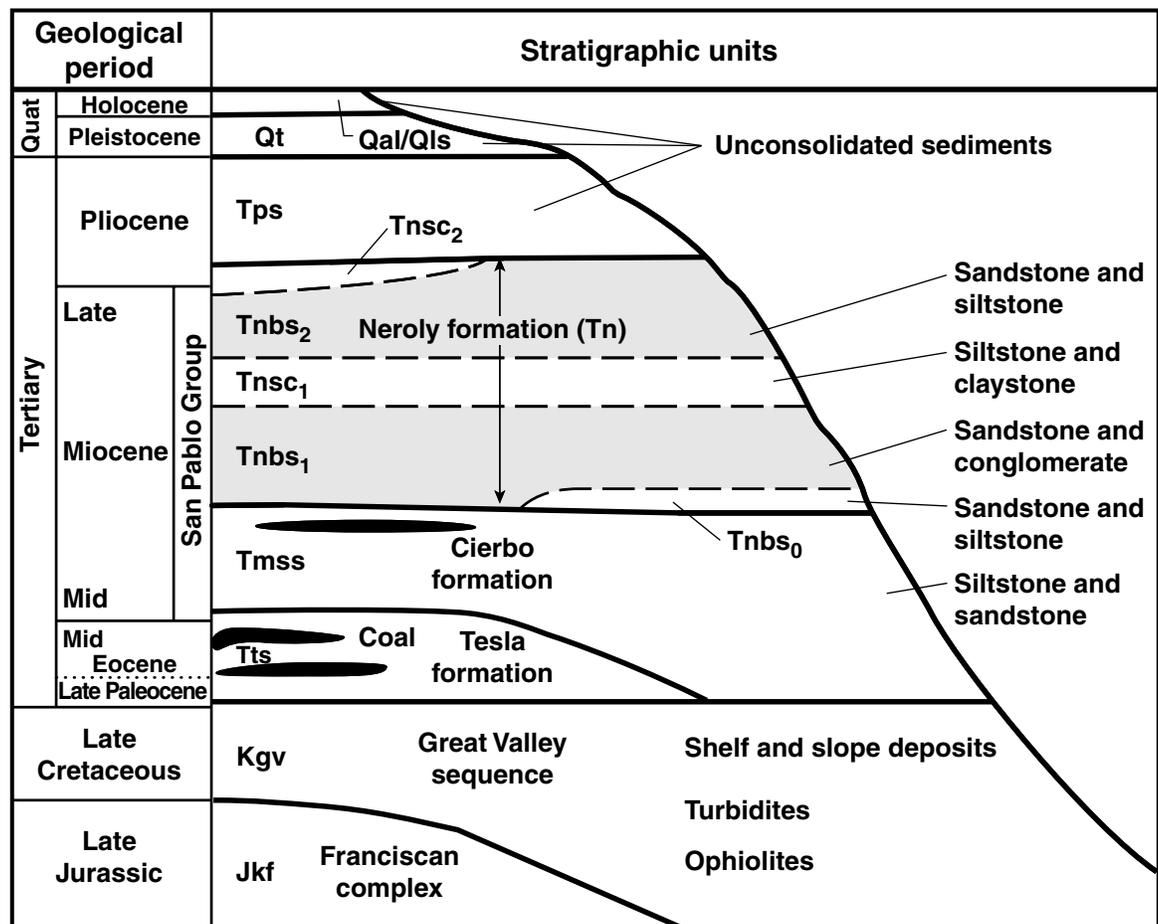


Figure 8-10. Site 300 stratigraphy (Webster-Scholten 1994).



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The Neroly Formation is the principal hydrologic unit within Site 300 and has therefore 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*, hereafter referred to as the Final SWRI Report [Webster-Scholten 1994]). The complete section of the Neroly Formation is about 150 m thick beneath Site 300.

The floodplain of Corral Hollow Creek lies along the southern boundary of Site 300 and borders portions of the General Services Area (GSA), the High Explosives Process Area, and the area of closed landfill Pit 6. Floodplain alluvium consists dominantly of coarse cobble and boulder-bearing terrace gravel derived from sources to the south, with lenses and local cappings of sandy silt and silty clay.

The bedrock sequence within Site 300 has been slightly deformed into several gentle, low-amplitude folds. The locations and characteristics of these folds, in combination with the regional fault and fracture patterns, locally influence ground water 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 (10.5 in). The site is underlain by gently dipping sedimentary bedrock dissected by steep ravines. The bedrock comprises interbedded conglomerates, sandstones, siltstones, and claystones (see **Figure 8-10**).

Ground water primarily occurs in the Neroly Formation upper and lower blue sandstone units (Tnbs₂ and Tnbs₁) and in the underlying Cierbo Formation (Tmss). Ground water can also be present in permeable Quaternary alluvium valley fill (Qal) during the winter rainy season. Some ground water is present as perched water-bearing zones beneath hilltops. The perched water-bearing zones primarily occur in the unconsolidated sediments of the Miocene-age nonmarine unit (Tps) in the Building 833 and 834 areas and in the Explosives Process Area. However, an extensive perched water-bearing zone occurs in Tnbs₁ sandstones in the northwestern portion of the East and West Firing Area. Fine-grained siltstone and claystone interbeds in Tnbs₁ 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 ground water flow occurs in fractures as well as in pores. Ground water is present under confined conditions in the southern half of the site but is generally unconfined elsewhere. **Figure 8-11** is a map of the potentiometric surface for the first continuous water-bearing zone at Site 300, which principally occurs in the Neroly lower blue sandstone aquifer (Tnbs₁).

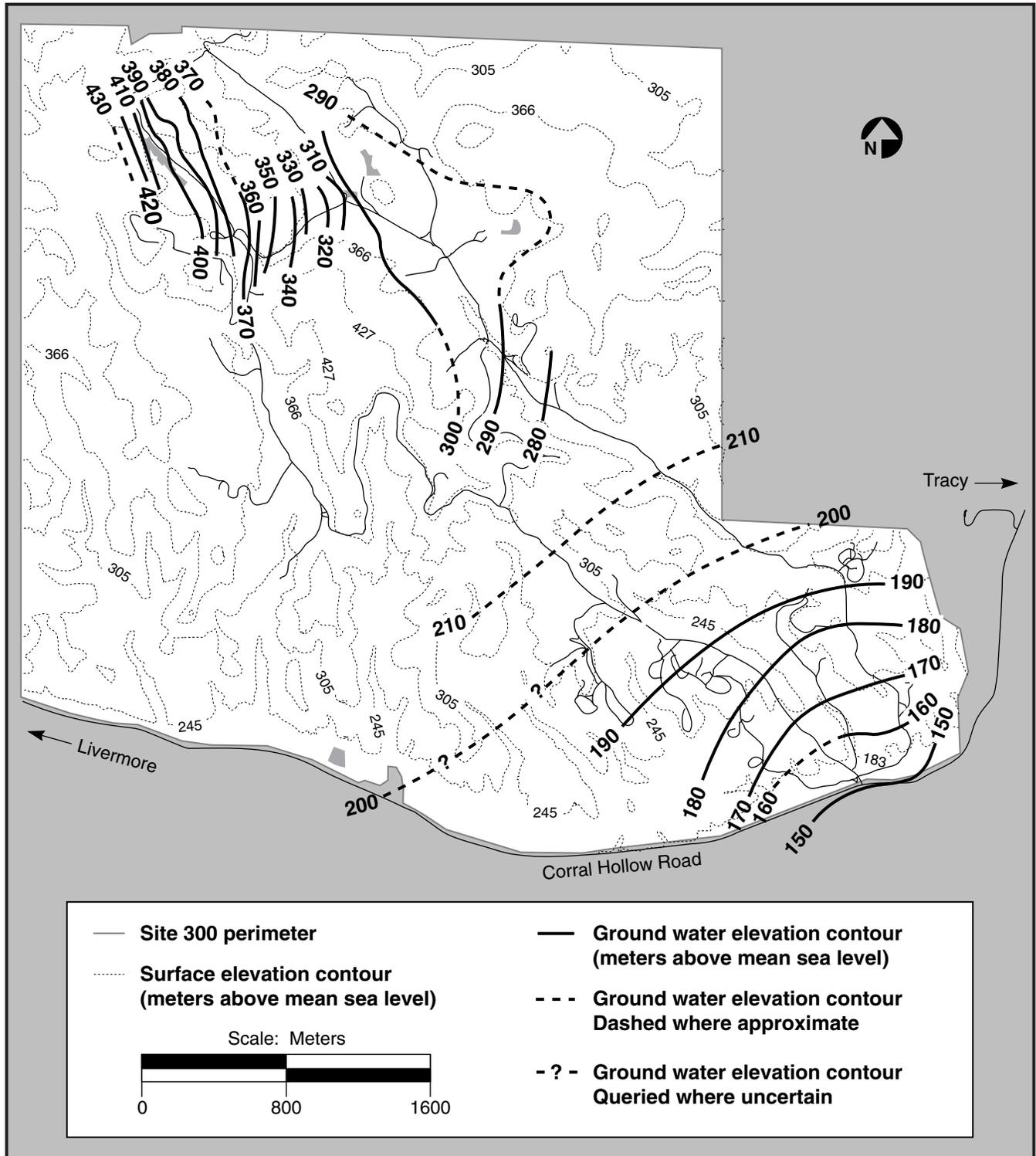


Figure 8-11. Approximate ground water elevations in the principal continuous water-bearing zone at Site 300.



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Recharge occurs where saturated alluvial valley fill is in contact with underlying permeable bedrock, and where bedrock strata crop out. Local recharge occurs on hilltops, creating the perched water-bearing zones in the Building 832, 834, and 854 areas. Low rainfall, high evapotranspiration rates, steep topography, and intervening aquitards generally preclude direct vertical recharge to the deeper bedrock aquifers.

Ground water flow in the bedrock follows the inclination, or dip, of the layers. The tectonic forces that uplifted the Altamont Hills faulted, gently folded, and tilted the once-horizontal sedimentary strata. A major structure, the east-west trending Patterson anticline, occupies a central location within the site. North of the anticline, bedrock dips east-southeast, and ground water flows generally east-northeast. South of the anticline, bedrock dips south-southeast, and thus ground water flows roughly south-southeast.

The Cierbo Formation (Tmss) is saturated beneath Doall Ravine, the Building 851 and 854 areas, and the southern part of the East Firing Area. The Tmss unit is unsaturated or does not otherwise yield water to wells in other parts of the East and West Firing Areas. The thickness of the Cierbo Formation is not well known because most boreholes are not deep enough to completely penetrate this formation. Some of the deeper wells in the GSA penetrate the uppermost Tmss. The continuity of saturation in the Tmss between the northwest and southeast areas of Site 300 is undetermined. Ground water in the Tmss occurs under unconfined to artesian conditions.

The Tps unit is the youngest bedrock unit identified at Site 300 and is generally present only on hilltops. Where present, ground water is typically perched, discontinuous, and ephemeral. The exception to this condition exists in the Explosives Process Area, where the extent of saturation in Tps sediments is significant. Ground water in the Tps unit is generally unconfined, although water under confined conditions does occur locally.

Quaternary alluvium (Qal) is present as valley fill in ravines throughout Site 300, but is saturated only in the Corral Hollow Creek stream channel, in Doall Ravine in the West Firing Area, and in southern Elk Ravine in the East Firing Area near a spring. Saturated Quaternary terrace alluvium deposits (Qt) are present at Pit 6, in the GSA, and in the Building 832 Canyon area; some of these ground water occurrences are ephemeral. Small quantities of ground water are present in some local landslide (Qls) deposits.

All ground water 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 ground water contamination at Site 300 is shown on **Figure 8-12**.



Study Area Highlights and Activities

Background information for LLNL environmental characterization and restoration activities at Site 300 can be found in the *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300* (Webster-Scholten 1994). In 1999, LLNL submitted the *Draft Final and Final Site-Wide Feasibility Study for Lawrence Livermore National Laboratory Site 300* (Ferry et al. 1999c) and the *Draft Final Proposed Plan for Environmental Cleanup at Lawrence Livermore National Laboratory Site 300* (Dresen et al. 1999).

Background and activities for each of the study areas are described in the following sections. Ground water remediation for Site 300 is discussed in more detail later in this chapter. See Chapter 9 for a discussion of 1999 ground water monitoring.

General Services Area

In the General Services Area (GSA), past leaks of solvents from storage areas and other facilities have resulted in several plumes of VOCs in ground water. Two ground water TCE plumes and two corresponding treatment facilities are present at both the eastern and central GSA. The VOC ground water plume in the eastern GSA is present in stream channel alluvium (Qal) at 3–9 m below ground surface; the plume, as defined by the detection limit, is about 183 m long (**Figure 8-13**). Ground water in the alluvium flows down Corral Hollow Creek, east and northeast. Maximum fourth quarter 1999 total VOC ground water concentrations from eastern GSA monitoring wells were 10 ppb. The Qal is hydraulically connected to the Neroly Formation lower blue sandstone (Tnbs₁) unit.

The two VOC ground water plumes in the central GSA are present in terrace alluvium (Qt) and Neroly Formation upper blue sandstone (Tnbs₂), at a depth of 3–9 m below ground surface. These VOC plumes are about 170 m and 350 m long (**Figure 8-14**). Maximum fourth quarter 1999 total VOC alluvial ground water concentrations were 1100 ppb. Deeper regional ground water also contains total VOCs at a maximum fourth quarter 1999 concentration of 20 ppb. This ground water occurs at depths of 11–56 m below ground surface.

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



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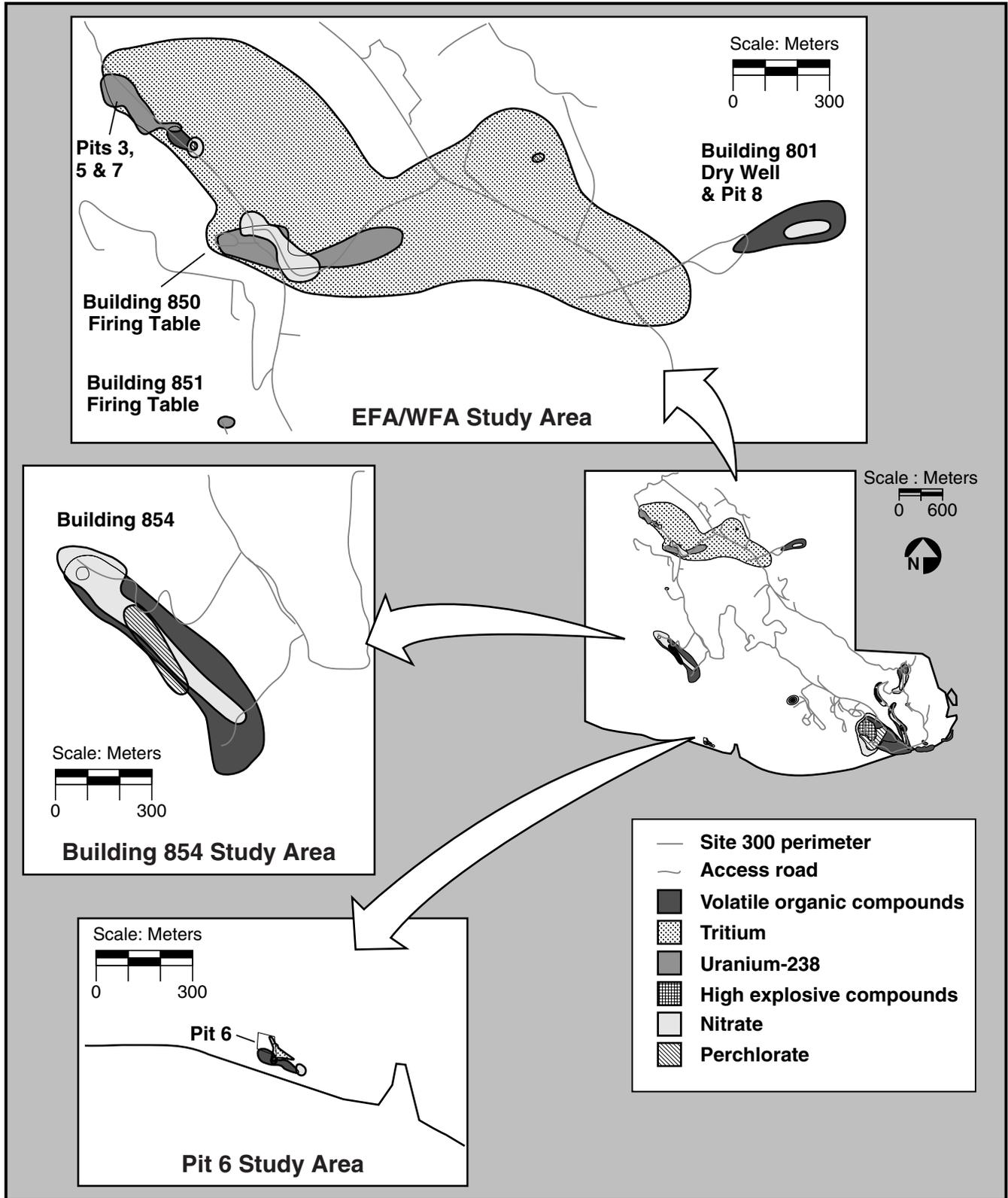
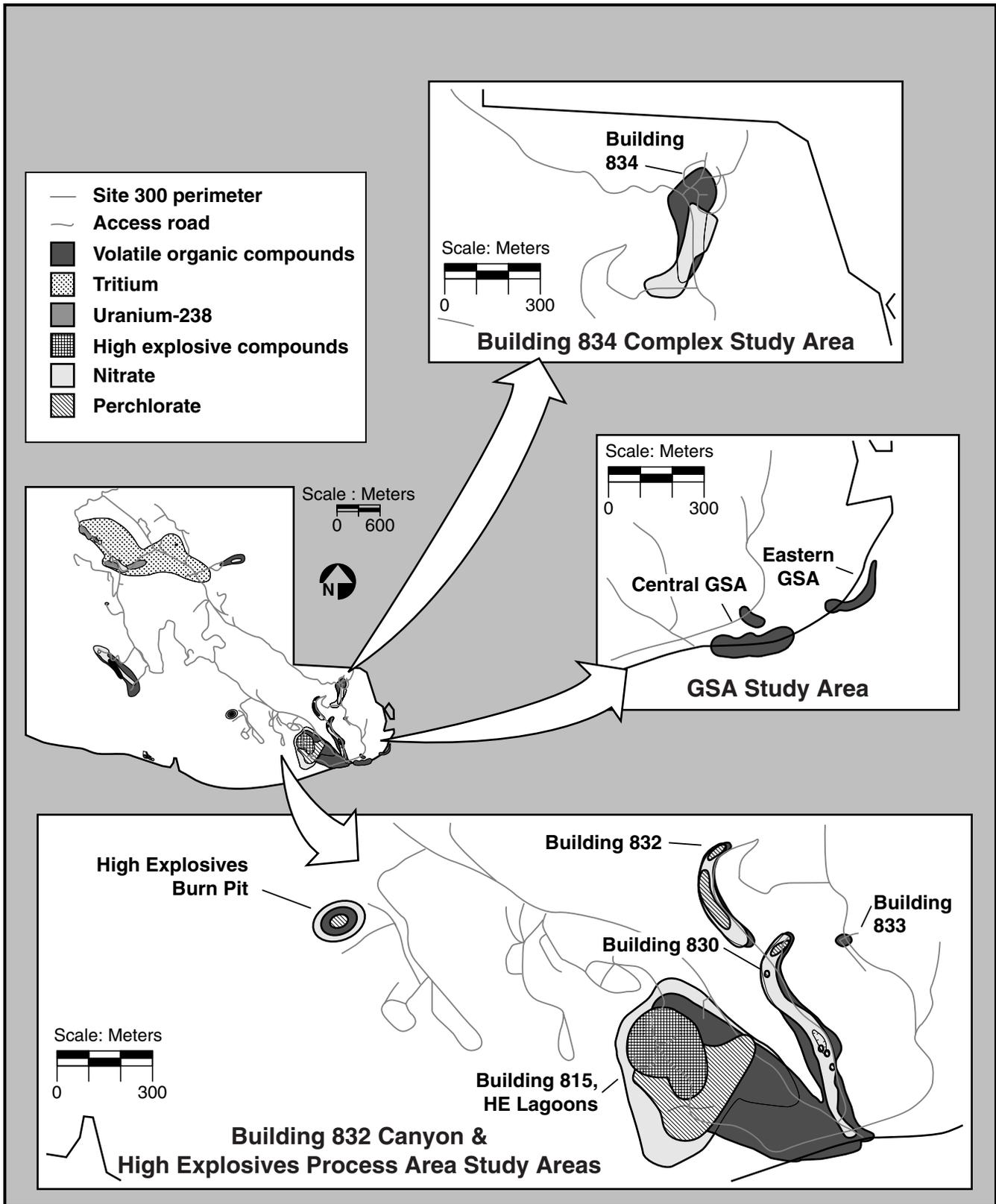


Figure 8-12. Extent of ground water contamination at Site 300.





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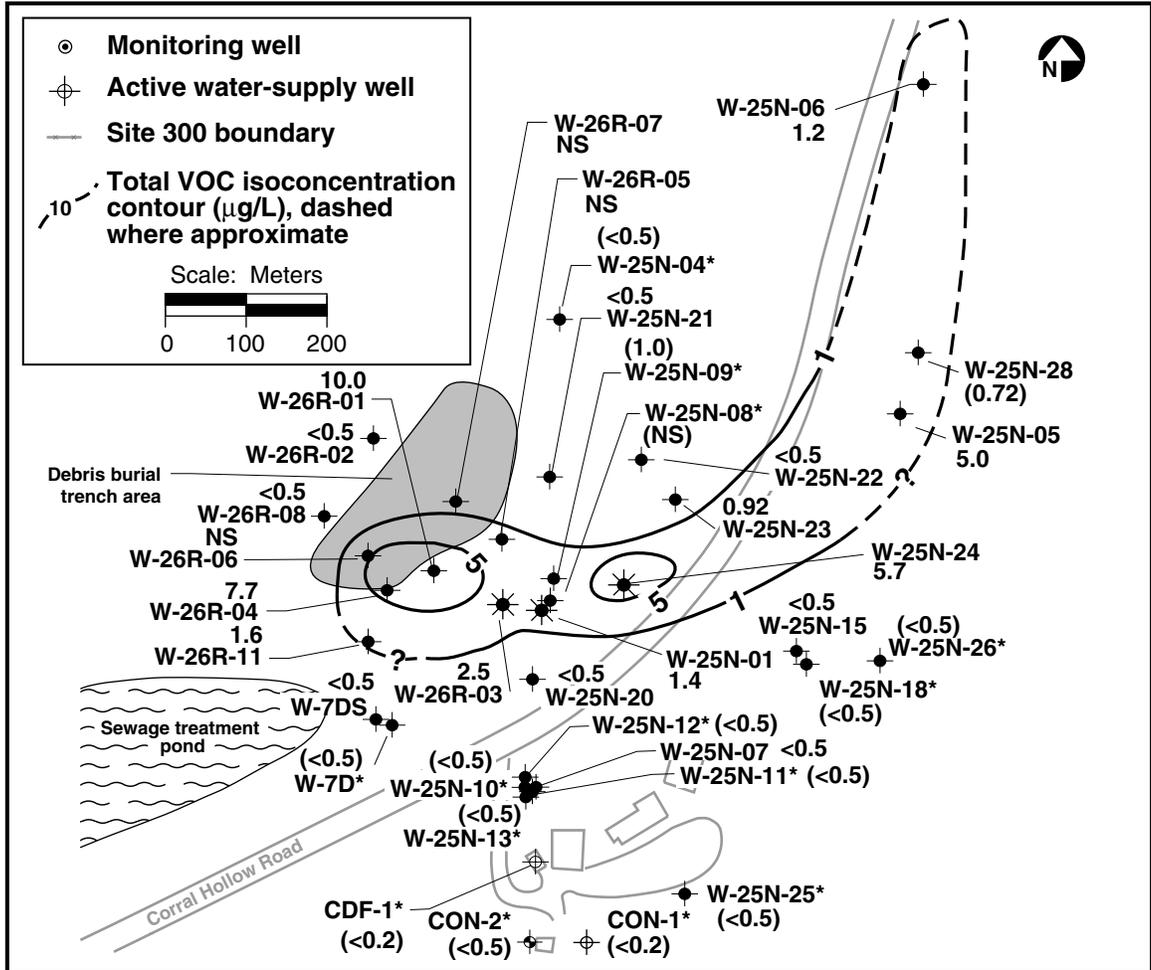


Figure 8-13. Total VOC concentrations in ground water in the eastern GSA and vicinity (fourth quarter, 1999). Monitor wells are completed in alluvial/shallow bedrock aquifer.

Using the results from several hydraulic tests, LLNL determined that the direction of plume migration may follow a previously unknown, now subterranean, river bed. It was observed in the fall of 1999 that the eastern GSA off-site plume (as defined by the >5 ppb TCE contour line) has been restricted to the Site 300 property. It had previously extended more than a mile down the Corral Hollow stream channel toward the City of Tracy, before the treatment facility started up in 1991. We estimate that, through the continued efforts of source elimination and hydraulic containment, LLNL will be able to close the eastern GSA within a few years.

After determining that the eastern GSA VOC plume was restricted to the site, LLNL reconsidered the need for an off-site treatment facility as originally planned for

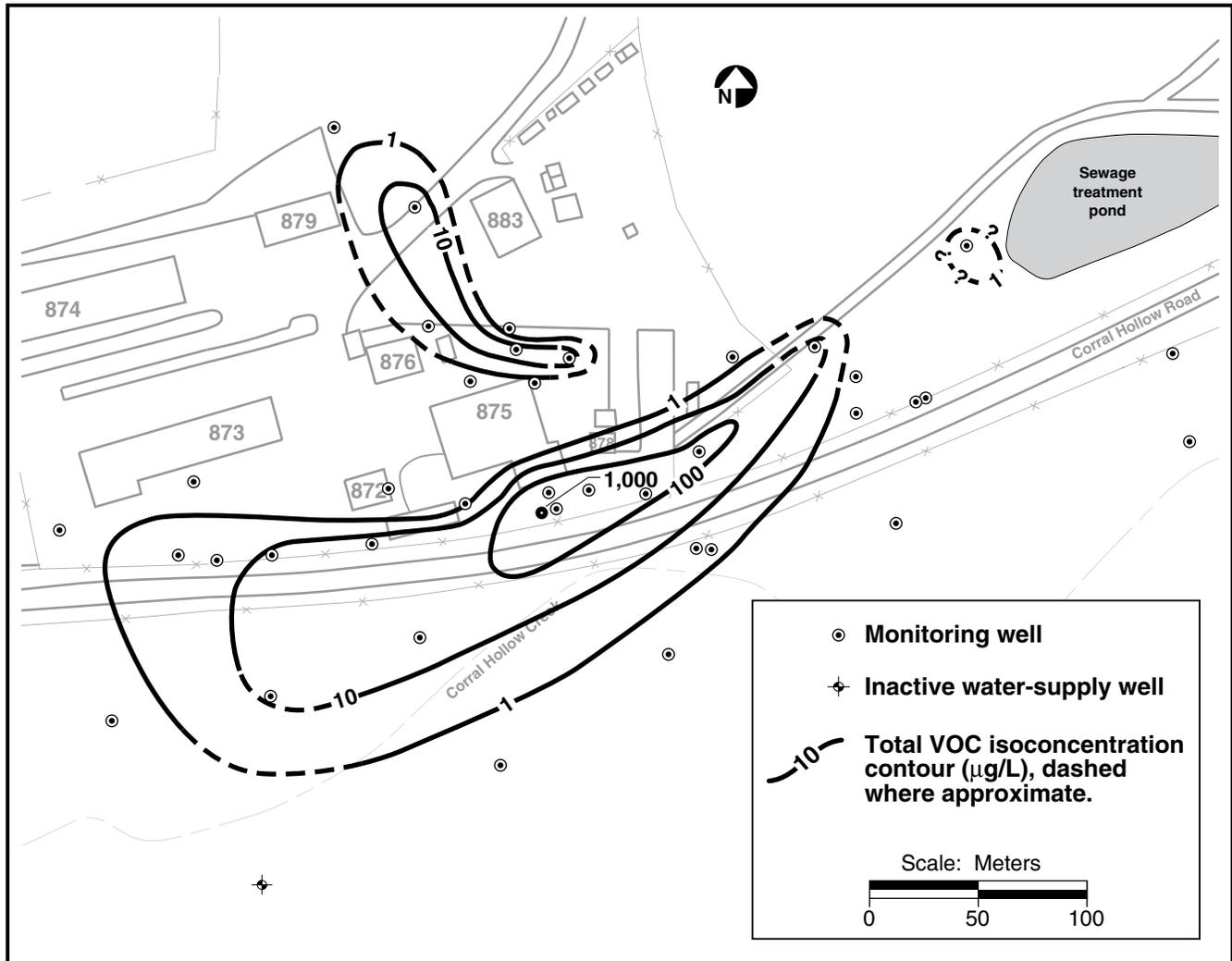


Figure 8-14. Total VOC concentrations in ground water in the central GSA (fourth quarter, 1999). Question marks indicate that the contour is unknown. Monitoring wells are completed in the Qt-Tnsc₁ hydrologic unit.

in the Record of Decision, or ROD. Chemical data indicate that trichloroethylene (TCE) concentrations have decreased to below drinking water standards in ground water from all off-site wells. Based on this information, LLNL has determined that an off-site extraction and treatment system is not needed or justified. The regulatory agencies have concurred that the off-site treatment system milestone could be delayed and the need would be re-evaluated during the GSA Five-Year Review.



8 Ground Water Investigation and Remediation

Building 834 Area

The Building 834 facility contains buildings where, in the past, TCE was used as a heat transfer fluid. Several large spills of TCE to the ground resulted in TCE contamination of a shallow perched water-bearing zone beneath the site. An isolated, discontinuous, perched water-bearing zone occurs in Pliocene non-marine gravels (Tps) and occurs at a maximum depth of 9 m (30 ft) below the center of the complex. This perched zone crops out on all sides of the hill housing the Building 834 complex and is isolated from the underlying regional aquifer by more than 90 m of vadose zone. The water-bearing zone contains maximum 1999 concentrations of TCE and 1,2-DCE of about 94,000 and 110,000 ppb, respectively. The resulting VOC plume is about 600 m long (**Figure 8-15**). Maximum ground water nitrate concentrations are about 205 ppm. A silicate oil (tert-butyl orthosilicate) has been detected at maximum 1999 concentrations of 770,000 ppb. Site characterization was enhanced by surveying the Building 834 area using passive soil vapor monitoring tools (Halden et al. 2000). Currently, ground water and soil vapor extraction and treatment, using air-sparging and GAC, respectively, are in progress.

High Explosives Process Area

The High Explosives Process Area was established in the 1950s to chemically formulate, mechanically press, and machine high explosives (HE) compounds into detonation devices that are tested in explosives experiments in the East and West Firing Areas of Site 300. Process waste water from HE machining operations containing HMX, RDX, and nitrate was discharged to nine former unlined lagoons at concentrations high enough to impact ground water. A TCE hardstand located near the former Building 815 steam plant is considered to be the primary source of TCE ground water contamination. HMX and RDX are the most frequent and widespread HE compounds detected in soil and ground water. TCE, nitrate, perchlorate, and RDX occur in two water-bearing zones within the HE Process Area. These two water-bearing zones occur in Tps sediments and Tnbs₂ sandstone, respectively. Ground water occurs in these two zones at depths of 2–30 m, and 20–76 m, respectively. The VOC (principally TCE) plumes in Tps strata are about 300 m and 200 m long. The TCE plume in Tnbs₂ strata is about 900 m long (**Figure 8-16**). The RDX plume is about 900 m long. The nitrate plume in Tnbs₂ strata is about 900 m long. The perchlorate plume in Tnbs₂ strata is 1500 m long. Current 1999 maximum concentrations of TCE, RDX, nitrate, and perchlorate are 160, 100, 102, and 33 ppb, respectively. In 1999, a treatment facility (B815-TF1) was installed near the Site 300 boundary to prevent off-site migration of VOCs in ground water. A small plume of TCE (maximum 1999 concentration of 310 ppb) also occurs in a local perched water-bearing zone that occurs in Tnsc₁ strata at a depth of 24–30 m below the HE burn pits; this plume is less than 5 m long. These burn pits were closed and capped under RCRA in 1998.

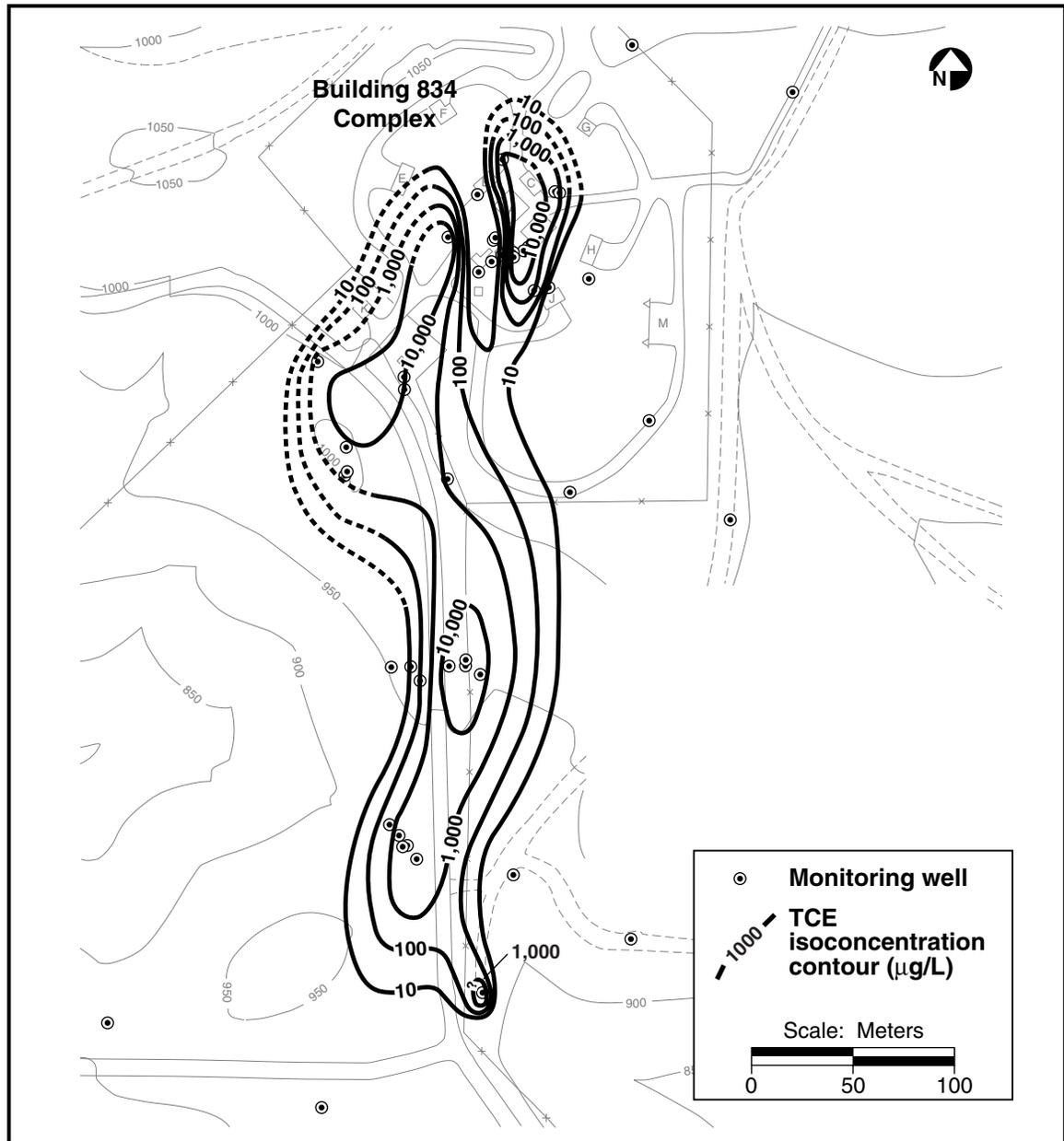


Figure 8-15. Distribution of total VOCs in ground water in the Qt-Tpsg hydrologic unit at the Building 834 complex (second quarter, 1999).



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Ground Water Investigation and Remediation

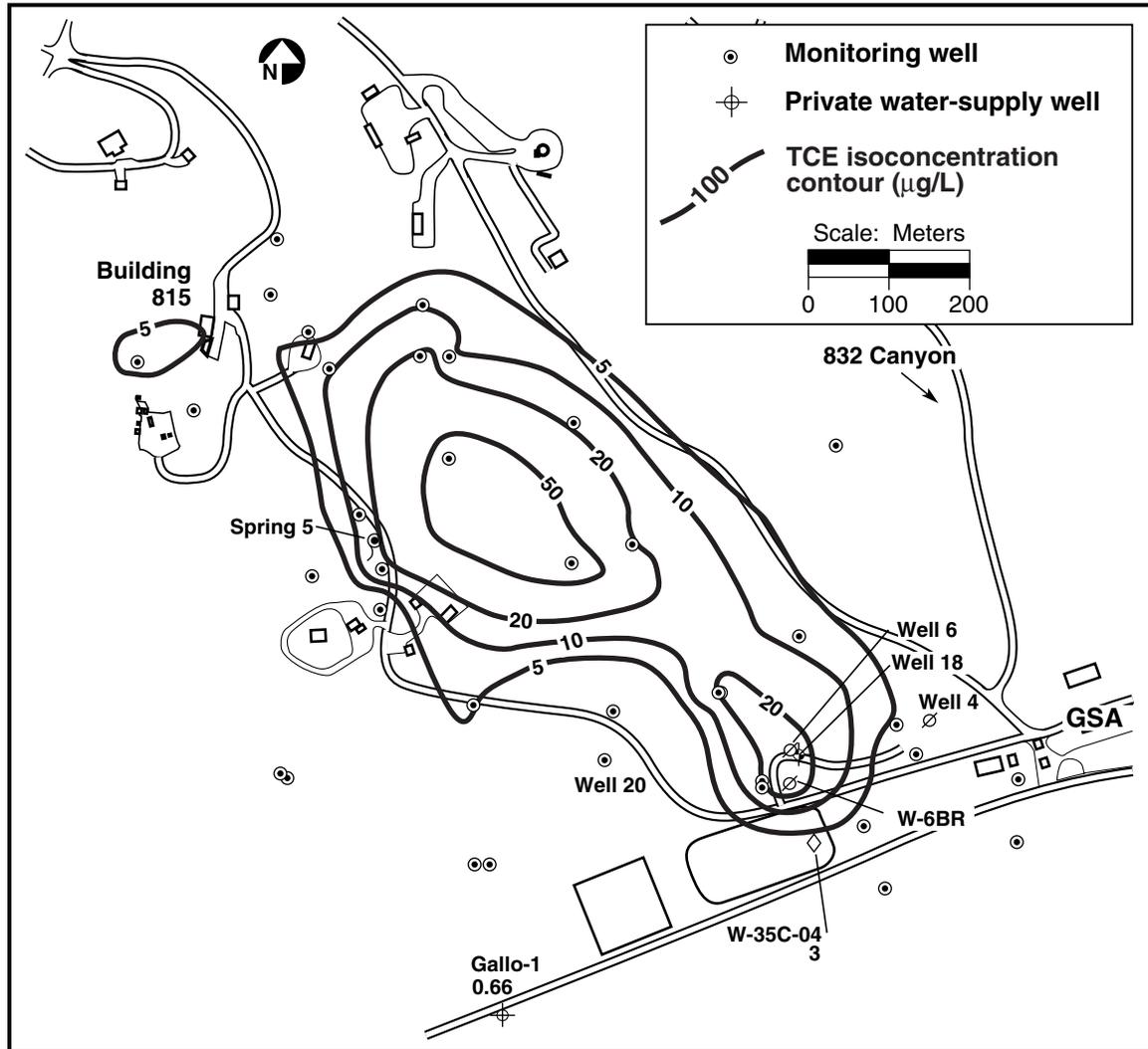


Figure 8-16. Trichloroethene (TCE) isoconcentration contour map in the Tnbs₂ aquifer in the HE Process Area (fourth quarter, 1999).

East and West Firing Areas

Explosives experiments conducted at outdoor firing tables in this area have generated wastes that in the past were disposed at several unlined landfills. Tritium has been released to ground water from landfill Pits 3 and 5 and the Building 850 firing table (Figure 8-17). Depleted uranium has been released to ground water from landfill Pits 5 and 7 and the Building 850 firing table. The resulting plumes occur in a perched water-bearing zone within Qal and Tnbs₁. The water-bearing zone occurs at depths of 5–20 m below surface. There are two overlapping plumes of tritium in ground water.

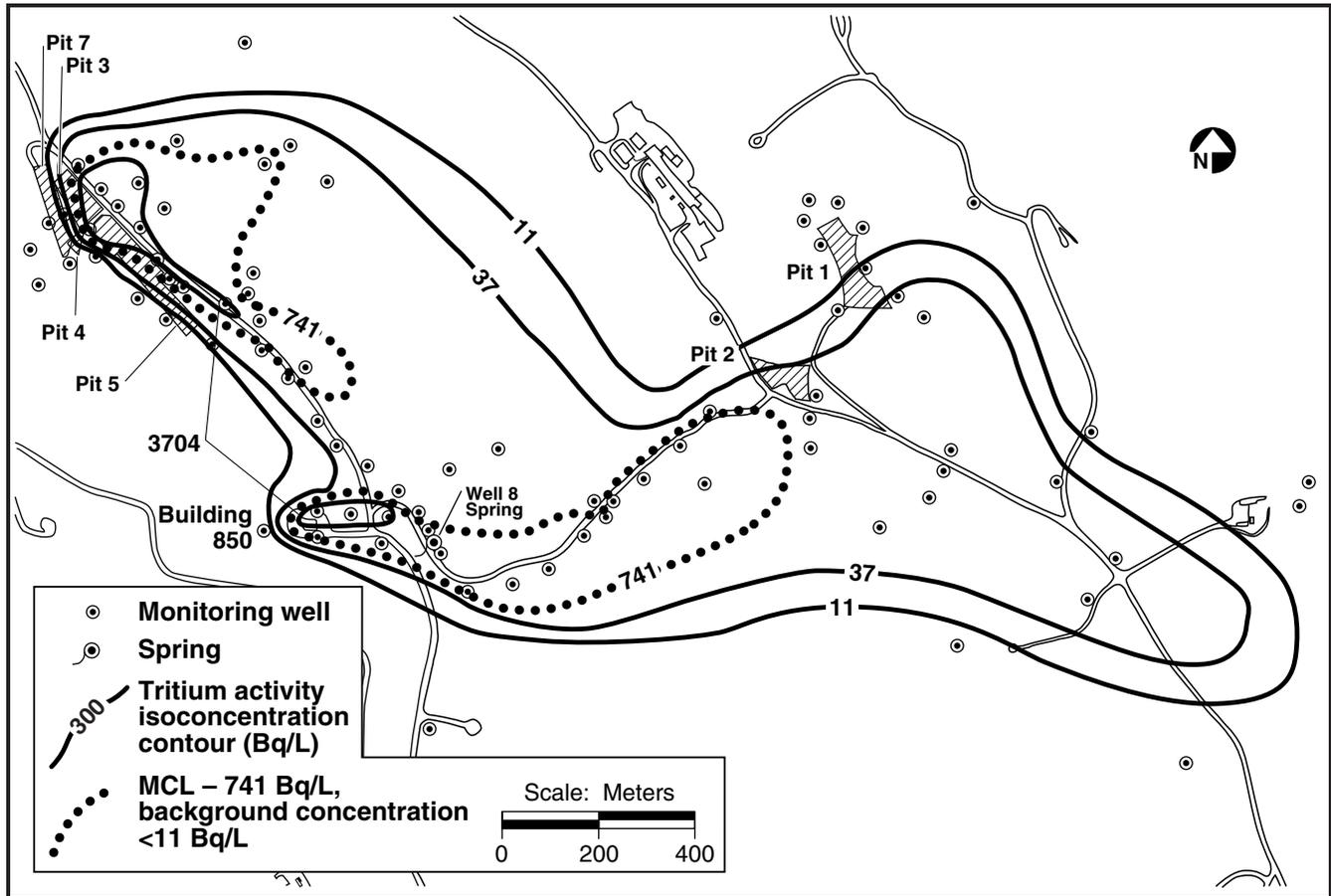


Figure 8-17. Distribution of tritium in ground water in the first water-bearing zone in the Building 850/Pits 3 and 5 area (second quarter, 1999).

The maximum 1999 tritium activity is about 36,963 Bq/L (999,000 pCi/L). The total length of the commingling tritium plumes is about 3000 m. The perched water-bearing zone is connected to the regional Tns₁ aquifer at the Elk Ravine Fault. Maximum 1999 ground water tritium activities in this aquifer are about 703 Bq/L (19,000 pCi/L). There are two smaller plumes of depleted uranium (uranium-238) in ground water, with maximum 1999 activities of less than 3.7 Bq/L (100 pCi/L). The depleted uranium is confined to the perched water-bearing zone; the lengths of these two uranium plumes are 370 m and 500 m. Computer modeling of the transport and fate of the tritium indicates that by the time the tritium and uranium in ground water reach the Site 300 boundary, these radionuclides will exist at near-background activity levels.

During 1999, LLNL installed a total of 15 new monitor wells in the East and West Firing Area. Ten of these wells were drilled to define the extent of tritium in ground water and the effects of the Elk Ravine Fault on ground water flow in the area northeast of the



8 Ground Water Investigation and Remediation

valley that houses landfill Pits 3, 5, and 7. Ground water tritium activity data from these wells indicate that the tritium plume emanating from the pits is somewhat more extensive than previously thought. The plume is now bounded by wells that sample ground water that contains background tritium activities. The other five wells were completed to monitor alluvial ground water in the landfill valley.

To determine the appropriate remediation strategy for the landfills, LLNL is currently conducting an evaluation of tritium sources within the landfills and is building a three-dimensional structural model and a finite element model of ground water flow and contaminant transport. To this end, during 1999, LLNL analyzed 68 samples from 16 boreholes for tritium activity and water content. The highest activity found was 255,300 Bq/L_{sm} (6.9 MpCi/L_{sm}) in a sample of waste from Pit 3.

Although tritium continues to leach into ground water from vadose zone sources at Building 850, the long-term trend in total ground water tritium activity in this portion of the tritium plume is one of decreasing activity at approximately the radioactive decay rate of tritium. The extent of the 740 Bq/L (20,000 pCi/L) MCL contour for this portion of the plume is shrinking.

During 1999, LLNL began its characterization of Freon-113 at Building 865 (the closed Advanced Testing Accelerator). Freon-113 was used as a degreasing agent at the facility. The Freon-113 was originally discovered in ground water samples from wells in the Pit 1 monitoring network, downgradient and southeast of Building 865. During 1999, LLNL completed two wells northeast of Building 865. Maximum Freon-113 concentrations in ground water in this area are significantly less than the 1.2 ppm MCL for Freon-113.

During 1999, LLNL began geological reconnaissance at the Building 812 firing table area. No monitor wells have yet been drilled at Building 812, a firing table where depleted uranium and thorium were used in explosives experiments. However, samples from an adjacent perennial spring indicate depleted uranium signatures. Well drilling will begin at the Building 812 area in 2000.

Several other contaminants in ground water are being investigated by LLNL at the East and West Firing Areas. Nitrate and perchlorate in the Building 850/Pits 3 and 5 areas occur at maximum 1999 concentrations of less than 110 ppm and 5 ppb, respectively. Trace amounts of TCE (less than 3 ppb) are also present in ground water near Pit 5. TCE also occurs in a small ground water plume monitored by two wells at the Building 801 firing table.



Depleted uranium isotopic signatures have been detected in ground water samples from wells adjacent to the Building 851 firing table, indicating that some depleted uranium is reaching ground water.

Building 854 Study Area

Trichloroethene in ground water was previously found to arise principally from leaks in the former overhead TCE brine system at Buildings 854E and 854F. Trichloroethene, nitrate, and perchlorate occur in ground water in the Building 854 area in Neroly Formation Tnbs₁ strata at maximum 1999 concentrations of 270 ppb, 200 ppm, and 16 ppb, respectively. The affected aquifer occurs at depths of 9–50 m below ground surface. The TCE plume is about 970 m long (**Figure 8-18**).

During 1999, LLNL continued to define the extent of TCE in ground water. Four new monitor wells were installed. On April 1, 1998, LLNL submitted the *Characterization Summary Report for the Building 854 Operable Unit* (Ziagos and Reber-Cox 1998c) to the regulatory agencies. On May 28, 1998, LLNL submitted to the regulatory agencies a letter detailing the CERCLA pathway for the operable unit (U.S. Department of Energy 1998d). LLNL installed and began operating a solar-powered portable treatment unit at Building 854 to treat extracted ground water containing VOCs. A second treatment unit will be installed in the future. Several additional wells will be installed during the summer of 2000.

Pit 6 Area

A small ground water TCE plume in a perched terrace alluvium (Qt) water-bearing zone discharges to the surface at small springs at the southeastern edge of the Pit 6 area. The perched water-bearing zone occurs at depths of 0–11 m below ground surface. The source of the TCE plume is the southeast corner of the Pit 6 landfill. The TCE plume is about 200 m long (**Figure 8-19**). Concentrations of VOCs in the plume have declined by more than tenfold since 1992. Current maximum TCE concentrations are about 6.3 ppb. Tritium (at maximum activities of 92.5 Bq/L [2500 pCi/L], nitrate (at maximum concentrations of 228 ppm), and perchlorate (at maximum concentrations of 57 ppb) also occur in the perched water-bearing zone. The lengths of the tritium and perchlorate plumes are 200 and 400 m, respectively. During 1997, a 2.4-acre engineered cap was constructed over the landfill as a CERCLA nontime-critical removal action. During 1998, the *Post-Closure Plan* (Ferry et al. 1998) for the Pit 6 cap was submitted to the regulatory agencies.



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Ground Water Investigation and Remediation

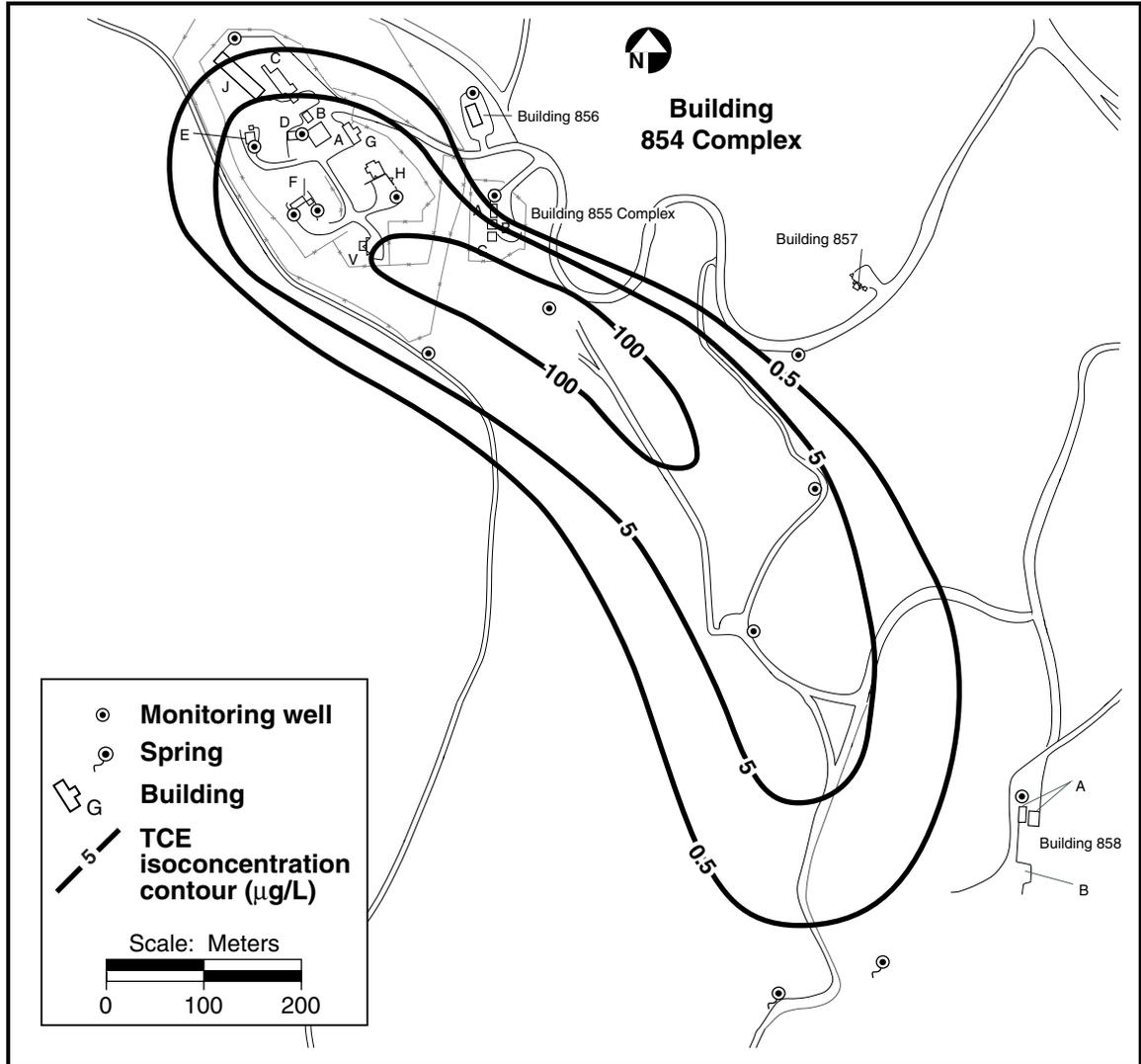


Figure 8-18. Distribution of TCE in ground water in the Building 854 area (second quarter, 1999).

Building 832 Canyon Study Area

At the Building 832 Canyon area (Buildings 830 and 832), solvents were released from weapons component test cells in the past. TCE and nitrate occur in ground water in Qal alluvium and in Neroly Formation sandstone units within Tnsc₁ silty-claystone strata 15–25 m beneath the Building 832 Canyon Study Area at maximum 1999 concentrations of 8000 ppb and 174 ppm, respectively. The TCE plume emanates from both the Building 830 and 832 areas and is about 1300 m long (**Figure 8-20**). Perchlorate has also been detected at a maximum concentration of 51 µg/L. Well drilling during 1999

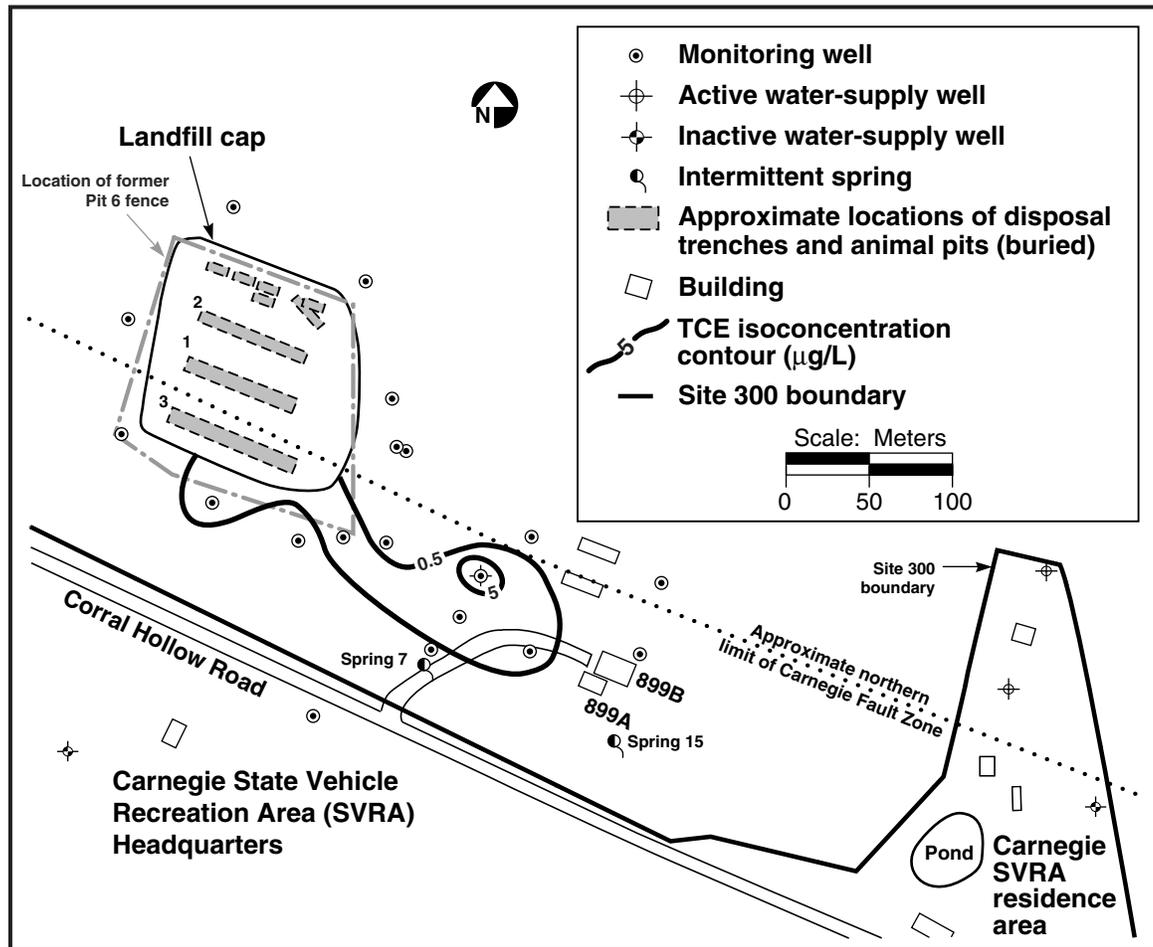


Figure 8-19. Distribution of TCE in ground water in the Pit 6 area (fourth quarter, 1999).

indicated that the TCE contaminant plume and the nitrate in ground water, both emanating from the Building 832 complex, are likely merging with the TCE and nitrate in ground water from the Building 830 area. Perchlorate has also been detected in ground water samples from 15 monitor wells in the area.

In 1999, LLNL linked ten wells in the Building 832 complex, near the suspected test cell release sites, to the Building 832-TF1 for vapor and ground water extraction and treatment and completed construction of the treatment system. LLNL also plans to use innovative, environmentally friendly (green) technologies to treat ground water in the Building 832 Canyon area. A DOE Technology Deployment Initiative (TDI) using iron filings as a treatment system for TCE is in the design and testing phase.



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Ground Water Investigation and Remediation

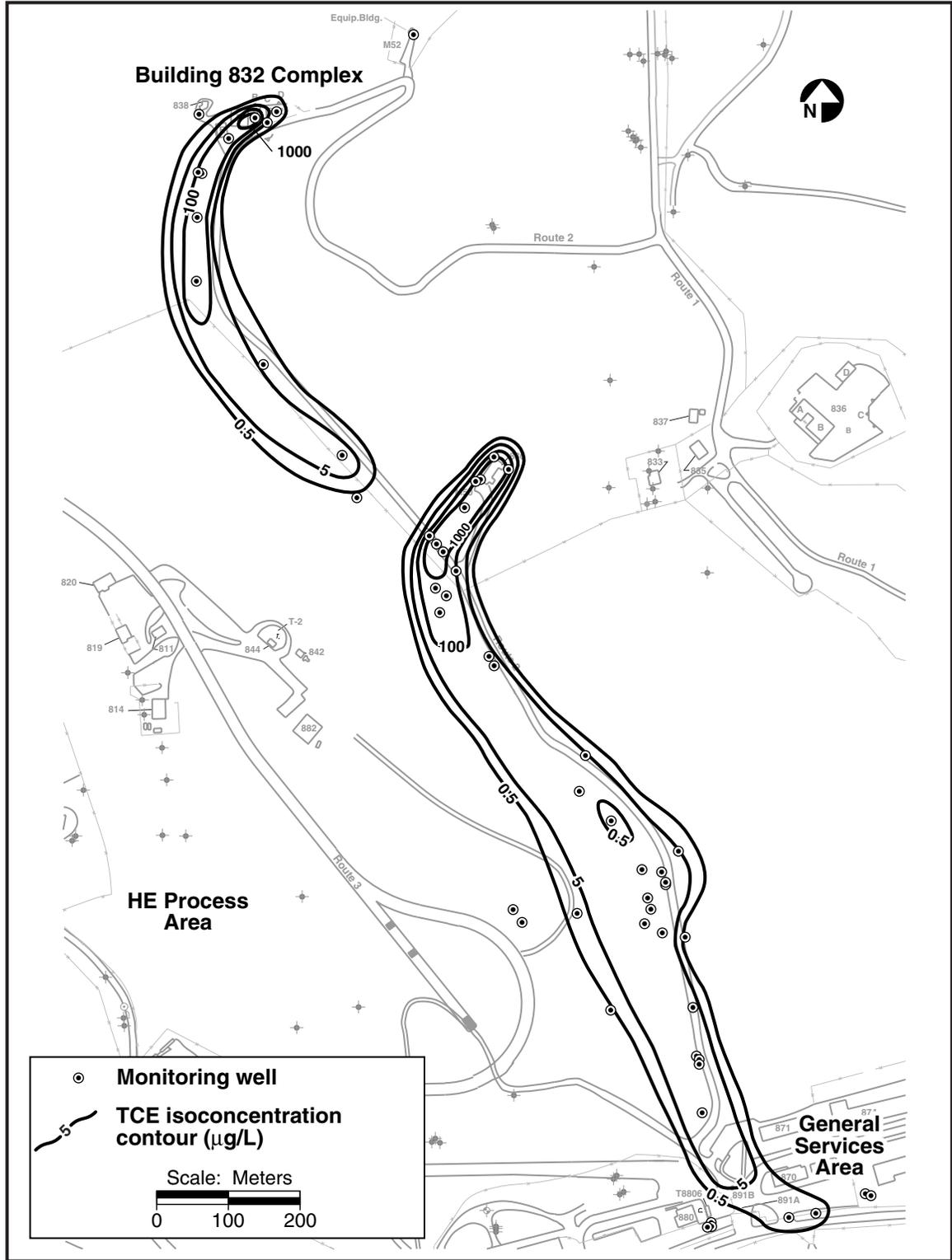


Figure 8-20. Distribution of TCE in ground water in the Building 832 Canyon (fourth quarter, 1999).



Environmental Remediation at Site 300

Dedicated ground water and soil vapor extraction and treatment facilities exist at the eastern GSA, central GSA, and Building 834 areas. During 1999, portable ground water treatment systems were installed at the Building 815 (HE Process Area) and Building 854 areas. A combined soil vapor and ground water treatment system was installed in the Building 832 Canyon Area. The central GSA, eastern GSA and Building 815 treatment facilities discharge to surface drainage courses. The other treatment systems discharge to air. **Table 8-5** summarizes calendar year 1999 and cumulative totals of volumes and masses of contaminants removed from ground water and soil vapor at Site 300. Also in 1999, treatment facility construction, design, and treatability testing activities continued at the High Explosives Process Area and the Building 832 Canyon area.

Table 8-5. Volatile organic compounds (VOCs) removed from ground water and soil vapor at Site 300.

Treatment area	Startup date	1999		Cumulative total	
		Water treated (ML) ^(a)	VOCs removed (kg)	Water treated (ML) ^(a)	VOCs removed (kg)
General Services Area					
Eastern GWTF ^(b)	1991	79.4	0.26	557.4	5.86
Central GWTF	1993	4.16	1.04	8.96	7.54
Building 834	1995	0.169	5.45	0.584	24.7
Building 815	1999	0.34	0.01	0.34	0.01
Building 832	1999	32.4	0.004	32.4	0.004
Building 854	1999	0.189	0.04	0.189	0.04
Pit 6	1998	— ^(c)	— ^(c)	0.268	0.0014
		Soil vapor treated (m ³)	VOCs removed (kg)	Soil vapor treated (m ³)	VOCs removed (kg)
General Services Area					
Central	1994	489,078	4.24	1,492,743	64.62
Building 834	1998	390,415	27.58	439,605	34.9
Building 832	1999	3,385.9	0.374	3,385.9	0.374

^a ML = 1 million liters.

^b GWTF = Ground water treatment facility.

^c Pit 6 is not routinely used for ground water treatment. A hydraulic pump test was conducted there in 1998.

General Services Area

The Remedial Design Document for the GSA Operable Units was submitted to the regulatory agencies in 1998. During 1999, the soil vapor extraction and treatment system in the central GSA dry-well source area was consistently operated and maintained to reduce



8 Ground Water Investigation and Remediation

VOC concentrations in soil vapors, remediate dense nonaqueous-phase liquids in the soil, and mitigate the VOC inhalation risk inside Building 875. The ground water extraction and treatment systems in the central and eastern GSA area were consistently operated and maintained to reduce VOC concentrations in the ground water to drinking water maximum contaminant levels (MCLs), prevent further migration of the contaminant plume, and dewater the shallow water-bearing zone in the Building 875 dry-well area to enhance soil vapor extraction. Wells W-7Q, W-7R, W-7S, and W-7T were installed within the central GSA as monitor wells. These wells are being considered as possible extraction wells for the expansion of the ground water treatment facility. Based on the NPDES permit five-year review, sampling requirements were reduced at the eastern GSA groundwater treatment facility.

The eastern GSA treatment facility employs granular activated carbon (GAC) canisters to remove VOCs from extracted ground water. Extracted central GSA ground water is run through an air-sparging PTU to remove VOCs. Extracted soil vapor at the central GSA is run through GAC canisters to remove VOCs.

Ground water treated at the eastern GSA ground water treatment facility was discharged off site to Corral Hollow Creek, in accordance with NPDES Permit No. CA0082651.

Table 8-5 shows the amount of the water treated and VOCs removed at the eastern GSA. The length of the eastern GSA TCE plume with concentrations over the cleanup standard of 5 ppb (MCL) has been reduced by more than 1400 m. The off-site portion of the plume now extends 200 m beyond the site boundary. TCE concentrations in influent from the eastern GSA ground water treatment system were reduced from 64 ppb in January 1992 to 3 ppb in November 1999. No longer do any off-site wells in the eastern GSA yield ground water TCE concentrations in excess of the cleanup standard of 5 ppb (MCL). LLNL estimates that 2 more years of ground water extraction and treatment will be required to achieve and maintain ground water VOC concentrations below MCLs at the eastern GSA.

At the central GSA, treated ground water was collected and batch-discharged in a remote Site 300 canyon, in accordance with the substantive requirement for wastewater discharge. TCE concentrations in central GSA ground water treatment system (GWTS) influent have been reduced from 9400 ppb in 1993 to 58 ppb in 1999. Volumes of water extracted and masses of VOCs removed from Central GSA ground water are tabulated in **Table 8-5**.

Four quarterly reports were submitted to the EPA and RWQCB in 1999 that detail the performance of the treatment facilities (Lamarre 1999a, b, c, and d). During 1999, the ground water extraction system at the central GSA was expanded to further contain the contaminant plume, increase mass removal, and eliminate contaminant sources as part



of a regulatory-driven milestone. Two monitoring wells located at known contaminant sources and one monitoring well located downgradient of the source were converted to extraction wells. With the increased flow, the existing treatment system was converted and upgraded from batch mode to continuous flow operation.

Following dewatering of bedrock through ground water extraction, soil vapor extraction and treatment of VOCs began in 1994. **Table 8-5** shows the amounts of soil vapor treated and VOCs removed at the central GSA. From 1994 through the end of 1998, VOC concentrations in the central GSA soil vapor extraction influent stream were reduced from 450 parts per million by volume (ppmv) to 2.3 ppmv. VOC concentrations in individual central GSA soil vapor extraction wells have also been significantly reduced.

The central GSA ground water treatment system is operating under substantive requirements for wastewater discharge issued by the Central Valley RWQCB. The central GSA treatment facility discharges to bedrock in the eastern GSA canyon, where the water percolates into the ground. The eastern GSA ground water treatment system operates under NPDES Permit No. CA0082651, issued by the Central Valley RWQCB for discharges into Corral Hollow Creek. The system operated under WDR91-052 until December 5, 1997, when WDR 97-242 was issued. Permit requirements for the central and eastern GSA ground water treatment system are listed in **Table 8-6**. Both the central and eastern GSA treatment systems operated in compliance with regulatory requirements during 1999. LLNL submitted quarterly reports for the GSA treatment systems to the California EPA and the RWQCB in accordance with the National Pollutant Discharge Elimination System Order No. 97-242 for the eastern GSA and the Substantive Requirements for Waste Discharge for the Central GSA (Lamarre 1999a, b, c, and d).

With the increased flow caused by the central GSA well field expansion, the existing treatment system was converted and upgraded from batch mode to continuous flow operation. An additional interlock was added to stop ground water extraction from all wells with pneumatic and electrical pumps during system shutdown. A new vortex meter was installed at the soil vapor extraction and treatment system to more accurately measure extracted air flow. A new 1000-gallon polyethylene effluent surge tank with liquid level switches replaced the Baker tank at the central GSA ground water extraction and treatment system.



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Ground Water Investigation and Remediation

Table 8-6. General Services Area ground water treatment system surface discharge permit requirements.

Parameter	Treatment facility	
	Central General Services Area	Eastern General Services Area
VOCs	Halogenated and aromatic VOCs	Halogenated VOCs
Maximum daily	5.0 µg/L	5.0 µg/L
Monthly median	0.5 µg/L	0.5 µg/L
Dissolved oxygen	Discharges shall not cause the concentrations of dissolved oxygen in the surface water drainage course to fall below 5.0 mg/L.	Discharges shall not cause the concentrations of dissolved oxygen in the surface water drainage course to fall below 5.0 mg/L.
pH (pH units)	Between 6.5 and 8.5, no receiving water alteration greater than ±0.5 units.	Between 6.5 and 8.5, no receiving water alteration greater than ±0.5 units.
Temperature	No alteration of ambient receiving water conditions more than 3°C.	No alteration of ambient receiving water conditions more than 3°C.
Place of discharge	To ground water during dry weather and to surface water drainage course in eastern GSA canyon during wet weather.	Corral Hollow Creek.
Flow rate	272,500 L (30-day average daily dry weather maximum discharge limit).	272,500 L per day.
Mineralization	Mineralization must be controlled to no more than a reasonable increment.	Mineralization must be controlled to no more than a reasonable increment.
Methods and detection limits for VOCs	EPA Method 601—detection limit of 0.5 µg/L. EPA Method 602—method detection limit of 0.3 µg/L.	EPA Method 601—detection limit of 0.5 µg/L.

Building 834 Complex

In 1999, the GWTS was operated at full scale. The system was automated to allow for 24-hour operation, in effect switching from a 5-day, 10-hour schedule, to around-the-clock operation for the five weekdays. The soil vapor extraction system tripled the mass removal at the site over 1998 by extracting an additional 7 kg of VOCs from the subsurface. To increase the effectiveness of the treatment system even more, LLNL expanded the extraction wellfield in 1999 by converting a number of monitoring wells into combined ground water and soil vapor extraction wells.

During 1999, there was a 357% increase in overall VOC mass removal over the removal in 1998. During 1998 the combined ground water and soil vapor VOC mass removal at Building 834 was 10.93 kg. During 1999, the combined VOC mass removal at Building 834 was 39.03 kg, of which 6 kg of VOCs were destroyed by in situ microbially mediated



reductive dehalogenation. The LLNL team working on Building 834 remediation received \$210,000 in additional funding to study the applicability of in situ bioremediation as a treatment technology (Ziagos et al. 1999). A peer-reviewed publication reported on the novel microbial process that exploits alkoxysiloxane lubricants as drivers for TCE bioattenuation at Building 834 (Halden et al. 1999).

Table 8-5 shows the amounts of water treated and VOCs removed at Building 834. Quarterly reports for the Building 834 treatment facility were submitted to the California EPA and the RWQCB in accordance with the Substantive Requirements for Waste Discharge (Lamarre 1999e, f, g, and h). Because treated ground water is discharged to misters and is not discharged to the ground, there are no treatment system surface discharge permit requirements for Building 834.

High Explosives Process Area

The final *Action Memorandum for the Building 815 Operable Unit Removal Action at Lawrence Livermore National Laboratory Site 300* (Ziagos and Jakub 1998) was submitted to the regulatory agencies on August 17, 1998. This report describes the main components of the removal action, estimates removal action costs, and addresses all verbal and written comments submitted by the community during the public workshop. The *Building 815 Removal Action Design Workplan for the High Explosives Process Area at Lawrence Livermore National Laboratory Site 300* (Ziagos and Reber-Cox 1998a) was submitted to the regulatory agencies on November 15, 1998. This report describes the removal action in more detail and provides a contingency plan to address foreseeable problems that may arise during this removal action.

Treatability testing began in 1998 to evaluate cost-effective ground water treatment technologies for the second phase of ground water cleanup. Removal and destruction technologies are being considered to remediate nitrates and HE compounds, including perchlorate. These technologies use granular-activated carbon, ion-exchange, or electro-migration for contaminant removal and ex-situ bioremediation for contaminant destruction. Phytoremediation, using indigenous grasses, is also being evaluated for treating nitrate-bearing ground water.

In 1999, a ground water treatment facility (B815-TF1) was installed near the Site 300 boundary to prevent off-site migration of VOCs in ground water. Using granular-activated carbon, the system pumps and treats water from two existing ground water monitoring wells. Depending on the performance from these two wells, additional wells may be added. **Table 8-5** shows amounts of water treated and VOCs removed in the treatment system.



8 Ground Water Investigation and Remediation

Pit 6 Landfill Area

The volume of water extracted and TCE mass removed during a hydraulic pump test at Pit 6 is tabulated in **Table 8-5**. The test ran from October 11 to December 3, 1998. The water was treated at an adjacent portable treatment unit using granular activated carbon.

Building 854 Area

In December 1999, a ground water treatment facility (B854-TF1) was installed near the TCE source area at Building 854F as a part of a ground water treatability study. The facility uses granular activated carbon to treat ground water and operates under draft waste discharge requirements. **Table 8-5** shows amounts of water treated and VOCs removed in the treatment system. Treated ground water is misted to air. A second facility will begin operation in the future.

Building 832 Canyon

The first step toward TCE mass removal in the operable unit (OU) was completed with the submittal and acceptance of the Building 832 Canyon OU Treatability Study Workplan in November 1997. This workplan set forth plans for ground water and soil vapor TCE extraction and treatment in 1999 and beyond, using portable treatment units, solar-powered water activated-carbon treatment units, and soil vapor extraction systems. Also under consideration is the use of a subsurface iron filings permeable reactive treatment wall in the lower canyon area to intercept the TCE-laden ground water, destroy the TCE and degradation products, and help control the migration of the TCE plume off site. In October 1999, the Building 832 Canyon ground water and soil vapor treatment system, B832-TF1, began continuous operation. This facility is operating under draft waste discharge requirements. **Table 8-5** shows volume of water treated and mass of VOCs removed in the treatment system. The treated water is discharged into the canyon.

Community Relations

During 1999, LLNL met three times with members of Tri-Valley Citizens Against a Radioactive Environment and their technical advisor as part of the activities funded by an EPA Technical Assistance Grant. A public workshop for the *Draft Site-Wide Feasibility Study* (Ferry et al. 1999) was held on March 23, 1999. A public workshop for the *Draft Site-Wide Proposed Plan* (Dresen et al. 1999) was held on December 30, 1999.



Ground Water Monitoring

*Eric Christofferson
Richard A. Brown
Sandra Mathews*

Introduction

Lawrence Livermore National Laboratory regularly samples and analyzes ground waters in the Livermore Valley and in the Altamont Hills. LLNL maintains multiple ground water monitoring programs to comply fully with environmental regulations, U.S. Department of Energy (DOE) orders, and the requirements of the Ground Water Protection Management Program (GWPMP). The objectives of the ground water monitoring programs described in this chapter are to measure compliance with waste discharge requirements and post-closure plans and to assess the impact, if any, of current LLNL operations on ground water resources.

DOE Order 5400.1 and the to-be-promulgated 10 CFR 834 require all DOE facilities to prepare a GWPMP that describes the site's ground water regime, areas of known contamination, remediation activities, programs to monitor the ground water, and the means to monitor and control potential sources of ground water contamination. Considerable ground water monitoring and remediation, discussed in Chapter 8, are carried out under Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) restoration efforts. Soil and sediment surveillance monitoring under the GWPMP is described in Chapter 10. Additional programs address the sanitary sewer system, building drains, and underground storage tanks.

Surveillance Monitoring

Ground water monitoring at LLNL complies with DOE Order 5400.1, which affirms DOE's commitment to protect the environment. LLNL conducts surveillance monitoring of ground water in the Livermore Valley and in the Altamont Hills through networks of wells and springs that include private wells off site and DOE CERCLA wells on site. The two monitored areas are not connected hydrologically; they are separated by a major drainage divide and numerous faults. The Livermore site in the Livermore Valley drains to San Francisco Bay via Alameda Creek. Most of Site 300 drains to the San Joaquin River Basin via Corral Hollow Creek, with a small undeveloped portion in the north draining to the north and east toward Tracy. In order to maintain a comprehensive, cost-effective monitoring program, LLNL determines the



9 Ground Water Monitoring

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 water resources. Because surveillance monitoring is geared to detecting substances at very low concentrations in ground water, it can detect contamination before it significantly impacts ground water resources. Wells at the Livermore site, in the Livermore Valley, and at Site 300 in the Altamont Hills are included in LLNL's surveillance monitoring plan. Historically, the surveillance and compliance monitoring programs have detected relatively elevated concentrations of various metals, nitrate, perchlorate, and depleted uranium (uranium-238) in ground water at Site 300. Subsequent CERCLA studies have linked several of these contaminants to past operations, while others are the objects of continuing study. Present-day administrative, engineering, and maintenance controls in place at both LLNL sites are specifically tailored to prevent damage to the environment.

Compliance Monitoring

The Compliance Ground Water Monitoring Program complies with numerous federal and state controls (see Chapter 2, **Table 2-4**, for a summary of LLNL permits). Compliance monitoring of ground water is conducted at Site 300 to satisfy state-issued permits associated with closed landfills containing solid wastes and with continuing discharges of liquid waste to surface impoundments, sewage ponds, and percolation pits. Ground water compliance monitoring at Site 300 is specified in Waste Discharge Requirement (WDR) orders issued by the Central Valley Regional Water Quality Control Board (CVRWQCB) and in landfill closure and postclosure monitoring plans. The WDRs and postclosure plans specify wells and effluents to be monitored, constituents of concern (COCs) to be measured, measurement frequency, inspections to be conducted, and the frequency and form of required reports. These monitoring programs include quarterly and semiannual monitoring of ground water, monitoring of various influent waste streams, and visual inspections. LLNL conducts additional operational monitoring of wastewater effluents discharged to surface impoundments and sewage evaporation and percolation ponds to comply with WDRs issued under California's Porter-Cologne Water Quality Control Act. Quarterly and annual written reports of analytical results, inspection findings, and maintenance activities are required for each monitoring network.

Table 9-1 in the Data Supplement shows the analytical methods and reporting limits for inorganic constituents (including specific radioisotopes analyzed by alpha spectroscopy and other sensitive methods), organic constituents, and radioisotopes in ground water.



Livermore Site and Environs

Livermore Valley

LLNL has monitored tritium in water hydrologically downgradient of the Livermore site since 1988. Tritium is potentially the most mobile ground water contaminant emanating from LLNL. Rain and storm water runoff in the Livermore Valley, which recharges local aquifers, contains small amounts of tritium from natural sources, past worldwide atmospheric nuclear weapons tests, and atmospheric emissions from LLNL. (See Chapters 4, 5, and 7 for further discussion of air emissions, rain, and storm water runoff.) Ground water samples were obtained during 1999 from 18 of 21 wells in the Livermore Valley (see **Figure 9-1**) and measured for tritium activity.

Ground water is recharged at the Livermore site from arroyos by rainfall. Recharge enters primarily through the arroyos (see also Chapter 7). Ground water flow at the Livermore site, which is generally westward, is discussed generally in Chapter 1 and

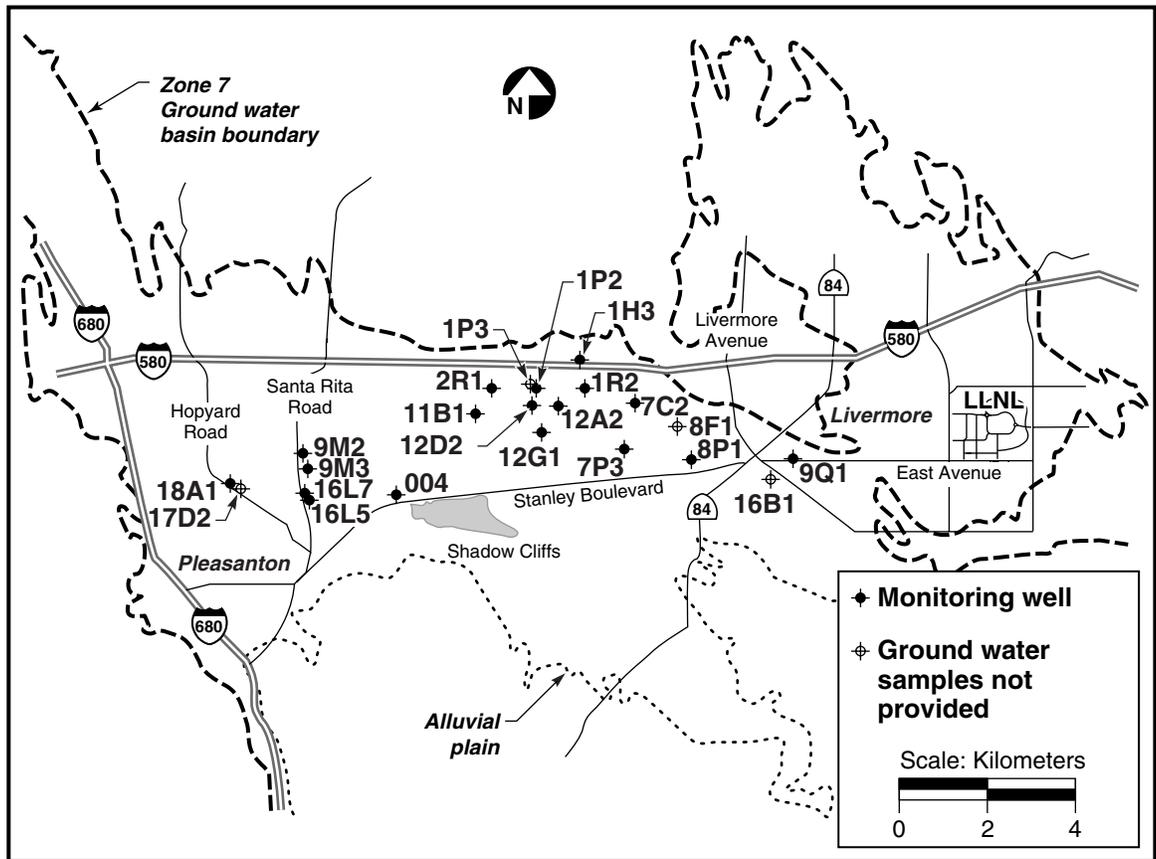


Figure 9-1. Locations of off-site tritium monitoring wells in the Livermore Valley.



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in detail in the *CERCLA Remedial Investigation Report for the LLNL Livermore Site* (Thorpe et al. 1990) and the annual *LLNL Ground Water Project* reports (Aarons et al. 2000).

Livermore Site Perimeter

LLNL designed a surveillance monitoring program to complement the Livermore Ground Water Project (discussed in Chapter 8). The intent of this network is to monitor for possible contaminants other than volatile organic compounds (VOCs), which are handled under the Livermore Site Ground Water Project. The perimeter portion of this surveillance ground water monitoring network makes use of three background monitoring wells near the eastern boundary of the site and seven western perimeter monitoring wells, located near the western boundary (see **Figure 9-2**). These seven wells located in the regions of Treatment Facilities A, B, and C (see **Figure 8-1**) meet the requirements of DOE Order 5400.1. These western perimeter wells monitor the uppermost aquifers for COCs that are outside, but very near to, the areas where ground water is being treated.

The screened interval for each surveillance monitoring well is in the uppermost saturated aquifer (or aquifers) at that well location. As discussed in Chapter 8, the alluvial sediments have been divided into seven hydrostratigraphic units (HSUs). HSUs are described in Chapter 8 and shown in **Figure 8-1**.

Two of the background wells, W-008 (screened in HSUs 3A/3B) and W-221 (screened in HSU 3A), were sampled and analyzed once for semivolatile organic compounds (SVOCs), semiannually for minerals, and quarterly for trace metals and most radioactive constituents in order to obtain sufficient data for statistical analyses. Background well W-017 (screened in the deeper HSU 5) was sampled and analyzed once during the third quarter for trace metals and radioactive constituents. The seven western perimeter wells screened in shallower HSUs 1B and 2 were sampled and analyzed annually for nonradioactive constituents and quarterly for many radioactive constituents. Each well was sampled and the water analyzed for metals and minerals, herbicides, gross alpha and beta, tritium, and other radioisotopes. Routine surveillance monitoring data for 1999 are presented in the Data Supplement (Tables 9-2 through 9-11). These monitoring results help establish baseline conditions for future monitoring and detect the presence of any COCs that may adversely affect public health or the environment.

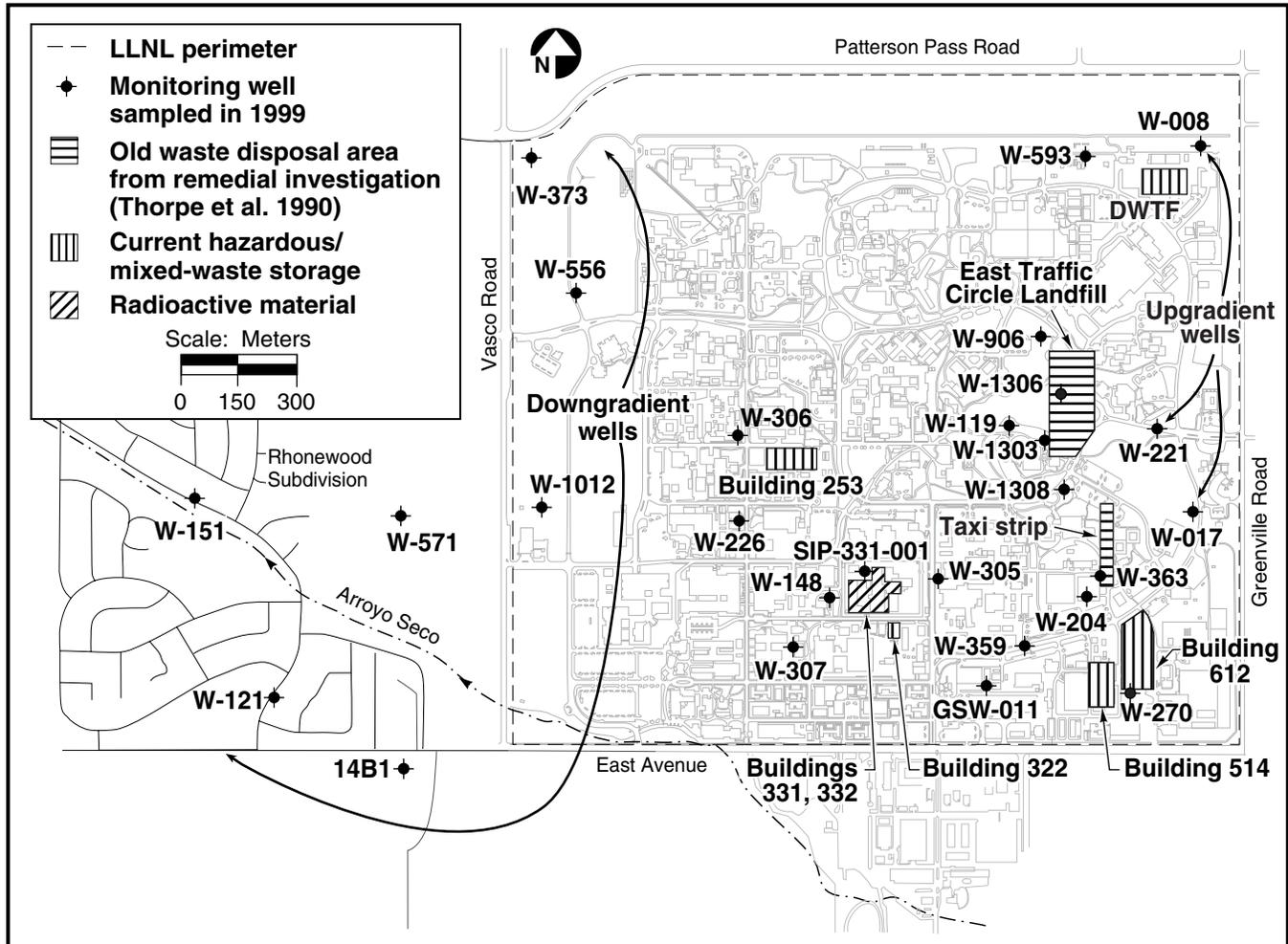


Figure 9-2. Locations of routine surveillance ground water monitoring wells at the Livermore site.

Livermore Site

Livermore site (interior) ground water sampling locations include areas where releases to ground may have occurred in the recent past or where previously detected COCs have low concentrations that do not require CERCLA remedial action. Monitoring wells screened in the uppermost aquifers are situated downgradient from, and as near as possible to, the potential release locations.

The Taxi Strip Area and the East Traffic Circle Landfill are two potential sources of ground water contamination for which surveillance monitoring wells were added to the surveillance monitoring network in 1997 (see **Figure 9-2**). Ground water samples from monitoring wells screened in HSUs 2 and 3A downgradient from the Taxi Strip Area and East Traffic Circle Landfill were analyzed for americium, plutonium, thorium,



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uranium, gross alpha and beta radiation, radium-226, radium-228, tritium, metals, polychlorinated biphenyls (PCBs), and general minerals. The locations of these wells—W-204, W-363, W-119, W-906, W-1303, W-1306, and W-1308—are shown in **Figure 9-2**. All surveillance monitoring analytical data for the Taxi Strip Area and the East Traffic Circle Landfill are presented in Data Supplement Tables 9-12 through 9-18.

Another potential source of ground water contamination is the Decontamination and Waste Treatment Facility (DWTF) in the northeastern portion of LLNL. Ground water samples were obtained downgradient from this facility from well W-593 during 1999 and were analyzed for the same suite of analytes as the East Traffic Circle Landfill and Taxi Strip Area (see Data Supplement Table 9-19).

The hazardous waste/mixed waste storage facilities around Buildings 514 and 612 are monitored by wells W-270, W-359, and GSW-011. These wells were sampled and analyzed for trace metals and radioactive constituents in 1999. In addition, ground water samples from well W-359 were also analyzed for minerals and for SVOCs. All surveillance monitoring analytical data from the Hazardous Waste Management Area are presented in Data Supplement Tables 9-20 through 9-22.

Ground water samples were also obtained downgradient from areas where minor releases of metals to 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. Soil samples obtained from the area show elevated concentrations (in comparison with LLNL's site background levels) of chromium, copper, lead, nickel, zinc, and occasionally other metals. LLNL removed contaminated soils near Building 322 in 1999 and replaced them with clean fill. The area was then paved over, making it less likely that metals will migrate from the site. Analytical results for dissolved metals in 1999 ground water samples are presented in Data Supplement Table 9-23.

Ground water samples were also obtained downgradient from a location where sediments containing metals (including cadmium, copper, lead, mercury, and zinc) had accumulated in a storm water catch basin near Building 253 (Jackson 1997). These ground water samples were obtained from monitoring wells W-226 and W-306 screened in HSUs 1B and 2, respectively. Analytical results for dissolved metals in these samples are presented in Data Supplement Tables 9-24 and 9-25.

The additional surveillance ground water sampling locations for 1999 surround the area where the Plutonium Facility (Building 332) and the Tritium Facility (Building 331) are located (see **Figure 9-2**). Possible contaminants include plutonium-239 and americium-241 from the Plutonium Facility and tritium from the Tritium Facility. Both plutonium and



americium are more likely to bind to the soils rather than to migrate into the ground water. Tritium, on the other hand, is likely to migrate into ground water if spilled in sufficient quantities. Upgradient of these facilities, well W-305 is screened in HSU 2; downgradient well W-148 is screened in HSU 1B; and SIP-331-001 is screened in HSU 2. Analytical results are presented in Data Supplement Tables 9-26 through 9-28.

Site 300

For surveillance and compliance ground water monitoring at Site 300, LLNL uses DOE CERCLA wells on site and private wells and springs off site. Representative ground water samples are obtained at least once per year; they are routinely measured for various elements (primarily metals), a wide range of organic compounds, nitrate, general radioactivity (gross alpha and gross beta), uranium activity, and tritium activity. Typically, Environmental Protection Agency- (EPA-) approved analytical methods are used because they are both accurate and sensitive. (See Data Supplement Table 9-1 for a complete list of COCs and for the EPA or other standard analytical methods used to measure them.)

Figure 9-3 shows the ground water sampling locations with wells and springs at Site 300. Although ground water from the uppermost water-bearing zone is the target of most of the sampling, at several locations up to three vertically separated water-bearing zones are sampled by means of multiple-completion installations fitted with Barcad devices. Barcads are identified in **Figure 9-3** by the capital letters A, B, and C at the end of a monitoring installation's identifier code. ("A" is assigned to the Barcad that samples the deepest of three, or deeper of two, water-bearing zones.)

Twelve ground water 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 (not shown in **Figure 9-3**) is located 6 km west of Site 300 in the upper reaches of the Livermore Valley watershed. Nine 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 that were installed for CERCLA characterization studies during the 1980s continue to be used to monitor several former landfills, a former open-air burn pit, two connected surface water impoundments, and two connected sewer ponds. The former landfills—which are identified as Pit 1, Pit 2, Pit 7 Complex, Pit 8, and Pit 9—are located in the Elk Ravine drainage area, while Pit 6, the former burn pit, the two surface



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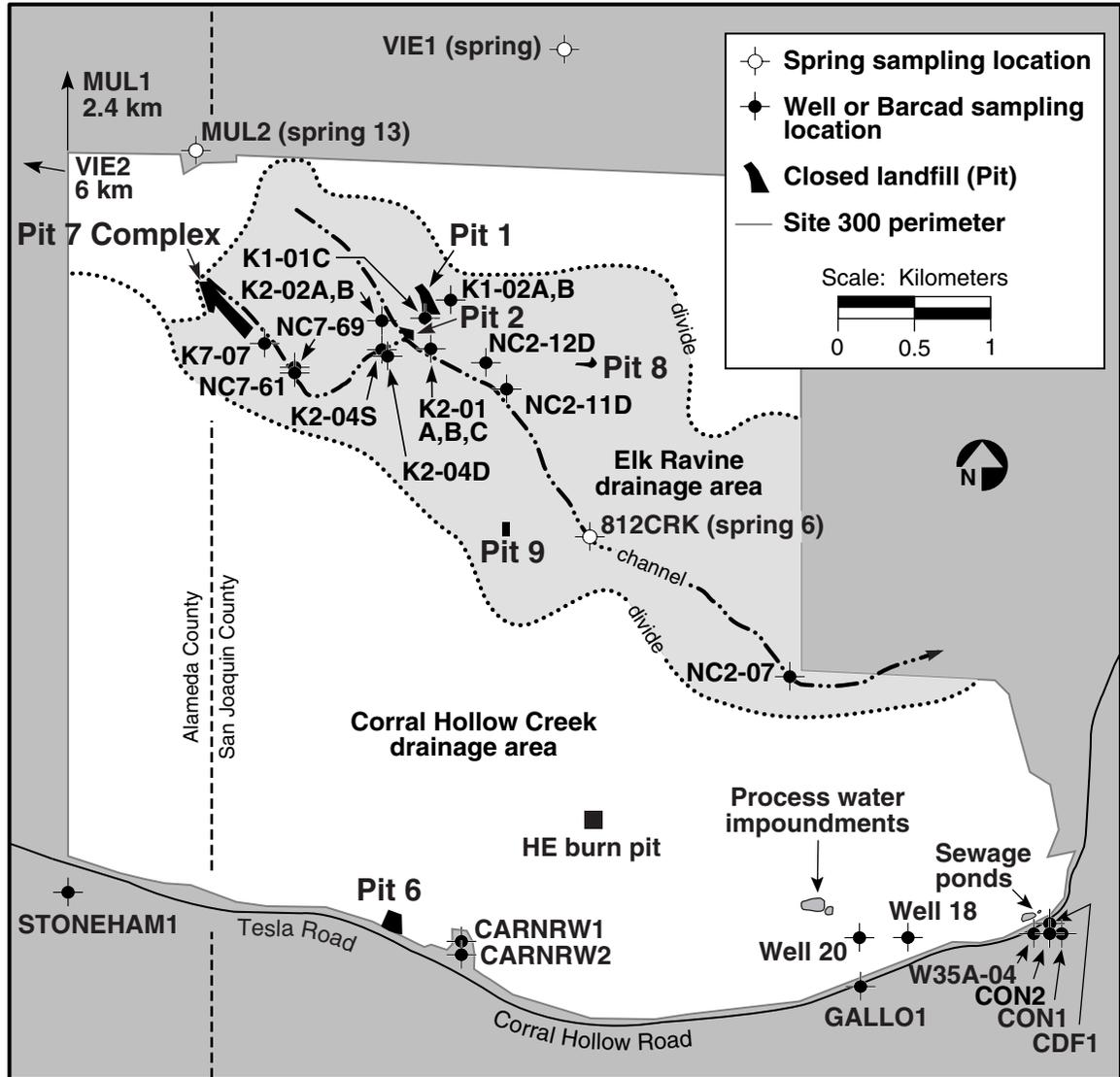


Figure 9-3. Locations of surveillance ground water wells, Barcads, and springs at Site 300.

impoundments, and the sewer ponds are located in the Corral Hollow Creek drainage area. Two on-site water supply wells, well 18 and well 20, are also used for surveillance monitoring purposes. Well 20 provides potable water to the site. Well 18 is maintained as a standby supply well.

Brief descriptions of the Site 300 ground water monitoring networks are given below. Networks within the Elk ravine drainage area are described first, followed by the networks in the Corral Hollow creek drainage area. CERCLA wells within Site 300 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 as described in Webster-Scholten 1994 (see also Chapter 8 for a summary of Site 300 stratigraphy and hydrogeology.) Ground water measurements made during 1999 that have not been published elsewhere are listed in tables in the Data Supplement that accompanies this volume. References to the publications that contain the remaining ground water data collected during 1999 are cited herein.

Elk Ravine Drainage Area

The Elk Ravine drainage area, a branch of the Corral Hollow Creek drainage system, includes most of northern Site 300 (see **Figure 9-3**). Storm water runoff from closed landfills within the Elk Ravine drainage area (Pits 1–5 and 7–9) collects in arroyos and quickly infiltrates into the ground. Ground water from wells that lie within the Elk Ravine drainage area are monitored for COCs because of the system of surface and underground flows that connect the entire Elk Ravine drainage area. The area contains eight of the nine closed landfills (Pits 1–5 and 7–9) and a number of firing tables where explosives tests have been conducted. The following descriptions of monitoring networks within Elk Ravine begin with the headwaters area and proceed downstream. (See Chapter 8 for a review of ground water contamination in this drainage area as determined from numerous CERCLA investigations.)

Pit 7 Complex

Monitoring requirements for the closed Pit 7 landfill in the Elk Ravine drainage area are specified in *Waste Discharge Requirements Order 93-100* (WDR 93-100) administered by the CVRWQCB (1993 and 1998) and in *LLNL Site 300 RCRA Closure and Post-Closure Plans— Landfill Pits 1 and 7* (Rogers/Pacific Corporation 1990).

The 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 comprises four adjacent landfills identified as Pits 3, 4, 5, and 7 (see **Figure 9-4**). From 1963 to 1988, the landfills received waste gravels and debris from hydrodynamic tests of explosive devices conducted on firing tables at Site 300. The gravels contained concrete, cable, plastic, wood, tritium, depleted uranium (uranium-238), beryllium, lead, and other metals in trace amounts. In 1988, 9440 m³ of gravel were removed from six firing tables at Site 300 and placed in Pit 7 (Lamarre and Taffet 1989). These were the last solid wastes to be placed in a landfill at Site 300.



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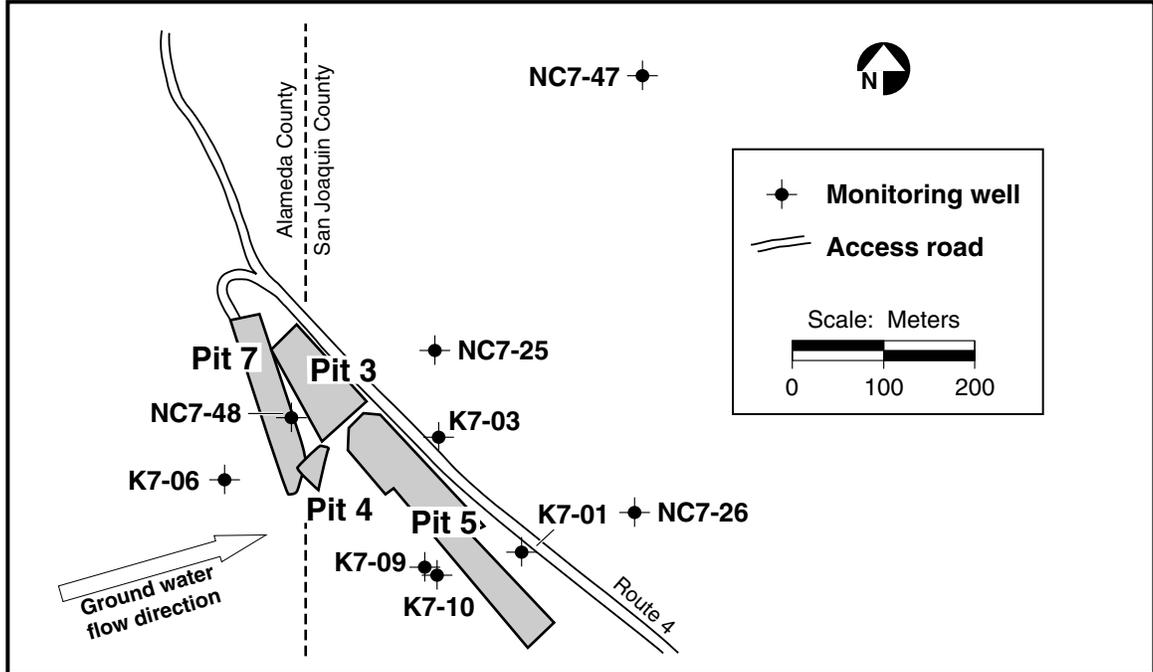


Figure 9-4. Locations of compliance ground water monitoring wells, Pit 7 complex.

The main objective of monitoring is the early detection of any release of COCs from Pit 7 to ground water. All detected COCs are investigated. Most of the COCs detected by the Pit 7 monitoring network have been previously linked to historical releases from other pits near Pit 7. Detected COCs such as arsenic, barium, and uranium are released from the underlying rocks and sediments where they occur naturally. Comparison of new data with historical data helps analysts to identify releases from wastes buried in Pit 7, versus releases from sources other than Pit 7, including natural sources. Most of the COCs detected during 1999 in the ground water near Pit 7 were released historically from Pits 3 and 5 (Webster-Scholten 1994). (See Chapter 8 for a review of the stratigraphy, hydrogeology, and ground water contamination in the Pit 7 area.)

As required by the monitoring and reporting program contained in WDR 93-100, LLNL obtained ground water samples quarterly from Pit 7 monitoring wells during 1999 and analyzed them 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). Field measurements of ground water depth, temperature, pH, and specific conductance were obtained at each well at the time of sample collection. Three quarterly reports and one annual report covering monitoring activities at Pit 7 during 1999 have been published previously (Christofferson and MacQueen 1999a, 1999b, 1999c, 2000). Tables and graphs of Pit 7 ground water data for 1999 can be found in *LLNL Experimental Test Site 300*



Compliance Monitoring Program for RCRA-Closed Landfill Pits 1 and 7, Annual Report for 1999 (Christofferson and MacQueen 2000).

Elk Ravine

As planned, ground water samples were obtained twice (semiannually) during 1999 from the widespread Elk Ravine surveillance monitoring network. Samples were analyzed for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), tritium and uranium activity, explosive compounds (HMX and RDX), and VOCs (EPA Method 601).

Pit 2

The closed Pit 2 landfill lies in the upper portion of Elk Ravine, about 320 m above sea level (**Figures 9-3 and 9-5**). The landfill primarily contains gravels and debris from hydrodynamic tests of explosive devices conducted at the Building 801 and 802 firing tables. The buried waste material contains depleted uranium (uranium-238), and trace amounts of beryllium, thorium, and (possibly) tritium.

As planned for surveillance purposes, LLNL obtained ground water samples twice (semiannually) during 1999 from the Pit 2 monitoring network (comprising mostly Barcad installations) and analyzed them for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium and uranium), and explosive compounds (HMX and RDX).

Pit 1

Monitoring requirements for the closed Pit 1 landfill are specified in *Waste Discharge Requirements Order 93-100* (WDR 93-100) administered by the CVRWQCB (1993 and 1998) and in *LLNL Site 300 RCRA Closure and Post-Closure Plans— Landfill Pits 1 and 7* (Rogers/Pacific Corporation 1990).

Pit 1 lies in the Elk Ravine drainage area about 330 m above sea level. The Resource Conservation and Recovery Act (RCRA)-closed Pit 1 landfill and the positions of the eight ground water wells used to monitor it are shown in **Figure 9-5**.

As required by the monitoring and reporting program contained in WDR 93-100, LLNL obtained ground water samples from Pit 1 monitoring wells every quarter during 1999. 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



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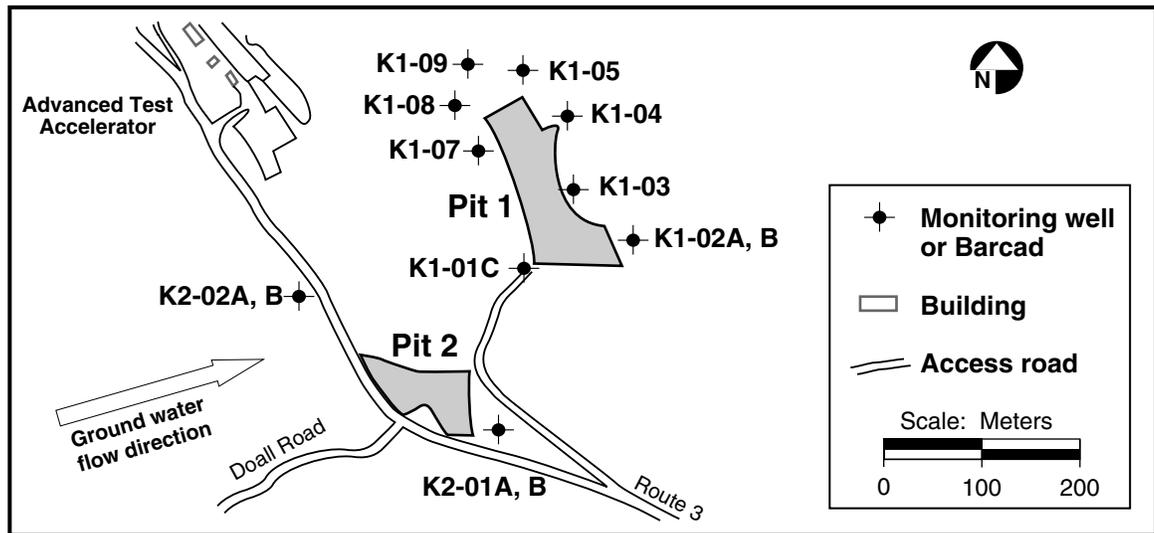


Figure 9-5. Locations of Pit 2 surveillance Barcads (K1-02A, K2-01A, K2-01B, and K2-02A) and surveillance well K2-02B, and Pit 1 compliance ground water monitoring wells (K1-01C, -07, -02B, -03, -04, -05, -08, and -09).

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 ground water depth, temperature, pH, and specific conductance were obtained at each well at the time of quarterly sample collection. Three quarterly reports and one annual report covering monitoring activities at Pit 1 during 1999 have been published previously (Christofferson and MacQueen 1999a, 1999b, 1999c, 2000). Tables and graphs containing Pit 1 ground water data for 1999 can be found in *LLNL Experimental Test Site 300 Compliance Monitoring Program for RCRA-Closed Landfill Pits 1 and 7, Annual Report for 1999* (Christofferson and MacQueen 2000).

Pit 8

The closed Pit 8 landfill is located in the Elk Ravine drainage area adjacent to the Building 801 firing table, where explosives experiments were conducted from 1958 to 1974. Approximately 40 m³ of untreated debris from the firing table were placed in the pit during that time. Buried debris may contain trace amounts of tritium, depleted uranium (uranium-238), lead, and beryllium.

Figure 9-6 shows the Building 801 and Pit 8 areas and the locations of the monitoring wells. The pit is located in a narrow ravine within the Elk Ravine drainage area about 350 m above sea level. Chemical analysis of soil and rock samples obtained from this area during CERCLA remedial investigations detected no COCs above background concentrations (Webster-Scholten 1994). However, low concentrations



of trichloroethylene (TCE) have been detected in ground water samples from Pit 8 surveillance monitoring wells, including upgradient well K8-01, since 1987. Previous remedial investigation links the TCE to a dry well near Building 801 that was once used to dispose liquid wastes (Webster-Scholten 1994).

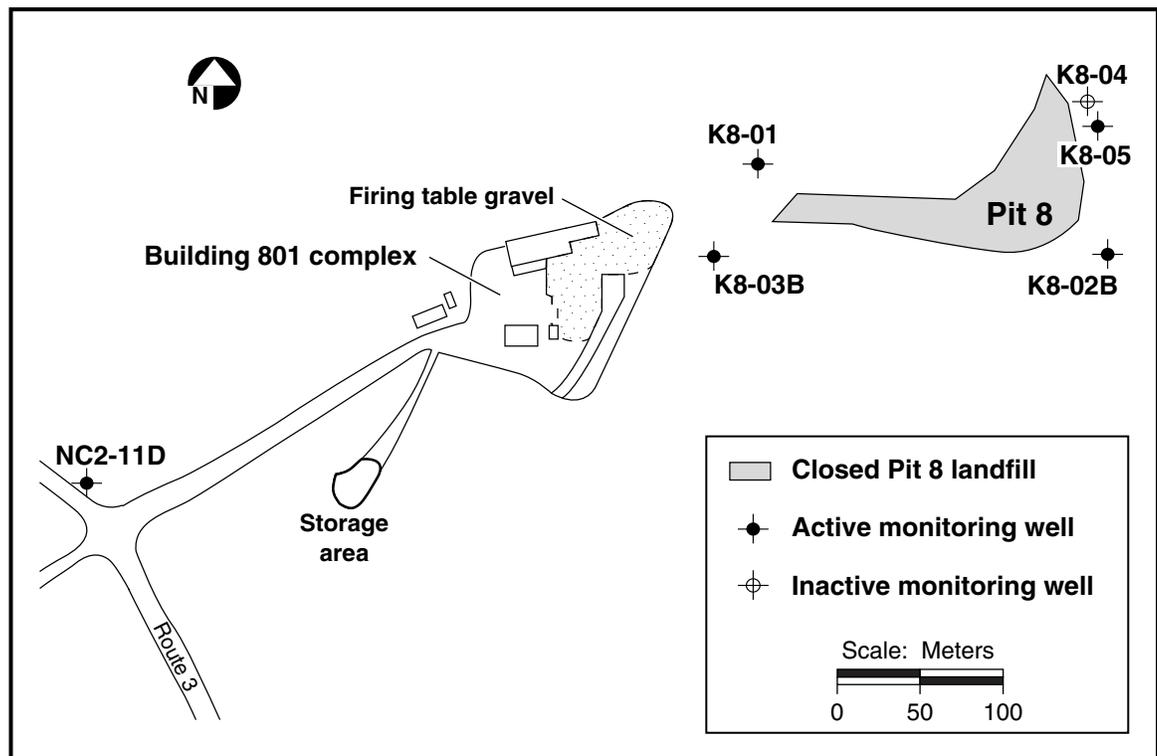


Figure 9-6. Locations of surveillance ground water monitoring wells, Pit 8, 1999.

Because of construction activities in the vicinity of Pit 8, ground water samples could be obtained from only two surveillance monitoring wells during 1999. Ground water samples from wells K8-01 and K8-02B were analyzed for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium and uranium), explosive compounds (HMX and RDX), and VOCs (EPA Method 601).

Pit 9

The Pit 9 landfill is centrally located within Site 300 about 340 m above sea level. Similar to the other closed landfills in Elk Ravine, the closed Pit 9 landfill contains firing table gravels and debris from explosives experiments conducted on the Building 845 firing table nearby.



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Figure 9-7 shows the locations of the four surveillance wells used to monitor the ground water in the vicinity of Pit 9. Ground water flows east-northeasterly beneath Pit 9 in the Neroly lower blue sandstone unit (Tnbs₁). The water table lies about 40 m below the ground surface at Pit 9. Monitoring well K9-02 is hydrologically upgradient from Pit 9, and wells K9-01, K9-03, and K9-04 are downgradient.

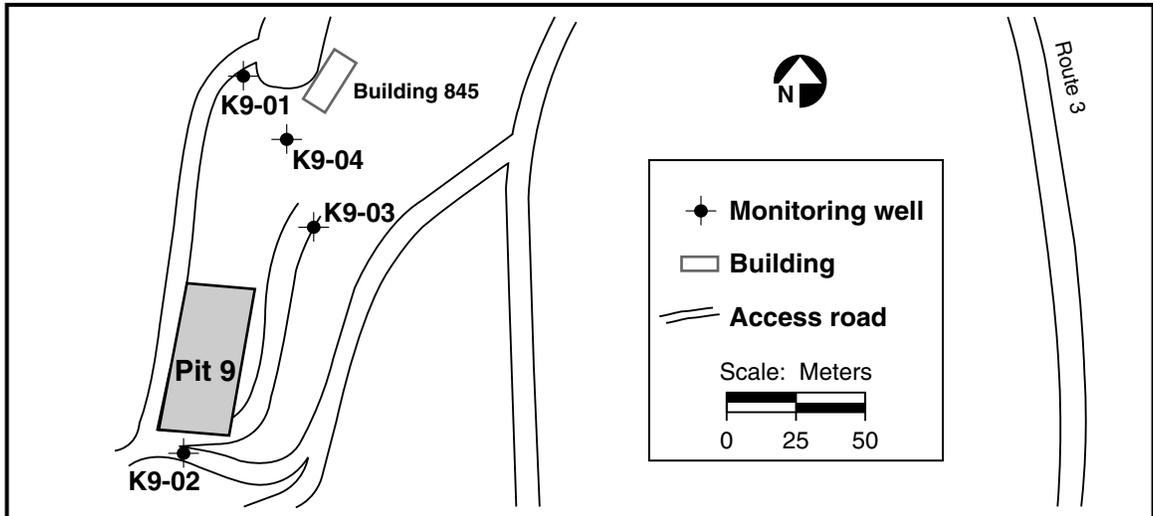


Figure 9-7. Locations of surveillance ground water monitoring wells, Pit 9, 1999.

As planned for surveillance purposes, the four Pit 9 monitoring wells were sampled once (annually) during 1999. Ground water samples from the four wells were analyzed for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium and uranium), explosive compounds (HMX and RDX), VOCs (EPA Method 601), and extractable organics (EPA Method 625).

Corral Hollow Creek Drainage Area

This section describes the ground water monitoring networks that are located in the southern half of Site 300 where runoff and ground water flow south to Corral Hollow creek. (See Chapter 8 for a review of ground water contamination in this drainage area as determined from numerous CERCLA investigations.)

Pit 6

Compliance monitoring requirements for the closed Pit 6 landfill in the Corral Hollow Creek drainage area are specified in the *Post-Closure Plan for the Pit 6 Landfill Operable Unit Lawrence Livermore National Laboratory Site 300* (Ferry et al. 1998). The closed Pit 6 landfill covers an area of about 1 hectare (2.5 acres). Its elevation is approximately 215 m above



sea level. From 1964 to 1973, approximately 1500 m³ of solid wastes were buried there in nine separate trenches. The trenches were not lined, consistent with historical disposal practices. Three larger trenches contain 1300 m³ of solid waste that includes empty drums, glove boxes, lumber, ducting, and capacitors. Six smaller trenches contain 230 m³ of biomedical waste, including animal carcasses and animal waste. Minor releases of VOCs—primarily the solvent TCE, and tritium—occurred prior to closure. During 1997, a multilayered cap was constructed over all the trenches, and a drainage control system was installed around the cap. The cap and the drainage control system are engineered to keep rainwater from contacting the buried waste (Ferry et al. 1998).

The Pit 6 disposal trenches were constructed in Quaternary terrace deposits (Qt) above and north of the Corral Hollow Creek flood plain. Surface runoff from the pit area flows southward to Corral Hollow Creek. The Carnegie-Corral Hollow Fault zone extends beneath the southern third of Pit 6. The northern limit of the fault zone is shown in **Figure 9-8**. Beneath the northern two-thirds of Pit 6, ground water flows south-southeast, following the inclination (dip) of the underlying sedimentary rocks. Ground water seepage velocities are less than 10 m/y. Depths to the water table range from 10–20 m. Beneath the southern third of Pit 6, a trough containing terrace gravel within the fault zone provides a channel for ground water to flow southeast, parallel to the Site 300 boundary fence (Webster-Scholten 1994). (See Chapter 8 for a review of the stratigraphy, hydrogeology, and ground water contamination in the Pit 6 area.)

Two ground water monitoring programs were implemented at the Pit 6 landfill during 1998 to ensure compliance with all regulations: (1) The Detection Monitoring Program (DMP), designed to detect any new release of COCs to ground water from wastes buried in the Pit 6 landfill, and (2) the Corrective Action Monitoring Program (CAMP), which operates under CERCLA, and monitors the movement of existing releases (see Chapter 8 for a summary of CAMP monitoring results for Pit 6). Twenty-four COCs, including VOCs and radioisotopes, are monitored in ground water near Pit 6 (Ferry et al. 1998). **Figure 9-8** shows the locations of Pit 6 and the wells used to monitor ground water there.

As required by the monitoring program contained in the postclosure plan, ground water at the Pit 6 monitoring wells was sampled quarterly during 1999. Samples were analyzed for inorganic COCs (mostly metals), general radioactivity (gross alpha and beta), tritium activity, uranium activity, VOCs (EPA Method 624), extractable organics (EPA Method 625), pesticides and PCBs (EPA Method 608), and herbicides (EPA Method 615). Field measurements of ground water depth, temperature, pH, and specific conductance were obtained at each well at the time of sample collection. Three quarterly reports and one annual report covering monitoring activities at Pit 6 during 1999 have been published previously (Christofferson and Taffet 1999a, 1999b, 1999c, 2000). Tables listing the 1999 ground water data for Pit 6 can be found in Christofferson and Taffet 2000.



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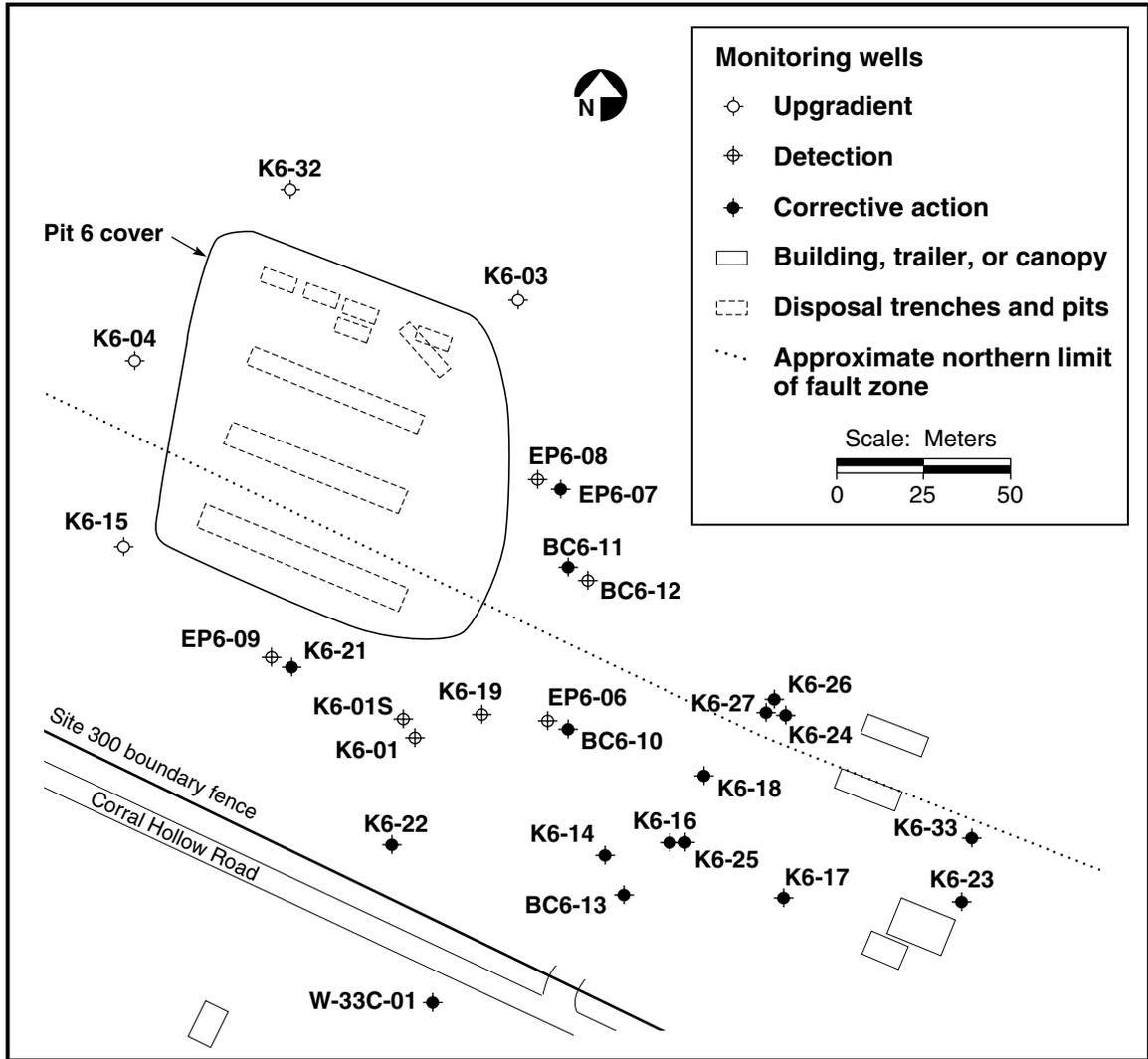


Figure 9-8. Locations of Pit 6 ground water monitoring wells.

HE Process Area Closed Burn Pits

The former High-Explosives (HE) Open Burn Treatment Facility, part of the Building 829 Complex, is located on a ridge within the southeast portion of Site 300 at an elevation of about 320 m (1050 ft) (see **Figure 9-9**). The facility included three shallow unlined pits constructed in unconsolidated sediments that cap the ridge (Tps formation). The former burn facility was covered with an impervious cap during 1998 following RCRA guidance. The facility was used to thermally treat explosives waste generated by research operations at Site 300. Surface water drains southward from the facility toward Corral Hollow Creek. The nearest site boundary lies about 1.6 km (4500 ft) to the south

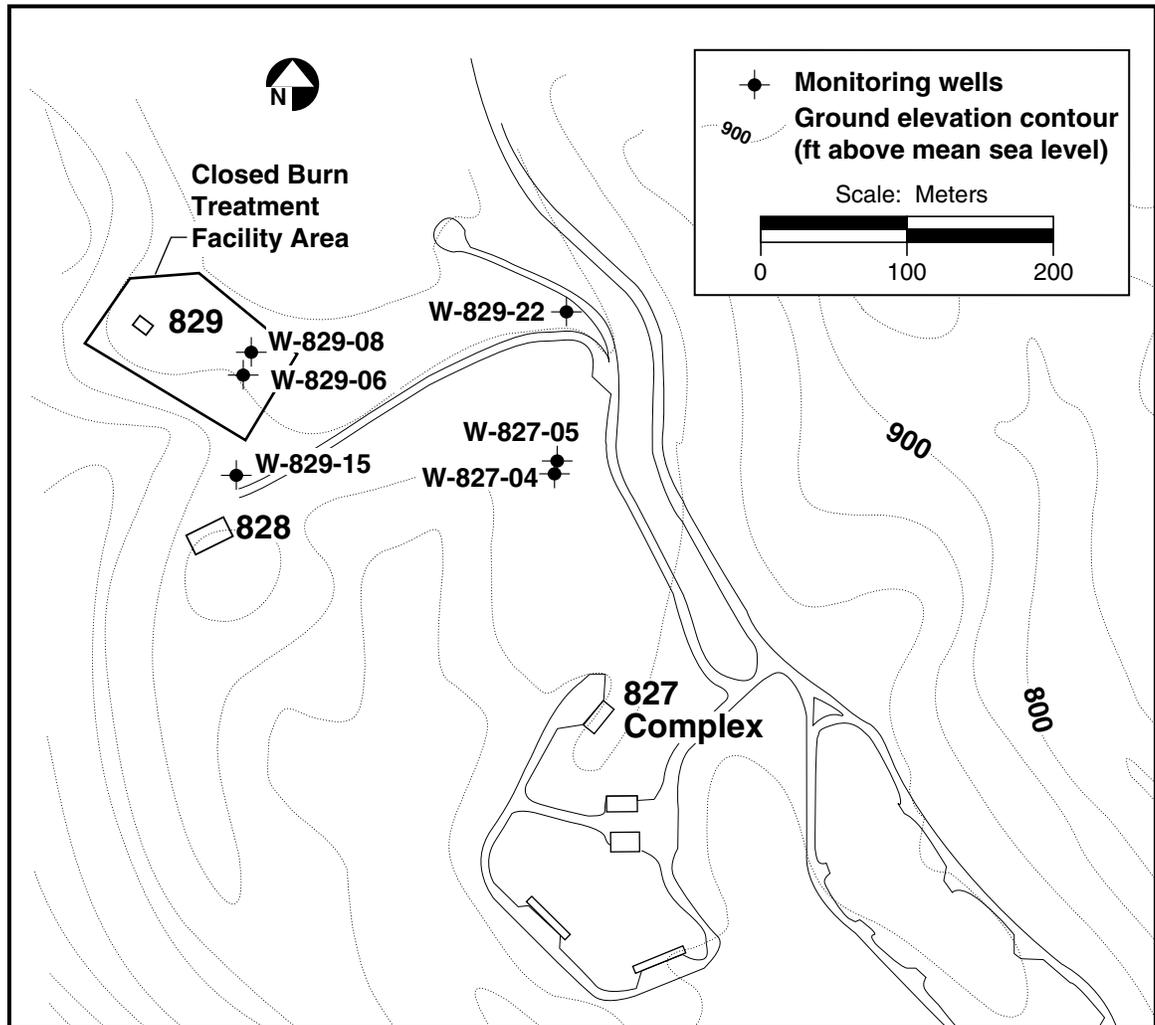


Figure 9-9. Locations of monitoring wells in Building 829 closed burn facility area.

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 (100 ft), is perched within the Neroly upper siltstone/claystone aquitard (Tnsc₂). The deeper zone, at a depth of about 120 m (400 ft), represents a regional aquifer within the Neroly upper sandstone member (Tnbs₂). (See Chapter 8 for a review of the stratigraphy, hydrogeology, and ground water contamination in this area.)

Based on ground water samples recovered from boreholes, previous CERCLA remedial investigations determined that the perched ground water beneath the burn facility was contaminated with VOCs, primarily TCE, but that the deeper regional aquifer was free of any contamination stemming from operation of the facility (Webster-Scholten 1994).



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Subsequent assays of soil samples obtained from shallow boreholes prior to closure revealed that low concentrations of HE compounds, VOCs, and metals exist beneath the burn pits (Mathews and Taffet 1997). Conservative transport modeling indicates that the shallow contamination will not adversely impact the regional aquifer, primarily because its downward movement is blocked by a 100-m-thick intervening aquitard. However, beginning in 1999, LLNL implemented the intensive ground water monitoring program for this area described in the post-closure plan (Mathews and Taffet 1997) to track the fate of contaminants in the perched water-bearing zone and to watch the deep regional aquifer for the appearance of any potential contaminants from the closed burn facility.

Figure 9-9 shows the locations of the closed burn treatment facility area and the six wells used to monitor the ground water. Two wells, W-829-06 and W-829-08, are screened in the perched water-bearing zone beneath the former burn facility. The remaining four wells are screened in the deep regional aquifer downgradient of the closed facility. During 1999, quarterly samples were obtained from five of the six monitoring wells. One of the deep wells, W-829-04, was dry during 1999. Ground water samples from the wells screened in the deep regional aquifer were analyzed quarterly for inorganic COCs (mostly metals), general minerals, explosive compounds (HMX, RDX, and TNT), VOCs (EPA Method 624), extractable organics (EPA Method 625), pesticides and PCBs (EPA Method 608), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium, radium, and uranium), total organic carbon (TOC), total organic halides (TOX), and coliform bacteria. Ground water samples from the two wells screened in the shallow perched water-bearing zone were analyzed for explosive compounds and VOCs for the first three quarters of 1999. Fourth-quarter samples of the perched ground water were subjected to the same analyses as described above for the deep ground water in the regional aquifer.

Water Supply Wells

Water supply wells 18 and 20 are located in the southeastern part of Site 300 (**Figure 9-3**). Both are deep, high-production wells. Well 20 supplied potable water at the site during 1999, while well 18 was maintained as a standby water supply well. Both wells are screened in the Tnbs₁. The well 18 screen extends upwards into the aquitard unit (Tnsc₁) that separates the upper (Tnbs₂) and lower blue sandstone units of the Neroly Formation. Each well can produce up to 1500 L/min of potable water. For many years, well 18 ground water samples have shown trace amounts of TCE. CERCLA studies have not yet determined the source of the TCE in well 18 (see Chapter 8 for locations of TCE plumes at Site 300).



As planned for surveillance purposes, ground water samples were obtained quarterly from these two on-site supply wells. Quarterly water samples from well 20 were analyzed for inorganic COCs (mostly metals), VOCs (EPA Method 502.2) explosive compounds (HMX, RDX), general radioactivity, and tritium activity. Quarterly water samples from standby well 18 were analyzed for arsenic, zinc, and VOCs; general radioactivity (gross alpha and gross beta); and tritium.

Explosives Process Area

WDR Order No. 96-248 establishes the basis for compliance monitoring of the two adjacent surface impoundments (see **Figure 9-10**). This includes quarterly monitoring of the ground water, monitoring of various influent waste streams to the surface impoundments, and visual observations of leachate collection and removal systems. Influent wastewater monitoring complements administrative controls that regulate the discharge of chemicals that could degrade the polyethylene liners of the impoundments. A three-tiered monitoring program comprising weekly visual inspections of the leachate collection and removal systems, quarterly inspections of lysimeters, and quarterly sampling of monitoring wells is in place to detect any release of chemicals from the surface impoundments in the Explosives Process Area.

As part of the Monitoring and Reporting Program (MRP) for the surface impoundments, contained in WDR 96-248, LLNL is required to obtain ground water samples quarterly from four monitoring wells (see **Figure 9-10**) and to establish statistical concentration limits for COCs in ground water beneath the surface impoundments.

WDR 96-248 establishes limits for discharges of COCs into the surface impoundments and requires monitoring of the photographic process and chemistry area wastewater retention tanks that discharge to the surface impoundments as well as direct discharges to the surface impoundments from explosives processing. Influent streams are monitored at a prescribed frequency for area-specific COCs.

Retention tanks containing photographic process rinsewater from Buildings 801, 823, 850, and 851 are sampled to confirm that discharges are consistent with effluent discharge limits specified in WDR 96-248. Discharges to the surface impoundments occur after samples are obtained, except for rinsewater from the Building 823 retention tanks, which is discharged automatically to the surface impoundments and sampled quarterly.

Samples of process wastewater from the Chemistry Area (Buildings 825, 826, and 827 complex) are collected when the retention tanks are ready for discharge to the surface impoundments. The wastewater is held in retention tanks until analytical results indicate compliance with WDR 96-248.



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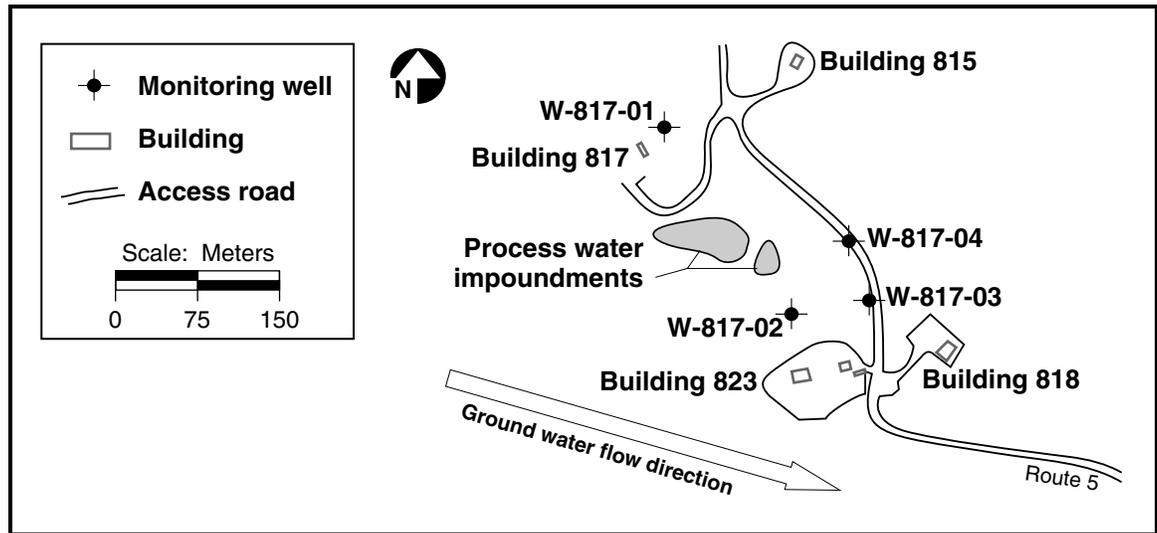


Figure 9-10. Locations of compliance ground water monitoring wells in the Explosives Process Area.

Process water discharges to the surface impoundments are analyzed for COCs that have been found (or are likely to be found) in the process water from each specified building within the Explosives Process Area. This monitoring program includes process area wastewater from Buildings 806/807, 809, and 817. WDR 96-248 requires annual analysis of this waste stream from Buildings 806/807, 809, and 817.

Percolation Pits

Percolation pits that are designed to accept discharges from mechanical equipment are located at Site 300 Buildings 806A, 827A, 827C, 827D, and 827E. In other remote Site 300 facilities, these types of waste streams are discharged to septic systems. This discharge is permitted by WDR 96-248. WDR 96-248 specifies monthly observations and monitoring requirements for overflows. Overflows of the percolation pits, should they occur, are sampled and analyzed to determine if any metals are present.

Sewage Evaporation and Percolation Ponds

Site 300 is not serviced by a publicly owned treatment works (POTW) as is the Livermore site; therefore, alternate methods of treating and disposing of sanitary waste are necessary. Sewage generated at buildings in the General Services Area is discharged into a lined evaporation pond. The wastewater is disposed of through evaporation from the pond. However, during rare periods of high rainfall, treated wastewater may overflow into an unlined percolation pond, where it enters the ground and the shallow ground water.



The environmental monitoring requirements for the sewage evaporation and percolation ponds (hereafter sewage ponds) are specified in MRP 96-248. The monitoring requirements include both wastewater monitoring and monitoring of the ground water to detect potential impacts of the sewage on ground water quality.

Wastewater is sampled quarterly at an influent location (ISWP) and within the pond (ESWP). Overflows are sampled as needed at location DSWP. The sampling locations are shown in **Figure 9-11**.

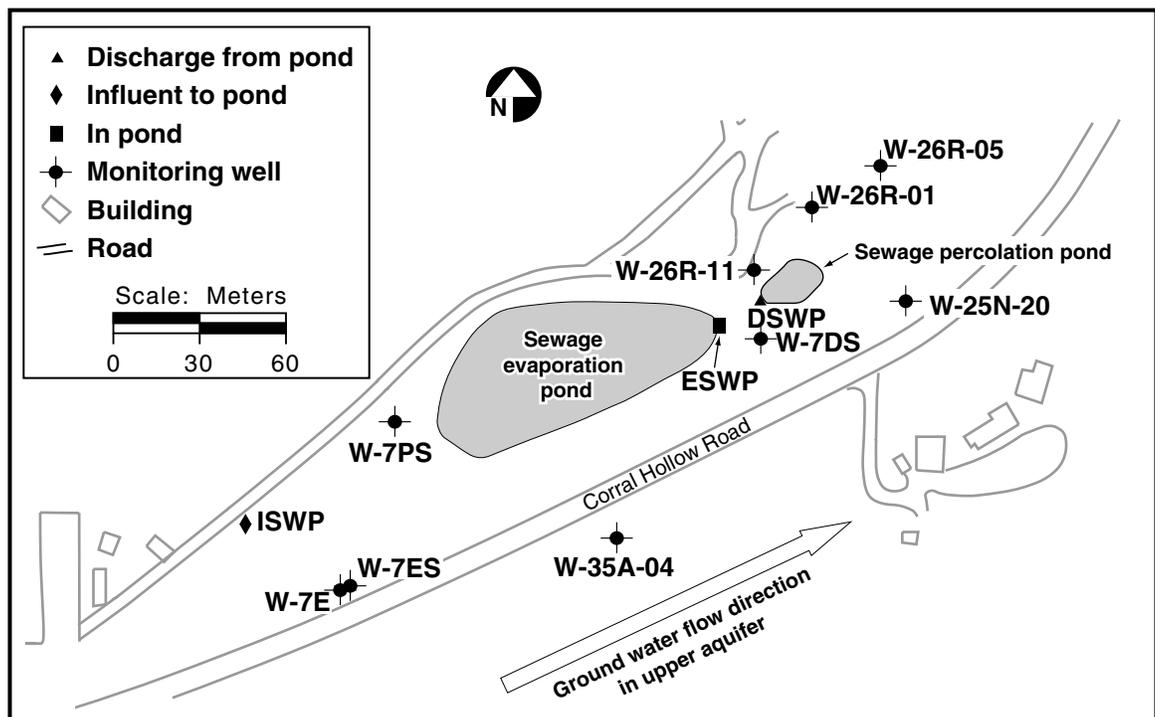


Figure 9-11. Sewage evaporation and percolation ponds, compliance ground water monitoring wells, and wastewater monitoring locations.

Nine ground water monitoring wells are sampled semiannually to provide information on the ground water quality in the vicinity of the sewage ponds (**Figure 9-11**). The wells are screened in three different geological formations (Qal, Tnbs₁, and Tnsc₁—see Chapter 8). Tnbs₁ (Neroly Formation lower blue sandstone unit) is the regional aquifer.

Off-site Surveillance Wells and Springs

As planned for surveillance purposes, ground water samples were obtained from two off-site springs and ten off-site wells during 1999. With the exception of one well, all off-site monitoring locations are near Site 300. The exception, well VIE2, is located at



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a private residence 6 km west of the site. It represents a typical Altamont Hills potable water supply well. 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 W-35A-04, are adjacent to the site on the south (**Figure 9-3**). Seven of the wells to the south are privately owned and were constructed to supply water for human consumption, stock watering, or fire suppression. The exception is well W-35A-04, which is a DOE CERCLA well that was installed for monitoring purposes only.

Ground water samples were obtained quarterly during 1999 at six off-site surveillance well locations south of Site 300. Of these, CARNRW1 and CON2 samples were analyzed for VOCs only (EPA Method 601). Samples from CARNRW2, CDF1, CON1, and GALLO1 were analyzed quarterly for inorganic COCs (mostly metals), general radioactivity (gross alpha and beta), tritium activity, explosive compounds (HMX and RDX), and VOCs (EPA Method 502.2). Additional analyses were conducted on third-quarter samples for uranium activity, extractable organics (EPA Method 625), pesticides and PCBs (EPA Method 608), and herbicides (EPA Method 615).

Ground water samples were obtained once (annually) during 1999 from four off-site surveillance monitoring locations—MUL1, MUL2, VIE1, and VIE2 (north of Site 300) and STONEHAM1 and W-35A-04 (south of Site 300). Samples were analyzed for inorganic COCs (mostly metals), general radioactivity (gross alpha and beta), tritium and uranium activity, explosive compounds (HMX and RDX), VOCs (EPA Method 502.2), extractable organics (EPA Method 625), pesticides and PCBs (EPA Method 608), and herbicides (EPA Method 615).

Sampling and Analytical Methods

Representative samples of ground water were obtained from monitoring wells in accordance with the *LLNL Livermore Site and Site 300 Environmental Restoration Project Standard Operating Procedures (SOPs)* (Dibley and Depue 1999). These protocols cover sampling techniques and specific information concerning the chemicals in ground water that are routinely searched for. Different sampling techniques were applied to different wells depending on whether they were fitted with submersible pumps, had to be bailed, or contained Barcad devices. See the Data Supplement for sampling details.

At Site 300, wastewater samples from the photographic and explosives process areas, sewage evaporation pond influent, water in the pond, and overflow water from the percolation pits pond were obtained in accordance with the standardized procedures



of the Operations and Regulatory Affairs Division (Tate et al. 1999). Standard sample handling and hygiene procedures were employed to prevent cross-contamination (e.g., wearing disposable gloves, decontaminating equipment between uses, and maintaining samples at $4 \pm 2^\circ\text{C}$). Replicates, field blanks, and trip blanks were obtained for quality assurance/quality control purposes. Analyses were performed by state-certified contract analytical laboratories.

Technologists collected wastewater samples from retention tanks in the Chemistry Area associated with Buildings 825, 826, and 827 using Hazardous Waste Management Procedure 411. Wastewater was held in retention tanks until analytical results were reviewed for compliance with WDR 96-248. Some of the analyses were performed by LLNL, which is state-certified for some analyses. The remainder of the analyses were done by off-site contract laboratories late in the year.

Results

This section presents the monitoring results for the Livermore site and environs as well as Site 300.

Livermore Site and Environs

Livermore Valley

Measurements of water samples obtained during the summer of 1999 from 18 wells (some of the wells were dry in 1999) in the Livermore Valley continue to show very low tritium levels compared with the 740 Bq/L (20,000 pCi/L) maximum contaminant level (MCL) established by the State of California. The highest tritium activity measured off site was 8.5 ± 2.4 Bq/L in a ground water sample from well 11B1 (see **Figure 9-1**), located about 11 km west of LLNL (results are reported in Data Supplement Table 9-29).

Tritium activity has been decreasing in Livermore Valley ground waters downgradient of LLNL. The median activities of tritium in ground water samples from these down-gradient wells decreased from 4.59 Bq/L in 1989 to -0.01 Bq/L in 1999 based on the five positive detections of tritium and 13 calculated values.



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Livermore Site Perimeter

Tritium activity ranged from -2.8 (calculated) Bq/L to 4.4 Bq/L in ground water samples from on-site background monitoring wells and from -4.4 (calculated) to 10.5 Bq/L in western perimeter monitoring wells.

The semivolatile organic compound di(2-ethylhexyl)adipate was detected in ground water samples collected from wells W-556 and W-373 (see **Figure 9-2**). This compound is a plasticizer. Concentrations analyzed were 3.9 µg/L in the W-556 sample and 5.2 µg/L in the W-373 sample (see Data Supplement Tables 9-10 and 9-11, respectively). The California drinking water MCL for di(2-ethylhexyl)adipate is 400 µg/L. No other organic compounds, excluding VOCs that were not COCs for this surveillance monitoring effort, were detected in the ground water during 1999.

The inorganic compounds detected, including dissolved trace metals and minerals, occur naturally in the ground water at variable concentrations. **Table 9-1** shows the three anions with the highest concentrations in two of the background wells (W-008 and W-221) and the seven western perimeter wells at LLNL. Concentrations of these major anions are higher in the background wells than in the western perimeter wells (see Tables 9-2 through 9-11 in the Data Supplement). Concentrations of chloride in background wells W-008 and W-221 are higher than California's recommended secondary MCL of 250 mg/L, while chloride concentrations in none of the western perimeter wells exceed 250 mg/L. Likewise, sulfate concentrations in background well W-008 exceed California's recommended secondary MCL of 250 mg/L, while sulfate concentrations in none of the western perimeter wells exceed 250 mg/L. Additionally, the boron concentration of 9.4 mg/L in background monitoring well W-008 in February 1999 is an order of magnitude higher than it is in the western perimeter wells. Poor ground water quality in the background portions of the site has been described previously in the remedial investigations (Thorpe et al. 1990).

Table 9-1. Concentration ranges for three major anions in background and western perimeter monitoring wells.

Hydrologic Flow	Concentration range (mg/L)					
	Bicarbonate (HCO ₃ ⁻)		Chloride (Cl ⁻)		Sulfate (SO ₄ ²⁻)	
	Range	Median	Range	Median	Range	Median
Background	220-330	270	280-560	400	77-340	209
Western perimeter	190-270	240	76-130	87	12-65	38



In March 1996, nitrate was first detected at concentrations greater than the MCL of 45 mg/L (68 to 80 mg/L) in ground water samples obtained from western perimeter monitoring well W-1012 (screened in HSU 2) (see **Figure 9-2**). From a ground water sample collected in February 1999, the concentration of nitrate for this well was 79 mg/L (see Data Supplement Table 9-9). This is the highest nitrate concentration measured in any on-site monitoring well during 1999. Because of the hydrologic influence of Treatment Facility B that pumps and treats ground water from HSUs 1B and 2 (see Chapter 8), ground water with high nitrate concentrations is not moving off site to the west. The highest concentration measured in an off-site well was below the MCL at 31 mg/L, in downgradient monitoring wells W-151 and W-571 (see Data Supplement Tables 9-7 and 9-8). Monitoring well W-571 is off site and downgradient from well W-1012, but is screened in HSU 1B. During 1999, concentrations of nitrate in on-site background wells W-008 and W-221 ranged from <0.5 mg/L (not detected) to 31 mg/L. Detected concentrations of nitrate in site western perimeter wells ranged from 12 to 31 mg/L. Fluctuations in nitrate concentrations have occurred since regular surveillance monitoring began in 1996, but nitrate concentrations have not increased overall in ground water from the western perimeter monitoring wells since 1996. The nitrate may originate as an agricultural residue (Thorpe et al. 1990).

Of the 22 metal COCs, nine were detected in western perimeter surveillance wells during 1999. Only chromium and hexavalent chromium exceeded California's MCL of 50 µg/L in western perimeter well W-373 (see Data Supplement Table 9-11). Ground water samples collected from this well are from HSU 1B, and the nearby Treatment Facility C (see **Figure 8-1**) treats ground water from HSU 1B for chromium. Consequently, concentrations of chromium (including hexavalent chromium) have been continually decreasing. Concentrations of iron reach 23% of California's secondary MCL in off-site monitoring well 14B1 (see Data Supplement Table 9-5). No other metal COC concentration exceeded 23% of its MCL or secondary MCL in ground water samples collected from western perimeter monitoring wells during 1999 (see Data Supplement Tables 9-2 through 9-11).

None of the ground water samples obtained from surveillance monitoring wells during 1999 had of any radioactivity that exceeded a drinking water MCL. A ground water sample collected from well W-593 reached 75% of the MCL (0.41 ± 0.12 Bq/L, see Data Supplement Table 9-19) for gross alpha radioactivity, but that radioactivity was not significantly higher than for background well W-008 (0.38 ± 0.10 Bq/L, see Data Supplement Table 9-2). Gross beta radioactivity was highest in background well W-008 (0.20 ± 0.10 Bq/L, see Data Supplement Table 9-2), but was only 11% of California's MCL for gross beta radioactivity. The highest tritium activity measured in a Livermore site perimeter ground water sample was 10.5 Bq/L, equal to 1.4% of the tritium MCL. The sample was from monitoring well W-373 (see Data Supplement Table 9-11).



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Activities of total uranium (U-234 + U-235 + U-238) continued to be highest in the background wells W-008, W-017, and W-221 during 1999. Activities of total uranium in those wells range from 0.19 ± 0.02 Bq/L to 0.30 ± 0.03 Bq/L (41% of California's MCL). (See Data Supplement Tables 9-2, 9-3, and 9-4). Activities of total uranium are significantly lower, from 0.024 ± 0.005 Bq/L (in well W-121) to 0.14 ± 0.02 Bq/L (19% of California's MCL in well W-1012), in ground water from each of the western monitoring wells. Uranium and its radioactive daughters, thorium-230, radium-226, and radon-222, occur naturally in the sediments and rock layers beneath and surrounding LLNL. Uranium activities did not exceed drinking water limits.

Livermore Site

Ground water downgradient of potential sources showed possible impact from two releases of metals to ground. Ground water at well W-307 near Building 322 showed a maximum concentration of chromium(VI) at $13 \mu\text{g/L}$, just slightly greater than $11 \mu\text{g/L}$, measured in background well W-017 (see Data Supplement Tables 9-23 and 9-4, respectively). Chromium (total) and chromium(VI) were detected at elevated concentrations in ground water samples from wells W-226 and W-306, downgradient from the Building 253 catch basin. Chromium (total) concentrations were measured as $71 \mu\text{g/L}$ and $19 \mu\text{g/L}$ (at well W-226) and $37 \mu\text{g/L}$ (at well W-306); chromium(VI) concentrations were 27 and $24 \mu\text{g/L}$ (at well W-226) and 25 , 33 , and $13 \mu\text{g/L}$ (at well W-306) (see Data Supplement Tables 9-24 and 9-25). The accumulated sediment in the catch basin is a potential source of several metals (Jackson 1997). Only the concentration of chromium (total) measured in a ground water sample collected from well W-226 on February 11, 1999, exceeded the MCL of $50 \mu\text{g/L}$ for chromium drinking water. Chromium concentration was measured again during the fourth quarter and was below the MCL (see Data Supplement Table 9-24).

The initial analytical results from well W-148, downgradient from both the Plutonium and Tritium Facilities, show plutonium-238 detected at 0.006 ± 0.002 Bq/L (0.17 ± 0.06 pCi/L). Meanwhile, the activity for plutonium-239+240 was analyzed at only 0.0002 ± 0.0004 Bq/L (0.006 ± 0.012 pCi/L). This was considered unusual because plutonium-239 might be expected, but not plutonium-238. Plutonium-239 is the isotope that was used in weapons development at LLNL, and all historical waste records at LLNL indicate the presence of plutonium-239 rather than plutonium-238. A second aliquot of this sample was analyzed with a result of 0.01 ± 0.01 Bq/L for plutonium-238. Another ground water sample was collected from this well on March 15, 2000, and was analyzed for americium-241 and expected plutonium radioisotopes; no radioisotopes were detected. A ground water sample was collected downgradient from the Plutonium Facility from SIP-331-001 on October 21, 1999, and analyzed for plutonium-239+240 along with other analytes. The initial analytical result for plutonium-239+240 was 0.004 ± 0.002 Bq/L (0.10 ± 0.06 pCi/L). However, this sample



from SIP-331-001 appeared to contain too much particulate matter. The remaining sample was then filtered and reanalyzed by both the off-site analytical laboratory and the on-site laboratory, and neither result indicated the presence of plutonium. The conclusion is that no dissolved plutonium is present in the ground water downgradient from the Plutonium Facility. Ground water samples will continue to be collected biannually from these wells and analyzed for americium and plutonium radioisotopes. (Analytical results from first quarter 2000 samples from both wells are below detectable limits for americium-241 and plutonium radioisotopes.)

Tritium activity in ground water samples collected from well W-148, downgradient from the Tritium Facility, reached 59 ± 7 Bq/L (1600 ± 180 pCi/L). This activity is less than 10% of the MCL of 740 Bq/L for tritium. The maximum tritium activity in ground water samples from SIP-331-001, downgradient from the Plutonium Facility but upgradient from the Tritium Facility, was 18 ± 3 Bq/L (480 ± 80 pCi/L), and the maximum tritium activity in well W-305, upgradient of both Superblock buildings, was 4.8 ± 2.5 Bq/L (128 ± 69 pCi/L) (see Data Supplement Tables 9-26 through 9-28).

Site 300

The following are summaries of Site 300 ground water surveillance and compliance monitoring results for 1999. Site 300 compliance monitoring results for 1999 have been published previously (Brown et al. 1999a, b, c, and 2000; Christofferson and MacQueen 1999a, b, c, and 2000; Christofferson and Taffet 1999a, b, c, and 2000). Compliance monitoring results for Site 300 that exceeded permitted concentration limits, i.e., statistical limits (SLs), or otherwise suggested a release of a COC to ground water, are discussed again in the following summaries. Surveillance monitoring results for 1999 have not been published elsewhere.

Elk Ravine Drainage Area

Pit 7

Compliance monitoring results for 1999 suggest that zinc was released to ground water from the RCRA-closed Pit 7 landfill. However, it is more likely that it came from waste buried in one of the other closed landfills nearby. Zinc has been detected historically at low, but increasing, concentration in ground water at monitoring well K7-03 since compliance monitoring began there in 1993 (see **Figure 9-4**). During 1999, zinc exceeded the SL of 72 $\mu\text{g/L}$ set in 1998 for well K7-03. It peaked at 160 $\mu\text{g/L}$ during the third quarter. Its fourth-quarter concentration was 70 $\mu\text{g/L}$, slightly below the SL. The abrupt rise and fall of zinc concentration observed during 1999 was likely caused by a



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slug release from a nearby source. Well K7-03 is located hydraulically downgradient of all four closed landfills constituting the Pit 7 Complex. Although LLNL is directed by WDR 93-100 to report any concentration of zinc in excess of its SL as an indication of a release from Pit 7, if such a release occurred, it must have predated pit closure in 1993. Since postclosure monitoring began in 1993, zinc has been detected only sporadically at monitoring well locations other than K7-03. It is improbable that there has been a postclosure release of zinc from Pit 7 because zinc was not detected at well NC7-48, which is located immediately downgradient of Pit 7 (**Figure 9-4**). Although a pre-1993 release of zinc from Pit 7 is not excluded by the historical data, it was likely released more recently from waste buried in the closed Pit 5 landfill, which is close to well K7-03. Pit 5 was inundated from below by rising ground water levels during several past winter rainy seasons (Taffet et al. 1996; Ziagos and Reber-Cox 1998b), which could have released metals to ground water.

A second-quarter total uranium activity of 0.7 Bq/L in ground water at monitoring well K7-01 slightly exceeded the statistical limit of 0.6 Bq/L set for that well. LLNL reported similar statistical evidence of a uranium release during 1998 (Galles 1998). Pits 3 and 5 are located near well K7-01 (**Figure 9-4**). Both Pits 3 and 5 are known to have been partially inundated by rising ground water during the El Niño winter of 1997–1998, when the site received more than double the average seasonal rainfall (Ziagos and Reber-Cox 1998b). Earlier CERCLA uranium investigations have characterized two small ground water plumes containing depleted uranium (uranium-238) that was released in the past from Pit 5, Pit 7, and possibly Pit 3 (Taffet et al. 1996; see Chapter 8 for a map of depleted uranium plumes existing at Site 300).

Tritium activity in the ground water at the Pit 7 monitoring well continued to increase above the MCL of 740 Bq/L (20,000 pCi/L) during 1999, reaching 28,500 Bq/L (770,000 pCi/L) during the fourth quarter. Previous CERCLA tritium investigations have characterized three coalescing plumes of tritium-bearing ground water that originate at Pits 3 and 5 and the Building 850 firing table on the west. The Building 850 plume extends eastward to Pit 1 (Webster-Scholten 1994, Taffet et al. 1996, Ziagos and Reber-Cox 1998b; see Chapter 8 for a map of tritium plumes existing at Site 300). Tritium activity above background occurs in ground water at several Pit 7 monitoring wells, but not at well NC7-48, which excludes Pit 7 as a significant tritium source. Modeling indicates that, given tritium's short half-life of 12.3 years and the relatively slow rate of ground water movement across the site, the activity of the released tritium in ground water will decrease to below the MCL before it reaches a site boundary (Taffet et al. 1996).



As in the past, traces of VOCs including TCE, 1,1-DCE, and trichlorofluoromethane (Freon 11) were detected by the monitoring network during 1999 at concentrations below their respective MCLs. Pit 7 is the likely source of the Freon 11. Previous CERCLA remedial investigations have characterized a small plume containing VOCs that were released in the past from waste buried in Pit 5 (Webster-Scholten 1994; see Chapter 8 for a map of VOC plumes existing at Site 300).

Elk Ravine

Analytical results for the Elk Ravine drainage area surveillance monitoring network for 1999 are listed in Data Supplement Table 9-30 (see **Figure 9-3**). As in past years, arsenic, barium, chromium, selenium, vanadium, and zinc were detected at low concentrations typical of ground water elsewhere in the Altamont Hills. Nitrate appears primarily in the uppermost water-bearing zone. Maximum concentrations were measured in ground water at monitoring wells NC7-61 (62 mg/L and 72 mg/L) and K2-04S (49 mg/L and 61 mg/L). Well NC7-69, which monitors a deeper water-bearing zone, shows very low nitrate concentration (2.7 mg/L). A CERCLA investigation of nitrate in Site 300 ground water is in progress (see Chapter 8 for a map of nitrate plumes existing at Site 300).

The explosive compounds HMX and RDX were detected at low concentrations up to 7 $\mu\text{g/L}$ in shallow ground water at one location, well NC7-61. Although these were the only explosives detected in ground water by surveillance monitoring outside the HE Process Area, it is not surprising at this location. This surveillance well is proximal to the Building 850 firing table, where explosives have been detonated for decades. The firing table is a known source of depleted uranium (uranium-238) and tritium in the ground water (see Chapter 8 for the CERCLA map of contaminant plumes).

Tritium activity was above background in many of the shallow ground water surveillance samples obtained during 1999 from Elk Ravine. Tritium, as tritiated water (HTO), has been released in the past from beneath the firing table at Building 850 (Taffet et al. 1996). HTO was transported to ground water beneath the Building 850 firing table gravels by percolating rainwater. HTO has also been released from closed landfill Pits 3 and 5 over the past decade during wetter-than-normal winters when ground water rose and contacted buried firing table wastes (Ziagos and Reber-Cox 1998b). The most recent release occurred during the wet El Niño winter of 1997–1998. The plumes are mostly shallow in the Neroly lower blue sandstone unit and overlying alluvium (see Chapter 8 for the CERCLA map of tritium plumes). Tritium activity was not discernible in ground water samples from the deeper water-bearing zone monitored at surveillance well NC7-69.



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The majority of the Elk Ravine surveillance network tritium measurements made during 1999 support earlier CERCLA studies, which show that, despite additional releases, the tritium contents and extents of the plumes are generally diminishing over time because of natural decay and dispersion (Ziagos and Reber-Cox 1998b). LLNL observe small increases in tritium activity at the distal end of the plume (wells K2-01C, NC2-11D, and NC2-12D), while those wells monitoring the bulk of the plume (NC7-61, K2-04D, and K2-04S) show relatively large decreases in tritium activity over the past several years. For example, tritium activity in ground water at well NC7-61 decreased from 6500 Bq/L in 1996 to 3500 Bq/L in 1999.

Surveillance measurements in Elk Ravine of gross alpha, gross beta, and uranium radioactivity were all low and indistinguishable from background. (Note that gross beta measurements do not detect the low-energy beta emission from tritium decay.)

Pit 2

No release of a COC from Pit 2 to ground water is indicated by the surveillance monitoring data obtained during 1999 (see **Figure 9-5**). Analytical results for the Pit 2 surveillance monitoring network are presented in Data Supplement Table 9-31. Several metals were detected at low concentrations. Most were below analytical reporting limits, which are in the parts per billion (ppb) range. None exceeded an MCL. Arsenic and barium concentrations were within the range of natural (background) concentrations in ground waters at Site 300 (Webster-Scholten 1994). The radioactivity measurements show only low background activities for gross alpha, gross beta, and tritium.

Pit 1

Compliance monitoring results for 1999 suggest that lead was released to ground water from the RCRA-closed Pit 1 landfill (see **Figure 9-5**). However, it more likely came from another source. Over the years, lead has been detected sporadically at low concentrations in ground water samples from monitoring wells located both upgradient and downgradient from Pit 1. Lead was detected more frequently in ground water samples obtained prior to the capping and RCRA-closure of Pit 1 in 1993, implying that the cap is effectively limiting the release of lead. The monitoring data do not point to Pit 1 as being a source of any other COC to ground water. More likely, the lead detected in ground water sampled at downgradient well K1-04 during 1999 is the same lead detected years before at upgradient well K1-01C.

Throughout 1999, tritium activity measured above background in the ground water at Pit 1 monitoring wells K1-01C, K1-02B, and K1-03, where it exceeded the SL. However, no release of tritium from Pit 1 is indicated by these measurements. Rather, the tritium



activity represents a distal lobe of the Building 850 tritium plume, which extends eastward to Pit 1 (see Chapter 8 for a CERCLA map of the Building 850 tritium plume extending to Pit 1).

Measurements of radium, thorium, and uranium made during 1999 in ground water samples from Pit 1 compliance monitoring wells all showed low activities indistinguishable from background.

The VOC 1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113) was detected during 1999 at a maximum concentration of 140 µg/L in ground water at Pit 1 monitoring wells K1-05, K1-08, and K1-09 (**Figure 9-5**). The drinking water MCL for this VOC is 1200 µg/L. Previous CERCLA investigations have linked the appearance of Freon 113 in Pit 1 monitoring wells to past spills in the Advanced Test Accelerator area, about 200 m west and cross-gradient from the affected wells (Webster-Scholten 1994; Taffet et al. 1996).

Pit 8

No release of a COC to ground water from Pit 8 is indicated by the surveillance monitoring data obtained during 1999. Analytical results for the Pit 8 surveillance monitoring network are presented in Data Supplement Table 9-32. Two VOCs, TCE and 1,2-DCA, were detected below their 5 µg/L MCLs. A relatively small VOC plume exists beneath this area (see Chapter 8), which originated prior to 1981 from waste discharged to a dry well upgradient of Pit 8, near Building 801 (Webster-Scholten 1994).

Arsenic, chromium, selenium, and vanadium were detected in concentrations similar to their natural levels in ground water elsewhere in the Altamont Hills.

Pit 9

No evidence for a release from Pit 9 is indicated by the surveillance monitoring data obtained during 1999. Analytical results for the Pit 9 surveillance monitoring network are presented in Data Supplement Table 9-33. COCs either were not detected or were indistinguishable from natural background concentrations. Since annual surveillance monitoring of ground water began there more than a decade ago, no evidence of a release of any COCs from Pit 9 has been recorded.

Corral Hollow Creek Drainage Area

Pit 6

No new release of designated COCs from Pit 6 is indicated by the compliance monitoring results for 1999. However, a release of benzoic acid, which is not a designated COC,



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is suggested by the data. Designated COCs known to have been released to ground water prior to pit closure continued to be detected, but their concentrations either remained steady during 1999, or followed historically decreasing trends.

Quarterly COC measurements were mostly below SLs. The few COC measurements that exceeded SLs were not confirmed by retests. At the time of the fourth-quarter sampling in October 1999, designated COCs were all below their respective MCLs.

During 1998, the VOC, 1,2-dichloroethane (1,2-DCA), exceeded its SL in ground water at well EP6-09 (see **Figure 9-8**). Subsequently, during the fall of 1998, a volume of about 270,000 L of VOC-contaminated water was pumped from well EP6-09. VOCs, including 1,2-DCA and TCE, were removed from the pumped water by air-sparging. Evidence of the success of this action was the subsequent decrease in TCE concentration to below the MCL, and the disappearance of detectable concentrations of 1,2-DCA in the ground water sampled at well EP6-09 during 1999.

The extractable organic compound bis(2-ethylhexyl)phthalate, which is not a designated COC, was detected during 1999 in one upgradient ground water sample at a concentration of 4 µg/L and in two downgradient samples at concentrations of 15 and 24 µg/L. This compound, with an MCL of 4 µg/L, was previously detected in 1998 in four ground water samples at concentrations up to 41 µg/L. The source of this compound is unknown. There is no record of it being placed in Pit 6, but the chemical has been used at Site 300.

The extractable organic compound benzoic acid, which has no MCL, was detected quarterly during 1999 at concentrations up to 75 µg/L in ground water samples from downgradient well K6-19. Of 104 total analyses made since November 1997 in ground water samples obtained throughout Site 300, benzoic acid has been detected in only five ground water samples, all obtained from well K6-19 during 1999. Although the first-quarter detection was not confirmed by two additional retest analyses, the chemical reappeared in increasing concentration during the second, third, and fourth quarters of 1999.

During 1999, tritium activity remained above background and relatively constant in ground water samples from two downgradient wells. The maximum activity recorded was 93.2 Bq/L, which is less than 13% of the 740 Bq/L MCL for tritium in drinking water. Relatively elevated tritium activity is contained within a small volume of ground water adjacent to Pit 6. Continued monitoring of tritium there is being conducted under CERCLA auspices (see Chapter 8 for a CERCLA map of the small tritium plume).



Building 929 Closed HE Burn Facility

Analyses of ground water samples obtained quarterly from the regional aquifer downgradient of the closed HE burn facility show no evidence of contamination from past operation of the facility. Except for the presence of coliform bacteria detected in ground water samples from a new well, W-829-22, the analytical results represent background concentrations of substances dissolved from natural sources in the underlying rocks (see **Figure 9-9**). Monitoring well W-829-22 was newly constructed in 1998. Bacteria may have been introduced during construction. Continued monitoring is necessary to determine their source. Analytical results for 1999 for three of the four wells that are used to monitor the deep regional aquifer are listed in Data Supplement Table 9-34. (A fourth deep well, W-827-04, was dry during 1999.)

As in the past, analyses of ground water samples obtained from the shallower perched ground water beneath the closed facility do show evidence of contamination. Analytical results for 1999 for the two wells that are used to monitor the perched ground water are listed in Data Supplement Tables 9-35. The primary contaminant in the perched ground water is TCE. TCE concentrations up to 310 $\mu\text{g}/\text{L}$ were measured during 1999. The perched water has a high total concentration of dissolved substances. Many of the inorganic analytes measured have natural sources in the surrounding rocks. The perched ground water does not contain clearly anthropomorphic chemicals such as pesticides, PCBs, herbicides, or the explosives compounds that were burned at the facility and that are known to exist at shallow depth in the soil above the perched ground water. However, perchlorate was detected in the perched ground water at concentrations up to 21 $\mu\text{g}/\text{L}$, and it may be linked to past operations at the closed burn facility. Similarly, nitrate was measured in the perched ground water at concentrations up to 230 mg/L , and it may be a contaminant from the closed facility above it. CERCLA investigations of perchlorate and nitrate in ground water at Site 300 are in progress.

Water Supply Wells

Analytical results for Site 300 water supply wells 18 and 20 are presented in Data Supplement Tables 9-36 and 9-37. As in past years, TCE was detected below the MCL of 5 $\mu\text{g}/\text{L}$ in surveillance ground water samples from well 18 (0.63, and 0.54 $\mu\text{g}/\text{L}$) (see **Figure 9-3**). The source of the TCE has not yet been identified. Methylene chloride was detected at low concentration in two quarterly water samples from well 20. However, both detections were accompanied by similar detections in field blanks or method blanks, which invalidate the results. Gross alpha, gross beta, and tritium activities in water samples from both production wells are very low and are indistinguishable from natural background activities. Barium (62 $\mu\text{g}/\text{L}$) and copper (11 $\mu\text{g}/\text{L}$) were detected once in well 20 water samples during 1999 at concentrations far below their MCLs of 1000 $\mu\text{g}/\text{L}$.



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Surface Impoundments

The two leachate collection and removal systems were monitored weekly for the presence of liquids. In 1999, no water was recovered from the leachate collection and removal system. The visual inspections indicate that the impoundment liners did not leak wastewater during 1999. No water has been observed in the leachate collection and removal system since liner repairs were made in 1997. No water was found in five lysimeters, which also indicates that the impoundment liners did not leak wastewater during 1999. Analytical results for all monitored constituents in Site 300 ground water beneath the surface impoundments are contained in the *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Annual/Fourth Quarter Report 1999* (Brown et al. 2000).

The explosive compounds (HMX, RDX, and TNT) and perchlorate are the compounds most indicative of discharges to ground water from the Explosives Process Area surface impoundments. However, prior to 1985, explosives wastewater was discharged into unlined ponds in the vicinity of the surface impoundments, where it infiltrated the soil and some reached ground water. Because of this past practice, it is necessary to discriminate between new releases from the surface impoundments and past releases from the unlined ponds. Analyses of ground water from upgradient monitoring well W-817-01 during 1999 showed HMX concentrations between 8.5 and 17.6 $\mu\text{g}/\text{L}$ (see **Figure 9-10**). HMX was not detected above the analytical reporting limit of 1.0 $\mu\text{g}/\text{L}$ in any of the ground water samples from the downgradient monitoring wells. Ground water samples from three wells contained detectable concentrations of the explosive compound RDX above the analytical reporting limit of 0.85 $\mu\text{g}/\text{L}$. The ground water samples containing RDX were from upgradient well W-817-01 (from 24 to 54 $\mu\text{g}/\text{L}$) and lower concentrations in downgradient wells W-817-03 and W-817-04. The RDX and HMX originated at closed disposal sites upgradient of the present surface impoundments (Raber and Carpenter 1983, Webster-Scholten 1994). Other explosive compounds or components of explosive compounds, 4-amino-2,6-dinitrotoluene and perchlorate, were detected in upgradient well W-817-01 and in several downgradient wells in this monitoring network. The concentrations observed in the downgradient wells do not exceed their permitted limits, but concentrations of perchlorate exceeded the California Department of Health Services' recommended limit of 18 $\mu\text{g}/\text{L}$ in drinking water. The remediation of these compounds is discussed in Chapter 8 of this document.

As in the past, ground water concentrations of arsenic and nitrate continued to exceed drinking water MCLs in ground water samples from all the surface impoundment monitoring wells during 1999. Concentrations of both arsenic and nitrate in ground water have historically exceeded their respective MCLs (0.050 mg/L for arsenic and 45 mg/L for nitrate) in this area. Background concentrations of arsenic in ground water monitoring wells upgradient from the surface impoundments have been measured at



concentrations above the drinking water MCL (Webster-Scholten 1994). Although the distribution of arsenic over time and throughout the area suggests a natural source, the occurrence and concentration of arsenic at Site 300 is the subject of a continuing CERCLA study. The remediation of all of these compounds (except for the element arsenic) is discussed in Chapter 8 of this document.

During 1999, all discharges into the surface impoundments were in compliance with discharge concentration limits. See the *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Annual/Fourth Quarter Report 1999* (Brown et al. 2000).

Percolation Pits

During 1999, the percolation pits at Buildings 806A, 827D, and 827E operated normally with no overflows. Standing water was regularly noted in the Building 827C percolation pit inspections, and the pit overflowed during the third quarter. A sample for metals analysis was collected from the overflow water. Ten metals were detected above the analytical reporting limit: aluminum, boron, total chromium, copper, iron, lead, manganese, molybdenum, nickel, and zinc. Water from the overflow infiltrated and saturated the soil surrounding the percolation pit but did not reach a surface water drainage course. Metals data for this overflow event are contained in the *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Annual/Fourth Quarter Report 1999* (Brown et al. 2000).

Sewage Evaporation and Percolation Ponds

All wastewater parameters for the sewage evaporation and percolation ponds complied with permits provisions and specifications throughout 1999, and there were no overflows to the percolation pond.

In June 1999 LLNL performed corrective actions to mitigate odors from the evaporation pond and modified operations to prevent a recurrence (see **Figure 9-11**). The modified operations included raising and maintaining a higher water level in the evaporation pond. LLNL requested permission from the CVRWQCB to operate the pond with reduced freeboard because of the change in operations. All other observations—levee condition, color, and odor—indicated normal operations.

All of the ground water monitored constituents were also in compliance with permitted limits. Nitrate concentrations in downgradient monitoring wells W-26R-01 and W-26R-05 decreased to 33 and 38 mg/L, respectively, during the third quarter. LLNL has not been able to determine the origin of this nitrate, but a sitewide study of nitrate at



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Site 300 is continuing, and LLNL continues to monitor these wells and nearby off-site wells for nitrate concentrations (see also Chapter 8).

Off-Site Water Supply Wells

Analytical results for the off-site water supply wells for 1999 are presented in Data Supplement Tables 9-40 to 9-44. Generally, no COC attributable to LLNL activities was detected in the off-site ground water samples. Arsenic and barium were widely detected at these locations, but their concentrations were below MCLs and consistent with natural sources in the rocks. Scattered detections of metals were all below MCLs and were probably related to metals used in pumps and supply piping.

As in past years, TCE was detected at concentrations up to 0.74 µg/L in the ground water samples obtained from well GALLO1 (see **Figure 9-3**). Previous CERCLA remedial investigations concluded that the TCE in the GALLO1 well water was likely caused by a localized surface spill on the property, possibly solvents used to service the private well (Webster-Scholten 1994). (Surveillance monitoring of a similarly sited well, GALLO2, was terminated in 1991 because of contamination from chemicals leaking from the pumping apparatus.) Radioactivity measurements of off-site ground water are all indistinguishable from natural background activities.

Environmental Impacts

The overall impact of LLNL Livermore site and Site 300 operations on off-site ground waters is minimal. With the exception of VOCs being remediated under CERCLA at both sites, current LLNL operations have no measurable impact on ground waters beyond the site boundaries.

Livermore Site and Environs

Ground water monitoring at the LLNL Livermore site and in the Livermore Valley indicates that LLNL operations have minimal impact on ground water beyond the site boundary. (See Chapter 8 for CERCLA remediation activities with VOCs.) During 1999, neither radioactivity nor concentrations of elements or compounds detected in ground water from any off-site monitoring well exceeded primary drinking water MCLs. The maximum tritium activity of 10.5 Bq/L (283 pCi/L), only 1.4% of the MCL, was detected in the ground water sample collected from on-site well W-373 in June (see **Figure 9-2**).



The maximum tritium activity measured off site in the Livermore Valley was even lower, 8.5 Bq/L, in well 11B1 (see **Figure 9-1**).

Of the Livermore on-site monitoring wells, no inorganic data exceeded primary MCLs, with the exceptions of chromium in monitoring well W-373 and nitrate in monitoring well W-1012 (see **Figure 9-2**). Chromium(VI) in ground water in the vicinity of monitoring well W-373 is being removed at Treatment Facilities B and C. The LLNL Ground Water Project reports on the treatment of ground water in the vicinity of the treatment facilities (see Chapter 8). Concentrations of nitrate in ground water samples collected from well W-1012 in June 1999 exceeded California's MCL of 45 mg/L. Nitrate above the MCL has not migrated off site. LLNL continues to monitor this well and monitoring well W-571, which is off site and about 350 meters downgradient from well W-1012, to determine if nitrate at concentrations above the MCL migrates off site.

The arroyo sediment data included in Chapter 10 indicate no potential adverse impact on ground water through the arroyos that cross the Livermore site.

Site 300

Ground water monitoring at Site 300 and adjacent properties in the Altamont Hills shows minimal impact of LLNL operations on ground water beyond the site boundaries.

Within Site 300, the chemicals detected in ground water beneath the High Explosives Process Area will not migrate off site. Plans to remediate TCE, explosive compounds such as RDX, perchlorates, and nitrate are currently being implemented under CERCLA auspices (see Chapter 8). Additionally, LLNL is investigating the distribution and origins of arsenic and zinc in this area.

VOCs, primarily the solvent TCE, have been released historically to shallow ground water at numerous locations at Site 300 (see Chapter 8 and references cited therein). With the exceptions of a small plume in the General Services Area area that extends minimally off site along Corral Hollow Road, all of the TCE-bearing ground water is on site. The plume extending off site from the Eastern GSA area is being drawn back to the site by pumping, and the TCE is being removed from the ground water.

Tritiated water and depleted uranium have been released to ground water from landfills and several firing tables in the northern part of Site 300. The boundaries of the slowly moving ground water plumes lie entirely within the site boundaries. Fate and transport models predict that the tritium will decay naturally to an activity below the drinking



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water MCL before the tritium-bearing ground water reaches a site boundary (Webster-Scholten 1994, Taffet et al. 1996).

Maximum uranium activities that could reach potential exposure points (hypothetical ground water supply wells) at the northern boundary of Site 300 are estimated to be 0.08 Bq/L from plumes originating at Pits 5 and 7, and 0.05 Bq/L at the eastern boundary of Site 300 from the plume originating at Building 850. These conservatively estimated maximum activities are small when compared with the 0.74 Bq/L California MCL for uranium in drinking water. The predicted incremental lifetime cancer risks from the released uranium are less than one-in-a-million at the hypothetical exposure points on the Site 300 boundary (Taffet et al. 1996). The VOCs, tritium, nitrate, Freon, perchlorate, and depleted uranium in the shallow ground water beneath Site 300 present no current health risks because the contaminated water is not used for potable domestic, livestock, or industrial water supplies.

Soil and Sediment Monitoring

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Introduction

The soil and sediment monitoring analysis that Lawrence Livermore National Laboratory performed in 1999 included work in four areas: surface soil in the Livermore Valley and at Site 300, sediment at the Livermore site, vadose zone soils at the Livermore site, and a special study at Big Trees Park in the City of Livermore.

Soil is weathered material, mainly composed of disintegrated rock and organic material, that sustains growing plants. Soil can contain pollutants originally released directly to the ground, to the air, or through liquid effluents. Department of Energy (DOE) guidance for environmental monitoring states that soil should be sampled to determine if there is measurable, long-term buildup of radionuclides in the terrestrial environment and to estimate environmental radionuclide inventories (U.S. Department of Energy 1991). The guidance recommends monitoring for radionuclides specific to a particular operation or facility as well as those that occur naturally. Particulate radionuclides are of major interest in the LLNL soil monitoring program because airborne particulate releases are the most likely pathway for LLNL-induced soil contamination.

Sediments are defined, for the purposes of this chapter, as finely divided, solid materials that have settled out of a liquid stream or standing water. The accumulation of radioactive materials in sediment could lead to exposure of humans through their ingestion of aquatic species, through sediment resuspension into drinking water supplies, or as an external radiation source (U.S. Department of Energy 1991). However, the LLNL Livermore site and Site 300 do not have habitats for aquatic species that are consumed by people, nor do they have surface drainage that directly feeds drinking water supplies.

Soils in the vadose zone—the region below the land surface where the soil pores are only partially filled with water—are collected in arroyo channels at the Livermore site as part of the Ground Water Protection Management Program (GWMPMP). Infiltration of natural runoff through arroyo channels is a significant source of ground water recharge, accounting for an estimated 42% of resupply for the entire Livermore Valley ground water basin (Webster-Scholten 1994). Soils in the shallow vadose zone are collected and analyzed to



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provide information about possible constituents that may be dissolved as runoff water infiltrates through the arroyo to the ground water.

In addition to the soil, sediment, and vadose zone soil sampling conducted on an annual basis, LLNL may also conduct special sampling to address areas of interest or concern, as in the case of Big Trees Park in Livermore. During previous sampling at this park in 1993 and 1995, plutonium had been detected at concentrations above fallout background. Continuing the work initiated by soil sampling at Big Trees Park in 1998, LLNL and the Agency for Toxic Substances Disease Registry (ATSDR) published reports summarizing the analytical results for soil samples collected at the park.

Sampling Locations

Since 1971, surface soil sampling in the vicinity of the LLNL Livermore site and Site 300 has been part of a continuing LLNL monitoring program designed to measure any changes in environmental levels of radioactivity and to evaluate any increase in radioactivity that might have resulted from LLNL operations. These samples have been analyzed for plutonium and gamma-emitting radionuclides, such as depleted uranium that is used in some explosive tests at Site 300. The inclusion of other gamma-emitting, naturally occurring nuclides (potassium-40 and thorium-232) and the long-lived fission product, cesium-137, provides background information and baseline data on global fallout from historical aboveground nuclear weapons testing. In addition, LLNL analyzes Site 300 soils for beryllium because it is a potentially toxic metal used at this site. Soils in the Livermore vicinity were analyzed for beryllium from 1991 to 1994. However, analysis for beryllium was discontinued at the Livermore site in 1995 because beryllium was never measured above background values.

Surface soil samples are collected at 19 locations in the Livermore Valley (**Figure 10-1**) and 15 locations at or near Site 300 (**Figure 10-2**). The locations were selected to represent background concentrations (distant locations unlikely to be affected by LLNL operations) as well as areas where there is the potential to be affected by LLNL operations. Areas with known contaminants, such as the Livermore Water Reclamation Plant (LWRP), are also sampled.

Site 300 soil sampling locations are established around firing tables and other areas of potential soil contamination. PRIM location was added to the sampling program in 1998 to correspond with air sampling conducted at that location. The PRIM site is downwind of Site 300 and sufficiently close to the Site 300 boundary to potentially be affected by

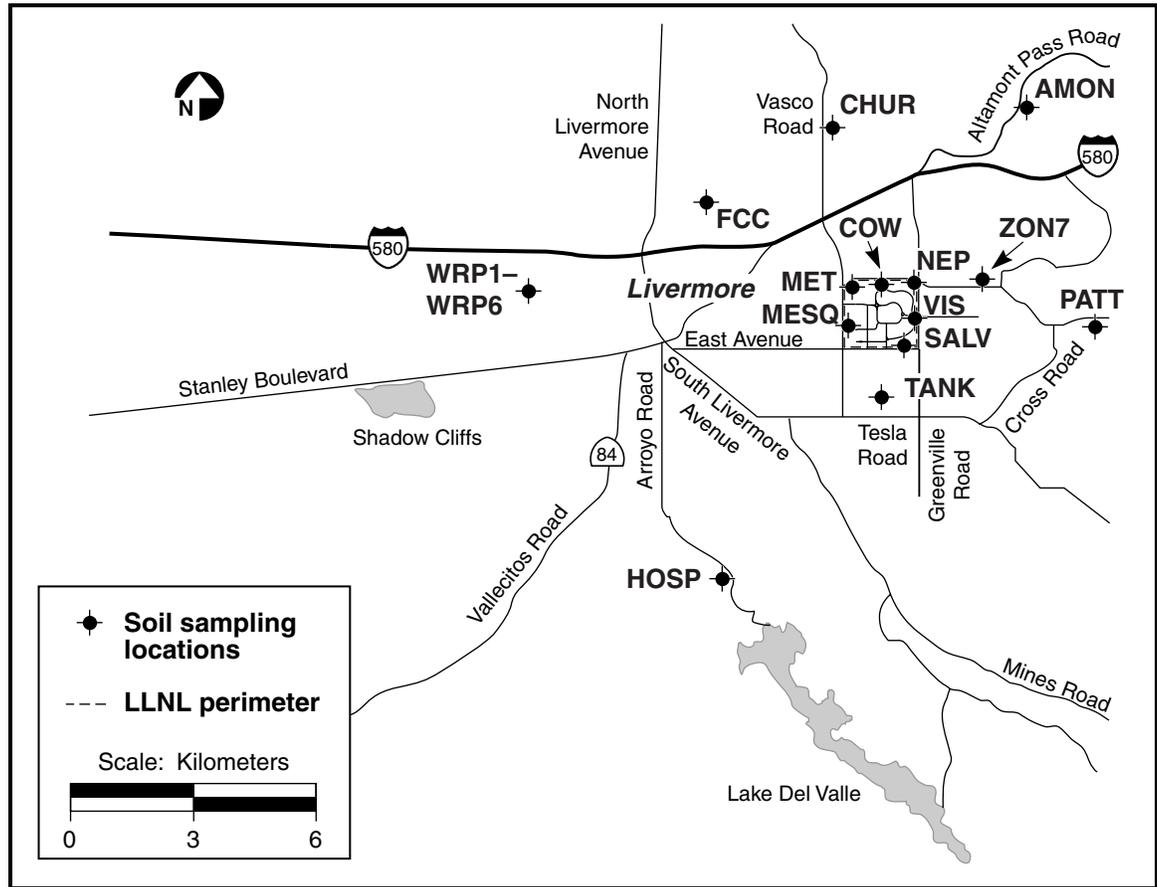


Figure 10-1. Surface soil sampling locations, Livermore Valley, 1999.

Site 300 operations. Approximately 10% of locations are sampled in duplicate; two identical samples are collected at each location chosen for this sampling. All soil and sediment sampling locations have permanent location markers for reference.

Similarly, sediment samples have been collected from selected arroyos and other drainage areas at and around the Livermore site since 1988; these locations largely coincide with selected storm water sampling locations (see Chapter 7). The number of sediment sampling locations was reduced in 1994 to correspond to reductions in storm water sampling locations. Although ALPO was added as a new sediment sampling location in 1997, it was not sampled in 1997, 1998, or 1999 because the location was continually under water from releases upstream of the Livermore site. Sediment sampling locations have not been established at Site 300. The drainage courses at Site 300 are steep, causing flowing water to scour the drainages, so that sediment is not deposited. Because of these conditions, sediment sampling at Site 300 is not warranted.



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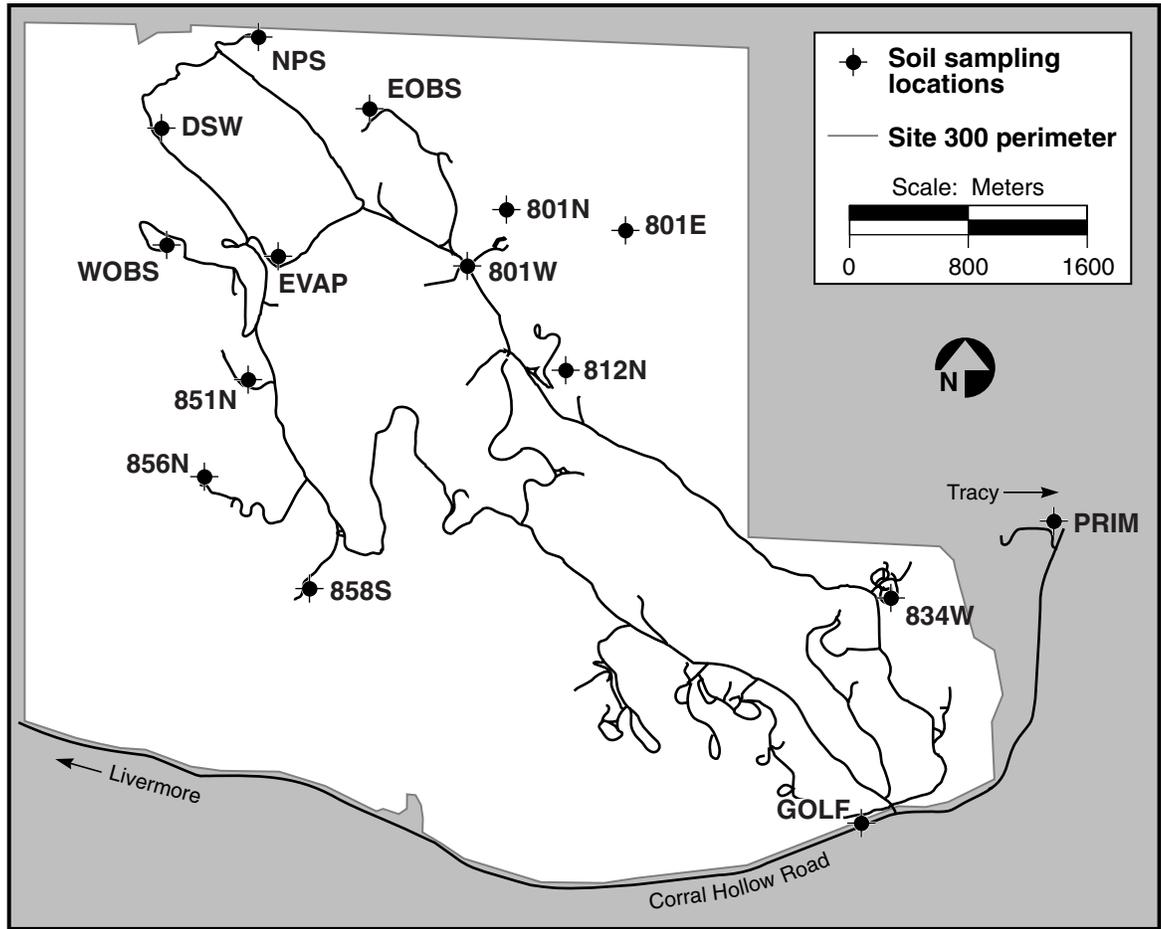


Figure 10-2. Site 300 surface soil sampling locations, 1999.

Vadose zone soil sampling has been conducted since 1996. These sampling locations correspond to the same selected storm water sampling locations as the sediment sampling locations (see **Figure 10-3**). The collocation of sampling for these three media facilitates comparison of analytical results. As with sediment samples, vadose zone samples are not collected at Site 300.

Methods

Surface soil, sediment, and vadose zone soil sampling is conducted according to written, standardized procedures (Tate et al. 1999). Soil samples are collected from undisturbed areas near permanent location markers. These areas generally are level, free of rocks, and unsheltered by trees or buildings. All surface soil samples are collected from the

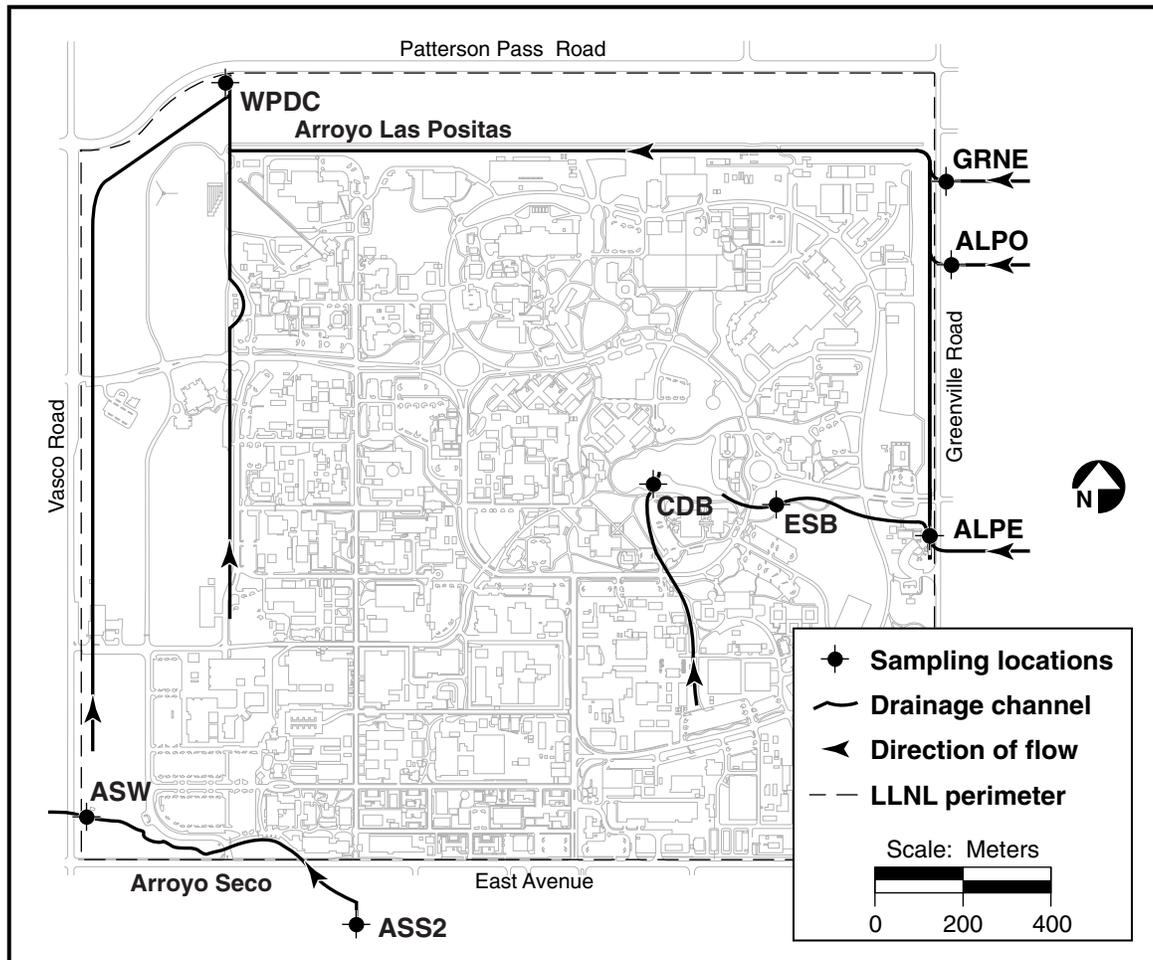


Figure 10-3. Sediment and vadose zone sampling locations on or near the Livermore site, 1999.

top 5 cm of soil because aerial deposition is the primary pathway for potential contamination, and resuspension of materials from the surface into the air is the primary exposure pathway to nearby human populations. Sediments are collected annually from drainages at and around the LLNL Livermore site after the cessation of spring runoff. Samples to be analyzed for particulate radionuclides are collected from the top 5 cm of soil; samples to be analyzed for tritium are collected 5–15 cm deep to obtain sufficient water in the sample for analysis. Vadose zone soil samples are collected at 30–45 cm deep for metals analysis, and at 45–65 cm deep for semi-volatile organic compound analysis.



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In 1999, surface soil samples in the Livermore Valley were analyzed for plutonium and gamma-emitting radionuclides. Samples from Site 300 were analyzed for gamma-emitting radionuclides and beryllium. Analysis of Site 300 soil samples for plutonium was discontinued in 1997 because plutonium has not been used at the site, and sample results have continuously been at background levels since sampling was begun in 1972. Sediment samples collected at the Livermore site were analyzed for plutonium and gamma-emitting radionuclides and tritium. Vadose zone samples were analyzed for total and soluble metals and for semi-volatile organic compounds.

Prior to radiochemical analysis, surface soil and sediment samples are dried, ground, sieved, and homogenized. The samples are analyzed by LLNL's Chemistry and Materials Science Environmental Services (CES) laboratory. The plutonium content of a 100-g sample aliquot is determined by alpha spectroscopy. Other sample aliquots (300 g) are analyzed for more than 150 radionuclides by gamma spectroscopy using a high-purity germanium (HPGe) detector (Hall and Edwards 1994a, b, and c). The 10-g subsamples for beryllium analyses are sent to a contract analytical laboratory and are analyzed by graphite-furnace atomic absorption spectroscopy. For sediment samples collected for tritium analyses, CES uses freeze-drying techniques to recover water from the samples and determines the tritium content of the water by liquid-scintillation counting. Vadose zone soil samples are analyzed by a contract laboratory. The analytical methods include the toxicity characteristic leaching procedure (TCLP, EPA Method 8240) for semi-volatile organic compounds, and soluble metals and total metals by EPA Methods 200.7, 245.2, 7471A, and 6010B. Chain-of-custody procedures are followed throughout the sampling, delivery, and analytical processes.

Livermore Valley Surface Soil Results

Table 10-1 presents summary data on the concentrations of plutonium-239+240, plutonium-238, americium-241, cesium-137, potassium-40, thorium-232, uranium-235, and uranium-238 in surface soils from the Livermore Valley sampling locations. Complete data for 1999 soil and sediment sampling are presented in Table 10-1 of the Data Supplement.

The concentrations and distributions of all observed radionuclides in soil for 1999 are within the ranges reported in previous years and generally reflect worldwide fallout and naturally occurring concentrations. The ratio of uranium-235 to uranium-238 generally reflects the natural ratio of 0.7%; however, there is significant uncertainty in the uranium-235/uranium-238 ratio because of the difficulty in measuring small quantities of uranium-238 by gamma spectroscopy.

**Table 10-1.** Summary of surface soil and sediment radioanalytical data, 1999.

Analyte and location	Detection frequency ^(a)	Median	IQR ^(b)	Maximum
²³⁸Pu (μBq/dry g)				
Livermore Valley soils	12/13	2.7	3.0	22.8
LWRP ^(c) soils	6/6	108	130	354
Livermore site sediments	4/7	5.0	23.6	211
²³⁹⁺²⁴⁰Pu (μBq/dry g)				
Livermore Valley soils	13/13	72.5	51	507
LWRP soils	6/6	2150	2230	6960
Livermore site sediments	7/7	84	382	2180
¹³⁷Cs (mBq/dry g)				
Livermore Valley soils	12/13	1.6	1.9	6.1
LWRP soils	6/6	1.1	1.4	4.0
Livermore site sediments	5/7	0.5	0.4	1.3
Site 300 soils	15/15	3.2	2.6	5.6
⁴⁰K (Bq/dry g)				
Livermore Valley soils	13/13	0.466	0.067	0.581
LWRP soils	6/6	0.359	0.040	0.407
Livermore site sediments	7/7	0.466	0.052	0.529
Site 300 soils	15/15	0.440	0.087	0.574
²³²Th (μg/dry g)^(d)				
Livermore Valley soils	13/13	7.5	1.2	9.2
LWRP soils	6/6	7.2	0.6	7.8
Livermore site sediments	7/7	5.9	2.0	8.6
Site 300 soils	15/15	10.2	2.5	14.2
²³⁵U (μg/dry g)^(e)				
Livermore Valley soils	13/13	0.020	0.005	0.024
LWRP soils	6/6	0.018	0.002	0.020
Livermore site sediments	7/7	0.016	0.006	0.024
Site 300 soils	15/15	0.025	0.012	0.148
²³⁸U (μg/dry g)^(f)				
Livermore Valley soils	13/13	1.6	0.5	2.5
LWRP soils	6/6	2.0	0.2	2.2
Livermore site sediments	6/7	1.9	0.8	2.7
Site 300 soils	15/15	2.3	2.1	71.3



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Table 10-1. Summary of surface soil and sediment radioanalytical data, 1999 (concluded).

Analyte and location	Detection frequency ^(a)	Median	IQR ^(b)	Maximum
³H (Bq/L extracted water)^(g) Livermore site sediments	4/7	4.5	— ⁽ⁱ⁾	75.1
²⁴¹Am (mBq/dry g)^(h) LWRP soils	2/6	<1.1	— ⁽ⁱ⁾	2.9
Be (mg/kg)^(j) Site 300 soils	15/15	0.6	0.2	2.5

^a Detection frequency = the fraction of samples having a measured value above the detection limit.

^b IQR = Interquartile range; the difference between the top of the third and the top of the first quartiles of the data.

^c LWRP = Livermore Water Reclamation Plant.

^d Thorium-232 activities in Bq/dry g can be determined by dividing the weight in µg/dry g by 247.3, and pCi/dry g can be determined by dividing by 9.15.

^e Uranium-235 activities in Bq/dry g can be determined by dividing the weight in µg/dry g by 12.5, and pCi/dry g can be determined by dividing by 0.463.

^f Uranium-238 activities in Bq/dry g can be determined by dividing the weight in µg/dry g by 80.3, and pCi/dry g can be determined by dividing by 2.97.

^g Only sediment samples are analyzed for tritium.

^h Americium-241 is detected only in LWRP soil samples.

ⁱ IQR is not calculated because of high incidence of reported values below detection limits.

^j Only Site 300 samples are analyzed for beryllium.

Plutonium has, in the past, been detected at levels above background at ZON7, the off-site soils sampling location near the LLNL Livermore site and in the prevailing downwind direction. Because of the high level of variability inherent in the measurement of soils, we do not always find plutonium above background levels at this location. In 1999, as in 1994 through 1998, plutonium-239+240 was detected at background levels, 156 µBq/dry g (4.2×10^{-3} pCi/dry g), at location ZON7. Since 1973, soil samples in this area have generally shown plutonium-239+240 values that are higher than background, and location VIS, one of the on-site locations upwind of ZON7, did exhibit a plutonium-239+240 value slightly above background, 507 µBq/dry g (1.4×10^{-2} pCi/dry g), in 1999. The slightly higher values at and near the Livermore site have been attributed to historic operations, which included the operation of solar evaporators for plutonium-containing liquid waste in the southeast quadrant (Silver et al. 1974). LLNL no longer operates the solar evaporators or engages in any other open-air treatment of plutonium-containing waste. Nonetheless, plutonium-239+240 from historic operations is carried off site by resuspension of soil by wind. Similarly, elevated



levels of plutonium-239+240 (resulting from an estimated 1.2×10^9 -Bq [32-mCi] plutonium release to the sanitary sewer in 1967 and earlier releases) were first observed in soils near LWRP during the early 1970s, and were again detected at LWRP sampling locations. As in 1997 and 1998, americium-241 was detected in LWRP samples; it is most likely caused by the natural decay of the trace concentrations of plutonium-241 that were present in the release.

Historical plots of median plutonium-239+240 concentrations in soil in the Livermore Valley upwind and downwind of the center of the LLNL Livermore site, at Site 300, and at LWRP are shown in **Figure 10-4**. Livermore Valley upwind and Site 300 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 1999 included sampling locations VIS, PATT, NEP, COW, and ZON7, compared with the upwind and historic Site 300 data. The concentrations of plutonium at the downwind locations reflect resuspension of low-level plutonium contamination from soils in the southeast quadrant of the Livermore site. Greater variability in plutonium-239+240 is seen in samples from LWRP. Because the plutonium-239+240 is likely to be present in discrete particles, the random presence or absence of the particles dominates the measured plutonium-239+240 in any given sample.

Livermore Site Sediment Results

Table 10-1 presents summary data on radionuclides detected in the sediment samples; a complete presentation of 1999 sediment data is found in Table 10-1 of the Data Supplement. The levels of plutonium-239+240 were generally at background concentrations, reflective of worldwide fallout. The moderately higher values at sampling locations CDB and ESB (see **Figure 10-3**) than the values at other locations may be attributed to historic activities in the southeast quadrant at LLNL; these locations are both in drainages for that area. Most other radionuclides were detected at levels similar to those reported from 1988 through 1998: cesium-137, a fission product, was found at worldwide background concentrations; potassium-40, thorium-232, uranium-235, and uranium-238—naturally occurring radionuclides—were detected at background concentrations. Tritium concentrations were within the range of previous data. Tritium in sediments was evaluated for differences upwind and downwind of the Livermore site for all data collected from 1988 to 1999. A statistically significant difference was found using the Tukey-Kramer honestly significant difference (HSD) test, with the downwind sediment samples having higher measured concentrations than the upwind sediment samples. Tritium in sediments will continue to be evaluated.



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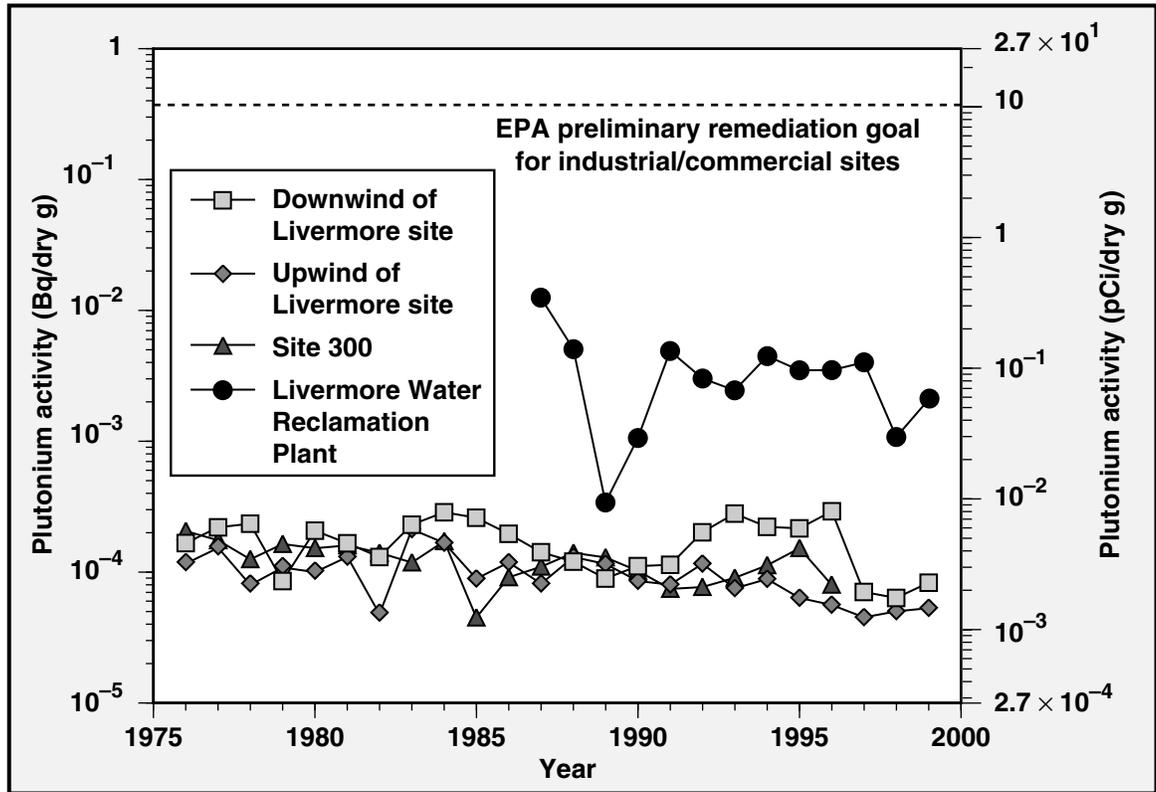


Figure 10-4. Median plutonium-239+240 activities in surface soils, 1976–1999. Upwind and downwind designations are relative to the center of the Livermore site.

Livermore Site Vadose Zone Soil Results

Analytical results for vadose zone soil samples are compared with soil reuse standards developed by LLNL and the San Francisco Bay Regional Water Quality Control Board (RWQCB) (Folks 1997, Marshack 1991). Metals background concentrations are based on naturally occurring levels in the soil, considering first the results for total metals and then the soluble metals test. There are no background levels for organic compounds or tritium. Soils containing materials at levels above background still may not adversely affect the ground water. If a metal exceeds both the total and soluble background values, or if there are any detected organic compounds or tritium, the designated level methodology (DLM) (i.e., application of a simple attenuation factor and specific water quality objectives) is used to determine the soluble levels of contaminants that would not adversely impact ground water beyond its beneficial uses. (Background and DLM de minimis values are presented in Tables 10-3 to 10-5 in the Data Supplement.)



All analytical results for organic compounds were below detection limits. All total metals concentrations were below background (see Tables 10-6 to 10-8 in the Data Supplement). Tritium results from the sediment sampling were evaluated by the DLM method and were all below de minimis levels (see the Data Supplement, Table 10-1).

Site 300 Results

Table 10-1 presents summary data on the concentrations of cesium-137, potassium-40, thorium-232, uranium-235, uranium-238, and beryllium in soil from the Site 300 sampling locations; a complete presentation of 1999 soils data for Site 300 is found in Table 10-2 of the Data Supplement. The concentrations and the distributions of all observed radionuclides in Site 300 soil for 1999 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%. Historical trends of uranium-238 concentrations from both the Livermore Valley and Site 300 are shown in **Figure 10-5**. Median values have remained relatively constant for both places. The highest values at Site 300 result from the use of depleted uranium in explosive experiments.

Environmental Impact

This section discusses the environmental impacts of operations at the LLNL Livermore site and Site 300 inferred from soil, sediment, and vadose zone soil monitoring.

Livermore Site

Routine surface soil, sediment, and vadose zone soil sample analyses indicate that the impact of LLNL operations on these media in 1999 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 7.0 mBq/dry g (0.19 pCi/dry g) for plutonium-239+240 measured at LWRP during 1999 represents 1.9% of the Environmental Protection Agency (EPA) preliminary remediation goal for commercial or industrial sites of 0.37 Bq/dry g (10 pCi/dry g) (U.S. Environmental Protection Agency 1991). Statistical analysis shows no general increase or decrease in plutonium-239+240 values with time. Moreover, all measured concentrations, regardless of location and year, have been a small fraction of the EPA preliminary remediation goal (shown in **Figure 10-4** for comparison). LLNL



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sampling of surface soil, sediment, and vadose zone soil will continue on an annual basis.

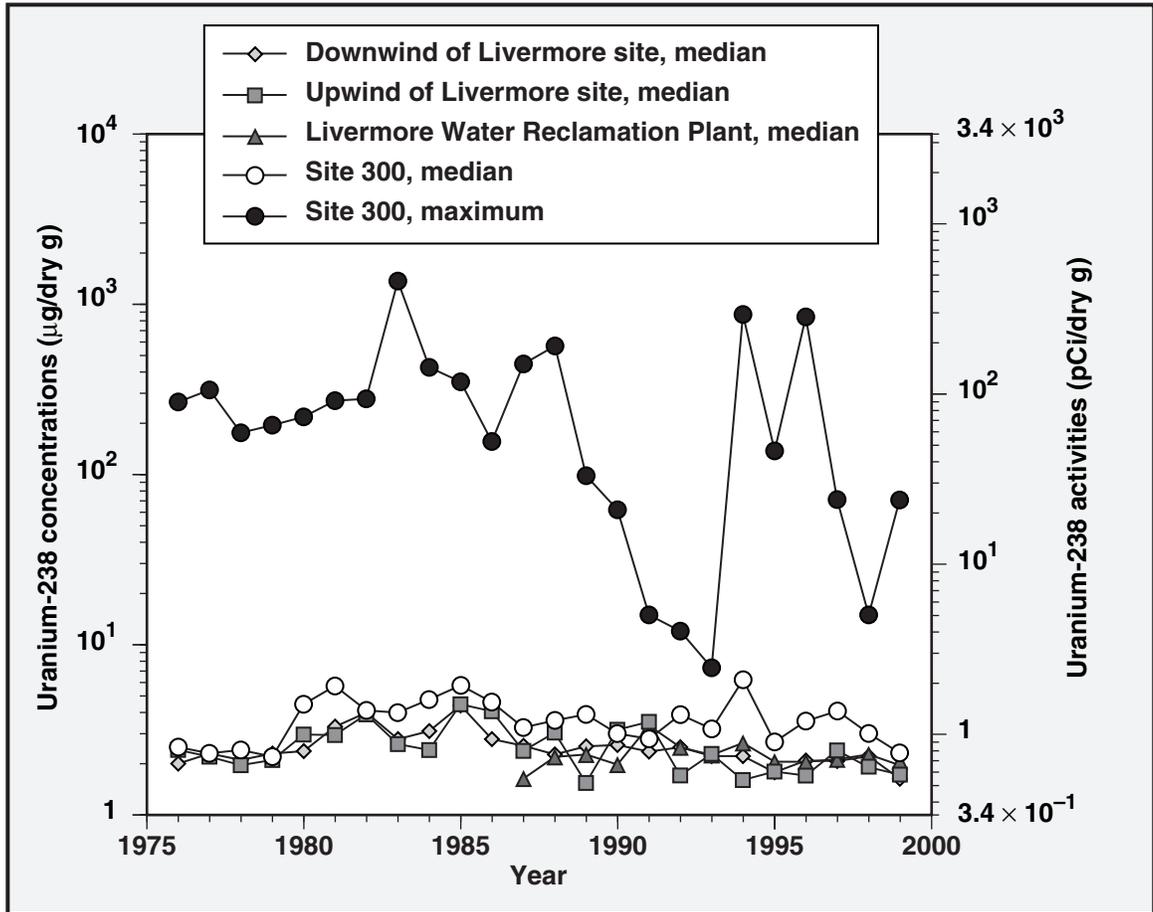


Figure 10-5. Uranium-238 concentrations in surface soils, 1976–1999.

Site 300

The concentrations of radionuclides and beryllium observed in soil samples collected at Site 300 are within the range of previous data and are generally representative of background or naturally occurring levels. The uranium-235/uranium-238 ratios that are indicative of depleted uranium occur near active and inactive firing tables at Buildings 801 and 812, from a small fraction of the operations at the firing table that disperse depleted uranium.



Big Trees Park

During the 1993 EPA investigation of plutonium in soils present in the southeast quadrant of the LLNL Livermore site, EPA personnel collected a soil sample at Big Trees Park in Livermore to obtain a background sample. This soil sample showed plutonium at a concentration higher than what is expected from global fallout for this region. The park was resampled by the EPA, LLNL, and the California Department of Health Services (DHS) in 1995. (Over the years, LLNL has frequently investigated the presence of radionuclides in local soils. Several of the studies are listed in **Table 10-2.**)

Table 10-2. Special soil studies.

Year	Subject	Reference
1971–1972	Radionuclides in Livermore Valley soil	Gudiksen et al. 1972; Gudiksen et al. 1973
1973	Radionuclides in San Joaquin Valley soil	Silver et al. 1974
1974	Soil study of southeast quadrant of Livermore site	Silver et al. 1975
1977	Sediments from LLNL to the San Francisco Bay	Silver et al. 1978
1980	Plutonium in soils downwind of the Livermore site	Toy et al. 1981
1990	195 samples taken in southeast quadrant for study	Gallegos et al. 1992
1991	Drainage channels and storm drains studied	Gallegos 1991
1993	EPA studies southeast quadrant	Gallegos et al. 1994
1993	Historic data reviewed	Gallegos 1993
1995	LLNL, EPA, and DHS sample soils at Big Trees Park	MacQueen 1995
1999	Summary of results of 1998 sampling at Big Trees Park	Gallegos et al. 1999
2000	Health Consultation, Lawrence Livermore National Laboratory, Big Trees Park 1998 Sampling	Agency for Toxic Substances Disease Registry 2000

As reported in MacQueen (1995), samples from 13 of the 16 locations sampled at the park during 1995 had plutonium concentrations consistent with background levels found throughout the Bay Area. These levels were 1/600 to 1/10,000 of the EPA's risk-based preliminary remediation goal (PRG) for plutonium for residential areas of 0.09 Bq/dry g (2.5 pCi/dry g) (U.S. Environmental Protection Agency 1991). Background values were found in all sandboxes, school grounds, and picnic areas, and under the large eucalyptus trees for which the park is named. Samples from two locations had plutonium concentrations slightly above background levels but were still 1% to 2% of the EPA's risk-based preliminary remediation goal for plutonium for residential areas. The four samples



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collected in 1995 near the 1993 EPA sampling location had results above background, with the highest concentration at this location, 0.038 Bq/dry g (1.02 pCi/dry g), being 40% of the PRG.

Based on the 1995 work, both the EPA and the California DHS concurred that there was no regulatory concern from any of the sample results, that there was no significant lifetime cancer risk resulting from the low concentrations of plutonium-239+240 in the soil samples, and that there was no unacceptable risk to human health or the environment.

In 1997, the ATSDR (which had contracted with the California DHS, Environmental Health Investigations Branch, to conduct a health consultation for plutonium) held a public meeting on the subject of plutonium at Big Trees Park. At this meeting, the regulatory agencies restated that, although the levels of plutonium at Big Trees Park were not a health concern, they were interested in knowing how the plutonium got to the park and the vertical extent of contamination at the park. The regulatory agencies determined that these questions warranted further investigation. ATSDR issued a draft report discussing these questions in 1998 and the final report in May 1999.

On the basis of the 1998 draft report, LLNL volunteered to conduct additional sampling and analysis to investigate how plutonium got to the park and to work with the regulatory agencies to ensure public concerns were addressed. In August and September 1998, more than 300 additional soil samples were collected at Big Trees Park. The sampling strategy was based on choosing sampling locations and analytes to provide (1) data to better determine the vertical and lateral extent of plutonium in soils at Big Trees Park, (2) data at locations and depths that are believed to be unique to each of three plutonium distribution pathways, (3) data at areas of public concern, and (4) additional data for locations previously identified as exhibiting above-background plutonium concentrations in soil.

The results of the 1998 sampling effort have provided much more information about the vertical and lateral extent of plutonium levels in soil at Big Trees Park. The results clearly show no systematic distribution of plutonium at depth. Of the 130 samples collected deeper than 10 cm to characterize the vertical extent of contamination, only four had concentrations of plutonium-239+240 above background levels determined from historic surveillance sampling. The results for samples collected to evaluate the lateral extent of contamination clearly show an increased level of plutonium along the park's northern boundary, where the ornamental trees are planted (Gallegos et al. 1999).

The results can also be used to draw conclusions about the route of transport of the plutonium to the park. Three routes to the park were investigated: (1) water-borne,



plutonium-contaminated sediments transported via Arroyo Seco, which cuts across the southwestern corner of the Livermore site and flows past Big Trees Park on its northern boundary; (2) plutonium-contaminated sewage sludge used as a soil amendment for planting the ornamental trees along the northern boundary of the park; and (3) aerial distribution of releases from the LLNL Plutonium Facility. The results for the samples collected to investigate the water-borne hypothesis were nearly all below detection limits. Because the concentrations of plutonium-239+240 were so low in these samples, the water-borne hypothesis is considered to be unlikely. In addition, annual surveillance monitoring of the arroyo shows no residual of past releases or evidence of recent release.

The sewage sludge hypothesis is based on the fact that from the early 1960s to the mid-1970s, the LWRP distributed sewage sludge to the public for use as soil amendments. The probable source of plutonium in the sludge is LLNL releases to the sanitary sewer, with the largest single release occurring in 1967. It is also known that the ornamental trees were planted in a row along the northern border of the park next to the arroyo some time between 1972 and 1975. Ten trees along the northern boundary of the park were selected for sampling. Paired with each tree location was another location at least 1 m beyond the irrigation berm that surrounds each tree. The results from these samples clearly show elevated levels of plutonium in samples taken near the trees but only background levels outside the tree wells. This distribution of plutonium at the park supports the theory that contaminated sewage sludge was used to fertilize trees at the northern border of the park.

In January 2000, ATSDR issued a report presenting that agency's evaluation of the data obtained as a result of the 1998 sampling (Agency for Toxic Substances Disease Registry 2000). The ATSDR concluded:

The most credible pathway by which plutonium radioisotopes reached Big Trees Park was the application of plutonium contaminated sewage sludge as a soil amendment. This is based on a comparison of the concentrations of both plutonium and heavy metals collected from within tree wells to the concentrations present outside the tree wells. Although there is an elevated concentration of plutonium in the park, the levels are below the levels of health concern set by EPA (Region IX preliminary remediation goals; less than a risk of one in a million) and below the recommended levels which NCRP [National Council on Radiation Protection] has set for requiring additional activities. No other pathway appears to be a viable pathway for the presence of plutonium in the park.



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Impact

The results of this extensive sampling effort demonstrate that the plutonium is not present at Big Trees Park, Livermore, at a level of health concern. All sample results were less than the PRG and were less than values measured as the result of previous sampling efforts at the park. The highest sample concentration from the 1998 sampling effort was 0.029 Bq/dry g (0.79 pCi/dry g) plutonium-239+240, well below the residential PRG of 0.093 Bq/dry g (2.5 pCi/dry g). Again, EPA, California DHS, and ATSDR concur that there is no unacceptable risk to human health or the environment from the levels of plutonium at the park.



Vegetation and Foodstuff Monitoring

S. Ring Peterson

Introduction

Lawrence Livermore National Laboratory has a vegetation and foodstuff monitoring program to comply with U.S. Department of Energy (DOE) guidance, which states that periodic sampling and analysis of vegetation should be performed to determine if there is measurable, long-term buildup of radionuclides in the terrestrial environment (U.S. Department of Energy 1991).

Tritium is the nuclide of major interest in the LLNL vegetation and foodstuff monitoring program. LLNL has historically released tritium to the air accidentally and during routine operations and tritium is the only radionuclide released from LLNL activities that occurs in detectable concentrations in vegetation and foodstuff. Tritium moves through the food chain as tritiated water and can be rapidly assimilated into plant water and then incorporated into the organic matter of plants through photosynthesis. It can contribute to human radiation dose if it is inhaled, absorbed through the skin, or ingested via vegetables, or milk and meats from animals that have eaten tritiated vegetation.

LLNL has been monitoring tritium in vegetation to some extent since 1966 and has performed vegetation sampling in the vicinity of the Livermore site and Site 300 as part of a continuing monitoring program since 1972. The monitoring program is designed to measure changes in the environmental levels of radioactivity, to evaluate the environmental effect of LLNL operations, and to calculate potential human doses from radionuclides in the food chain.

In 1977, LLNL added wine to the LLNL monitoring program. Wine is now the most important agricultural product in the Livermore Valley, representing an approximately \$80-million annual industry, based on sales. Although the tritium concentrations in all wines are low, the sampling data indicate that Livermore Valley wines contain statistically more tritium than do wines from other California wine-producing regions.

In the past, other foodstuffs (cow milk, goat milk, and honey) leading to potential dose were also monitored for tritium. At present, however, only tritium concentrations in vegetation and wine are used to assess potential ingestion dose from tritium emitted



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Vegetation and Foodstuff Monitoring

during LLNL operations. During 1999, LLNL collected and analyzed samples of herbaceous vegetation and wine. Potential human doses from these foodstuffs were calculated using the monitoring data and the dose models presented in Appendix A. In addition, as part of a continuing study, LLNL determined the potential tritium dose to the maximally exposed individual from a pine tree at the Livermore site. This tree serves as a diffuse source of tritium because it loses tritium to the air through evapotranspiration of tritium-contaminated water in the root zone. The dose was calculated using the U.S. Environmental Protection Agency (EPA) model, CAP88-PC.

Methods

The methods used for monitoring vegetation and wine are presented briefly in the following sections and in more detail in the Data Supplement. All vegetation and wine sampling was conducted according to written and approved standardized procedures (Tate et al. 1999).

Vegetation

LLNL staff collected vegetation samples, usually annual grasses, quarterly from 22 fixed locations in the Livermore Valley, San Joaquin County, and Site 300. The samples were then analyzed for tritium.

Location maps are provided in **Figures 11-1** and **11-2**. Sample locations were selected to represent vegetation from: (1) locations near LLNL that can be affected by LLNL operations, (2) background locations where vegetation is similar to that growing near LLNL but is unlikely to be affected by LLNL operations, and (3) areas of known or suspected LLNL-induced contamination. Sampling locations for 1999 were the same as those in 1998.

Wine

Three types of wine samples were collected and analyzed for tritium concentrations: wine produced from grapes grown in the Livermore Valley, wine produced from grapes grown in California outside the Livermore Valley, and wine produced from grapes grown in Europe (France, Germany, and Italy). The wines were purchased from local retailers to represent what the general public could buy and drink during 1999.

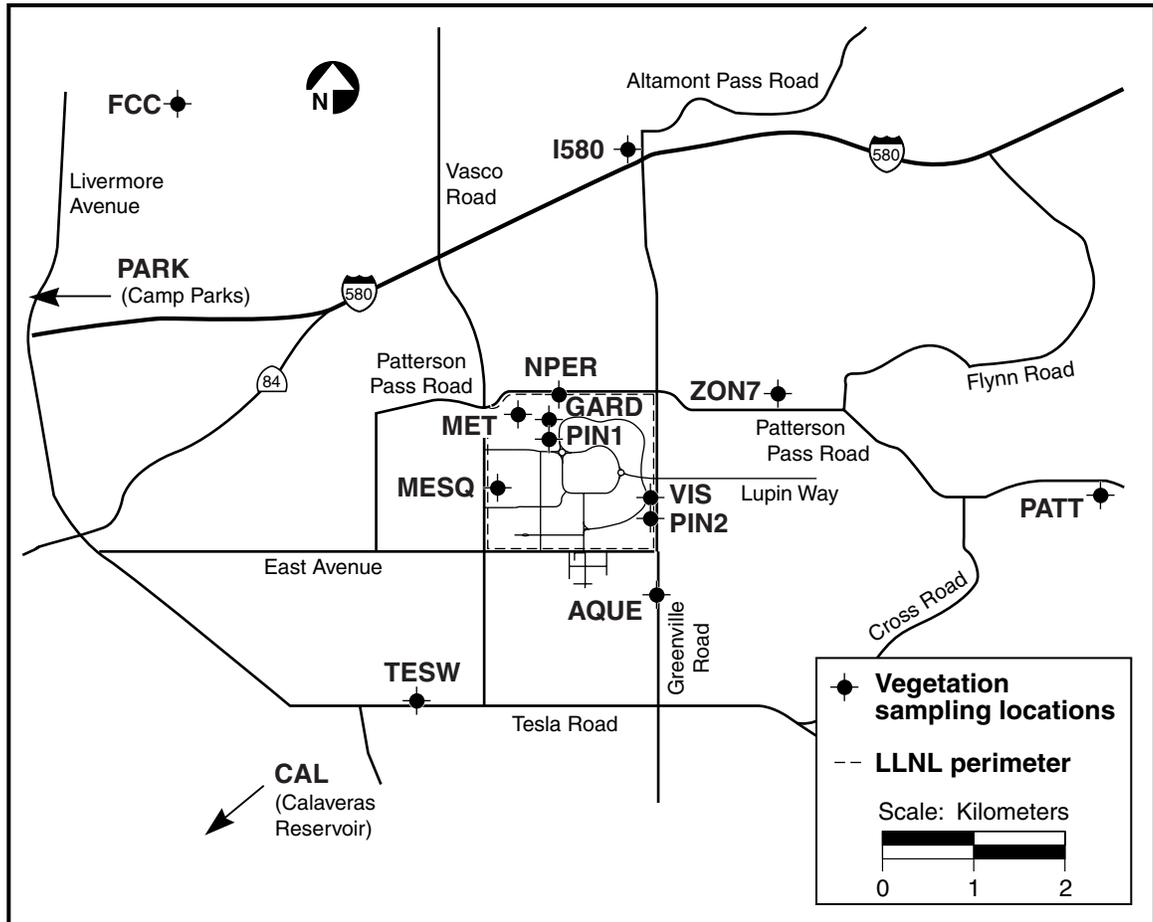


Figure 11-1. Livermore site and Livermore Valley vegetation sampling locations, 1999.

Data from the analysis of tritium in wine can be used to estimate the potential tritium dose received by consumers during the year of purchase. However, because wines purchased in 1999 are from grapes that were harvested in 1996, 1997, and 1998, the 1999 sampling data cannot be used to indicate how LLNL's operations affected concentrations of tritium in wines produced from grapes grown in 1999. To analyze trends and help determine the impact of LLNL operations on tritium in wine for the year when the grapes were harvested, LLNL corrects the wine sample concentrations for the radiological decay that has occurred between the approximate date of the grape harvest and the date when the wine was analyzed in the laboratory. Comparisons can then be made of wine concentrations that represent the year when the grapes were exposed to the tritium.



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Vegetation and Foodstuff Monitoring

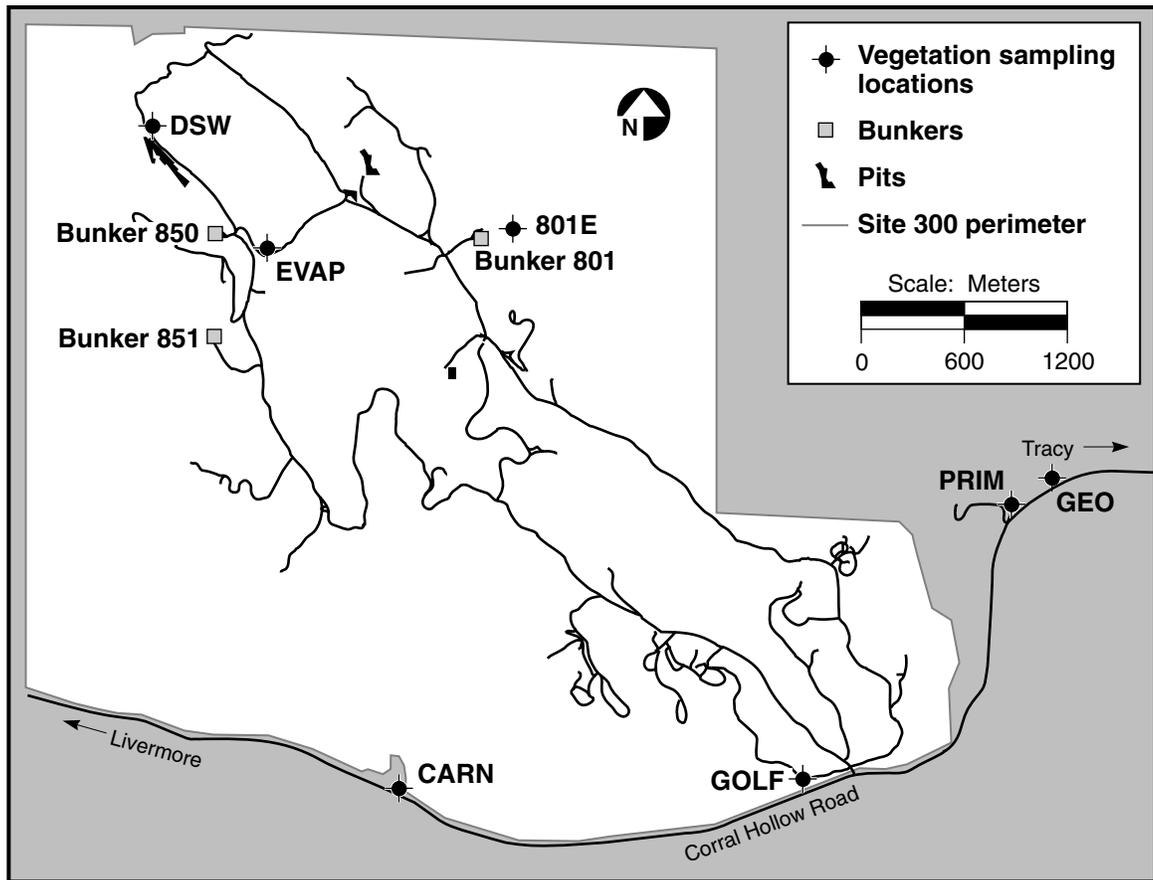


Figure 11-2. Site 300 vegetation sampling locations, 1999.

Results

The results of vegetation monitoring for the Livermore site and Site 300 and of wine monitoring are presented in the following sections.

Livermore Site

Vegetation

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

- Near—locations within 1 km of the Livermore site perimeter. Near locations include AQUE, GARD, MESQ, NPER, MET, PIN2, and VIS.



- Intermediate—locations in the Livermore Valley 1–5 km from the Livermore site perimeter that are often downwind and, thus, potentially under the influence of tritium releases at the site. The intermediate locations are I580, PATT, TESW, and ZON7.
- Far—locations unlikely to be affected by LLNL operations. One background location (CAL) is more than 25 km away. The other two (FCC and PARK), although in the Livermore Valley, are unlikely to be affected by LLNL operations because they are more than 5 km from the Livermore site and are generally upwind.
- PIN1—location of a pine tree rooted in an area of known tritium contamination on the Livermore site.

Table 11-1 shows summary tritium data for vegetation collected for the LLNL vegetation monitoring program in 1999 (individual sampling values are presented in the Data Supplement of this report). **Figure 11-3** shows the 1999 medians of the tritium concentrations for PIN1, Near, and Intermediate Livermore locations as a continuation of historic median concentrations from 1971 to 1998. The values for 1998 and 1999 Far locations are the lowest positive measured concentrations rather than the medians; medians for 1998 and 1999 are negative for the Far location and, hence, cannot be plotted on a logarithmic scale. Although the concentration in Far vegetation appears to drop by about a factor of 10 in 1998, it is highly unlikely that any difference exists among 1998, 1999, and recent preceding years. The apparent difference is caused by a change in how the analytical laboratory reported concentrations less than the detection limit.

For 1999, the data for tritium in vegetation were compared using Scheffé's and Games/Howell multiple comparisons (Scheffé 1953; Games and Howell 1976). These tests are the most appropriate tests for these distributions of data. Unlike previous years, the Near group was not found to be significantly different from the Intermediate and Far groups. This was caused by unusually high observed values of tritium in vegetation at VIS, PIN2, and I580 for the first quarter of 1999 when tritium releases were unusually high. When the Near group (without first quarter values for VIS and PIN2) is compared with the Intermediate group (without the first quarter value for I580) and the Far group, results are similar to previous years. Both tests show concentrations of the Near group to be significantly higher than concentrations from both the Intermediate and Far groups. The highest median tritium results for individual vegetation sampling locations were found at the Near locations, PIN2 and VIS, which are located near each other downwind of the Livermore site.



Table 11-1. Concentrations of tritium in plant water (Bq/L), 1999.

Location ^(a)	Detection frequency ^(b)	Median	Interquartile range	Maximum	Dose ($\mu\text{Sv/y}$) ^(c)	
					Median	Maximum
Near Livermore site ^(d)	25/28	7.0	9.9	100	0.034	0.48
Livermore site PIN1 ^(e)	4/4	150	120	280	8.0×10^{-6} ^(f)	1.5×10^{-6} ^(f)
Livermore site intermediate locations	7/16	1.4	4.2	100	0.0068	0.48
Livermore site far locations	0/12	-0.72	1.8	0.68	— ^(g)	0.0033
Location DSW at Site 300 ^(e)	1/4	1.6	1.3	3.1	0.0078	0.015
Location EVAP at Site 300 ^(e)	3/4	170	370	480	0.81	2.3
All other locations at Site 300	5/20	-0.015	1.6	4.0	— ^(g)	0.019

Note: Radioactivities are reported as the measured concentration and either an uncertainty ($\pm 2\sigma$ counting error) or as being less than or equal to the detection limit. If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection. See the main volume, Chapter 14, Quality Assurance.

- ^a See **Figures 11-1** and **11-2** for sampling locations.
- ^b Detection frequency means the fraction of samples taken having a measured value above the detection limit.
- ^c Ingestion dose is calculated based on conservative assumptions that an adult's diet is exclusively vegetables with this tritium concentration, and that meat and milk are derived from livestock fed on grasses with the same concentration of tritium. See Appendix A, Methods of Dose Calculations.
- ^d Includes PIN2; plant water concentrations are similar among plant types.
- ^e Sampling location in known area of contamination.
- ^f For this dose calculation, PIN1 is treated as a diffuse source of tritium (because human beings do not eat pine needles). Dose, calculated using CAP88-PC, is to the maximally exposed individual.
- ^g Dose is not calculated when the median concentration is negative.

In 1997, PIN1, a pine tree growing in a known area of tritium contamination at the Livermore site, was monitored on a monthly basis to estimate emissions for compliance with National Emissions Standards for Hazardous Air Pollutants (NESHAPs). In 1998, the tree sampling was coordinated with the quarterly vegetation sampling. Since 1998, NESHAPs calculations to the sitewide maximally exposed individual (SW-MEI) are based on quarterly observations. To assess the contribution of soil water tritium to PIN1, LLNL also sampled a second tree (PIN2) that is not in tritium-contaminated soil. Concentrations of tritium in PIN2, like in all other vegetation sampled near the Livermore site, are from air and soil water in quasi-equilibrium with air. When samples from PIN1 were compared with samples from each Near location, concentrations of tritium in PIN1 were found to be significantly higher than concentrations at all other locations except the downwind locations, VIS and PIN2.

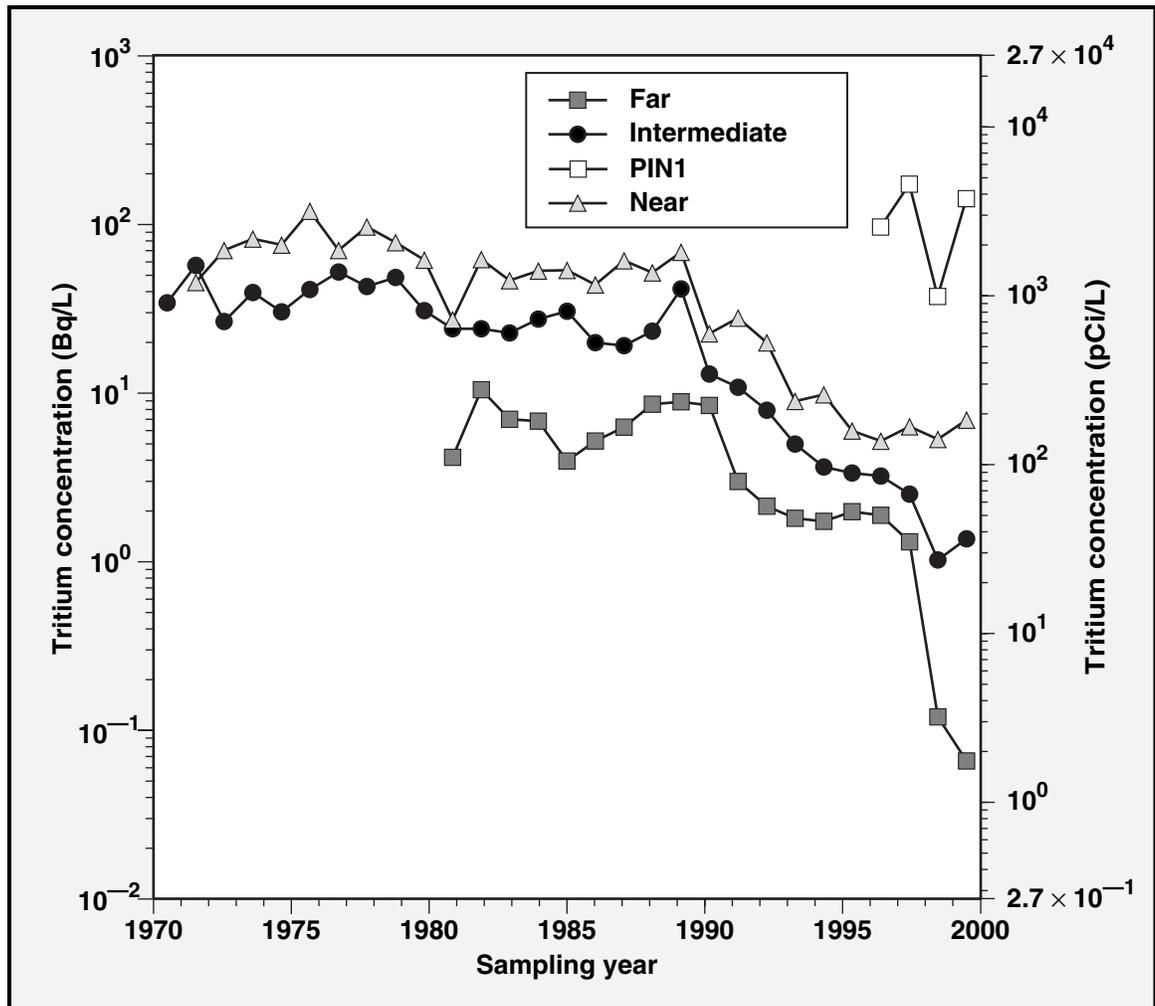


Figure 11-3. Median tritium concentrations in Livermore site and Livermore Valley plant water samples, 1971–1999. (For Far vegetation for 1998 and 1999, the values are the lowest positive.)

Wine

The results from the 1999 wine tritium analyses are shown in **Table 11-2**. Tritium concentrations are within the range of those reported in previous years and remain low in wines from all areas. The data for the 1999 sampling year were analyzed using Scheffé and Games/Howell multiple comparisons. The results of the comparisons are the same as in previous years. Both analyses show that the mean tritium concentration of the 12 Livermore wines is statistically greater than that of the six California wines. When the Livermore, California, and European wines were compared using the Scheffé test, no significant difference was noted among the groups because of the high



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variability of Livermore Valley wines. The variability in the Livermore Valley wines is due to some grapes being exposed to higher concentrations of tritium in air and in precipitation than others.

Table 11-2. Tritium in retail wine (Bq/L), 1999.^(a)

Region	Detection frequency ^(b)	Median	Interquartile range	Mean	Maximum	Dose ^(c) (nSv/y)
Livermore Valley	12/12	1.7	0.68	2.4	8.3	2.2
California	6/6	0.43	0.15	0.45	0.57	0.40
Europe	4/4	1.5	0.30	1.3	1.6	1.2

Note: Radioactivity is reported as the measured concentration and an uncertainty ($\pm 2\sigma$ counting error). If the uncertainty is greater than the concentration, the result is considered to be a nondetection.

- ^a Wines from a variety of vintages were purchased and analyzed during 1999. The concentrations reported are those at the time the bottles were opened.
- ^b Detection frequency means the fraction of samples taken having a measured value above the detection limit.
- ^c This dose is calculated using the assumption of drinking 52 L wine/year and using the mean concentration of sampled wines.

Concentrations corrected to vintage year are plotted in **Figure 11-4**. The downward trend seen in wines from all locations is not statistically significant. Depending upon the test used, 1982 and 1983 are statistically different from several other vintage years. The 1996 Livermore Valley wines were significantly higher in tritium than those from both 1995 and 1997 (Scheffé's test) and were significantly higher than those in just 1997 (Games/Howell test). Data from 1998 could not be included because the sample comprised only two bottles. As mentioned, wines are sampled randomly; and, quite by chance, the 1996 wines unequally represent vineyards close to LLNL.

Site 300

Vegetation

There are seven monitoring locations for vegetation at Site 300. Of these, five (CARN, GOLF, GEO, 801E, and PRIM) detect changes in atmospheric tritium concentrations. Vegetation from locations DSW and EVAP grows in areas of known ground water contamination. Plants with long roots sometimes absorb tritium concentrations from ground water rather than from air.

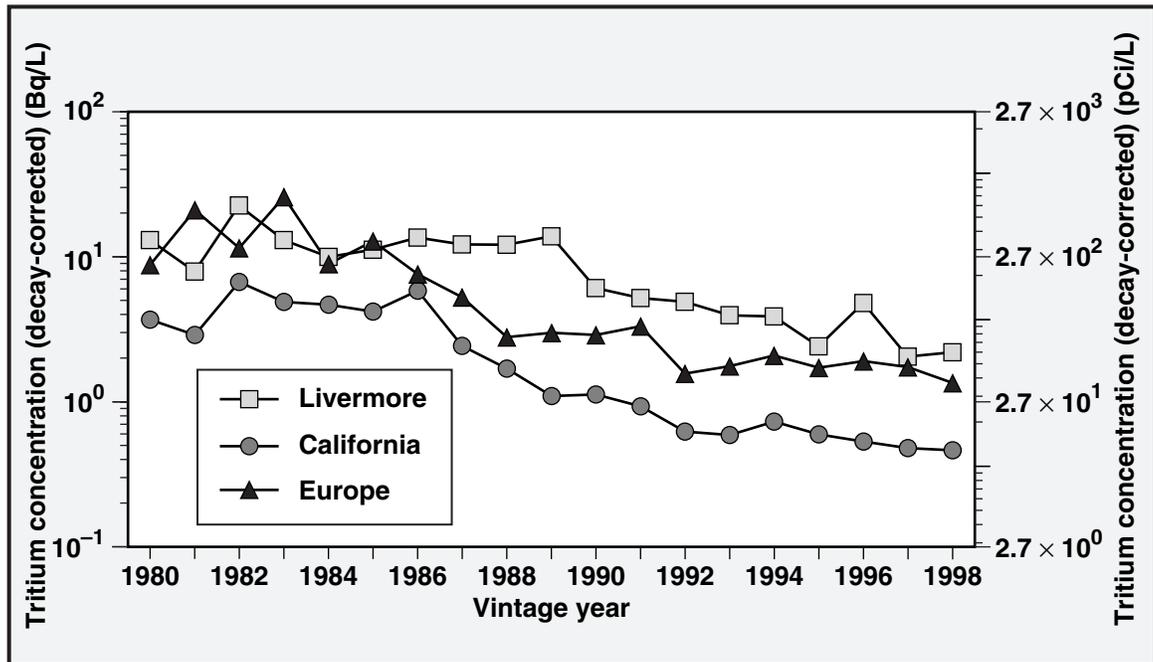


Figure 11-4. Mean tritium concentrations in retail wines decay-corrected from the sampling year to the vintage year.

Table 11-1 shows summary tritium data for vegetation collected at Site 300 during 1999. Historic values for tritium at Site 300 sampling locations are shown in **Figure 11-5**. Of the seven sampling locations at Site 300, six yielded results in 1999 at or near the detection limits. Only EVAP yielded results above detection limits; DSW, normally high (except for 1994), had tritium concentrations at detection limits. The extremely low concentrations for 1998 and 1999 plotted for locations other than DSW and EVAP are caused by having to graph the lowest positive result because the median is negative and the scale of the figure is logarithmic. The apparent difference among 1999, 1998, and preceding years is caused by a change in how the analytical laboratory reported concentrations lower than detection limits.

The highest tritium result for a single vegetation sample occurred at location EVAP (see **Table 11-1**), which is near a spring where ground water flows near the surface and evaporates. The ground water in this area is contaminated with tritium that comes from three sources: Pit 3, Pit 5, and the firing table at Building 850 (see the discussion of wells NC7-61 and NC7-69 in Chapter 9, Ground Water Monitoring). Evaluation of the 1999 data for Site 300 using the Scheffé test yielded no significant differences among the various sampling locations; this is a result of the high variability of the data and the low number of data points.

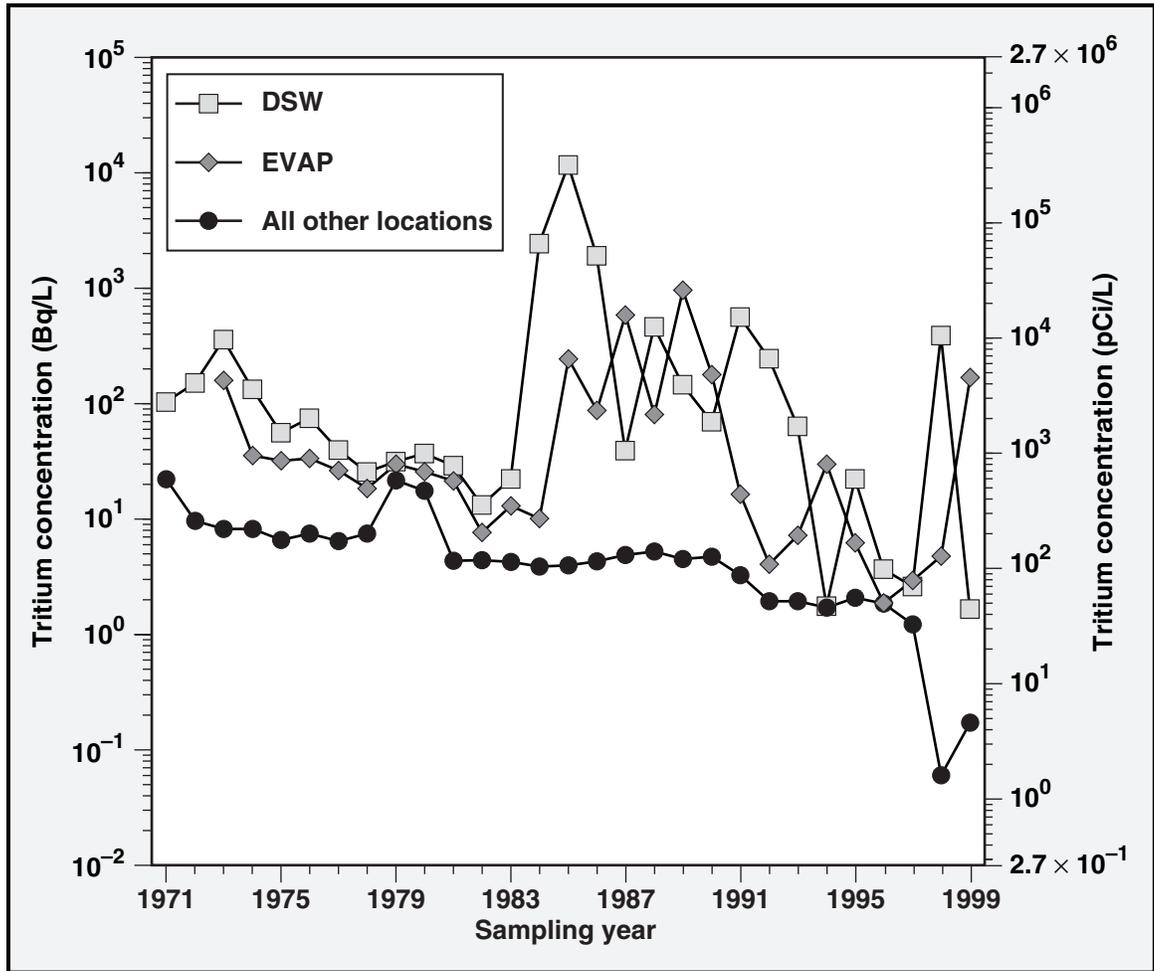


Figure 11-5. Median tritium concentrations in plant water at Site 300 sampling locations, 1971–1999. When the median is negative (e.g., all other locations for 1998 and 1999), the lowest positive concentration has been substituted.

Environmental Impact

In 1999, the environmental impacts of LLNL operations on vegetation and wine were small and are presented below for the Livermore site and Site 300.



Livermore Site

LLNL impacts on vegetation in the Livermore Valley remained minimal in 1999. The effective dose equivalents shown in **Table 11-1** were derived using the dose conversion factors provided by DOE (U.S. Department of Energy 1988) and the dose pathway model from U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109 (1977). Appendix A provides a detailed discussion of dose calculation methods. The dose from ingested tritium is based on the conservative assumptions that an adult's diet (Table A-2, NRC maximum) consists exclusively of leafy vegetables with the measured tritium concentrations, and meat and milk from livestock fed on grasses with the same concentrations. In actuality, the vegetables consumed by an adult contain tritium at lower levels than those reported because most vegetables are imported from other areas. Similarly, tritium concentrations in food consumed by local livestock are at or below the concentrations in vegetation measured at the Intermediate and the Far locations. Nevertheless, based on these extremely conservative assumptions, the maximum potential dose from ingestion of affected vegetation for 1999 for the Livermore Valley is 0.50 μSv (0.050 mrem).

Doses are calculated based on measured tritium in plant water without the contribution of organically bound tritium (OBT). Dose conversion factors of 1.8×10^{-11} Sv/Bq for tritium in the plant or animal water (HTO) and 4.2×10^{-11} Sv/Bq for OBT have been published by the International Commission on Radiological Protection (1996). These show the relative importance of ingested HTO and OBT to dose. In vegetables, the dose from HTO is greater because the fraction of the plant that is organic matter is quite small (10–25%). For example, about 10% of the ingestion dose from leafy vegetables (about 10% dry matter) is from OBT. OBT becomes increasingly important when the fraction of dry matter increases. Pork, for example, has a dry-matter content of about 30–50% (Ciba-Geigy Ltd. 1981), and the resulting ingestion dose from pork is about half from OBT and half from HTO. The OBT in grain, which is 88% dry matter, contributes nearly 90% of the total grain ingestion dose. Given the differences in OBT dose contribution from different foods, the importance of OBT to ingestion dose depends on what quantities of what kinds of foods are consumed. An extremely unlikely diet very high in OBT would, at most, give an OBT contribution to dose equal to that of HTO. Thus, conservatively, the maximum total tritium dose from ingestion of vegetables and foodstuffs from the Livermore Valley for 1999 could be 1.0 μSv (0.10 mrem), well below any level of concern.

The dose values for PIN1 shown in **Table 11-1** were calculated in a different manner from those for edible vegetation because it is unreasonable to assume that any person is directly ingesting pine needles. The pine tree is treated as a diffuse source of tritium to the atmosphere via the contaminated transpirational stream. LLNL used an estimated



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tritium transpiration rate from the tree as input data to the EPA regulatory model CAP88-PC. LLNL modeled air dispersion of the transpired tritium and calculated a resulting dose from inhalation, skin absorption, and potential ingestion from air concentrations at the location of the maximally exposed individual. This total dose is based on the conservative assumptions that 100% of the individual's time is spent at this location and that his/her diet consists exclusively of vegetables with the measured tritium concentration, and meat from livestock fed on grasses with the same concentration. The resulting maximum dose for PIN1 of 1.5×10^{-5} μSv (1.5×10^{-6} mrem) is considerably lower than ingestion doses calculated directly from measured concentrations in vegetation because the tree is only an indirect source of air/vegetation contamination.

No health standards exist for radionuclides in wine. However, all the wine tritium levels were far below drinking water standards. In fact, even the highest detected Livermore Valley value (8.3 Bq/L or 224 pCi/L) represents only 1.1% of the California drinking water standard (740 Bq/L or 20,000 pCi/L). Doses from wine consumption can be calculated according to methods for water ingestion, as described in Appendix A.

Based on the conservative assumption that wine is consumed at the same rate as water (370 L/year or 1 L/day), the annual dose that corresponds to the highest detected 1999 Livermore Valley tritium value in wine is 53 nSv (5.3 μrem). Assuming a more realistic average wine consumption (52 L/year or 1 L/week of wine) and the mean tritium values from the three sampling areas, the annual doses from Livermore, European, and California wines would be 2.2 nSv (0.22 μrem), 1.2 nSv (0.12 μrem), and 0.40 nSv (0.040 μrem), respectively.

The potential ingestion dose from all foodstuffs grown near the Livermore site was realistically well below 1.0 μSv (0.10 mrem) for 1999. This is a factor of 3000 lower than an annual background dose (~3000 μSv or 300 mrem) and a factor of 100 lower than the dose from a typical chest x-ray (100 μSv or 10 mrem) (Shleien and Terpilak 1984). Therefore, although tritium levels are elevated slightly near the Livermore site, doses from tritium ingestion are negligible.

Site 300

In general, LLNL impacts on tritium concentrations in vegetation at Site 300 for 1999 were insignificant. With the exception of vegetation from previously identified sites of contamination, the tritium levels at Site 300 were at or near the limits of detection and



comparable to those observed in previous years. The areas where tritium is known to be present in the subsurface soil are well delineated and localized.

The calculated maximum potential annual ingestion dose from vegetation at sampling location EVAP, based on the maximum value of 480 Bq/L (13,000 pCi/L), is 2.3 μ Sv (0.23 mrem). This dose, based on the conservative modeling assumptions described above, is theoretical, because vegetation at Site 300 is not ingested either by people or by livestock. In comparison, the potential annual dose (also theoretical) from vegetation at all other locations at Site 300 could not be calculated because the median concentration is below the limit of detectability.

Environmental Radiation Monitoring

Nicholas A. Bertoldo

Introduction

In accordance with federal regulations and Department of Energy (DOE) Orders 5400.1 and 5400.5, Lawrence Livermore National Laboratory monitors gamma radiation to establish radiation levels in its vicinity and to determine the direct environmental radiological impact of its operations. Gamma radiation in the environment primarily occurs naturally from terrestrial and cosmic sources. Because environmental radiological monitoring is used as one measure of the potential radiation dose that the public may receive as the result of LLNL operations, LLNL has developed an extensive radiological monitoring network for the Livermore site perimeter, Site 300 perimeter, and off-site locations. Gamma radiation has been measured at the Livermore site since 1973 and at Site 300 since 1988. The absorbed gamma radiation dose imparted to thermoluminescent dosimeters (TLDs) is the result of TLD exposure to both terrestrial and cosmic radiation sources as well as LLNL sources, if any.

Cosmic Radiation Component

Gamma radiation in air is produced by the interaction of cosmic rays, which contain high-energy particles and emanate primarily from beyond the solar system, with atmospheric nuclei. The cosmic radiation component accounts for about half the observed site annual average gamma radiation.

Terrestrial Radiation Component

Terrestrial gamma radiation is primarily caused by naturally occurring isotopes of the uranium, thorium, and actinium decay series that are present in soil worldwide and that produce gamma radiation during radioactive decay. The concentration of naturally occurring radionuclides in soil is variable and is determined by the ratio of thorium-232 to uranium-238 (present in these regions at the time of the earth's formation over four billion years ago), which ranges from 3 to 4 around the world. By



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characterizing the natural background radiation, LLNL can determine whether or not there is a contribution to gamma exposure from Laboratory operations.

General Methods

LLNL deploys TLDs in the field to assess the environmental impact of laboratory operations at both the Livermore site and Site 300. This assessment is done by comparing the gamma radiation data acquired from the Livermore perimeter site locations to various locations monitored in the Livermore Valley, and gamma-radiation data from Site 300 perimeter locations to locations in the City of Tracy and near Site 300.

As previously mentioned, the variability of the naturally occurring radioisotopes present in the soil due to geological formations is the largest contributor to variations in measurements. Meteorological conditions contribute to seasonal variability, as does cosmic variation.

LLNL deploys TLDs at the beginning of each quarter of the year and retrieves them from the monitoring locations as near to the end of the quarter as possible in order to have a 90-day exposure period. All data are normalized to a 90-day standard quarter basis in order to make valid comparisons.

Details of the TLD calculations and reporting of external gamma radiation dose are described in an Operations and Regulatory Affairs Division procedure.

Monitoring Locations

In 1999, external doses from gamma radiation were monitored at 14 Livermore site perimeter locations (shown in **Figure 12-1**) and at 23 Livermore Valley locations (**Figure 12-2**), which are used for background comparison to perimeter location data. Similarly, gamma doses are monitored at eight perimeter monitoring locations at Site 300 (**Figure 12-3**). Additionally, five off-site locations near Site 300 and two locations in nearby Tracy are also monitored for comparison with the Site 300 data. Summary dose calculations for all gamma-monitoring locations are presented in **Table 12-1**.

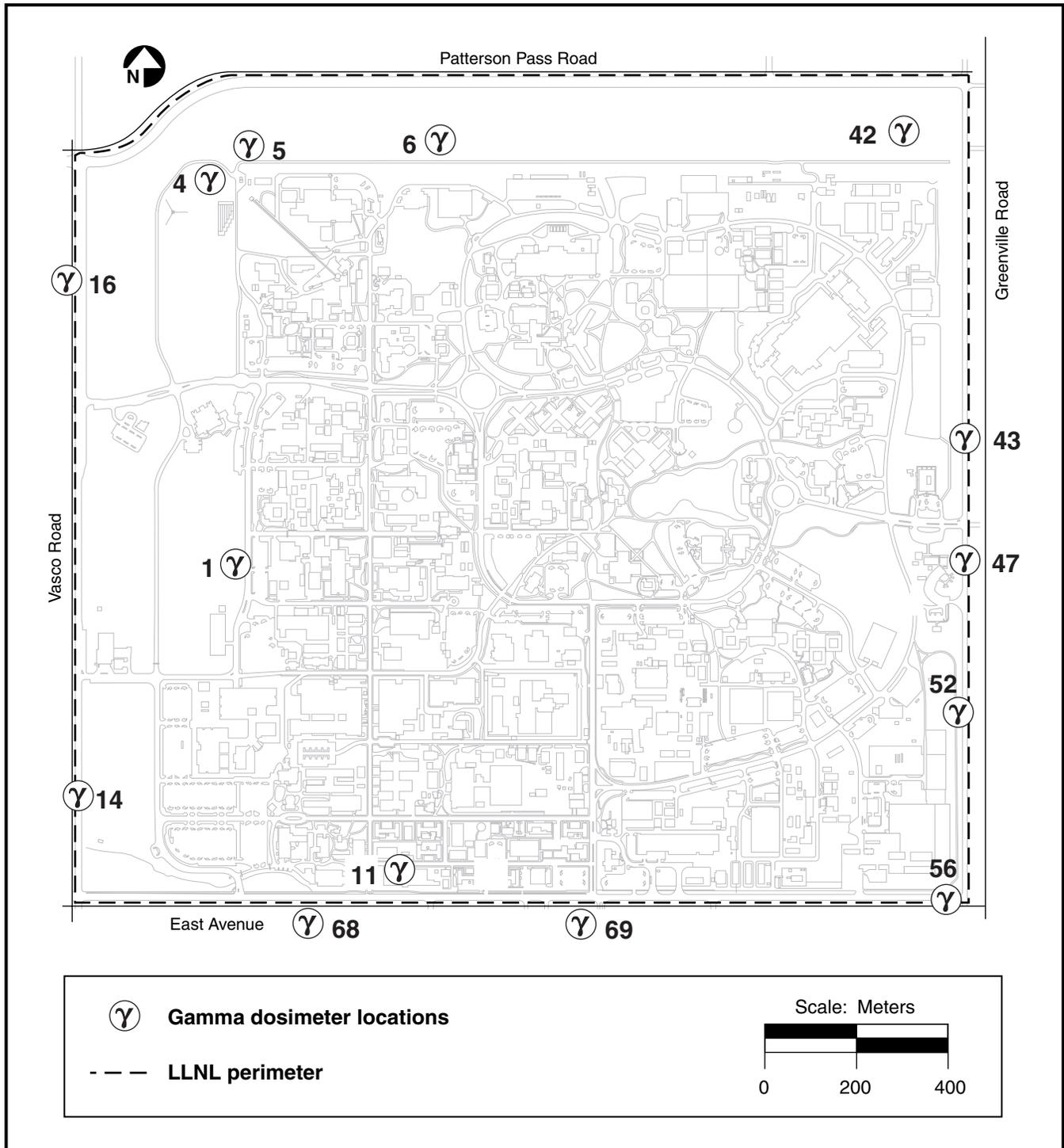


Figure 12-1. Gamma dosimeter locations, Livermore site, 1999.



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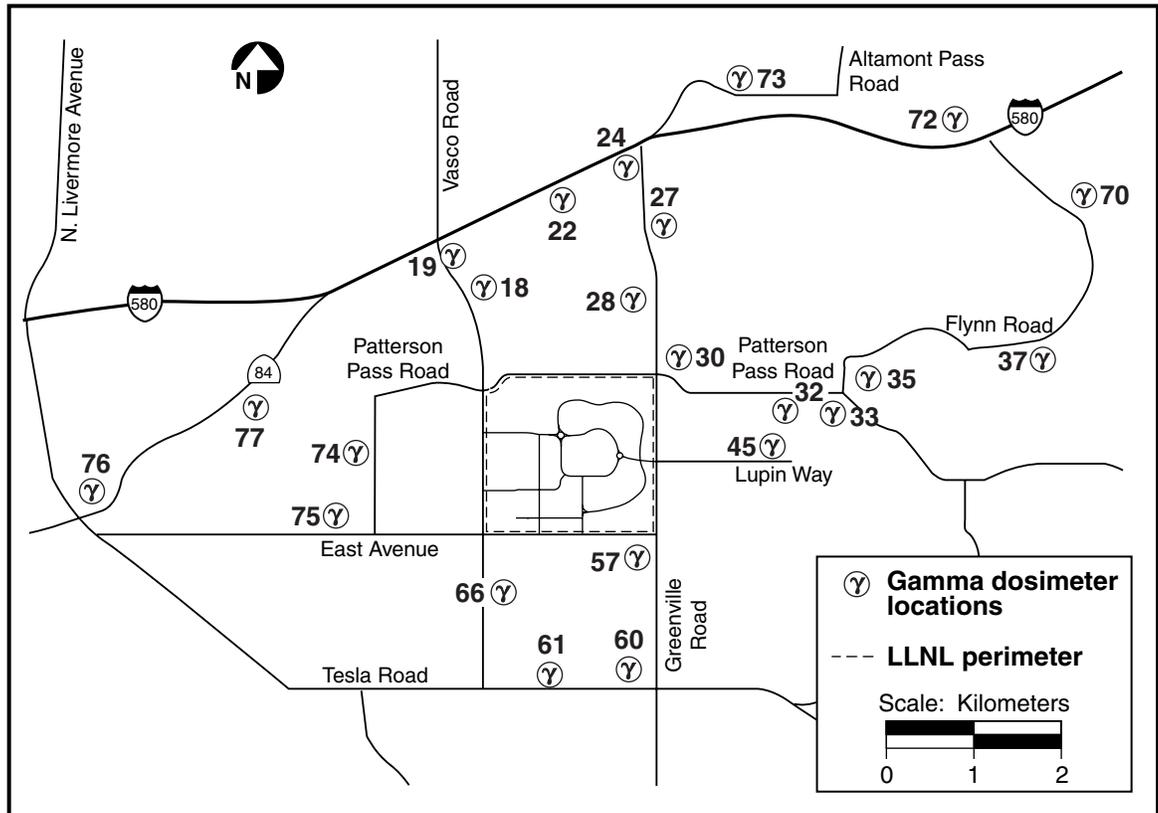


Figure 12-2. Gamma dosimeter locations, Livermore Valley, 1999.

Collocated Monitoring Locations

The State of California Department of Health Services, Radiological Health Branch (CDHS-RHB) performs routine, independent gamma monitoring at several sites collocated with LLNL's TLD network. CDHS-RHB site locations correspond to several Livermore site perimeter, valley, Site 300, and off-site locations near Site 300. Although CDHS-RHB has been co-monitoring these locations for several years, CDHS-RHB personnel have added other sites to their network and continue to monitor at one Livermore site perimeter location that LLNL discontinued in its TLD monitoring network in 1995. This location, which lies approximately halfway between site 14 and site 16 on the Vasco Road perimeter, was formerly designated as a valley site location in 1994 although it is actually located just outside the LLNL perimeter at Vasco Road and the Mesquite Way perimeter entrance. The nine locations monitored by CDHS-RHB are LLNL-15, -19, -28, -47, -75, -78, -91, -96, and -99. CDHS-RHB added location LLNL-47 to its network in the third quarter 1999. (See Figures 12-1, 12-2, and 12-3 for these corresponding locations.)

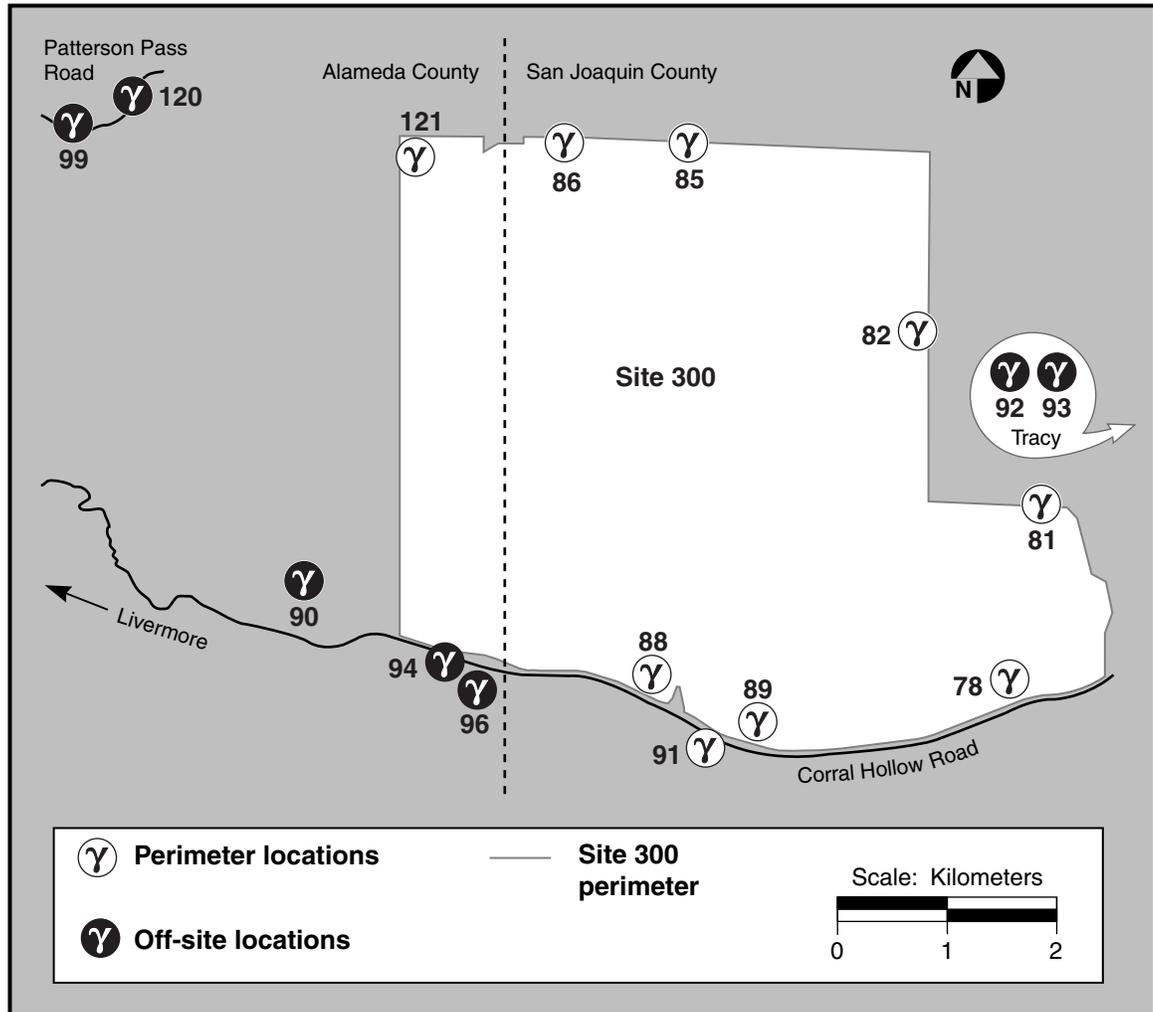


Figure 12-3. Gamma dosimeter locations, Site 300 and vicinity, 1999.

Table 12-1. Summary of dose calculations for gamma-monitoring locations (mSv)^(a) at all LLNL sites, 1999.

Quarter	Location				
	Livermore site Mean 2 SE ^(b)	Livermore Valley Mean 2 SE	Site 300 Mean 2 SE	Tracy Mean 2 SE	Near Site 300 Mean 2 SE
First	0.142 ± 0.006	0.140 ± 0.005	0.172 ± 0.009	0.148 ± 0.01	0.187 ± 0.025
Second	0.144 ± 0.006	0.143 ± 0.006	0.175 ± 0.008	0.144 ± 0.024	0.189 ± 0.023
Third	0.144 ± 0.007	0.143 ± 0.007	0.181 ± 0.015	0.147 ± 0.013	0.201 ± 0.027
Fourth	0.146 ± 0.006	0.143 ± 0.006	0.178 ± 0.010	0.152 ± 0.017	0.189 ± 0.036
Annual dose	0.577 ± 0.025	0.571 ± 0.022	0.706 ± 0.040	0.591 ± 0.066	0.770 ± 0.109

^a 1 mSv = 100 mrem.

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



Results of Gamma Monitoring

Figure 12-4 shows gamma doses for the Livermore site perimeter, Livermore Valley, and Site 300 from 1988 through 1999. Beginning in 1995, all quarterly gamma radiation data points were normalized to standard, 90-day quarters, as is the practice of the Nuclear Regulatory Commission (NRC) (Struckmeyer 1994). Correcting the data to standard quarters to normalize the data to the same number of days deployed reduces the variability caused by exposure duration.

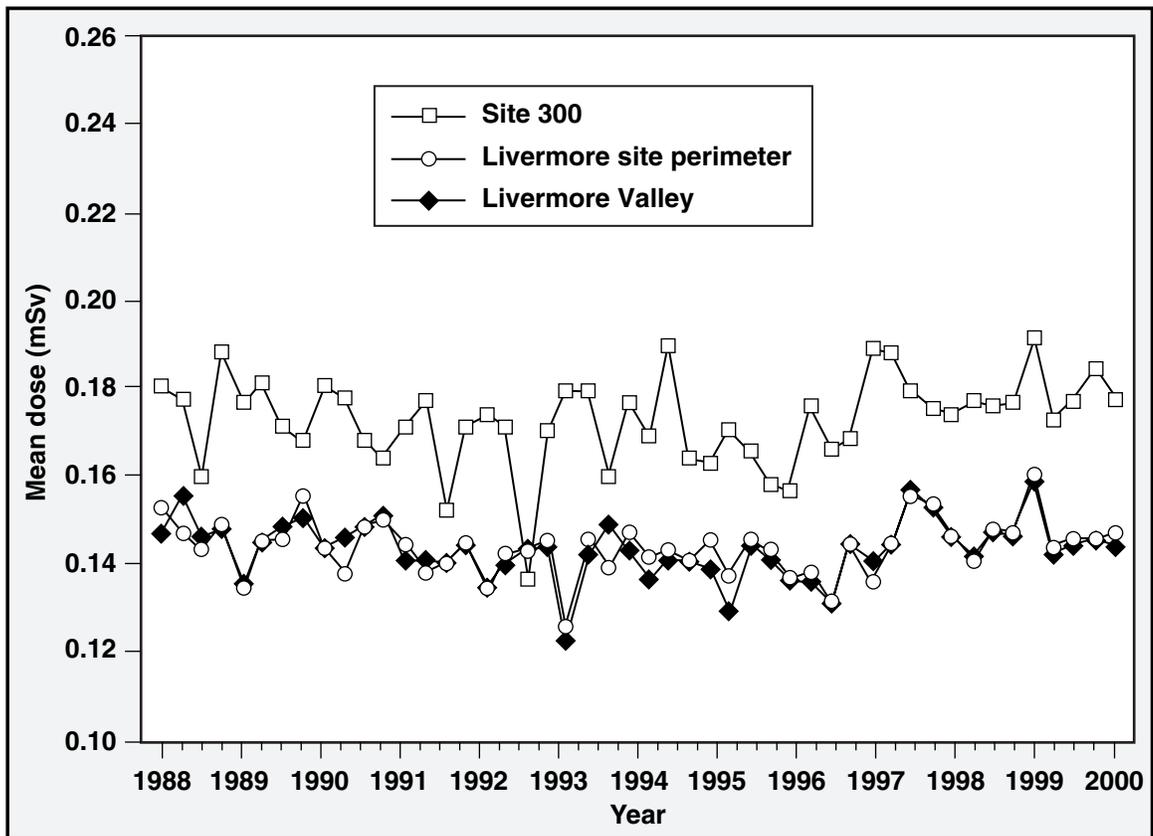


Figure 12-4. Quarterly gamma dose measurements at the Livermore site perimeter, Livermore Valley, and Site 300, 1988–1999.



Livermore Site

Table 12-1 presents a summary of the quarterly and annual TLD gamma radiation dose equivalents for the Livermore site perimeter locations and Livermore Valley off-site locations. The mean 1999 dose equivalent from external, direct-radiation exposure at the Livermore site perimeter, 0.577 mSv, is statistically the same as the background external dose measured in the Livermore Valley, 0.571 mSv. **Table 12-2** lists the yearly doses due to direct gamma radiation at the Livermore site perimeter. All doses fall within the predicted range for background radiation, and no LLNL operational impacts are discernible.

Table 12-2. Annual dose by year at the Livermore site perimeter caused by direct gamma radiation.^(a)

Year	mSv	mrem
1988	0.59	59
1989	0.58	58
1990	0.58	58
1991	0.56	56
1992	0.56	56
1993	0.57	57
1994	0.56	56
1995	0.56	56
1996	0.55	55
1997	0.59	59
1998	0.60	60
1999	0.58	58

^a Data normalized to standard 90 days per quarter (360 days per year).

Site 300

As seen in **Table 12-1**, the measured Site 300-perimeter annual average dose in 1999 was 0.706 mSv, the measured dose at the off-site locations near Site 300 was 0.770 mSv, and the measured doses in and near Tracy were 0.591 mSv. All doses are within the predicted range for background radiation, and no LLNL operational impacts are discernible.



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At Site 300, the initial TLD network design limited monitoring to the Site 300 perimeter and two locations in and near the City of Tracy, which were chosen to represent background radiation levels. However, the region around Site 300 has higher levels of naturally occurring uranium present in the local geological area called the Neroly Formation. The mean dose measured in the off-site locations of the area around Site 300, which is used to represent the high end of background radiation from this formation, was 0.772 mSv and is greater than the Site-300 perimeter dose of 0.710 mSv. The Tracy area, with a dose of 0.626 mSv, is underlain by a geological substrate composed of alluvial deposits of clays, sands, and silts overlying bedrock. The difference in doses can be directly attributed to the difference in geologic substrates.

The doses at the Livermore-site perimeter and in the Livermore Valley are comparable from 1988 to 1999. However, while Site 300 doses are similarly comparable, TLDs there continue to record slightly higher direct gamma doses than do the Livermore site and the Livermore Valley, which is expected, given the differences in geology among these sites.

Environmental Impact

Although the contribution of cosmic radiation may vary due to the sun cycle, the sum of the measured terrestrial and cosmic radiation dose has been observed to range from 0.6 to 0.7 mSv/y. In addition, variability caused by the local geology and meteorology will also affect this range slightly. Direct radiation doses measured at the Livermore site perimeter in 1999 are near these predicted values and are statistically equivalent to the Livermore Valley doses, which are considered natural background levels. Although measured gamma exposure at Site 300 and the local vicinity are slightly higher than reported for the Livermore site and Livermore Valley, their range is attributed primarily to the variation of the geological substrate containing radionuclides of natural origin. The annual gamma radiation measured by the TLD network indicates that the exposure level is not elevated above natural background for any of the monitoring sites because of LLNL operations.



Radiological Dose Assessment

Robert J. Harrach

Introduction

Radiological doses to the public result from both natural and man-made radiation. The total dose received by individuals and populations can be determined by measurements and calculations. This chapter describes Lawrence Livermore National Laboratory's radiological dose assessments, which are made to determine the impact of LLNL operations. It includes a discussion of the analyses performed to demonstrate LLNL's compliance with the radiological National Emission Standards for Hazardous Air Pollutants (NESHAPs; Title 40 *Code of Federal Regulations* [CFR], Part 61, Subpart H).

Background Information

Because this chapter is written for a diverse readership, from scientists and regulators to interested citizens with limited scientific training, a description is given of concepts, methods, tools, and other basic material in the first three sections as well as in two supplements at the end of the chapter. Supplement 13-1, *Radiation Basics*, covers the different sources and types of radiation and the units used to quantify radiation, and it provides perspective on the wide range of radiation levels that people commonly encounter. Supplement 13-2, *Radiation Control Measures at LLNL*, sketches the standard operating procedures used to protect employees, the public, and the environment from uncontrolled releases and unsafe levels of radiation. Readers desiring to go directly to the chapter's principal results can turn to the *Radiological Doses to the Public from LLNL Operations* section.

Releases of Radioactivity to Air

Air releases are by far the major source of public radiological exposures from LLNL operations. In contrast, releases to ground, surface, and sewerable waters are not sources of direct public exposures because these waters are not directly consumed or used by the public. Water releases can cause indirect exposures, which are treated as



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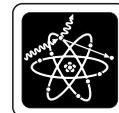
special cases; for example, a recent case considered the possible dose to the public from inhalation and ingestion of soil contaminated by sewer effluent containing radioactivity (U.S. Department of Health and Human Services 1999). Apart from such unusual occurrences, measurements and modeling of air releases determine LLNL's radiological dose to the public.

Data are gathered by three principal means: routine surveillance air monitoring for radioactive particles and gases, both on and off Laboratory property (described in Chapter 5); continuous monitoring of stack effluent at selected facilities at the Livermore site (described in Chapter 4); and usage inventories at all noncontinuously monitored or unmonitored facilities housing radioactive materials management areas and for radioactive materials used in explosive experiments at Site 300 (usage inventories are described in LLNL's NESHAPs annual reports [e.g., Gallegos et al. 2000]).

Despite this "air emphasis," it should be noted that LLNL's extensive environmental monitoring program embraces all media and a wide range of potential contaminants, not limited to radioactive ones. In addition to air monitoring and the three categories of water monitoring already mentioned, the Laboratory samples soil, sediment, vegetation, and foodstuff, and measures environmental (gamma) radiation. Monitoring has been described extensively since 1971 in LLNL's environmental reports (e.g., Larson et al. 1999; see also Chapters 4 through 11 in the present report) and in LLNL's triennially updated *Environmental Monitoring Plan* (e.g., Tate et al. 1999) and its associated procedures and guidance documents.

Air Dispersion and Dose Models

Theoretical/calculational models are needed to describe the transport and dispersion in air of contaminants and the doses received by exposed persons. Various factors dictate this need for modeling: (1) the amounts of LLNL-generated radioactive material dispersed into the atmosphere cause doses thousands of times smaller than those caused by natural background radiation (arising from irradiation by cosmic rays, inhalation of radon gas, exposure to radioactive materials in soil and rock, and ingestion of naturally occurring radionuclides present in our food and water; see Supplement 13-1), so it is difficult to demonstrate compliance with standards through physical measurements alone; (2) all potentially significant exposure pathways need to be taken into account when estimating dose impacts; and (3) the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) sanction the use of specific computer codes that implement their approved dosimetry and dispersion models for evaluating potential doses to the public from both routine and unplanned releases. Advantages



of a well-developed modeling capability include its utility in source design and optimization (e.g., estimating effects of hypothetical and/or dangerous sources) and in interpreting past events (e.g., in dose reconstruction).

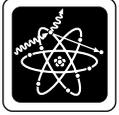
The computer programs used at LLNL to model air releases and their impacts feature idealized, gaussian-shaped plumes and can be run on personal computers. The CAP88-PC code (Parks 1992), in particular, incorporates dosimetric and health effects data and equations that are mandated by EPA to be used in compliance assessments. Furthermore, CAP88-PC accommodates site-specific input data files to characterize meteorological conditions and population distributions for both individual and collective dose evaluations, and the code is relatively easy to use and understand. For these reasons, CAP88-PC has been the “workhorse” modeling tool for LLNL’s regulatory compliance assessments since its availability in March 1992, particularly as applied to chronic releases of radioactivity to air occurring in the course of routine operations.

Radiation Protection Standards

The release of radionuclides from operations at LLNL and the resultant radiological impact to the public are regulated by both DOE and EPA.

DOE environmental radiation protection standards, provided under the authority of the Atomic Energy Act of 1954 and the DOE Organization Act of 1977 (both as amended), are defined in DOE Order 5400.5, *Radiation Protection of the Public and the Environment*. The standards for controlling exposures to the public from operations at DOE facilities that are incorporated in this order are based on recommendations by the International Commission on Radiological Protection (ICRP). The radiological impact to the public is assessed in accordance with DOE Order 5400.1, *General Environmental Protection*. Current indices and links to DOE orders appear on the Department of Energy Directives website (U.S. Department of Energy 1998c).

The primary DOE radiation standards for protection of the public are 1-millisievert-per-year (1-mSv/y) or 100-millirem-per-year (100-mrem/y) whole-body effective dose equivalent (EDE) for prolonged exposure of a maximally exposed individual in an uncontrolled area and 5-mSv/y (500-mrem/y) EDE for occasional exposure of this individual. (EDEs and other technical terms are discussed in Supplement 13-1 and defined in the glossary of this report.) These limits pertain to the sum of the EDE from external radiation and the committed 50-year EDE from radioactive materials ingested or inhaled during a particular year that may remain in the body for many years.



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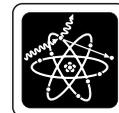
Radionuclide emissions to the atmosphere from DOE facilities are further regulated by the EPA, under the authority of Section 112 of the Clean Air Act. Subpart H of NESHAPs, under 40 CFR 61, sets standards for public exposure to airborne radioactive materials (other than radon) released by DOE facilities; radon is regulated by Subparts Q and T. NESHAPs implements the dosimetry system recommended by the ICRP in Publication 26 (International Commission on Radiological Protection 1977).

The EPA's radiation dose standard, which applies only to air emissions, limits the EDE to members of the public caused by activities/operations at a DOE facility to 0.1 mSv/y or 100 μ Sv/y (10 mrem/y). EPA regulations specify not only the allowed levels, but also the approved methods by which airborne emissions and their impacts must be evaluated. With respect to all new and/or modified projects, NESHAPs compliance obligations define the requirements to install continuous air effluent monitoring and to obtain EPA approval for startup of operations. NESHAPs regulations require that any operation with the potential to produce an annual-averaged off-site dose greater than or equal to 1 μ Sv/y (0.1 mrem/y), taking full credit for emission-abatement devices, such as high-efficiency particulate air (HEPA) filters, must obtain EPA approval prior to startup of operations. This same calculation, but without taking any credit for emission abatement devices, determines whether or not continuous monitoring of emissions to air from this project is required. These requirements are spelled out in Volume III of LLNL's online *Environment, Safety, and Health (ES&H) Manual* in the chapter, "Air Quality Compliance," which can be found at the following Internet address: http://www.llnl.gov/es_and_h/ecm/chapter_12/chap12.html

Reporting Requirements

All DOE facilities that conduct significant environmental protection programs are required by DOE to prepare an annual environmental report for the site, covering activities of the previous calendar year involving releases to all media via all pathways. Because DOE facilities and operations are subject to the regulatory requirements of EPA, in particular 40 CFR 61, Subpart H, DOE facilities are further required to submit an annual report to the EPA, via DOE, showing compliance with NESHAPs (addressing only releases to air).

Details on reporting requirements and citation of pertinent DOE orders and federal regulations are available in the chapter on radiological dose assessment in earlier environmental reports (e.g., Harrach et al. 1997) or LLNL's radiological dose assessment guidance document (Harrach 1998).



Evaluation of Sources of Radioactive Emissions

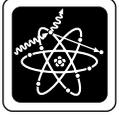
The starting point for an assessment of radiological dose is to identify and properly characterize all significant sources of radioactive emissions at a site. LLNL's sources are determined in three principal ways: (1) by monitoring airborne gases and particulate matter at selected field points in and around the Livermore site and Site 300 (continuous surveillance air monitoring), (2) by direct measurement of the emission rate at the source (continuous effluent monitoring), and (3) by an inventory process.

Inventoried Sources

Radiological operations areas are any locations where radioactive materials are used or stored, or where activation products occur. Several such areas at the Livermore site have effluent monitoring systems in place in their exhaust pathways, allowing a direct measurement of their emission rates. For unmonitored or noncontinuously monitored radiological operations areas, source terms for potential releases are inferred from radionuclide inventories, in accordance with EPA methods.

Experimenters and facility managers provide inventory data, following a protocol designed and administered by LLNL's Environmental Protection Department. A full (100%) inventory is conducted every three years; only the "key" Livermore site facilities, defined as those in a ranked list that collectively accounted for 90% or more of the previous year's Livermore site radiological dose to members of the public, are reinventoried annually. LLNL conducted complete radionuclide inventories for operations in 1994 and again in 1997. In addition, all new radiological operations areas (ones that commenced operations in the year under evaluation) are inventoried, and data on radionuclides used in all Site 300 explosives experiments are provided each year. A description of LLNL's inventory process, including examples of the inventory form and accompanying instructions, is given in the guidance document for preparation of NESHAPs annual reports (Gallegos 1998).

For dose-assessment modeling of unmonitored or noncontinuously monitored sources, the effective emission rate is calculated from radiological usage inventories by applying EPA-specified fractions for potential release to air of materials in different physical states (solid, liquid, powder, or gas) for each radioisotope. The inventory quantity (in becquerels or curies) is multiplied by a state-dependent release fraction to give the potential annual release to air, i.e., the "effective" emission rate, in accordance with 40 CFR 61, Appendix D. If the material is an unconfined gas, the release fraction is 1.0; for liquids and powders, 1.0×10^{-3} is used; and for solids, 1.0×10^{-6} . In the same way, if the radioactive material is encapsulated or sealed for the entire year (i.e., it was not used



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and release to air was prevented), then its release fraction is considered to be zero. For materials that were encapsulated or sealed for part of the year, or that resided in different facilities over the course of the year, “time weighting factors” are introduced to properly account for the release potential. Information on inventories and descriptions of the diffuse sources can be found in the guidance document (Gallegos 1998) and in NESHAPs annual reports.

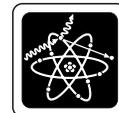
Monitored Sources

Stack Effluent Monitoring

Actual measurements of radionuclides in effluent flow are the basis for reported emissions from continuously monitored sources. At the close of 1999, six buildings at the Livermore site had continuously monitored discharge points: Buildings 175, 177, 251, 331, 332, and 491; taken together, these buildings feature 76 continuously operating monitors. Two other facilities (Buildings 292 and 490) had effluent monitoring systems removed during 1999. The monitoring systems are described in the LLNL *NESHAPs 1999 Annual Report* (Gallegos et al. 2000), as well as in Chapter 4.

The most significant monitored source in terms of public dose impact is the Tritium Facility, Building 331, at the Livermore site. Each of the two 30-m stacks on this facility has both a continuous-monitoring ion-chamber alarm system and continuous molecular-sieve samplers (see Chapter 4 in the Data Supplement). The sieve samplers, which can discriminate between tritiated-water vapor (HTO) and molecular tritium (HT), provide the values used for environmental reporting. The alarmed ion chambers provide real-time tritium concentration release levels (HT plus HTO). Monitoring of these stacks provides an accurate measure of the total quantity (in becquerels or curies) of tritium released to the environment, time-resolved over the course of the year. Because the stacks have known properties (height, flow rate, and diameter) and the wind field properties (wind speed, direction, and fluctuation characteristics) are continuously monitored, these data are optimal inputs to modeling. The quality of data on source emission rates, emission conditions (e.g., stack height, diameter, and flow velocity), and wind patterns affects the accuracy of air dispersion and dose assessment modeling more than any other input factors.

Discharge points at Buildings 175, 177, 251, 332, and 491 are monitored for gross alpha and gross beta radioactivity. Air samples for particulate emissions are extracted downstream of HEPA filters and prior to the discharge point to the atmosphere. Particles are collected on membrane filters. Sample results are generally found to be below the



minimum detectable concentration (MDC) of the analysis; for details, consult Chapter 4 in this report and the 1999 NESHAPs annual report (Gallegos et al. 2000).

Among the six continuously monitored facilities at the Livermore site, probably only the Plutonium Facility (Building 332) and the Tritium Facility (Building 331) require monitoring under the EPA's 0.1-mrem/y standard alluded to in the subsection, Radiation Protection Standards. The other four are continuously monitored for programmatic or other reasons. For example, continuous monitoring is maintained at the Heavy Elements Facility (Building 251) in lieu of undertaking a modeling and measurement effort that would be required to demonstrate that monitoring is not needed.

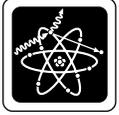
Dose calculations based on effluent monitoring data are expected to be considerably more accurate than those relying on usage-inventory data, physical-state release-to-air fractions, emission-abatement factors, and time factors.

Surveillance Air Monitoring

To provide wide-area coverage complementing the stack effluent monitoring, surveillance air monitors are placed at selected locations on the Livermore site and Site 300 and in their vicinities to detect radioactive gases and particulate matter in ambient air. In addition, dose rates from external penetrating radiation (gamma rays) are measured using thermoluminescent dosimeters (TLDs). Siting of the air monitors and TLDs is done in accordance with the LLNL *Environmental Monitoring Plan* (Tate et al. 1999). Surveillance air monitors are also placed in the vicinity of known diffuse (extended area) emission sources at the Livermore site, specifically those associated with Buildings 292, 331, 514, and 612. Such monitors are also located in and around the Livermore site's southeast quadrant, and at on-site locations that provide wide coverage of Site 300. These special monitors measure the concentrations of radionuclides present in the air near the sources and allow a direct determination of their environmental impact (see Chapter 5). The surveillance air monitors not only are useful in gauging releases from routine operations; they have also proven valuable in quantifying the magnitude of accidental releases and their dose impacts.

Determinations of Dose

This section briefly describes the way LLNL estimates doses to the public for compliance purposes. It touches on the main modeling approaches, identifies the key hypothetical receptors that represent the most exposed public individuals, discusses some important



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aspects regarding the modeling of tritium, and briefly notes some of the special modeling challenges raised by diffuse sources and explosives experiments.

Principal Modeling Approaches

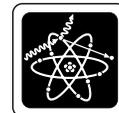
LLNL's primary calculational tool for estimating dose and risk to the public from routine operations and most unplanned releases is the computer code CAP88-PC. The user's guide (Parks 1992) provides useful information on the code, including discussions of the basic equations and key input and output files. Additional information, for example, about LLNL-site-specific data files and several important caveats on use of the code, has been presented in earlier environmental reports (e.g., Harrach et al. 1998) and more fully in the LLNL radiological dose assessment guidance document (Harrach 1998).

Other codes such as EPA's INPUFF code (Peterson and Lavdas 1986) or the HOTSPOT code (Homann 1994) are used as needed to address unplanned releases or transient releases from normal operations or accidents. Many other gaussian-plume-type computer models are available; see, for example, the annotated lists in *Atmospheric Dispersion Modeling Resources* (Oak Ridge 1995) and *Supplement B to the Guideline on Air Quality Models (Revised)* (U.S. Environmental Protection Agency 1993).

A complementary approach to deriving effective dose equivalents or EDEs using the built-in dosimetry model in CAP88-PC or other codes is to explicitly calculate them using mathematical formulas from, e.g., the Nuclear Regulatory Commission's Regulatory Guide 1.109 (1977), which incorporate dose conversion factors consistent with those in the International Commission on Radiation Protection's document number 30 (1980). This approach, outlined in Appendix A of this report, has been used historically at LLNL (preceding the availability of CAP88-PC) and can be used to evaluate annual doses to the public inferred from sampling of local environmental media (air, water, vegetation, and wine).

Identification of Key Receptors

When assessing probable off-site impacts, LLNL pays particular attention to three potential doses. First is the dose to the "sitewide maximally exposed individual member of the public" (SW-MEI; defined below). Second is the dose to the maximally exposed individual (MEI) member of the public from a given emission point. Third is the collective or "population dose" received by people residing

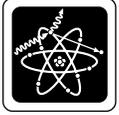


within 80 km of either of the two LLNL sites, adding the products of individual doses received and the number of people receiving them.

The SW-MEI is defined as the hypothetical member of the public at a single, publicly accessible location (where members of the public reside or abide) who receives the greatest LLNL-induced EDE from all sources at a site (e.g., the Livermore site). This dose sums the contributions of all emission points for evaluation under the EPA's 100- $\mu\text{Sv}/\text{y}$ (10-mrem/y) standard. Public facilities that could be the location of the SW-MEI include schools, churches, businesses, and residences. This hypothetical person is assumed to reside at this location 24 hours per day, 365 days per year, continuously breathing air having the ground-level radionuclide concentration, and consuming a specified fraction of food and drinking water that is affected by the releases of radioactivity from the site. Thus, the SW-MEI dose is not received by any actual individual and is used as a health-conservative estimate (i.e., over-estimate) of the highest possible dose to any member of the public. The location of the SW-MEI is sensitive to the frequency distribution of wind speeds and directions and locations of key sources in a given year and can change from one year to the next. At the Livermore site, the SW-MEI in 1999 was located at the UNCLE Credit Union, about 10 m outside the controlled eastern perimeter of the site. This location lies 948 m from the principal radionuclide source, the Tritium Facility (Building 331), in an east-northeast direction (the typical prevailing wind direction). At Site 300, the 1999 SW-MEI was located in an experimental area termed "Bunker 2," operated by Primex Physics International. Bunker 2 lies about 300 m outside the east-central boundary of Site 300, 2.38 km east-southeast of the principal firing table at Building 801.

The location of the MEI is generally different for each emission point. The MEI dose is used to evaluate whether continuous monitoring of each particular emission point is required and whether it is necessary to petition the EPA for permission to start up an activity (new or modified project), as discussed in the Reporting Requirements section.

Doses to the MEI, with and without allowance for abatement, are a major consideration when new projects or changes to existing 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). The possible environmental and worker safety issues raised by each proposed activity or project are examined from several different points of view in a process coordinated by LLNL's Environmental Protection Department, including a review and evaluation of potential emissions of radionuclides and air toxics. Air-quality compliance requirements for projects are described in "Air Quality Compliance" in Volume III of the *ES&H Manual* at the following Internet address: http://www.llnl.gov/es_and_h/ecm/chapter_12/chap12.html



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Assessment Assumptions Regarding Tritium

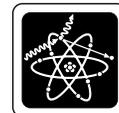
Several aspects of tritium dose estimates based on CAP88-PC should be noted.

Relative Contributions to Dose from HTO and HT Emissions

Tritium (^3H) emissions account for the major dose from operations at the Livermore site. These emissions exist in two major chemical forms: tritium oxide or tritiated water vapor (HTO) and tritium gas (HT). The doses received by exposure to these two forms differ greatly. HTO enters the body by ingestion, inhalation, and dermal absorption; HT enters by inhalation. Ingested HTO is distributed throughout the entire body and eliminated at the same rate as body water (apart from the small fraction metabolized). Inhaled HTO dissolves in the fluids of the lung and is absorbed. In contrast, very little of the HT that enters the body via inhalation is retained; most is exhaled. The EDE from inhalation of tritium gas is lower by a factor of about 10,000 than that from tritium oxide inhalation (International Commission on Radiological Protection 1994 and 1996), and, overall, HTO is traditionally considered to be 25,000 times more toxic (Eckerman et al. 1988; International Commission on Radiological Protection 1979). HT requires conversion to HTO (oxidation) to produce significant dose. Such conversion, predominately in soil and, to a lesser extent, in vegetation following deposition, is a complicated process to model. LLNL is preparing a new tritium model, designed for incorporation into regulatory compliance codes such as CAP88-PC, to calculate the contribution of HT releases to dose.

Emissions of HTO are expected to be the major contributor to the tritium dose, particularly for nearby individual receptors, such as the MEI and SW-MEI; typically, LLNL enters into CAP88-PC only the curies of HTO released to air, disregarding the HT component. A more conservative approach would be to treat all HT as HTO in dose calculations. In April 1999, EPA mandated that LLNL do exactly that when calculating dose to the public for NESHAPs compliance purposes. For a discussion of this issue and the dose impacts, see the LLNL NESHAPs annual reports for 1998 and 1999 (Biermann et al. 1999; Gallegos et al. 2000). It should be noted that this HT "dual" doses problem concerns only the Livermore site; at Site 300, tritium makes a negligible contribution to the public dose.

In 1999, Tritium Facility emissions were divided between 214 curies of HTO and 67 curies of HT, and the result of treating HT as HTO for the 1999 assessment was to increase the Livermore site dose to the SW-MEI by about 21% compared to the value obtained using the previous procedure. The population dose from Livermore site operations, which gives greater weight to the emissions from the tall stacks of the Tritium Facility than does the SW-MEI dose, was increased by 28% when treating HT as though it were HTO. This report emphasizes doses excluding contributions from



HT because (1) we believe it is more accurate to do so than to represent HT as fully converted to HTO, and (2) to provide continuity with doses reported in the past.

Dose-Rate-Conversion Factor for Tritium

The dose-rate-conversion factor that CAP88-PC uses for inhalation-plus-dermal-absorption of tritium is outdated and more conservative than the values quoted in recent literature. The ICRP in its publication ICRP 30 (1979) recommended that skin intake should be 50% of lung intake, revising its earlier recommendation stated in ICRP 2 (1959) that skin intake equals lung intake. The CAP88-PC dose-rate-conversion factor for tritium contains the 1959 recommendation, producing an inhalation-plus-dermal-absorption dose that is too large by a factor $4/3$ relative to the more recent recommendation; see Attachment 3 in the *NESHAPs 1995 Annual Report* (Gallegos et al. 1996). LLNL's new tritium model, alluded to in the previous section, will incorporate ICRP 30 (1979) values.

Overestimate of Ingestion Dose for Tritium

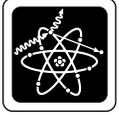
CAP88-PC overestimates the ingestion dose from tritium in a manner that depends on input selections, according to a recent article by Barry Parks (Parks 1999). The cause can be traced to three key assumptions implicit in the software that may not be immediately apparent to the user: (1) the contribution of home-grown food, (2) the distances at which food is produced, and (3) the number of people consuming locally produced food. Documentation on how these overestimates can occur is also available on the Internet at the following address:

<http://www.er.doe.gov/production/er-80/cap88/tritium.html>

These defects will not be addressed in the new LLNL tritium model.

Contribution from Ingestion of Organically Bound Tritium

The dose-rate-conversion factor for ingestion of organically bound tritium (OBT) is larger than that for ingestion of tritium in the free water of plants and animals. However, because the concentration of free-water tritium exceeds the concentration of tritium in organic matter for most dietary components in LLNL's ingestion dose assessment, free-water tritium makes the dominant contribution to dose, per unit weight consumed. LLNL's standard operating procedure is to disregard the OBT contribution. However, effort is underway to include the contribution of OBT to dose in the assessment as part of the capability to be offered in LLNL's tritium model; see also the discussion in Appendix A in this report.



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Special Modeling Problems

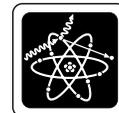
Nonstack releases may require special measurements and calculations to characterize the source. Both the Livermore site and Site 300 provide important examples in this regard.

Diffuse Sources

Nonstack releases often fall into the classification of “diffuse sources.” One example is the leakage of tritium-contaminated water from an underground retention tank at Building 292 at the Livermore site, which results in the release of tritium to the atmosphere via soil moisture evaporation and root-uptake and transpiration by plants—from one pine tree in particular. A discussion of this source appears in the Livermore Site Diffuse Sources section in the *NESHAPs 1993 Annual Report* (Harrach et al. 1994); subsequent NESHAPs annual reports provide updates. Emissions from certain difficult-to-characterize sources sometimes can be inferred from data obtained by LLNL’s routine surveillance air monitoring program, in which the ambient air at selected locations within and outside Laboratory boundaries is continuously monitored for tritium gas and radioactive particles. For example, the operations in the Building 612 waste storage yard at the Livermore site are characterized using data from an air monitor in the yard. Another example is the diffuse source caused by resuspension of depleted uranium in soil at Site 300; an air monitor at the location of the SW-MEI measures the annual-average concentration of uranium in air. A theoretical model described in the *NESHAPs 1995 Annual Report* (Gallegos et al. 1996) was developed to distinguish between the contribution made to these Site 300 data by LLNL-operations-contributed uranium, compared to the considerably larger contribution from naturally occurring uranium. The routine air surveillance monitoring program also has been particularly useful in registering the magnitude of unplanned releases; an example of this type is provided by the accidental release of curium-244 from Building 513 in 1997, discussed in the Executive Summary, Chapter 2, and Chapter 12 of LLNL’s *Environmental Report 1997* (Harrach et al. 1998), as well as in the 1997 NESHAPs annual report (Gallegos et al. 1998).

Modeling Dose Impacts from Explosives Experiments at Site 300

Special consideration must be given to modeling releases of radionuclides into the atmosphere from explosive tests at Site 300, compared to conventional stack or area sources. During experiments, an explosive device containing depleted uranium is placed on an open-air firing table and detonated. A cloud of explosive decomposition products forms promptly (on a roughly 1-minute time-scale) over the firing table, typically reaching a height of several hundred meters, and disperses as it is carried downwind. (The depleted uranium does not contribute to the explosive energy, which is entirely of chemical origin.)



In the absence of measurements of the cloud properties, we assume for compliance modeling purposes that it instantaneously reaches an initial height and size governed by known empirical scaling laws for detonations, in which the scaling parameter is the TNT-equivalent explosive mass. The specific equations we use for the maximum elevation, H_{\max} , reached by the plume and the diameter, D , of the cloud of decomposition products have been described elsewhere (Harrach et al. 1998, Harrach 1998).

Transport and dispersion of the quickly formed cloud are modeled using a gaussian-plume air-dispersion code. A puff-code-based modeling methodology was submitted to EPA for approval in 1992 (Biermann et al. 1993). It would treat these transient explosive events as short-duration bursts or puffs, would incorporate some of the effects of the hilly terrain at Site 300, and would use meteorological data appropriate to the cloud-dispersal period. EPA decided that, from the standpoint of regulatory compliance, the use of CAP88-PC to model these explosives experiments was adequate, despite the recognized difficulties. CAP88-PC simulates each explosive experiment or shot as a continuous, year-long, stack-type emission (i.e., the total activity released in a time period of order 1 minute in the explosion is treated as though it were released gradually over the course of an entire year), with meteorological data corresponding to annual-average conditions at Site 300. As inputs to the code, the scaling results for H_{\max} and D are used as a fixed plume height and stack diameter.

LLNL uses isotopic ratios for depleted uranium. The masses of the three uranium isotopes with atomic weights 238, 235, and 234 in depleted uranium occur in the weight-percentages 99.8, 0.2, and 5×10^{-4} , respectively. The inventory for each explosive experiment specifies the mass of depleted uranium used: $M_{DU}(\text{kg})$. Multiplying this quantity by the respective specific activities gives the total number of curies for each isotope in the cloud. For example, the fraction by weight of uranium-238 in depleted uranium is 0.998, and its specific activity is 3.33×10^{-4} Ci/kg, giving 3.33×10^{-4} (Ci/kg) $\times M_{DU}(\text{kg})$ as the number of curies of uranium-238 in the cloud. The corresponding values for uranium-235 and uranium-234 are 4.29×10^{-6} (Ci/kg) $\times M_{DU}(\text{kg})$ and 3.10×10^{-5} (Ci/kg) $\times M_{DU}(\text{kg})$, respectively.

In the absence of detailed data about the explosive experiments, several highly conservative assumptions are made in our calculations. These assumptions are (1) 100% of the depleted uranium present in the experiment is completely aerosolized and dispersed as a cloud; (2) the median particle size is the CAP88-PC default value of 1 μm ; and (3) the lung clearance class for inhaled material is class Y. (Note: Clearance of inhaled material from the lung to the blood or to the gastrointestinal tract depends on the chemical form [e.g., U_3O_8] of the radionuclide and is classified as D, W, and Y, respectively, for clearance times of order days, weeks, and years.) These assumptions



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may produce a dose that is too high by a factor of 10 or more. We believe a more realistic release-to-air fraction for the uranium is no greater than 0.2, but we lack sufficient documentation to use a value other than 1.0. Also, the median particle size may be much larger than 1 μm , and a sizable fraction of the aerosolized particles might be more properly characterized by lung clearance class D, which produces a dose by inhalation of depleted uranium that is smaller by a factor of about 16 compared to class Y. Even with these assumptions, the MEI and SW-MEI individual doses as well as the collective or population dose that we calculate annually for the explosive experiments are very small compared with natural background levels and regulatory standards (see, e.g., the Summary and Conclusions section of this chapter).

Radiological Doses to the Public from LLNL Operations

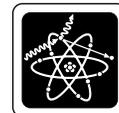
Nearly 200 emission points were reported on in the 1999 modeling runs. These emission sources were of several types: stacks and other exhaust pathways from buildings, diffuse area sources generally external to buildings, and open-air firing tables at Site 300 where explosives experiments were conducted.

The principal diffuse sources at the Livermore site in 1999 were the waste storage and drum sampling areas at the Building 612 Yard, a waste accumulation area located outside the Tritium Facility (Building 331), and the Building 514 Tank Farm. The principal diffuse sources at Site 300 are evaporation of tritium and resuspension of depleted uranium over the total land area of the site.

This section summarizes the main results of LLNL's calculations for 1999 operations and exhibits the trends in these results over recent years. For further details, especially regarding the diffuse sources at the two sites, see the *LLNL NESHAPs 1999 Annual Report* (Gallegos et al. 2000).

Dose Breakdown by Facility

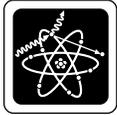
Table 13-1 lists all LLNL facilities and diffuse sources having the potential to release radioactivity into the environment during 1999. For each facility or building, the table gives the number of stacks or other exhaust avenues discharging radionuclides; lists the dose to the SW-MEI caused by the single, most dominant emission point at each facility; and identifies the types of operations occurring in the building or facility or the nature of the diffuse source. Corresponding data are included for the Site 300 explosive



experiments. Facilities in which no operations using radionuclides took place in 1999 or in which any radionuclides present were encapsulated or sealed for the entire year are excluded from **Table 13-1**.

Table 13-1. Sources of radiation dose from LLNL releases (measured and potential) to air: stacks and other exhaust pathways from buildings containing radiological operations, and diffuse area sources.^(a,b)

Bldg	Facility	Potential emission points	Maximum EDE ^(c) (μSv/y)	Operations
Livermore site point sources				
131	Offices and laboratories, Mechanical & Electrical Engineering	3	6.5×10^{-6}	Display of parts
132N	Offices and laboratories; Chemistry & Materials Sciences; Nonproliferation, Arms Control & International Security (NAI); and others	10	3.3×10^{-9}	Preparation of samples for radiochemical analysis; analysis of aqueous solutions and waste samples
132S	See Building 132N	1	2.5×10^{-10}	Transfer of uranium
151	Isotope Sciences Chemistry & Materials Science Environmental Services Laboratory	30	1.5×10^{-4}	Application of nuclear and isotope sciences to a wide range of research; sample analysis of waste streams and environmental media for radionuclide content
174	Laser Isotope Separation	1	1.5×10^{-11}	Pulse laser experimentation
175	Laser Isotope Separation	6	0.0 ^(d)	Cleaning and refurbishing uranium parts
177	Laser Isotope Separation	8	1.2×10^{-2}	Sample preparation, cleaning of parts, processing uranium oxide powders, melting uranium in crucibles under vacuum, liquid uranium corrosion studies
194	Physics & Space Technology	2	9.4×10^{-5}	High-energy linear accelerator, positron beam generation and experiments; materials science experiments
212	Physics & Space Technology	2	6.8×10^{-11}	Physics experiments, residual contamination from previous operation of rotating target neutron source (no longer operating)
222	Chemistry & Materials Science	8	5.0×10^{-6}	Chemical analyses, cleaning equipment, waste sample preparation and analysis, decontamination, x-ray fluorescence analysis, sample digestion
231	Chemistry & Materials Science; Engineering, Weapons Engineering; Safeguards & Security	18	4.8×10^{-5}	Materials research and testing, metals processing and characterization, electron-beam welding, grinding/polishing, casting, microscopy, sample preparation, storage
235	Chemistry & Materials Science	3	3.1×10^{-11}	Material structure studies, precision cutting, ion implantation, metallurgical studies, sample preparation



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Table 13-1. Sources of radiation dose from LLNL releases (measured and potential) to air: stacks and other exhaust pathways from buildings containing radiological operations, and diffuse area sources^(a,b) (continued).

Bldg	Facility	Potential emission points	Maximum EDE ^(c) (μSv/y)	Operations
241	Chemistry & Materials Science	8	1.8×10^{-6}	Materials properties research and testing on plutonium and uranium; hybridization studies with nucleic acids from soil bacteria
251	Heavy Elements Facility, Physics & Space Technology			Storage of transuranic isotopes prior to disposal
	Seismically hardened area	4	0.0 ^(d)	
	Unhardened areas	28	8.8×10^{-6}	
253	Hazards Control	6	3.3×10^{-8}	Chemical analysis and counting of radioactive samples
254	Hazards Control	3	1.9×10^{-12}	Bioassays; analytical services; urine analyses for radionuclides
255	Hazards Control	2	9.8×10^{-5}	Radiation standards and instrument calibration
281	Chemistry & Materials Science	7	1.6×10^{-8}	Sample preparation, radioactivity migration studies, tracers, Nevada Test Site ground water samples
282	Physics & Space Technology	1	6.2×10^{-12}	Residual tritium contamination from past activities
292	Environmental Programs	3	2.3×10^{-5}	Tritium contamination from prior operations
298	Laser Fusion Program	3	3.5×10^{-5}	Laser fusion targets research and development
321	Mechanical Engineering, Materials Fabrication	6	3.1×10^{-7}	Milling, shaping, heat treating, and machining depleted uranium parts
322	Mechanical Engineering	1	4.3×10^{-9}	Cleaning and plating of depleted uranium
327	Mechanical Engineering	1	1.6×10^{-7}	Nondestructive ultrasonic material evaluation
331	Tritium Facility, Defense & Nuclear Technologies	2	$6.5 \times 10^{-1(d,e)}$	Tritium research and development, facility decontamination and decommissioning operations
332	Plutonium Facility, Defense Sciences Program	8	0.0 ^(d)	Plutonium research
361	Biology and Biotechnology Research	14	4.6×10^{-6}	DNA labeling, sequencing, hybridization, and enzyme assay; human genome research; P-32 labeling; DNA protein interaction studies; gel electrophoresis
362	Biology and Biotechnology Research	2	9.5×10^{-8}	Characterization of metabolic pathways
363	Biology and Biotechnology Research	5	6.4×10^{-9}	Human urine sample project, rotary evaporation, labeling of biological materials, isotopic labeling
364	Biology and Biotechnology Research	4	4.9×10^{-7}	DNA labeling, DNA and protein extraction, sample preparation
365	Biology and Biotechnology Research	3	5.3×10^{-8}	Housing research animals, animal research, equipment decontamination
366	Biology and Biotechnology Research	1	5.9×10^{-8}	DNA labeling

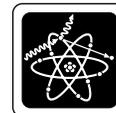


Table 13-1. Sources of radiation dose from LLNL releases (measured and potential) to air: stacks and other exhaust pathways from buildings containing radiological operations, and diffuse area sources^(a,b) (continued).

Bldg	Facility	Potential emission points	Maximum EDE ^(c) ($\mu\text{Sv/y}$)	Operations
381	Laser Fusion	1	7.0×10^{-9}	Tritium handling for laser target research and development
391	Laser Fusion	1	7.4×10^{-5}	Housing of high-energy laser; fusion-target irradiation
490	Laser Isotope Separation	1	0.0 ^(d)	U.S. Enrichment Corporation isotope separation operations, including vaporization of uranium for enrichment
491	Laser Isotope Separation	1	0.0 ^(d)	U.S. Enrichment Corporation isotope separation operations
513	Hazardous Waste Management	2	1.0×10^{-5}	Sampling, treatment, and storage of hazardous, mixed, and radioactive waste; process optimization and treatability studies
514	Hazardous Waste Management	2	1.3×10^{-2}	Vacuum filtration of treated waste water, waste consolidation
612	Hazardous Waste Management	4	2.0×10^{-2}	Waste sampling; waste repackaging for shipment off site; analysis of waste treatment and treatability samples; decontamination of compactor baler
Site 300 point sources				
801	Flash x-ray machine	1	5.2×10^{-7}	Flash x-ray photography of explosives experiments
801	Site 300 firing table at Building 801	— ^(f)	1.2×10^{-1}	Detonation of explosives
810A	Site 300 firing table support	1	1.2×10^{-7}	Assembly of explosives
851	Site 300 firing table at Building 851	— ^(f)	2.1×10^{-1}	Detonation of explosives
851	Linear accelerator	1	9.6×10^{-6}	Research
Livermore site diffuse sources^(g)				
170	Area of soil contamination	1	8.4×10^{-5}	Remediation activities at soil staging area
223	Contaminated facility	1	1.7×10^{-3}	Decontamination and decommissioning activities
292	Spill area	1	7.3×10^{-7}	Evaporation and transpiration of tritiated water from underground tank leakage
331	Tritium Facility (external)	1	6.1×10^{-2}	Outdoor temporary placement of contaminated parts and equipment awaiting transport and storage
514	Hazardous Waste Management Tank Farm	1	3.2×10^{-2}	Processing of liquid hazardous, mixed, and radioactive wastes in open-topped tanks
612	Hazardous Waste Management storage yard	2	1.8×10^{-1}	Storage of low-level waste; drum sampling and waste accumulation areas
—	Southeast quadrant of Livermore site	1	4.2×10^{-3}	Ground contaminated with Pu-239 from past waste management operations



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Table 13-1. Sources of radiation dose from LLNL releases (measured and potential) to air: stacks and other exhaust pathways from buildings containing radiological operations, and diffuse area sources^(a,b) (concluded).

Bldg	Facility	Potential emission points	Maximum EDE(c) (μSv/y)	Operations
Site 300 diffuse sources^(g)				
—	All Site 300 land area	1	6.0×10^{-4}	Evaporation of tritium from contaminated soil and water
—	All Site 300 land area	1	1.2×10^{-2}	Resuspension of uranium in contaminated soil
804	Open area	1	6.0×10^{-6}	Low-level waste staging area

^a LLNL NESHAPs 1999 Annual Report (Gallegos et al. 2000).

^b Areas in which no operations using radionuclides took place in 1999 or in which all radionuclides were encapsulated or sealed for the entire year are not included in this table. Table entries refer to routine operations, not unplanned releases.

^c The maximum EDE to the SW-MEI member of the public from a single discharge point, among all discharge points modeled for the indicated facility or building. The SW-MEI is defined in the Identification of Key Receptors section. See the Glossary for list of acronyms.

^d The effluents from the facility are monitored. Zeroes refer to monitored values below the minimum detectable concentration, as discussed, for example, in the Air-Emission Data section of the *LLNL NESHAPs 1999 Annual Report* (Gallegos et al. 2000).

^e This dose takes into account only HTO emissions from the Tritium Facility stacks. If, instead, the emissions of HTO and HT are combined, and the sum treated as though it were entirely HTO for purposes of evaluating the maximum potential dose to the public, the dose from the principal stack was 0.86 μSv/y, rather than 0.65 μSv/y. (See the Assessment Assumptions Regarding Tritium section.)

^f Open-air dispersal in 1999.

^g Diffuse sources are described briefly in the Special Modeling Problems section and more fully in the *LLNL NESHAPs 1999 Annual Report* (Gallegos et al. 2000).

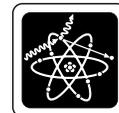
The principal feature shown in the table is that LLNL has a large number of very small radioactive sources and only a few that could be considered significant. As shown more clearly in subsequent tables, about a half-dozen sources account for nearly all of the dose to members of the public, and the total dose is quite small compared with federal standards for radiation protection of the public.

Unplanned Releases

There were no unplanned atmospheric releases at the Livermore site or Site 300 in 1999.

Doses to Site-Wide Maximally Exposed Individuals

The 1999 calculated EDE to the SW-MEI from Livermore-site point sources was 0.73 μSv (0.073 mrem). Emissions from the two 30-m stacks at the LLNL Tritium Facility



(Building 331) accounted for most of this: 0.67 μSv (0.067 mrem), or about 92%. For the Livermore site, the SW-MEI dose caused by diffuse emissions in 1999 was 0.28 μSv (0.028 mrem). Combining point and diffuse sources, the total annual dose was 1.0 μSv (0.10 mrem), divided 72% and 28% between point and diffuse source emissions. This is about twice last year's total, principally reflecting a nearly two-fold increase in emissions from the stacks of the Tritium Facility (Building 331): 7.9×10^{12} Bq (214 Ci) of HTO in 1999, compared to 4.1×10^{12} Bq (110 Ci) the previous year. Calculating dose as directed by EPA (treating HT as HTO), the total annual dose to the SW-MEI from Livermore-site operations was 1.2 μSv (0.12 mrem), with 77% attributed to point sources and 23% to diffuse sources (see the Assessment Assumptions Regarding Tritium section).

The calculated EDE to the SW-MEI at Site 300 in 1999 was 0.35 μSv (0.035 mrem), with 0.34 μSv (0.034 mrem) caused by emissions in the course of explosives experiments at the Building 801 and 851 firing tables. The remaining 0.012 μSv (0.0012 mrem), or a little over 3% of the total, was attributed to Site 300 diffuse sources; the resuspension of LLNL-contributed uranium in surface soils throughout Site 300 was responsible for nearly all of this dose from diffuse sources. **Table 13-2** summarizes doses to the public SW-MEI for the Livermore site and Site 300 over the last decade.

Table 13-3 shows the potential public dose values attributed to firing table experiments for 1990 through 1999, correlated with the total amounts of depleted uranium and the total quantity of high explosives used each year in the experiments. (Only experiments that included depleted uranium are considered; most have none.) The 1999 firing table total is typical of values in recent years (see the "point source dose" column for Site 300 in **Table 13-2**). The data show that variations from year to year in these doses mainly correspond to differences in the amount of depleted uranium used in the tests.

Table 13-4 lists the facilities that were primarily responsible for the LLNL dose; the contributions from all emission points at each facility have been summed. These facilities collectively accounted for approximately 93% of the total EDE resulting from Livermore site operations and for more than 99% of the total EDE from Site 300 operations. The principal radionuclide(s) are indicated for each facility. Tritium was the overall dominant radionuclide at the Livermore site, accounting for about 90% of the Livermore site dose. At Site 300, practically the entire dose was attributed to the isotopes present in depleted uranium having atomic numbers 238, 235, and 234.



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Table 13-2. Doses (μSv) calculated for the SW-MEI for the Livermore site and Site 300, 1990 to 1999.

Year	Total dose	Point source dose	Diffuse source dose
Livermore site			
1999	1.0 ^(a)	0.73 ^(a)	0.28 ^(a)
1998	0.49	0.25	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	2.3	— ^(b)	— ^(b)
1990	2.4	— ^(b)	— ^(b)
Site 300			
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 Calculating dose by the alternative method as directed by EPA, the total dose for 1999 was 1.2 μSv , and the point source dose was 0.94 μSv ; see the discussion in the Assessment Assumptions Regarding Tritium section.

^b Diffuse source doses were not reported separately from the total dose for the Livermore site for 1990 and 1991.

^c No diffuse emissions were reported at Site 300 for years prior to 1993.



Table 13-3. Annual dose to the SW-MEI from explosives experiments on firing tables at Site 300, 1990–1999, related to the total quantity of depleted uranium used in the experiments and the total quantity of high explosives driving the detonations.

Year	Dose to SW-MEI		Total depleted U used in experiments (kg)	Total HE ^(a) used in depleted U experiments (kg)
	(μ Sv)	(mrem)		
1999	0.34	0.034	216	168
1998	0.19	0.019	230	192
1997	0.11	0.011	163	122
1996	0.33	0.033	272	112
1995	0.20	0.020	165	199
1994	0.49	0.049	230	134
1993	0.11	0.011	99	74
1992	0.21	0.021	151	360
1991	0.44	0.044	221	330
1990	0.57	0.057	340	170

^a HE = high explosives.

Table 13-4. Major contributors to LLNL's radiation dose via airborne emissions, 1999.

Facility or operation ^(a)	Dominant radionuclide(s)	EDE at SW-MEI ^(b)	
		μ Sv/y	mrem/y
Livermore site			
B331/Tritium Facility	³ H	0.67 ^(c)	0.067 ^(c)
B612 Yard Area ^(d)	³ H	0.18	0.018
B331 External Waste Accumulation Area ^(d)	³ H	0.061	0.0061
B514 Tank Farm ^(d)	Various	0.032	0.0032
Sum of all other sources	Various	0.074	0.0074
Total		1.0^(c,e)	0.10^(c,e)
Site 300			
B851/firing table	²³⁸ U, ²³⁴ U, ²³⁵ U	0.21	0.021
B801/firing table	²³⁸ U, ²³⁴ U, ²³⁵ U	0.12	0.012
Soil resuspension ^(d)	²³⁸ U, ²³⁴ U, ²³⁵ U	0.012	0.0012
Total		0.35^(e,f)	0.035^(e,f)

^a The facilities cited here are discussed in the text of this report and in more detail in the *LLNL NESHAPs Annual Reports*.

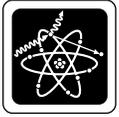
^b These doses represent the sum of all emission points from a given facility (for example, both stacks on Building 331), in contrast to the dose values in **Table 13-1**, which represent the dose from the single largest emission point at each facility. The SW-MEI member of the public is defined in the Identification of Key Receptors section.

^c Calculating dose as directed by EPA yields 0.88 μ Sv/y for the Tritium Facility, which raises the total dose to 1.2 μ Sv/y. (See the Assessment Assumptions Regarding Tritium section.)

^d Diffuse sources (see text).

^e These Livermore site and Site 300 totals represent 1.0% and 0.35%, respectively, of the federal standard.

^f Total does not exactly match the sum of entries because of rounding.



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The relative significance of inhalation and ingestion is different for tritium and uranium and depends on the assumptions made about the origin of food consumed by a person receiving the dose. For the conditions we assumed when assessing individual doses—namely that milk is imported while the remainder of the food is produced locally—ingestion dose is larger than inhalation dose in the case of tritium, approximately in the ratio 80% to 20%. For uranium, these numbers are nearly reversed: 17% by the ingestion pathway versus 83% via inhalation. For both uranium and tritium, external doses from air immersion and ground irradiation were negligible.

Temporal Trends in Dose to the SW-MEI

The trends in dose to the SW-MEI from emissions at the Livermore site and Site 300 over the last ten years are shown graphically in **Figure 13-1** (see also **Table 13-2**). The general pattern, particularly over the last eight years, shows year-to-year fluctuations around a quite low dose level, staying at about 1% of the federal standard.

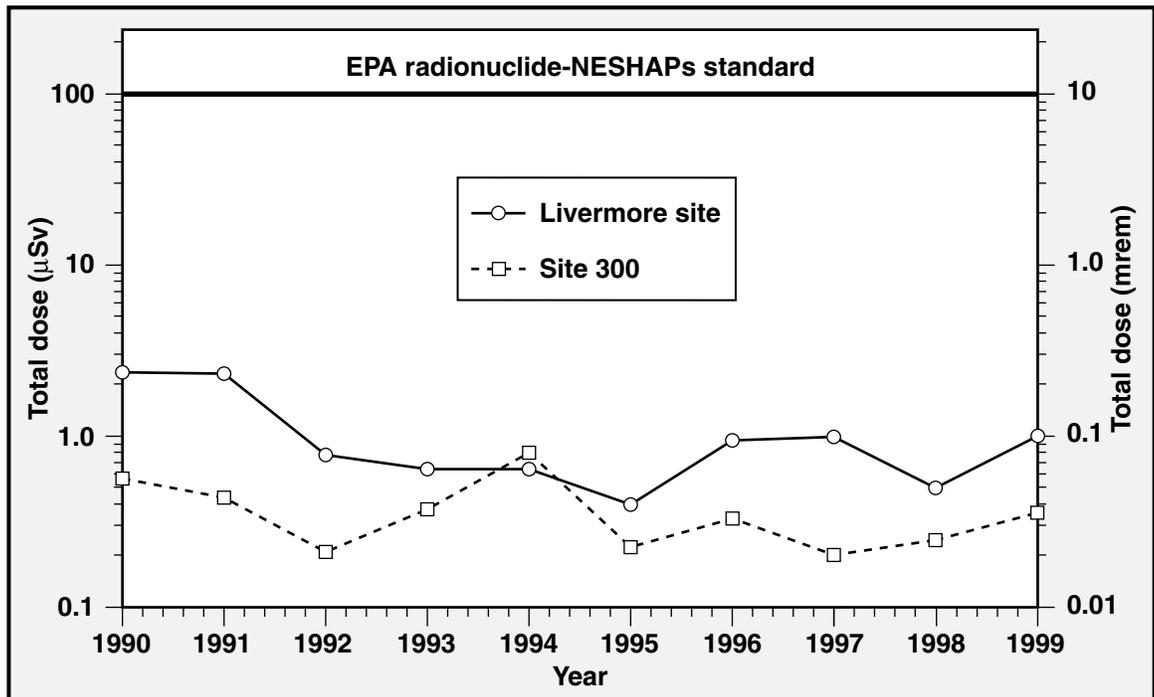
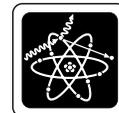


Figure 13-1. Annual dose to the site-wide maximally exposed individual member of the public, 1990 to 1999.



The SW-MEI dose estimates reported are intentionally conservative, erring on the side of predicting potential doses that are several times higher than would actually be experienced by any member of the public. Potential doses from Site 300 firing table operations are especially so, as explained in the Special Modeling Problems section.

Collective Doses to Exposed Populations

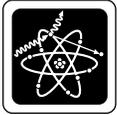
Population doses, or collective EDEs, for both LLNL sites were calculated out to a distance of 80 km in all directions from the site centers using CAP88-PC. For releases of radionuclides to air, CAP88-PC evaluates the four principal exposure pathways: ingestion through food and water consumption, inhalation, air immersion, and irradiation by contaminated ground surface.

The collective EDE caused by 1999 Livermore site operations was 0.017 person-Sv (1.7 person-rem), which is 2.5 times the 1998 result of 0.068 person-Sv (0.68 person-rem), principally traceable to the nearly twice as large emissions from the Tritium Facility stacks in 1999 compared to 1998. This population dose, when calculated as directed by EPA, was 0.022 person-Sv (2.2 person-rem), which is about 2.5 times the corresponding result from last year and 1.3 times the dose obtained when neglecting conversion of HT to HTO. The collective EDE from Site 300 operations in 1999 was 0.11 person-Sv (11 person-rem), which is the same as the previous year's value. These levels of variation in population dose from one year to the next are within the expected range of operations-driven fluctuations in small radiation quantities.

Table 13-5 compares background and medical-treatment-related doses to the maximum potential doses caused by LLNL operations. The population doses attributed to LLNL operations are some 200,000 times smaller than ones from natural background radiation, and the maximum potential individual doses to maximally exposed public individuals from Livermore site and Site 300 operations are about 2500 times smaller.

Summary and Conclusion

The annual radiological dose from all emissions at the Livermore site and Site 300 in 1999 was found to be well below the applicable standards for radiation protection of the public, in particular the NESHAPs standard. This standard limits to 100 $\mu\text{Sv}/\text{y}$ (10 mrem/y) the EDE to any member of the public, arising as a result of releases of radionuclides to air from DOE facilities. Using EPA-mandated computer models, actual



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LLNL meteorology, and population distributions appropriate to the two sites, the dose to the LLNL site-wide maximally exposed members of the public from 1999 operations were as follows:

- Livermore site: 1.0 μSv (0.10 mrem)—72% from point-source emissions, 28% from diffuse-source emissions, using LLNL's standard calculational assumptions. Calculating dose by the method of treating HT as HTO as directed by EPA, the total annual dose to the SW-MEI from Livermore site operations was 1.2 μSv (0.12 mrem), divided 77% and 23% between point and diffuse sources.
- Site 300: 0.35 μSv (0.035 mrem)—96.5% from explosive experiments, classified as point-sources, 3.5% from diffuse-source emissions.

Table 13-5. Comparison of background (natural and man-made) and LLNL radiation doses, 1999.

Location/source	Individual dose ^(a)		Population dose ^(b)	
	(μSv)	(mrem)	(person-Sv)	(person-rem)
Livermore site sources				
Atmospheric emissions	1.0 ^(c)	0.10 ^(c)	0.017 ^(c)	1.7 ^(c)
Site 300 sources				
Atmospheric emissions	0.35	0.035	0.11	11
Other sources^(d)				
Natural radioactivity ^(e,f)				
Cosmic radiation	300	30	1,900	190,000
Terrestrial radiation	300	30	1,900	190,000
Internal (food consumption)	400	40	2,500	250,000
Radon	2,000	200	12,500	1,250,000
Medical radiation (diagnostic procedures) ^(f)	530	53	3,300	330,000
Weapons test fallout ^(f)	11	1.1	68	6,800
Nuclear fuel cycle	4	0.4	25	2,500

^a For LLNL sources, this dose represents that experienced by the SW-MEI member of the public.

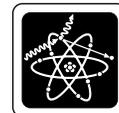
^b The population dose is the collective (combined) dose for all individuals residing within an 80-km radius of LLNL (approximately 6.3 million people for the Livermore site and 5.4 million for Site 300), calculated with respect to distance and direction from each site.

^c Calculating dose by the alternative method as directed by EPA, the individual dose was increased to 1.2 μSv (0.12 mrem), and the population dose to 0.022 person-Sv (2.2 person-rem) for the Livermore site; see the Doses to Site-Wide Maximally Exposed Individuals, and Collective Doses to Exposed Populations sections.

^d From National Council on Radiation Protection and Measurements (1987a and b).

^e These values vary with location.

^f This dose is an average over the U.S. population.



The major radionuclides accounting for the doses were tritium at the Livermore site and the three isotopes in depleted uranium (^{234}U , ^{235}U , and ^{238}U) at Site 300.

The collective EDE or population dose attributable to LLNL operations in 1999 was estimated to be 0.017 person-Sv (1.7 person-rem) for the Livermore site and 0.11 person-Sv (11 person-rem) for Site 300. Calculating dose as directed by EPA, the Livermore site value was 0.022 person-Sv (2.2 person-rem). These doses include exposed populations of 6.3 million people for the Livermore site and 5.4 million for Site 300 living within a distance of 80 km from the site centers, based on 1990 census data.

The dose to the maximally exposed member of the public resulting from Livermore-site and Site-300 operations was approximately 2500 times smaller than the dose from background radiation, and the population dose from LLNL operations in 1999 was about 200,000 times smaller than that caused by natural radioactivity in the environment (see **Table 13-5** and **Figure 13-2** in Supplement 13-1).

We conclude that the potential radiological doses from LLNL operations were well below regulatory standards and were very small compared with doses normally received by these populations from natural background radiation sources, even though highly conservative assumptions were used in the determinations of LLNL doses. These maximum credible doses indicate that LLNL's use of radionuclides had no significant impact on public health during 1999.



Chapter 13 Supplements

Supplement 13-1: Radiation Basics

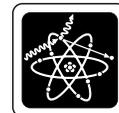
Natural and Man-Made Radiation

By far, the greatest part of radiation received by the world's population comes from natural sources—primarily cosmic rays that impinge on the earth's atmosphere from space and radionuclides naturally present in our environment, such as radioactive materials in soil and rocks. Among these terrestrial sources are carbon-14, potassium-40, rubidium-87, uranium-238, thorium-232, and other radioactive elements, such as radon, that arise from decay of uranium and thorium. The source of human exposure to natural radiation can be external (from substances staying outside the body) or internal (from substances inhaled in air or ingested in food and water). Individual doses vary with location. The level of cosmic radiation increases with altitude because less air is overhead to act as a shield. The earth's poles receive more cosmic radiation than the equatorial regions because the earth's magnetic field diverts the radiation. The levels of terrestrial radiation differ from place to place around the United States and around the world, mainly because of variations in soil and rock composition.

Adding to this pervasive natural or background radiation is man-made radiation from radionuclides used in medicine, consumer products, energy production, and nuclear weapons production. Exposure to man-made sources can be controlled more readily than exposure to most natural sources. However, nuclear explosives tested in the atmosphere in the 1950s and 1960s spread radioactivity across the surface of the globe, and the 1986 nuclear reactor accident at Chernobyl affected a large area. At present, medical treatment is the largest common source of public exposure to man-made radiation. Individual medical doses vary enormously—someone who has never had an x-ray examination may receive zero medical dose while patients undergoing treatment for cancer may receive many thousands of times the annual-average dose they would receive from natural radiation. Another source of public exposure to man-made radiation is consumer products, including luminous-dial watches, smoke detectors, airport x-ray baggage inspection systems, and tobacco products.

Radioactivity

Generally, naturally occurring isotopes are stable, but notable exceptions include carbon-14, potassium-40, thorium-232, uranium-235, and uranium-238, which occur



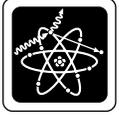
naturally but are radioactive. There are three main categories of nuclear decay: alpha, beta, and gamma. Alpha decay is the spontaneous emission of an alpha particle (a bound state of two protons and two neutrons—the nucleus of a helium atom) from a nucleus containing a large number of protons (most commonly 82 or more). Beta decay is the spontaneous conversion of a neutron to a proton in the nucleus with the emission of an electron, and gamma decay is the spontaneous emission of high-energy photons (high-frequency electromagnetic radiation) by nuclei.

Radioisotopes decay at quite different rates; the “half-life,” or length of time for half of the atoms to decay, spans a wide range from small fractions of a second to millions of years. For example, tritium (the radioactive form of hydrogen) has a 12.3-year half-life, compared to 24,131 years for plutonium-239.

Some radioisotopes decay by forming radioisotopes that, in turn, decay into other radioisotopes until a stable state is achieved. For example, an atom of uranium-238 can undergo alpha decay, leaving behind a daughter, thorium-234, which is also radioactive. The transformations of the decay chain continue, ending with the formation of lead-206, a stable isotope.

Radioactivity can be hazardous because radiation (alpha particles, beta particles, gamma rays, and other subatomic particles such as neutrons) can be released with great energy. This energy is capable of altering the electronic configuration of atoms and molecules, especially by stripping one or more electrons off the atoms of the irradiated material, thereby disrupting the chemical activity in living cells. If the disruption is severe enough to overwhelm the normal restorative powers of the cell, the cell may die or become permanently damaged. Cells are exposed to many naturally occurring sources of disruption, including naturally toxic chemicals in food, microbes that cause disease, high-energy radiation from outer space (cosmic rays), and heat and light (including the sun’s rays, which can cause sunburn and skin cancer). Consequently, cells and living organisms have evolved the capacity to survive limited amounts of damage, including that caused by radioactivity.

Three main factors determine the radiation-induced damage that might be caused to living tissue: the number of radioactive nuclei that are present, the rate at which they give off energy, and the effectiveness of energy transfer to the host medium, i.e., how the radiation interacts with the tissue. Alpha radiation can be halted by a piece of paper and can scarcely penetrate the dead outer layers of skin. Radioisotopes that give off alpha radiation are generally not health hazards unless they get inside the body through an open wound or are ingested or inhaled. In those cases, alpha radiation can be especially damaging because its disruptive energy can be deposited within a small



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distance, resulting in significant energy deposition in a few cells. Beta radiation from nuclear decay typically penetrates a centimeter or two of living tissue. It, therefore, deposits energy over many cells, decreasing the damage to any single cell. Gamma radiation is extremely penetrating and can pass through most materials, being significantly attenuated only by thick slabs of dense materials, such as lead.

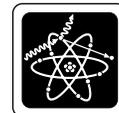
Measurement of Radioactivity and Dose

The rate at which a nucleus decays is expressed in units of becquerels (abbreviated Bq) where 1 Bq is one decay per second, or alternatively expressed in curies, Ci, where 1 Ci equals 3.7×10^{10} (37 billion) decays per second, or 3.7×10^{10} Bq (approximately equal to the decay rate of 1 gram of pure radium). Becquerels and curies are not measures of the effect of radiation on living tissue; the effect on living tissue depends on the efficiency of energy deposition as the radiation traverses matter.

The amount of energy deposited in living tissue is called the “dose.” The amount of radiation energy absorbed per gram of tissue is called the “absorbed dose” and is expressed in units of rads or grays (Gy), where 1 Gy equals 100 rads; 1 Gy equals 1 joule per kilogram. Because an absorbed dose produced by alpha radiation is more damaging to living tissue than the same dose produced by beta or gamma radiation, the absorbed dose is multiplied by a quality factor to give the dose equivalent. The quality factor for alpha radiation is 20; for beta and gamma, 1. The dose equivalent is measured in units of rem or sieverts (Sv) with 1 Sv equal to 100 rem. Also commonly used are millirem (mrem) and millisievert (mSv), which are one-thousandth of a rem and sievert, respectively.

Just as one type of radiation can be more damaging than others, some parts of the body are potentially more vulnerable to radiation damage than are others; therefore, the different parts of the body are given weightings. For example, a radiation dose from iodine-131 is more likely to cause cancer in the thyroid than in the lung. The reproductive organs are of particular concern because of the potential risk of genetic damage. Once particular organs are weighted appropriately, the dose equivalent becomes the “effective dose equivalent” (EDE), also expressed in rem or sievert. This allows dose equivalents from nonuniform exposure of the body to be expressed in terms of an EDE that is numerically equal to the dose from uniform exposure of the whole body that entails the same risk as the nonuniform exposure.

The EDE describes doses to individuals. When individual EDEs received by a group of people are summed, the result is called the “collective effective dose equivalent,” often



referred to as the “population dose,” and is expressed in person-sievert or person-rem. Finally, to account for the long-term effects of radionuclides as they continue to decay and affect generations of people, we calculate the dose over many years, summing the effect over time. This is termed the “collective effective dose equivalent commitment.” Most of our discussion in this chapter deals with the EDE and the collective EDE.

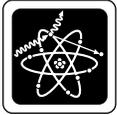
Doses from Natural and Man-Made Radioactivity

The pie chart in **Figure 13-2** illustrates the distribution of annual average radiation doses from natural and other common sources in the United States, according to the National Council on Radiation Protection and Measurement (1987b). The average radiation dose from natural sources is 3.0 mSv/y (300 mrem/y). Approximately 0.3 mSv/y (30 mrem/y) of this exposure comes from high-energy radiation from outer space (cosmic rays). Terrestrial sources, mainly radionuclides in rock and soil, also account for approximately 0.3 mSv/y (30 mrem/y) of the average natural dose. Another significant part of the dose comes from radionuclides ingested through food and drink, resulting in approximately 0.4 mSv/y (40 mrem/y). Potassium-40 and carbon-14 are common radionuclides in food.

The remaining 2.0 mSv/y (200 mrem/y) or 67% of the average dose from natural sources in the United States comes from radon gas. Radon is one of the major radionuclides produced by uranium decay, and inhalation dose is dominated by radon’s short-lived decay products.

As noted earlier, medical treatment is the largest common source of public exposure to man-made radiation, and most of it is delivered as medical x-rays. These contribute 0.39 mSv (39 mrem) to the average whole-body annual dose in the United States. Nuclear medicine contributes 0.14 mSv (14 mrem) to the average dose, and consumer products add 0.1 mSv (10 mrem). Thus, for a typical member of the public in the United States, radiation from medical procedures and consumer products results in a dose of approximately 0.63 mSv/y (63 mrem/y). The annual average dose from other man-made sources, including fallout from nuclear testing, is less than 0.03 mSv (3 mrem). As described in this chapter, the contributions from LLNL operations to the dose of even the most affected resident are on the order of 1 μ Sv/y (0.1 mrem/y) and would not be discernible on the scale shown in **Figure 13-2**; LLNL’s contributions are listed under “Other” in the figure.

Deviations from the average levels shown in **Figure 13-2** can be quite large, depending on an individual’s place of residency, occupation, eating habits, and other lifestyle



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choices, such as frequency of air travel. Radon dose, for example, varies significantly with geographic location; levels several times higher than the average occur in some regions of the United States. At LLNL and its environs, radon-induced doses as low as half the average are typical. Doses from cosmic rays increase with elevation above sea level, producing several tenths of mSv (tens of mrem) differences between cosmic-ray doses in coastal and mountain communities, and imparting a dose of about 0.05 mSv (5 mrem) to a passenger flying round-trip between Los Angeles and New York City.

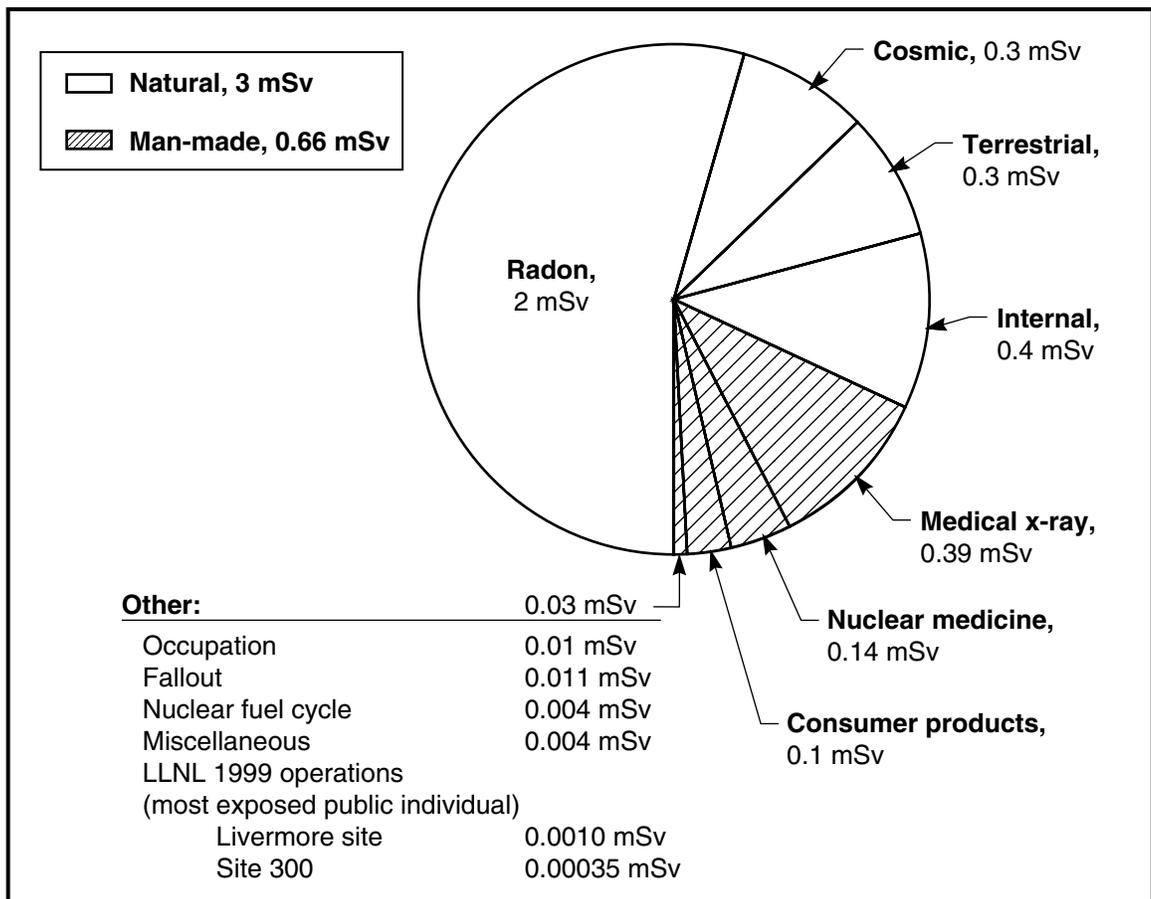
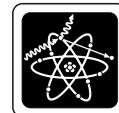


Figure 13-2. Typical annual radiation doses from natural and man-made sources (National Council on Radiation Protection 1987b).

A useful Internet reference with links to a large quantity of material on effects and risks from radiation is the "Radiation Information Network" at the following Internet address:
<http://www.physics.isu.edu/radinf/>



Supplement 13-2: Radiation Control Measures at LLNL

Radioisotopes used at LLNL include uranium, transuranics, biomedical tracers, tritium, and mixed-fission products. Protection of employees and the public from the uncontrolled release of radioactive materials into the environment is a primary consideration for LLNL. This effort takes several forms, as summarized here. More detailed information can be found in LLNL's online *ES&H Manual*; see, for example, Volume I, Chapters 1 and 2 at the following Internet addresses:

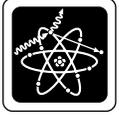
http://www.llnl.gov/es_and_h/hsm/chapter_1/chap1.html

http://www.llnl.gov/es_and_h/hsm/chapter_2/chap2.html

When an operation or facility is designed at LLNL, a thorough assessment of potential radiation hazards is conducted, and radioisotope-handling procedures and work enclosures are determined for each project, depending on the isotope, the quantity being used, and the type of operations being performed. Radioisotope handling and working environments include glove boxes, exhaust hoods, and laboratory bench tops. The controls might include limiting physical access and using shielding, filters, and remote handling equipment. Exhaust paths to the atmosphere include HEPA-filtered stacks, stacks without abatement devices, roof vents, and ordinary room air ventilation channels.

Appropriate monitoring, control, training, emergency response, and other requirements are called out in various facility documents related to each operation. These may include a Discipline Action Plan (DAP), Integration Work Sheet (IWS), Safety Analysis Report (SAR), Operational Safety Plan (OSP), and/or Facility Safety Plan (FSP), and will include a document reviewing the operation under the NEPA compliance guidelines. These documents are reviewed by environmental analysts, industrial hygienists, and health physicists to assess the safety of the operation, its compliance with current occupational and public health and environmental standards, the adequacy of proposed engineering and administrative controls, and the adequacy of proposed training requirements for personnel. This part of the control program enables LLNL personnel who work with radiation and radioactivity to recognize and prevent the execution of unsafe operations.

Another form of LLNL's radiation control program involves direct monitoring of the workplace environment. This monitoring includes sampling of the air and surfaces in the facilities where radioactive materials are handled, as well as the use of personal dosimetry and bioassay programs to monitor potential worker exposure to direct radiation and radioactive isotopes. Direct monitoring of the workplace environment helps to determine the effectiveness of a facility's radiation control program as well as providing information on worker exposures.



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The surveillance and effluent monitoring of radiation in air, ground and surface waters, sewerable water, soil and sediment, and vegetation and foodstuff, as discussed in Chapters 2 and 4 through 11 of this report, play an important role in LLNL's program to control radiation releases. These measurements can signal anomalous releases, should they occur, and they directly gauge the degree of success of LLNL's radionuclide discharge control program in limiting exposures of the public. LLNL implemented a quality assurance/quality control (QA/QC) process to ensure the accuracy, precision, and reliability of these monitoring data (see Chapter 14, Quality Assurance, and the Quality Control for 1999 Radiological Accounting Update and Modeling section, in the *LLNL NESHAPs 1999 Annual Report* [Gallegos et al. 2000]).

In addition to routine QA/QC measures carried out each year, LLNL's Assurance Review Office (ARO) conducted a special self-assessment, during February through May in 1999, focused on LLNL's radiological releases to air. The ARO assessment addressed the adequacy of effluent monitoring, ambient air sampling, computer modeling, quality assurance, laboratory sample analyses, data reliability, and reporting. All of the five potential noncompliance conditions or practices identified in the ARO assessment have been addressed.

Development of the Livermore Valley and the San Joaquin Valley has enlarged the populations and decreased the distance between sources of emissions and the residents who might be exposed. People live and work within several hundred meters of LLNL's boundaries. It is, therefore, increasingly important that the Laboratory's assessments provide the best information possible regarding the radiological impact of its operations.

Quality Assurance

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Introduction

Quality assurance (QA) is a system of activities and processes that are put in place to ensure that monitoring and measurement data meet user requirements and needs. Quality control (QC) consists of procedures that are used to verify that prescribed standards of performance in the monitoring and measurement process are met. U.S. Department of Energy (DOE) orders and guidance mandate QA requirements for environmental monitoring of DOE facilities. DOE Order 5400.1 identifies QA requirements for radiological effluent and surveillance monitoring and specifies that a QA program consistent with the DOE order addressing quality assurance is established. This order sets forth policy, requirements, and responsibilities for the establishment and maintenance of plans and actions that assure quality in DOE programs.

Lawrence Livermore National Laboratory conducted QA activities in 1999 at the Livermore site and Site 300 in accordance with the *Environmental Protection Department Quality Assurance Management Plan* (Revision 3), based on DOE Order 5700.6C, which prescribes a risk-based, graded approach to QA. This process promotes the selective application of QA and management controls based on the risk associated with each activity in order to maximize effectiveness and efficiency in resource use.

The DOE *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. Department of Energy 1991) requires that an environmental monitoring plan be prepared. LLNL environmental monitoring is conducted according to procedures published in Appendix B of the LLNL *Environmental Monitoring Plan* (Tate et al. 1999). LLNL or commercial laboratories analyze environmental monitoring samples using U.S. Environmental Protection Agency (EPA) standard methods, when available. When EPA standard methods are not available, custom analytical procedures, usually developed at LLNL, are used. The radiochemical methods used by LLNL laboratories are described in procedures unique to the laboratory performing the analyses. LLNL uses only State-of-California-certified laboratories to analyze its environmental monitoring samples. In addition, LLNL requires all analytical laboratories to maintain adequate QA programs and documentation of methods.



Quality Assurance Activities

Nonconformance reporting and tracking is an LLNL QA process for ensuring that Environmental Protection Department (EPD) activities meet the department's QA requirements and that problems are found, identified, resolved, and prevented from recurring. LLNL generated 111 Nonconformance Reports (NCRs) related to environmental monitoring in 1999 compared to 92 in 1998 and 87 in 1997.

Fifty-nine of the 111 NCRs generated in 1999 were due to problems with analytical laboratories. Twenty-one were related to minor problems with sewer monitoring equipment, and another 13 were due to minor problems with air-monitoring equipment. Errors in documentation, training, or procedures accounted for another 12 NCRs; the remaining six were related to other monitoring networks.

LLNL addresses analytical laboratory problems with the appropriate laboratory as they arise. Many of the NCRs that were written in response to problems with the 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 NCRs related to the analytical laboratories. The majority of these problems were corrected by reanalysis, resampling, reissued reports, or corrected paperwork, and associated sample results were not affected.

LLNL addresses internal documentation, training, and procedural errors by conducting formal and informal training. These errors generally do not result in lost samples but may require extra work on the part of sampling and data management personnel to resolve or compensate for the errors.

Analytical Laboratories

LLNL entered into new Blanket Service Agreements (BSAs) with seven analytical laboratories in March 1999; of these seven, four are continuing service, and three are serving the Laboratory for the first time. LLNL is working closely with its analytical laboratories to minimize the occurrence of problems in the future.



Participation in Laboratory Intercomparison Studies

The LLNL Chemistry and Materials Science Environmental Services (CES) Environmental Monitoring Radiation Laboratory (EMRL) and the Hazards Control Department's Analytical Laboratory (HCAL) participated in the DOE Environmental Monitoring Laboratory (EML) intercomparison studies program. A review of the EML studies indicates that 55 of 58 results reported by CES and 10 of 10 results reported by HCAL fell within the established acceptance control limits.

CES EMRL participated in two DOE Mixed Analyte Performance Evaluation Program (MAPEP) studies in 1999. Sixteen of 16 analytes reported by CES for the first study and 23 of 23 analytes reported by CES for the second study fell within acceptable limits.

CES has implemented changes that are intended to address the root causes of unacceptable intercomparison study results and prevent future results from falling outside the acceptance control limits.

Details of the intercomparison study results, including the follow-up explanation and response for data that fell outside the acceptance control limits, are presented in the Data Supplement. Although contract laboratories are also required to participate in laboratory intercomparison programs, permission to publish their results for comparison purposes was not granted for 1999.

LLNL uses the results of intercomparison program data to identify and monitor trends in performance and to solicit corrective action responses for unacceptable results. If a laboratory has unacceptable performance 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. Continued unacceptable performance or failure to prepare and implement acceptable corrective action responses could result in formal notification of unsatisfactory performance by the LLNL Procurement Department (for off-site contract laboratories). If the problem still cannot be corrected, the BSA with the contract laboratory could be terminated or use of the on-site laboratory could be suspended.

A joint performance evaluation committee composed of members from EPD, CES, and Lawrence Berkeley National Laboratory is creating a systematic process for evaluating laboratory performance using performance evaluation samples. A method for evaluating the results of intercomparison studies will be developed by that committee.



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 and are intended to be identical in all respects. Collocated samples processed and analyzed *by the same organization* 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 organizations* provide interlaboratory information about the precision of the entire measurement system (U.S. Environmental Protection Agency 1987). Collocated samples may also be used to identify errors—for example, mislabeled samples or data entry errors.

Tables 14-1 through **14-3** 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 14-1** and **14-2** are based on data pairs in which both values are detections (see Statistical Methods in this chapter). **Table 14-3** is based on data pairs in which either or both values are nondetections.

Precision is measured by the percent relative standard deviation (%RSD); see the EPA's *Data Quality Objectives for Remedial Response Activities: Development Process*, Section 4.6 (1987). Acceptable values for %RSD vary greatly with matrix, analyte, and analytical method; however, lower values represent better precision. The results for %RSD given in **Table 14-1** 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 slope equal to 1 and intercept equal to 0, as illustrated in **Figure 14-1**. Allowing for normal analytical variation, the slope of the fitted line should be between 0.7 and 1.3, and the absolute value of the intercept should be less than the detection limit. The coefficient of determination (r^2) should be greater than 0.8. These criteria apply to pairs in which both results are above the detection limit.

When there were more than eight data pairs with both results in each pair considered detections, precision and regression analyses were performed; those results are presented in **Table 14-1**. 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 average, minimum, and maximum ratios for selected analytes are given in **Table 14-2**. The mean ratio should be between 0.7 and 1.3.



Table 14-1. Quality assurance duplicate sampling. Summary statistics for analytes with more than eight pairs in which both results were above the detection limit.

Medium	Analyte	N ^(a)	% RSD ^(b)	Slope	r ² ^(c)	Intercept	
Air	Gross alpha	24	24.1	1.03	0.88	4.75×10^{-6} (Bq/m ³)	
	Gross beta	73	13.5	0.878	0.97	4.94×10^{-5} (Bq/m ³)	
	Beryllium ^(d)	15	22.6	0.935	0.60	-0.73 (pg/m ³)	
	Uranium-234+233	12	3.57	0.958	0.91	6.34×10^{-10} (µg/m ³)	
	Uranium-235 by mass	12	3.05	0.789	0.94	5.3×10^{-7} (µg/m ³)	
	Uranium-238 by mass	12	3.2	0.792	0.97	7.43×10^{-5} (µg/m ³)	
	Tritium ^(e)	25	16.5	0.675	0.93	0.0593 (Bq/m ³)	
Ground water	Gross alpha	12	19.2	0.867	0.81	0.0178 (Bq/L)	
	Gross beta	21	12.4	0.744	0.76	0.0459 (Bq/L)	
	pH	9	0.262	1.01	0.99	-0.0686 (units)	
	Arsenic	20	7.01	0.959	0.99	5.36×10^{-4} (mg/L)	
	Barium	15	3.78	0.991	1.00	-4.86×10^{-4} (mg/L)	
	Chromium	9	6.73	1.01	1.00	3.1×10^{-6} (mg/L)	
	Copper ^(d)	9	30	0.630	0.32	0.00835 (mg/L)	
	Nitrate (as NO ₃) ^(d)	18	18.2	0.848	0.71	12.3 (mg/L)	
	Potassium	31	3.82	0.961	0.99	0.221 (mg/L)	
	Trichloroethene	12	4.71	0.935	1.00	0.0624 (µg/L)	
	Tritium	14	17.5	0.960	1.00	6.31 (Bq/L)	
	Uranium-234+233	24	7.92	0.917	0.98	0.00231 (Bq/L)	
	Uranium-235+236 ^(d)	22	25.3	0.552	0.66	0.00369 (Bq/L)	
	Uranium-238	22	8.87	0.906	0.99	0.00348 (Bq/L)	
	Vanadium	9	1.21	0.99	0.99	9.60×10^{-4} (mg/L)	
	Runoff (from rain)	Bicarbonate alkalinity (as CaCO ₃)	11	18.4	1.04	0.99	-2.98 (mg/L)
		Electrical conductivity	10	11.4	1.07	1.00	-41.3 (µmho/cm)
pH		10	1.61	0.98	0.88	0.0665 (units)	
Aluminum ^(e)		14	36.6	1.40	0.53	0.554 (mg/L)	
Chloride		12	7.44	1.05	1.00	1.79 (mg/L)	
Copper		9	14.4	1.06	0.90	3.27×10^{-4} (mg/L)	
Fluoride		12	12.4	1.04	0.99	-0.0116 (mg/L)	
Iron ^(e)		16	23.4	1.26	0.49	0.73 (mg/L)	
Manganese ^(d)		12	25.4	1.15	0.61	0.0232 (mg/L)	
Orthophosphate		11	19.1	0.831	0.96	0.0296 (mg/L)	
Sulfate		12	7.27	1.03	1.00	0.019 (mg/L)	
Zinc ^(d)		12	31.3	0.432	0.26	0.0402 (mg/L)	



Table 14-1. Quality assurance duplicate sampling. Summary statistics for analytes with more than eight pairs in which both results were above the detection limit (concluded).

Medium	Analyte	N ^(a)	% RSD ^(b)	Slope	r ² ^(c)	Intercept
Sewer	Gross alpha ^(d)	16	29.4	0.854	0.68	4.93 × 10 ⁻⁵ (Bq/mL)
	Gross beta	52	10.8	0.992	0.97	4.34 × 10 ⁻⁵ (Bq/mL)
	Aluminum ^(d)	11	27.6	0.89	0.41	0.136 (mg/L)
	Copper ^(d)	12	34.5	0.884	0.39	0.0142 (mg/L)
	Iron ^(d)	12	31.3	1.17	0.58	-0.267 (mg/L)
	Lead	11	44.7	1.14	0.91	-0.00184 (mg/L)
	Zinc ^(e)	12	17.4	1.02	0.70	-0.032 (mg/L)

^a Number of duplicate pairs included in regression analysis.

^b 75th percentile of percent relative standard deviation (%RSD) where $\%RSD = \left(\frac{200}{\sqrt{2}}\right) \left(\frac{|x_1 - x_2|}{x_1 + x_2}\right)$ 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.

When one of the results in a pair is a nondetection, then the other result should be less than two times the detection limit. **Table 14-3** identifies the sample media and analytes for which at least one pair failed this criterion. Analytes with fewer than four pairs are omitted from the table.

Collocated sample comparisons are more variable when the members of the pair are analyzed by different methods or with different criteria for analytical precision. For example, radiological analyses using different counting times or different laboratory aliquot sizes will have different amounts of variability.

These analyses show generally good agreement between routine samples and QA duplicates: 90% of the pairs have a precision better than 27%. 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 41 data sets reported in **Table 14-1**, four did not meet the criterion for acceptability because of outliers. **Figure 14-2** illustrates a set of collocated pairs with one outlier.



Table 14-2. Quality assurance duplicate sampling. Summary statistics for selected analytes with eight or fewer pairs in which both results were above the detection limit.

Medium	Analyte	N	Mean ratio	Minimum ratio	Maximum ratio
Air	Plutonium-239+240	2	1.1	1	1.2
Aqueous	Gross alpha	1	0.64	0.64	0.64
	Gross beta	2	0.75	0.67	0.84
	Uranium-234+233	1	1.3	1.3	1.3
	Uranium-238	1	1.2	1.2	1.2
	Ground water	Radium-226	4	1.1	0.74
	Radium-228	1	1.1	1.1	1.1
Rain	Tritium	2	1.00	1	1.1
Runoff (from rain)	Gross alpha	1	0.41	0.41	0.41
	Gross beta	5	1.8	0.91	3.3
	Tritium	2	1.3	0.43	2.2
	Uranium-234+233	1	0.99	0.99	0.99
	Uranium-235+236	1	1.7	1.7	1.7
	Uranium-238	1	0.92	0.92	0.92
	Soil	Cesium-137	4	0.92	0.84
	Potassium-40	4	0.97	0.94	1
	Plutonium-238	2	1.3	1	1.5
	Plutonium-239+240	3	0.89	0.71	0.99
	Radium-226	4	1	0.92	1.1
	Radium-228	4	0.98	0.94	1
	Thorium-228	4	0.96	0.93	1
	Uranium-235	4	0.87	0.79	1.1
	Uranium-238	2	1.1	0.61	1.5
Sewer	Tritium	8	1.1	0.5	1.7
Vegetation	Tritium	5	1.1	0.89	1.4



14 Quality Assurance

Table 14-3. Quality assurance duplicate sampling. Summary statistics for analytes with at least four pairs in which one or both results were below the detection limit.

Medium	Analyte	Number of inconsistent pairs ^(a)	Number of pairs	Percent of inconsistent pairs
Air	Gross alpha	3	61	4.9
	Tritium	2	20	10
Ground water	Gross alpha	1	17	5.9
	1,2-Dichloroethene (total)	1	20	5
	Arsenic	1	8	12
	cis-1,2-Dichloroethene	1	23	4.3
	Chromium	1	14	7.1
	Nickel	1	26	3.8
	Nitrate (as NO ₃)	1	11	9.1
	Runoff (from rain)	Gross alpha	2	4
	Carbonate alkalinity (as CaCO ₃)	1	9	11
	Beryllium	1	8	12
	Copper	1	7	14
	Nitrate (as NO ₃)	4	6	67
	Nitrate (as N)	3	6	50
Sewer	Gross alpha	1	36	2.8
	Bis(2-ethylhexyl)phthalate	1	4	25
	Benzyl alcohol	2	5	40
	Chromium	3	9	33
	Freon 113	1	7	14
	Tritium	1	44	2.3
	Mercury	1	5	20
	Nickel	1	5	20

^a An inconsistent pair is one in which one result is a nondetection and the other result is a detection greater than two times the detection limit.

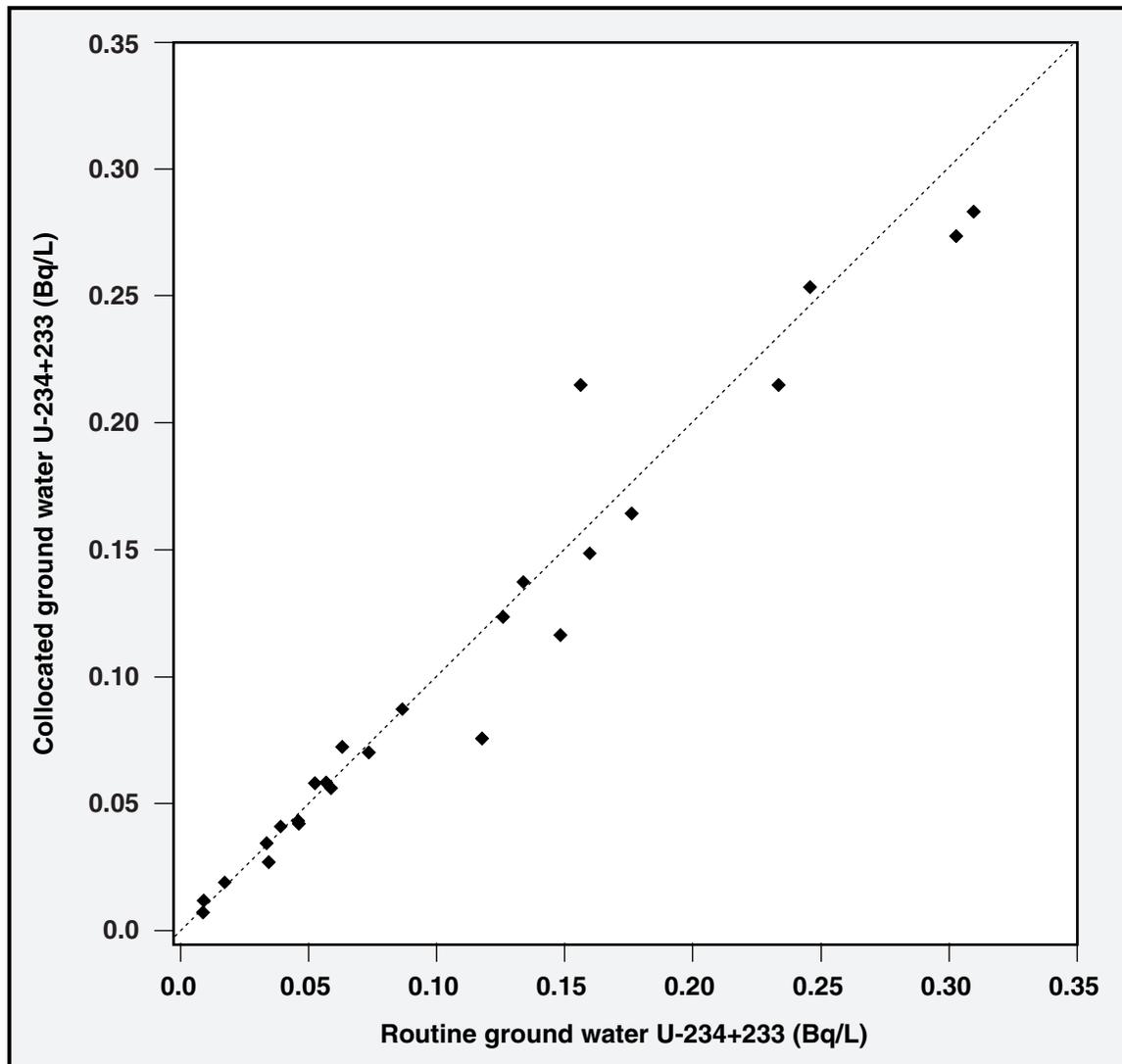


Figure 14-1. Ground water uranium-234+233 concentrations from collocated samples. These data lie close to a line with slope equal to 1 and intercept equal to 0.

The other results that do not meet the criterion for acceptability consist of data sets where there is a lot of scatter. This tends to be typical of nondetections and measurements at extremely low concentrations, as illustrated in **Figure 14-3**. Low concentrations of radionuclides on particulates in air highlight this effect even more because one or two radionuclide-containing particles on an air filter can significantly affect results. Other causes of high variability are sampling and analytical methodology. Analyses of total organic carbon and total organic halides in water are particularly difficult to control. Of the 41 data sets in **Table 14-1**, 11 show sufficient variability in results to make them fall outside the acceptable range.



Statistical Methods

Statistical methods used in this report have been implemented in accordance with the *Environmental Monitoring Plan* (Tate et al. 1999). These methods reduce the large volumes of monitoring data to summary estimates suitable for temporal and spatial comparisons. Attention is given to estimating accuracy, bias, and precision of all data.

Radiation Units

Data for 1999 have been reported in Système Internationale (SI) units to conform with standard scientific practices and federal law. Values in the text are reported in becquerels (Bq) and millisieverts (mSv); equivalent values in picocuries (pCi) and millirems (mrem) are given in parentheses.

Sampling Completeness

Planned samples and actual samples collected and analyzed in 1999 are summarized in **Table 14-4**.

Data review and analysis are conducted in accordance with the *Environmental Monitoring Plan* (Tate et al. 1999) and the data analysis procedure developed by EPD's Operations and Regulatory Affairs Division. These documents contain detailed information regarding the acceptability of data and the procedures that are followed for the identification, notification, and correction of suspect data.

Radiological Data

The precision of radiological analytical results is displayed in the Data Supplement tables as the 2σ counting uncertainty. The counting uncertainties are not used in summary statistic calculations. Any radiological result exhibiting a 2σ counting uncertainty greater than or equal to 100% is considered to be a nondetection. The reported concentration is derived from the number of sample counts minus the number of background counts. A sample with a low concentration may, therefore, have a negative value; such results are reported in the tables and used in the calculation of summary statistics and statistical comparisons.

Some Data Supplement tables provide radioactivity sensitivity values instead of, or in addition to, a reported value when the radiological result is below the detection criterion. Such results are displayed in the tables with a less-than symbol. These values

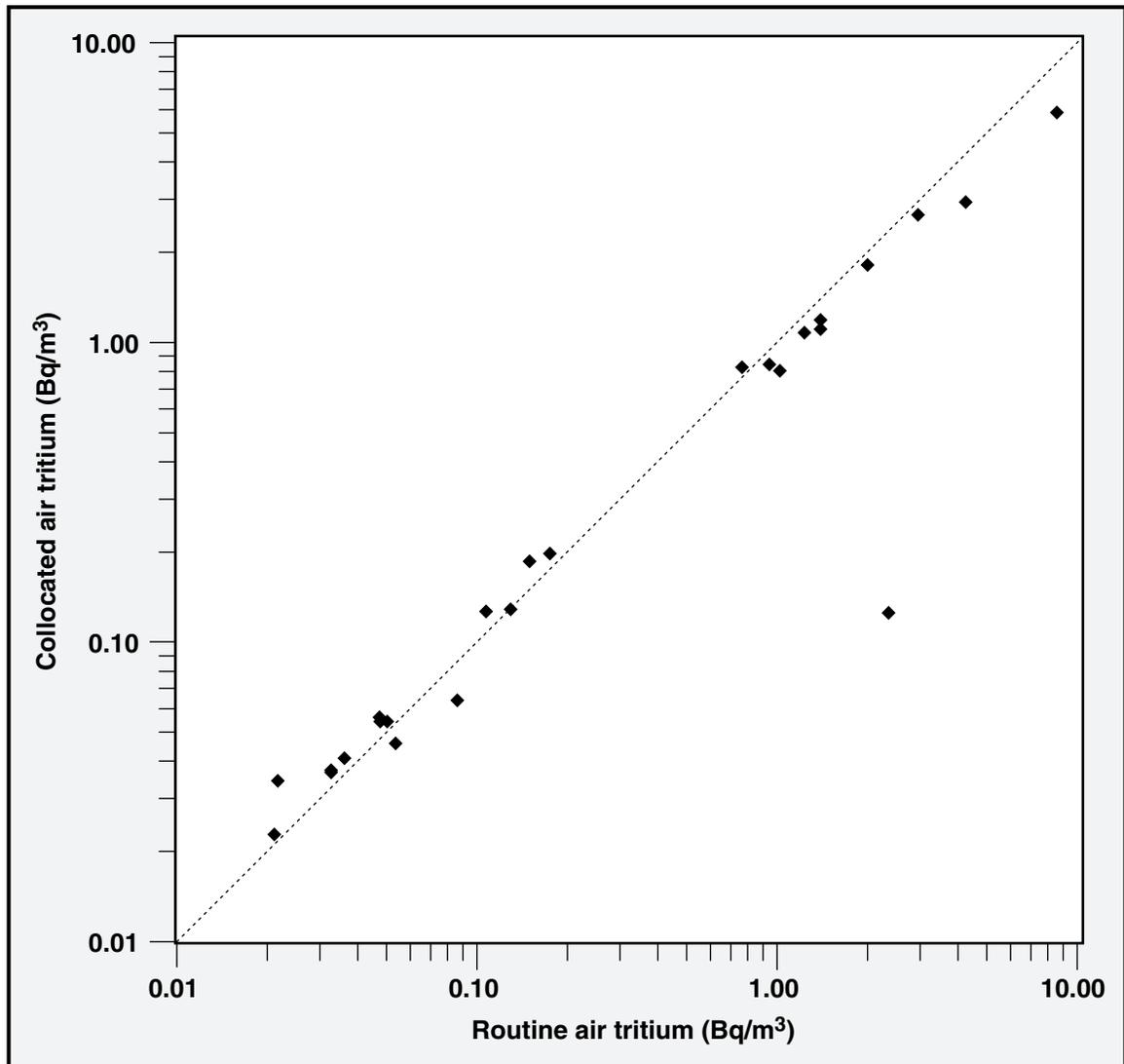


Figure 14-2. Air tritium concentrations from collocated samples showing an outlier.

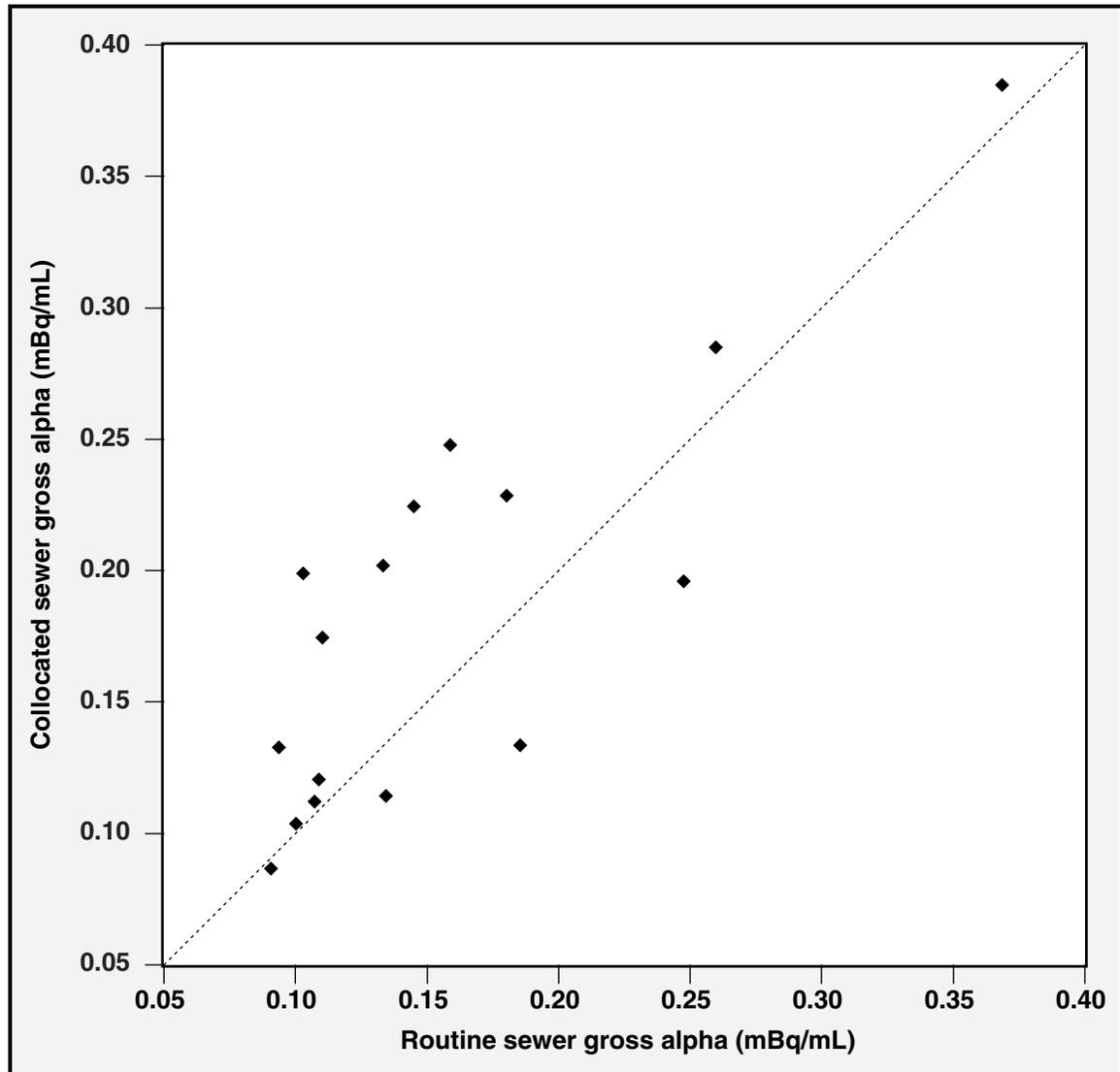


Figure 14-3. Sewer gross alpha concentrations from collocated samples showing a lot of scatter.

can be described as the smallest concentration of radioactive material that can be detected (distinguished from background) with a large degree of confidence. These radioactivity sensitivity values are referred to as minimum detectable concentrations (MDC) in Chapters 4 and 5, limits of sensitivity (LOS) in Chapter 6, and detection limits (DL) in Chapters 7 and 9. The Chemistry and Materials Science Environmental Services (CES) Laboratory calculates these three values (MDC, LOS, and DL) in the same manner and reports them in the same units as measurements that are considered detections.

**Table 14-4.** Sampling completeness in 1999, Livermore site and Site 300.

Environmental medium	Number of analyses planned	Number of analyses completed	Completeness (%)	Reason(s) for lost samples
Air particulate (Livermore site)				
Radiological parameters	1274	1269	99.6	Access to area denied (1); power failure (2); equipment problem (1); sampler error (1)
Beryllium	96	96	100	
Air particulate (Site 300)				
Radiological parameters	668	655	98	Access to area denied (4); power failure (2); lab error (2); power outage because of electrical work in area (5)
Beryllium	72	71	99	Power outage because of electrical work in area (1)
Air tritium				
Livermore site	494	471	95	Unacceptable flow rate (14); insufficient total flow (1); power failure (3); broken flask (1); equipment problems (1); flask not attached properly (1); no explanation (2)
Site 300	26	25	96	Flask not attached properly (1)
Soil				
Livermore	42	42	100	
Site 300	32	32	100	
Arroyo sediment (Livermore site only)	36	32	89	Location inundated and could not be sampled (4)
Vegetation				
Livermore site and vicinity	68	68	100	
Site 300	32	32	100	
Wine	25	25	100	
Rain				
Livermore site	90	63	70	Insufficient rainfall (26); sampling bucket stolen (1)
Site 300	7	4	57	Insufficient rainfall during sample period (3)
Storm water runoff				
Livermore site	590	578	98	No evidence of flow in area (12)
Site 300	149	119	80	No evidence of flow in area (29); sampler error (1)



Table 14-4. Sampling completeness in 1999, Livermore site and Site 300 (concluded).

Environmental medium	Number of analyses planned	Number of analyses completed	Completeness (%)	Reason(s) for lost samples
Drainage Retention Basin				
Field measurements	884	884	100	
Samples	115	115	100	
Releases	56	56	100	
Other surface water (Livermore only)	58	58	100	
Ground water				
Livermore site	504	494	98	Overlooked; sampled in subsequent quarter (10)
Site 300	2505	2346	94	Well dry or insufficient sample (121), well pump inoperable (28), well inaccessible because of construction (7), sampler error (3)
Livermore Valley wells	27	22	81	Samples not provided (5)
Sewage				
B196	912	910	99.8	Sampler error (2)
C196	358	357	99.7	Laboratory results invalid (1)
LWRP ^(a) effluent	130	128	98.5	LWRP did not supply sample (2)
Digester sludge	80	72	90	LWRP did not supply sample (6); digester offline (2)
WDR-96-248				
Surface impoundment wastewater	54	54	100	
Surface impoundment ground water	147	147	100	
Sewage ponds wastewater	54	53	98	Missed duplicate (1)
Sewage ponds ground water	110	107	97	Missed duplicate (2); missed analysis (1)
Thermoluminescent dosimeters (TLDs)				
Livermore site	156	155	99	TLD missing (1)
Livermore Valley	104	99	95	TLD missing (5)
Site 300	76	75	99	TLD missing (1)
Cooling towers (Site 300 only)	24	18	75	Sampler error (6)

a LWRP = Livermore Water Reclamation Plant.



Nonradiological Data

Nonradiological data that are reported as being below the reporting limit also are displayed in the tables with a less-than symbol. The reporting limit values are used in the calculation of summary statistics as explained below.

Statistical Comparisons

Standard comparison techniques (such as regression, t-tests, and analysis of variance) have been used where appropriate to determine the statistical significance of trends or differences between means. All such tests of significance have been performed at the 0.05 level. When such a comparison is made, it is explicitly stated in the text as being “statistically significant” or “not statistically significant.” Other uses of the word “significant” in the text do not imply that statistical tests have been performed. Instead, these uses relate to the concept of practical significance and are based on professional judgment.

Summary Statistics

Determinations of measures of central tendency and associated measures of dispersion are calculated according to the *Environmental Monitoring Plan* (Tate et al. 1999). For data sets that do not contain values below the detection criterion, the measures of central tendency and dispersion are the median and interquartile range (IQR). The IQR is the range that encompasses the middle 50% of the data set. The IQR is calculated by subtracting the 25th percentile of the data set from the 75th percentile of the data set. When necessary, the percentiles are interpolated from the data. Software vendors may use slightly different formulas for calculating percentiles. Radiological data sets that include values less than zero may have an IQR greater than the median.

For data sets with one or more, but fewer than one-half, of the values below the detection criterion, the measure of central tendency is the median. If the values of the detection limits and the number of values below the detection limit permit (determined on a case-by-case basis), dispersion is reported as the IQR. Otherwise, no measure of dispersion is reported. Statistics are calculated using the reported detection limit value for nonradiological data or the reported value for radiological data.

For data sets with one-half or more of the values below the detection criterion, the central tendency is reported as less than the median value. Dispersion is not reported.



Quality Assurance Process for the Environmental Report

Unlike the preceding discussion, which focused on standards of accuracy and precision in data acquisition and reporting, a discussion of QA/QC procedures for a technical publication per se must deal with how to retain content accuracy through the publication process. Because publication of a large, data-rich document like this site annual environmental report involves many operations and many people, the chances of introducing errors are great. At the same time, ensuring quality is more difficult because a publication is less amenable to the statistical processes used in standard quality assurance methods.

The QA procedure we used concentrated on the tables and figures in the report and enlisted 53 authors, contributors, and technicians to check the accuracy of sections other than those they had authored or contributed to. In 1999, the 85 illustrations and 68 tables in the main volume and the 121 tables in the Data Supplement were checked. Checkers were assigned illustrations and tables and given a copy of each item they were to check along with a quality control form to fill out as they checked the item. Items to be checked included figure captions and table titles for clarity and accuracy, data accuracy and completeness, figure labels and table headings, units, significant digits, and consistency with text. When checking numerical data, checkers randomly selected 10% of the data and compared it to values in the master database. If all 10% agreed with the database, further checking was considered unnecessary. If there was disagreement in the data, the checker compared another 10% of the data with the database values. If more errors were found, the checker had then to verify every piece of data in the table or illustration.

A coordinator guided the process to ensure that forms were tracked and the proper approvals were obtained. Completed quality control forms and the corrected illustrations or tables were returned to the report editors, who were responsible for ensuring that changes, with the agreement of the original contributor, were made. This QA check resulted in the correction of data errors and omissions on 9% of the illustrations, 12% of the tables in the main volume, and 7% of the tables in the Data Supplement. Other corrections were made to footnotes, headings, titles in tables, graph axes, callouts, and captions in figures.

Appendix A.

Methods of Dose Calculations

S. Ring Peterson

Introduction

Lawrence Livermore National Laboratory calculates doses to the public for radiation protection purposes using the U.S. Environmental Protection Agency's (EPA's) model, CAP88-PC (Parks 1992), and discusses them in detail in Chapter 13 (Radiological Dose Assessment). Emission rates of radionuclides from stacks and diffuse sources are used as input to CAP88-PC. In addition, doses may be calculated from concentrations in air, vegetation, and water measured during routine monitoring to estimate the potential impact of LLNL operations on surrounding populations. A different model than CAP88-PC is required for these calculations. Because CAP88-PC is expected to overestimate doses to the public, doses calculated from environmental measurements should be lower, even when assumptions about intake rates are conservative. In Chapters 5, 7, 9, and 11, LLNL has calculated doses from inhalation and ingestion of water and locally produced foodstuffs based on measured concentrations in the various media and conservative assumptions about intake rates. In this appendix, LLNL calculates doses using different models, compares assumptions, and presents the bulk transfer parameters used to calculate the doses in the chapters.

The data on radionuclide concentrations in air, vegetation, water (i.e., potential drinking water such as rain water), and wine are necessary inputs to the dose-rate equations described here. Although other radionuclides are released to the environment in small quantities by LLNL activities, tritium is the only radionuclide that can be measured in the local food chain and is responsible for the dose received by the public. Thus, although the equations presented in this chapter can be applied to any radionuclide, only the dose from tritium will be calculated and discussed here. In the following equations, doses from inhalation and ingestion of vegetables and water or wine are calculated directly from measured tritium concentrations. Doses from ingesting milk and meat are calculated from measured concentrations in vegetation.

Appendix A. Methods of Dose Calculations

Dose Calculation Methods

The dose calculation methods given here for the ingestion and inhalation/skin absorption pathways for tritiated water (HTO) are based on the Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109, *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluent* (U.S. Nuclear Regulatory Commission 1977). The dose coefficients used in these calculations were obtained from the committed dose equivalent tables for DOE dose calculations (U.S. Department of Energy 1988) and are consistent with those specified in ICRP 30, *Limits for Intakes of Radionuclides by Workers* (International Commission on Radiological Protection [ICRP] 1979). The dose calculation for inhalation of tritiated hydrogen (HT) gas uses a dose-rate conversion factor from ICRP 68, *Dose Coefficients for Intakes of Radionuclides by Workers* (ICRP 1994). A comparison of dose coefficients is shown in **Table A-1**.

Table A-1. Comparison of dose coefficients for tritium; units are $\mu\text{Sv Bq}^{-1}$.

	DOE	CAP88-PC ^(a)	ICRP
HTO (inhalation and skin absorption)	$1.5^{(b)} \times 1.73 \times 10^{-5}$	3.41×10^{-5}	$1.5^{(b)} \times 1.8 \times 10^{-5}$
HT (inhalation)	$3.31 \times 10^{-13(c)}$		1.8×10^{-9}
HTO (ingestion)	1.73×10^{-5}	2.43×10^{-5}	1.8×10^{-5}
OBT ^(d) (ingestion)			4.2×10^{-5}

^a Computer code required by the EPA for modeling air emissions of radionuclides.

^b 1.5 accounts for dose from HTO absorbed through the skin from air.

^c Units are $\mu\text{Sv/Bq} \times \text{s/m}^{-3}$ because dose is considered external from air submersion.

^d Organically bound tritium.

Although the analytical laboratories report concentrations in pCi and the DOE's dose-rate conversion factors have units of mrem/pCi, LLNL uses Système Internationale (SI) units of becquerel (Bq) for concentration and millisievert (mSv) or microsievert (μSv) for dose in compliance with Presidential Executive Order 12770, Metric Usage in Federal Government Programs (July 25, 1991). The conversion factors are as follows:

$$1 \text{ Bq} = 27 \text{ pCi}$$

$$1 \text{ mSv} = 100 \text{ mrem}; 1 \mu\text{Sv} = 0.1 \text{ mrem}$$

All units have been converted to SI units in the following dose calculations.

The annual whole-body dose rate from ingestion of a particular food or drink is expressible as a product of three factors: the rate at which the food or drink is consumed (e.g., kg/y), the radionuclide concentration (e.g., Bq/kg) in the food or drink, and the dose rate conversion factor (e.g., $\mu\text{Sv/Bq}$) for the radionuclide. In the following subsections, equations of this type are used to estimate the annual dose from tritium

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ingested from water (or wine) and food (e.g., leafy vegetables, produce, milk, and meat). Similar formulas are given for the inhalation/skin absorption dose for HTO and inhalation dose for HT.

Different models recommend different consumption rates. In Appendix E of the NRC Regulatory Guide 1.109, two annual diets are recommended, one for maximum intake and one for average intake (see **Table A-2**). Two diets from CAP88-PC are also shown in **Table A-2**. One diet is recommended for all radionuclides except tritium and ¹⁴C. The diet shown for tritium has been estimated from the CAP88-PC assumption that daily diet consists of 1638 g of water obtained from food. This assumption accounts for a complete diet with more food than an average person would eat. Values for fresh weight, protein, carbohydrate, and fat fractions, used to estimate the total water content of various foodstuffs, come from Ciba-Geigy (1981). Assumptions about the fractions of fruit, grain, root crops, and fruit vegetables that make up "produce" come from NRC Regulatory Guide 1.109.

Table A-2. Examples of annual inhalation and ingestion rates.

	NRC maximum	NRC average	CAP88-PC tritium	CAP88-PC other nuclides
Leafy vegetables (kg)	64	23 (est)	28	18
Produce (kg)	520	190	274	176
Milk (L)	310	110	185	112
Meat (kg)	110	95	111	85
Drinking water (L)	730	370	0	0
Inhalation (m ³)	8000	8000	8038	8038

It is clear from **Table A-2** that the NRC maximum consumption rates are much higher than the other consumption rates, with the exception of meat. CAP88-PC's (tritium) estimated rates are high but are still relatively low except for meat, and it is known that tritium doses estimated with CAP88-PC are conservative. LLNL has calculated the dose from maximum dietary intake (less produce) since these dose rate formulas were first used in the site environmental annual report (Silver et al. 1980). The NRC's maximum dietary intake is still used to estimate doses from water, food (less produce), and wine in Chapters 5, 7, 9, and 11 so that estimated doses can be compared year after year. In this appendix, however, we will use the average NRC intake plus produce concentrations, assuming (conservatively) that concentrations in produce equal concentrations in grass measured in LLNL's environmental monitoring program. This approach should yield more realistic doses that are nevertheless conservative. After the following equations, the numbers needed to estimate doses for both sets of assumptions will be presented.

Appendix A. Methods of Dose Calculations

Annual Dose from Potable Water

The effective dose equivalent for tritium in drinking water (D_{water}) in $\mu\text{Sv}/\text{y}$ is calculated using the following equation:

$$D_{\text{water}} (\mu\text{Sv}/\text{y}) = C_w \times U_w \times DC_{\text{HTO}} \quad (\text{A-1})$$

where

$$\begin{aligned} C_w &= \text{concentration of tritium measured in drinking water (Bq/L)} \\ U_w &= \text{water consumption rate (L/y)} \\ DC_{\text{HTO}} &= \text{dose coefficient } (\mu\text{Sv/Bq}) \text{ for HTO} \end{aligned}$$

The tritium dose from ingestion of potable water, assuming average intake of water, is then

$$\begin{aligned} D_{\text{water}} (\mu\text{Sv}/\text{y}) &= 730 (\text{L}/\text{y}) \times 1.73 \times 10^{-5} (\mu\text{Sv}/\text{Bq}) \times C_w (\text{Bq}/\text{L}) \\ D_{\text{water}} (\mu\text{Sv}/\text{y}) &= 6.4 \times 10^{-3} \times C_w (\text{Bq}/\text{L}) \end{aligned}$$

In Chapter 7, we have used this equation to estimate doses from drinking water; the dose is calculated by multiplying the water concentration by 1.24×10^{-2} (based on annual water intake of 730 L). This equation can also be used to calculate the effective dose equivalent from wine (see Chapter 11).

Annual Dose from Food Ingestion

The effective dose equivalent from ingestion of food (D_{food}) is calculated by summing the contributions from leafy vegetables, produce, milk, and meat to the diet. The concentrations in these foodstuffs are based on measured tritium concentrations in annual grasses (see Chapter 11), and we assume that concentrations in leafy vegetables and produce are similar. Concentrations in milk and meat are calculated from measured concentrations in vegetation using the equations from NRC Regulatory Guide 1.109.

Therefore

$$D_{\text{food}} (\mu\text{Sv}/\text{y}) = D_{\text{veg_and_prod}} + D_{\text{meat}} + D_{\text{milk}} \quad (\text{A-2})$$

Appendix A. Methods of Dose Calculations

where

$D_{\text{veg_and_prod}}$ = $\mu\text{Sv}/\text{y}$ dose from ingestion of leafy vegetables and produce (for calculations in Chapter 11, only leafy vegetables are considered)

D_{meat} = $\mu\text{Sv}/\text{y}$ dose from ingestion of meat

D_{milk} = $\mu\text{Sv}/\text{y}$ dose from ingestion of milk

Leafy Vegetation and Produce

For dose calculations, we make the conservative assumption that the leafy vegetation and produce are 100% water; therefore, $\text{Bq}/\text{L} = \text{Bq}/\text{kg}$. Note that the calculations in Chapter 11 are only for leafy vegetables.

$$D_{\text{veg_and_prod}} (\mu\text{Sv}/\text{y}) = U_{\text{veg_and_prod}} \times C_{\text{veg}} \times DC_{\text{HTO}} \quad (\text{A-3})$$

where

$U_{\text{veg_and_prod}}$ = intake rate (kg/y) of leafy vegetation and produce

C_{veg} = concentration measured (Bq/L) in annual grasses and weeds

DC_{HTO} = dose coefficient ($\mu\text{Sv}/\text{Bq}$) for HTO

The tritium dose from ingestion of leafy vegetables and produce is then

$$D_{\text{veg_and_prod}} (\mu\text{Sv}/\text{y}) = [23 (\text{leafy}) + 190 (\text{produce}) (\text{kg}/\text{y})] \times 1.73 \times 10^{-5} (\mu\text{Sv}/\text{Bq}) \times C_{\text{veg}} (\text{Bq}/\text{kg})$$

$$D_{\text{veg_and_prod}} (\mu\text{Sv}/\text{y}) = 3.7 \times 10^{-3} \times C_{\text{veg}} (\text{Bq}/\text{L})$$

For the calculations in Chapter 11, C_{veg} is multiplied by 1.1×10^{-3} (based on 64 kg annual intake of leafy vegetables).

Note: In this and some of the following equations, the dimensions associated with a multiplicative factor are not shown explicitly; the dimensions of the dependent variable and measured quantity are shown explicitly. For example, the above factor 3.7×10^{-3} carries units of $(\text{L} \cdot \mu\text{Sv}) \div (\text{y} \cdot \text{Bq})$.

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Meat (Beef)

The dose from ingestion of meat is calculated:

$$D_{\text{meat}} (\mu\text{Sv/y}) = U_{\text{meat}} \times C_{\text{meat}} \times DC_{\text{HTO}} \quad (\text{A-4})$$

where

$$U_{\text{meat}} = \text{intake rate (kg/y)}$$

$$C_{\text{meat}} = \text{predicted concentration in meat at time of consumption from the contribution of vegetation } (C_{\text{meat_veg}}) \text{ and drinking water } (C_{\text{meat_w}})$$

$$DC_{\text{HTO}} = \text{dose coefficient } (\mu\text{Sv/Bq}) \text{ for HTO}$$

and

$$C_{\text{meat_veg}} = F_f (\text{d/kg}) \times Q_f (\text{kg/d}) \times C_{\text{veg}} (\text{Bq/kg}) \times \exp(-\lambda_i t_s)$$

$$C_{\text{meat_w}} = F_f (\text{d/kg}) \times Q_w (\text{kg/d}) \times C_w (\text{Bq/kg}) \times \exp(-\lambda_i t_s)$$

where

$$F_f = \text{average fraction of an animal's daily intake of radionuclide appearing in each kilogram of animal flesh [(Bq/kg) in meat per (Bq/d) ingested by the animal] (d/kg): } 1.2 \times 10^{-2} \text{ d/kg}$$

$$Q_f = \text{amount of feed consumed (kg/d): } 50 \text{ kg/d}$$

$$Q_w = \text{amount of water consumed (kg/d): } 50 \text{ L/d (1 L = 1 kg)}$$

$$C_{\text{veg}} = \text{concentration measured in vegetation (Bq/L)}$$

$$C_w = \text{concentration measured in drinking water (Bq/L)}$$

$$\lambda_i = \text{radiological decay constant (d}^{-1}\text{): } 1.5 \times 10^{-4} \text{ d}^{-1}$$

$$t_s = \text{time from slaughter to consumption (d): } 20 \text{ d}$$

Therefore

$$\begin{aligned} C_{\text{meat_veg}} &= 1.2 \times 10^{-2} (\text{d/kg}) \times 50 (\text{kg/d}) \times C_{\text{veg}} (\text{Bq/kg}) \\ &\quad \times \exp[(-1.5 \times 10^{-4}) \times 20] \\ &= 0.6 \times C_{\text{veg}} (\text{Bq/L}) \end{aligned}$$

$$\begin{aligned} C_{\text{meat_w}} &= 1.2 \times 10^{-2} (\text{d/kg}) \times 50 (\text{L/d}) \times C_w (\text{Bq/L}) \times \exp[(-1.5 \times 10^{-4}) \times 20] \\ &= 0.6 \times C_w (\text{Bq/L}) \end{aligned}$$

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The tritium dose rate from meat consumption is then

$$\begin{aligned} D_{\text{meat}} (\mu\text{Sv}/\text{y}) &= 95 (\text{kg}/\text{y}) \times \{ [0.6 \times C_{\text{veg}} (\text{Bq}/\text{kg})] + [0.6 \times C_{\text{w}} (\text{Bq}/\text{L})] \} \\ &\quad \times 1.73 \times 10^{-5} (\mu\text{Sv}/\text{Bq}) \\ &= [9.9 \times 10^{-4} \times C_{\text{veg}} (\text{Bq}/\text{L})] + [9.9 \times 10^{-4} \times C_{\text{w}} (\text{Bq}/\text{L})] \end{aligned}$$

The dose calculation for meat in Chapter 11 multiplies 1.1×10^{-3} times C_{veg} (based on meat intake of 110 kg/y). In Chapter 11, only the contribution from vegetation ingested by the meat animal is calculated.

Cow Milk

The dose from consumption of milk is calculated:

$$D_{\text{milk}} (\mu\text{Sv}/\text{y}) = U_{\text{milk}} \times C_{\text{milk}} \times DC_{\text{HTO}} \quad (\text{A-5})$$

where

$$U_{\text{milk}} = \text{intake rate (L/y)}$$

$$C_{\text{milk}} = \text{predicted concentration in milk at time of consumption from the contribution of vegetation } (C_{\text{milk_veg}}) \text{ and drinking water } (C_{\text{milk_w}})$$

$$DC_{\text{HTO}} = \text{dose coefficient } (\mu\text{Sv}/\text{Bq}) \text{ for HTO}$$

and

$$C_{\text{milk_veg}} = F_{\text{m}} (\text{d}/\text{L}) \times Q_{\text{f}} (\text{kg}/\text{d}) \times C_{\text{veg}} (\text{Bq}/\text{kg}) \times \exp(-\lambda_{\text{i}} t_{\text{f}})$$

$$C_{\text{milk_w}} = F_{\text{m}} (\text{d}/\text{L}) \times Q_{\text{w}_\text{m}} (\text{L}/\text{d}) \times C_{\text{w}} (\text{Bq}/\text{L}) \times \exp(-\lambda_{\text{i}} t_{\text{f}})$$

where

$$F_{\text{m}} = \text{average fraction of an animal's daily intake of radionuclide appearing in each kilogram of milk [(Bq/L) in milk per (Bq/d) ingested by the animal] (d/L): } 1.0 \times 10^{-2} \text{ d/L}$$

$$Q_{\text{f}} = \text{amount of feed consumed by the milk cow (kg/d): } 50 \text{ kg/d}$$

$$Q_{\text{w}_\text{m}} = \text{amount of water consumed by the milk cow (kg/d): } 60 \text{ L/d} \\ (1 \text{ L} = 1 \text{ kg})$$

$$C_{\text{veg}} = \text{concentration measured in vegetation (Bq/kg)}$$

$$C_{\text{w}} = \text{concentration measured in drinking water (Bq/L)}$$

$$\lambda_{\text{i}} = \text{radiological decay constant (d}^{-1}\text{): } 1.5 \times 10^{-4} \text{ d}^{-1}$$

Appendix A. Methods of Dose Calculations

t_f = time from milking to milk consumption (d): 2 d

Therefore

$$\begin{aligned} C_{\text{milk_veg}} &= 1.0 \times 10^{-2} \text{ (d/L)} \times 50 \text{ (kg/d)} \times C_{\text{veg}} \text{ (Bq/kg)} \\ &\quad \times \exp[(-1.5 \times 10^{-4}) \times 2] \\ &= 0.5 \times C_{\text{veg}} \text{ (Bq/L)} \end{aligned}$$

$$\begin{aligned} C_{\text{milk_w}} &= 1.0 \times 10^{-2} \text{ (d/L)} \times 60 \text{ (L/d)} \times C_w \text{ (Bq/L)} \times \exp[(-1.5 \times 10^{-4}) \times 2] \\ &= 0.6 \times C_w \text{ (Bq/L)} \end{aligned}$$

The tritium dose rate from directly consumed milk is then

$$\begin{aligned} D_{\text{milk}} \text{ (}\mu\text{Sv/y)} &= 110 \text{ (L/y)} \times \{ [0.5 \times C_{\text{veg}} \text{ (Bq/kg)}] + [0.6 \times C_w \text{ (Bq/L)}] \} \\ &\quad \times 1.73 \times 10^{-5} \text{ (}\mu\text{Sv/Bq)} \\ &= 9.5 \times 10^{-4} \times C_{\text{veg}} \text{ (Bq/L)} + 1.1 \times 10^{-3} \times C_w \text{ (Bq/L)} \end{aligned}$$

The dose calculation for milk in Chapter 11 multiplies 2.7×10^{-3} times C_{veg} (based on milk intake of 310 L/y). In Chapter 11 only the contribution from vegetation ingested by the cow is calculated.

Whole Body

$$\begin{aligned} D_{\text{food}} \text{ (}\mu\text{Sv/y)} &= [3.7 \times 10^{-3} \times C_{\text{veg}} \text{ (Bq/L)}] && \text{(dose from leafy (A-6)} \\ & && \text{vegetables and produce)} \\ &+ [9.9 \times 10^{-4} \times C_{\text{veg}} \text{ (Bq/L)}] && \} \\ &+ [9.9 \times 10^{-4} \times C_w \text{ (Bq/L)}] && \text{(dose from meat)} \\ & && \} \\ &+ [9.5 \times 10^{-4} \times C_{\text{veg}} \text{ (Bq/L)}] && \} \\ &+ [1.1 \times 10^{-3} \times C_w \text{ (Bq/L)}] && \text{(dose from milk)} \end{aligned}$$

Summing the above, the total annual dose rate from the food ingestion pathway for tritium (measured tritium in vegetation and drinking water) is then

$$D_{\text{food}} (\mu\text{Sv}/\text{y}) = [5.6 \times 10^{-3} \times C_{\text{veg}} (\text{Bq}/\text{L}) + 2.1 \times 10^{-3} \times C_{\text{w}} (\text{Bq}/\text{L})]$$

In previous years, this equation has had more than double the input from drinking water ($5.4 \times 10^{-3} \times C_{\text{w}}$) and about 84% of the input from food ($4.8 \times 10^{-3} \times C_{\text{veg}}$). In Chapter 11, based on maximum food intakes and no intake of water, C_{veg} is multiplied by 4.8×10^{-3} .

Inhalation and Skin Absorption Doses

Doses caused by inhalation of radionuclide-contaminated air can be estimated in a way analogous to the preceding treatment of ingestion doses. The starting point is to evaluate the radionuclide concentration in air, χ (Bq/m^3), at the location of interest. Measurements of tritium in air are found in the chapter on air monitoring (Chapter 5).

The dose from HTO arises from the processes of inhalation and skin absorption. For inhalation/skin absorption dose, the known concentration of tritium in air is multiplied by the inhalation rate of a human to obtain the number of becquerels of tritium inhaled. Dose coefficients provided by the DOE (U.S. Department of Energy 1988) are used to relate the intake of radioactive material into the body to dose commitment. The dose coefficient for inhalation is the same as for ingestion. However, to account for skin absorption, the inhalation factor is multiplied by 1.5. These dose factors provide estimates of the 50-year dose from a one-year intake of radioactivity.

The inhalation/skin absorption dose is expressible as

$$D_{\text{inh/sa}} (\mu\text{Sv}/\text{y}) = 1.5 \times U_{\text{air}} \times C_{\text{air}} \times DC_{\text{HTO_inh}} \quad (\text{A-7})$$

where

1.5 = the factor that accounts for skin absorption

U_{air} = air intake rate (m^3/y)

C_{air} = HTO concentration measured in air at the receptor (Bq/m^3)

$DC_{\text{HTO_inh}}$ = dose coefficient ($\mu\text{Sv}/\text{Bq}$) for inhalation

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The whole-body inhalation dose rate from HTO is then

$$\begin{aligned} D_{\text{inh/sa}} (\mu\text{Sv/y}) &= 1.5 \times 8000 \text{ m}^3/\text{y} \times C_{\text{air}} \times 1.73 \times 10^{-5} \mu\text{Sv/Bq} \\ &= 0.21 \times C_{\text{air}} (\text{Bq/m}^3) \end{aligned}$$

Doses in Chapter 5 are calculated as shown here. The breathing rate of 8000 m³/y has been corrected from 8400 m³/y used in previous years to conform to NRC 1.109.

In the recent past, HT doses were treated as immersion doses (Eckermann and Ryman 1993), because HT has a low-energy β particle and behaves similarly to ⁴¹Ar. However, the dose from HT is dominated by the small fraction that is metabolized. HT is therefore treated as a soluble gas, and an inhalation dose is calculated.

For tritium gas (HT), an inhalation dose is expressible as

$$D_{\text{inh_HT}} (\mu\text{Sv/y}) = C_{\text{air_HT}} \times U_{\text{air}} \times DC_{\text{HT}} \quad (\text{A-8})$$

where

$C_{\text{air_HT}}$ = concentration of HT in air at location X; estimated by dispersion modeling (Bq/m³)

U_{air} = air intake rate (m³/y)

DC_{HT} = effective dose per unit intake ($\mu\text{Sv/Bq}$)

The whole-body inhalation dose rate from HT is then

$$\begin{aligned} D_{\text{inh_HT}} (\mu\text{Sv/y}) &= 8000 \text{ m}^3/\text{y} \times C_{\text{air_HT}} \times 1.8 \times 10^{-9} \mu\text{Sv/Bq} \\ &= 1.4 \times 10^{-5} \times C_{\text{air_HT}} (\text{Bq/m}^3) \end{aligned}$$

Comparison of Model Predictions

The use of different models and different assumptions will result in very different dose predictions. Because the protection of the public is paramount, it should be shown by more than one model and more than one set of assumptions that the dose to the public is acceptably low. In CAP88-PC, doses are based on air concentrations calculated from dispersion of annual releases to the atmosphere. The transfer of tritium from air concentration to dose is based on assumptions within the code that cannot be altered by the user (e.g., absolute humidity, fractions of vegetables, milk, and meat that are ingested). Of course, as with NRC Regulatory Guide 1.109, the fractions of each food type that are

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contaminated may be selected. In this appendix, equations have been shown that calculate dose from measured air (or predicted air, for HT) and plant water concentrations using a set of assumptions different from those used in CAP88-PC. The total dose from HTO releases from the Livermore site predicted using CAP88-PC is a factor of 1.8 times higher than the dose predicted using the equations shown here.

Assumptions about the transfer of tritium through the environment and the amount of contaminated food consumed annually can vary considerably among models (see **Tables A-2** and **A-3**). Use of different assumptions can result in estimated doses being very different and is the reason for most of the uncertainty associated with doses predicted by simulation models. Because the health of people is at stake, the models err on the side of overestimating doses. One way to reduce the uncertainty and increase the accuracy of model predictions is to use environmental monitoring data whenever possible. Because of LLNL's comprehensive monitoring program, reliable concentration data for air, vegetation, and water can be used in models to improve dose predictions.

Table A-3. Comparison of hypothetical annual doses from HTO at the Visitor's Center.

Doses in $\mu\text{Sv/y}$	CAP88-PC ^(a) (from predicted air concentrations)	NRC Regulatory Guide 1.109 (from observed air concentrations)
Inhalation	0.14	0.019
Leafy vegetables and produce	0.44	0.063
Milk	[0.27]	0.055
Meat	0.16	0.051
Drinking water	Not calculated	0.22
Total ingestion dose (food and water)	0.60 [0.87]	0.39
Total dose from HTO	0.74 [1.0]	0.41

^a Numbers in brackets (i.e., dose from milk) are not calculated for reported LLNL doses. See *LLNL NESHAPs 1998 Annual Report* (Biermann et al. 1999), *Guidance for Radiological Dose Assessment* (Harrach 1998), and Chapter 13.

Concentrations of tritium in air (Chapter 5) are monitored at 11 on-site locations, including the Visitor's Center (VIS), which is a convenient location for comparing doses from different modeling approaches. The measured median air concentration (HTO) at VIS for 1999 was 0.0899 Bq/m^3 , which is only 18% of the HTO concentration estimated by CAP88-PC at VIS (0.502 Bq/m^3) from all Livermore site releases. Also measured at VIS are vegetation (median value 17 Bq/L) (Table 11-1, Data Supplement) and rainwater (median value 34.6 Bq/L) (Table 7-12, Data Supplement). Measured concentrations in vegetation can be used, as shown, to estimate tritium intake from vegetables by people and from pasture vegetation by animals. A conservative assumption can be made that rainwater is consumed as drinking water, which will

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result in a much higher estimated dose than could ever be achieved by drinking local tap water. Wine from the Livermore Valley is also measured and, for 1999, had a median concentration of 1.7 Bq/L (**Table 11-2**).

The assumptions behind both CAP88-PC and NRC Regulatory Guide 1.109 are conservative and different from each other. They were chosen so that a predicted dose will be far in excess of what is likely to be received. In our example, both models assume the person lives at VIS 100% of the time. For LLNL calculations, CAP88-PC assumes that 100% of the vegetables and meat in the diet are grown at the location at which the dose is calculated (i.e., at VIS, in our example). This assumption is highly conservative, of course, and represents the possibility that all vegetables and meat for ingestion can be grown locally. Milk has not been included because there are no milk cows in the Livermore Valley. For our comparison, the NRC Regulatory Guide 1.109 assumes that essentially the entire diet [leafy vegetables, produce, milk, and meat (beef)] is grown there. CAP88-PC, being a model for atmospheric releases only, does not calculate concentrations in water, so the drinking water pathway is ignored in both models for this comparison. Drinking water is included in Regulatory Guide 1.109, for both animals and people (**Table A-3**).

Doses calculated by CAP88-PC for predicted (0.502 Bq/m^3) air concentrations are compared in **Table A-3** with doses calculated using the NRC equations and observed (0.0899 Bq/m^3) air concentrations. Differences in results are caused by different assumptions (**Tables A-1** and **A-2**), different models, and the lower observed air concentrations compared with predicted air concentrations. Given the relatively high concentration of tritium in rainwater in 1999, resulting from slightly elevated emissions from the Tritium Facility during January, February, and March, the 1999 dose from potential drinking water is half the total tritium dose. Rainwater drunk by cows triples the ingestion dose from milk or meat over that which would be received if drinking water were not contaminated. It would be much more realistic, and yet still conservative, to calculate doses from drinking water using the highest observed values of drinking and surface waters (**Table 7-21**, Data Supplement) for animals and people, respectively. If this is done, drinking water would be 0.356 Bq/L from location ORCH, surface water would be 1.2 Bq/L from location SHAD, and the total dose from tritium would be reduced from $0.41 \text{ } \mu\text{Sv/y}$ to $0.12 \text{ } \mu\text{Sv/y}$.

All dose estimates for HTO shown in **Table A-3** are high because of highly conservative assumptions. Dose estimates made with NRC Regulatory Guide 1.109 are also high because of the unusually high concentration in rainfall that contributes 50% directly to the total tritium dose. However, although these doses are high compared with doses that would result using less conservative assumptions, they are nevertheless a small fraction

of the EPA's radiation dose standard to a member of the public of 100 $\mu\text{Sv}/\text{y}$ from an atmospheric release. More realistic assumptions would reduce the dose at VIS significantly. For example, the Visitor's Center is not a subsistence farm nor does anyone live there. Realistically, the assumptions used in these calculations can be applied only to someone living at a location where the majority of that person's diet is grown and consumed.

Tritium Doses Not Calculated by CAP88-PC or NRC Regulatory Guide 1.109

A small contribution to dose arises from air concentrations of tritiated hydrogen (HT) gas. The concentration of HT in air is not measured at VIS, but using release rates from the Tritium Facility and the dispersion model in CAP88-PC, we calculate a concentration of 0.13 Bq/m³. From this an insignificant inhalation dose from HT of 1.9×10^{-6} $\mu\text{Sv}/\text{y}$ is calculated. The measured HTO concentrations in air and vegetation account for the dose from any HT that has been converted to HTO in the environment.

Dose from ingestion of organically bound tritium (OBT) is known to be higher than that from ingestion of an equal amount of tritium in the free water of plants and animals. The higher dose coefficient for OBT reflects this fact (**Table A-1**). The concentration of tritium in organic matter can be estimated by knowing the dry matter content and water equivalent factor (the fraction of dry matter that combusts to water; L kg⁻¹) of foodstuffs (Ciba-Geigy Ltd. 1981). Using the assumptions of the NRC model and estimated concentrations of HTO and OBT in Bq/kg fresh weight, doses for total tritium (HTO and OBT) from vegetables, milk, and meat are 0.072, 0.063, and 0.073 $\mu\text{Sv}/\text{y}$, respectively, based on the 17 Bq/L in plant water measured at VIS. By including OBT, the doses are increased by 15, 15, and 43%, respectively. The greater effect on dose from beef is caused by the relatively high dry matter content of beef. The overall food ingestion dose is increased from 0.17 to 0.21 $\mu\text{Sv}/\text{y}$, but this is still 35% of the potential food ingestion dose (0.60 $\mu\text{Sv}/\text{y}$ —milk not included) predicted at VIS by CAP88-PC.

Immersion in water is another pathway to dose from tritium because tritium can be absorbed through the skin. The LLNL pool had a median concentration for 1999 of 5 Bq/L (Table 7-21, Data Supplement). The intake of water by skin diffusion is 0.4 mL per minute (Osborne 1968). If it is assumed that a swimmer spends 250 hours a year in the pool, the resulting dose will be 0.54 nSv.

Appendix A. Methods of Dose Calculations

Dose Implications

In this appendix, LLNL has compared doses predicted with two models—CAP88-PC and NRC 1.109—and different assumptions for a hypothetical individual living at the Visitor's Center. Furthermore, doses from inhalation of HT, ingestion of organically bound tritium, and swimming have been estimated. Based on measurements of HTO in air, vegetation, and waters and on the following assumptions, the dose to a hypothetical individual living at the Visitor's Center is presented on **Table A-4**.

Table A-4. Individual living at Visitor's Center.

Assumption	Annual dose
Breathes air with the highest tritium concentrations of any perimeter location except POOL	Inhalation dose: 0.019 μ Sv HTO + 1.9×10^{-6} μ Sv HT = 0.019 μ Sv
Raises and eats all his own vegetables, milk, and beef (and the animals eat pasture and grain grown for them at the Visitor's Center)	Ingestion dose from food, including OBT: 0.21 μ Sv
Drinks rainwater collected in the winter and stored for the rest of the year	Drinking water dose, 0.22 μ Sv
Drinks three bottles of Livermore Valley wine each week	Dose from drinking wine, 3.6×10^{-3} μ Sv
Swims in the LLNL pool 250 hours per year	Immersion dose, 5.4×10^{-4} μ Sv

The total annual dose resulting from these assumptions is 0.45 μ Sv (compare this to **Table A-3**), which is 0.45% of the EPA's radiation dose limit to the member of the public from an atmospheric release. It is 4.5% of an annual effective dose equivalent of 10 μ Sv, which corresponds to the National Council on Radiation Protection and Measurements' (1987a) concept of Negligible Individual Risk Level. Thus, even though artificially high, this dose is still small.

Appendix B.

Reports for Regulatory Agencies

Title	Agency	Frequency
AB2588 Emissions Report	Bay Area Air Quality Management District San Joaquin Valley Unified Air Pollution Control District	Every 2 years
Air Emission Permit Renewals and Emissions Report	Bay Area Air Quality Management District San Joaquin Valley Unified Air Pollution Control District	Yearly
Recycling Unit Contingency/Business Plans	Department of Toxic Substances Control	As required
Conditional Exemption Unit Contingency Plans	Department of Toxic Substances Control	As required
PCB Annual Report	Environmental Protection Agency	Yearly
Medical Waste Permit	Alameda County Emergency Health Services and Department of Public Health Services, San Joaquin County	As required
Explosive Waste Treatment Facility—Site 300 Permit	Department of Toxic Substances Control	Every 10 years
Main Site Part A&B Hazardous Waste Permit (includes contingency plans and closure plans)	Department of Toxic Substances Control	Every 10 years
Site 300 Container Storage Area (B883) and Explosive Waste Storage Facility Permit	Department of Toxic Substances Control	Every 10 years
Cultural Resource Management Plan	Department of Energy California State Historic Preservation Officer	As required
RCRA Section 3016 Report, Inventory of Federal Agency Hazardous Waste Facilities	Department of Energy Environmental Protection Agency	As required
Less-than-90-Day Waste Accumulation Area Contingency Plans	Department of Toxic Substances Control	As required
SB14 Documentation Plan	Department of Toxic Substance Control	Every 4 years
Ozone Depleting Chemicals Phase Out Report	Department of Energy Environmental Protection Agency	Yearly
DOE Annual Waste Minimization Report	Department of Energy	Yearly

Appendix B. Reports for Regulatory Agencies

Title	Agency	Frequency
Waste Minimization Certification for Site 300	Department of Toxic Substances Control	Yearly
Monthly NEPA Report	Department of Energy under NEPA	Monthly
NEPA Reviews, Proposed LLNL/Department of Energy Projects	Department of Energy	As required
CEQA Review for Department of Energy/UC Contract Renewal	University of California	Every 5 years before contract renewal
CEQA Reviews, Proposed LLNL/UC Projects	University of California	As required
Spill Prevention Control and Countermeasures Plans (Livermore Site and Site 300) Plan	Environmental Protection Agency San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	Every 3 years or when there are significant changes
Closure Plans for any hazardous waste/product underground storage tanks (UST) removed from service	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Closure Report for any hazardous waste/product UST removed from service	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Monitoring Program and Emergency Response Plan for any hazardous waste/ product	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Closure Reports for greater than 90-day hazardous waste aboveground storage tank (AST) operated under Interim Status and removed from service	Department of Toxic Substances Control	As required
Engineering Assessments for RCRA hazardous waste tanks	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Installation Plans for new hazardous waste/product UST	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Hazardous Waste/Product UST Operating Permit	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	Every 3 years; annual fee
Less-than-90-Day Hazardous Waste Tank Contingency Plans (for Permitted Underground Tank Systems at Livermore Site)	Department of Toxic Substances Control	As required
Tank Monitoring Program for Hazardous Waste AST	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	Prior to new tank use

Appendix B. Reports for Regulatory Agencies

Title	Agency	Frequency
Tank Modification/Approval Plan for hazardous waste/product UST	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Monthly Sewer Monitoring Report	Livermore Water Reclamation Plant	Monthly
Site 300 Pits 1 and 7 Compliance Monitoring Reports	Central Valley Regional Water Quality Control Board Environmental Protection Agency Department of Toxic Substances Control	Quarterly and yearly
Site 300 Quarterly Cooling Tower Discharge Report	Central Valley Regional Water Quality Control Board	Quarterly
Wastewater Point-Source Monitoring Semi-Annual Report	Livermore Water Reclamation Plant	Twice a year
Storm Water Pollution Prevention Plans (Livermore Site and Site 300)	San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board	As required
Storm Water Pollution Prevention Plans for Construction (Livermore Site and Site 300)	San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board	As required
Ground Water Protection Management Program	Department of Energy	Every 3 years or as required
Storm Water Monitoring Programs (Livermore Site and Site 300)	San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board	As required
Industrial Storm Water Discharge Annual Reports (Livermore Site and Site 300) and Site 300 Cooling Tower Annual Report	San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board	Yearly
Storm Water Pollution Prevention Annual Certifications for Construction Projects (Livermore Site and Site 300)	San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board	Yearly
Quarterly and Annual Compliance Reports for Explosive Process Area Surface Impoundments, Sewage Evaporation and Percolation Ponds, and Percolation Pits	Central Valley Regional Water Quality Control Board	Quarterly and yearly

Appendix B. Reports for Regulatory Agencies

Title	Agency	Frequency
DRB Quarterly/Annual Monitoring Reports	Department of Toxic Substances Control San Francisco Bay Regional Water Quality Control Board Environmental Protection Agency Department of Energy	Quarterly and yearly
Hazardous Material Business Plan and Chemical Inventory	Alameda County Health Care Services Agency and San Joaquin County Office of Emergency Services	Yearly or as required
SARA 311/MDDS Reporting	California Emergency Planning and Response Commission	As required
SARA 313/Toxic Release Inventory	Department of Energy/State and Federal EPA	Yearly
Beryllium in Ambient Air Monitoring	Bay Area Air Quality Management District	Quarterly
Radiological NESHAPs Annual Report	Environmental Protection Agency	Yearly
Environmental Monitoring Plan	Department of Energy	Every three years
Site Annual Environmental Report	Department of Energy	Yearly
Site 300 Pits 1 and 7 Landfill Closure Caps Inspection/Monitoring Independent Engineering Evaluation	Department of Toxic Substances Control Central Valley Regional Water Quality Control Board Environmental Protection Agency	Yearly
Biennial Hazardous Waste Report	Department of Toxic Substances Control (under Environmental Protection Agency delegated authority)	Every 2 years
Annual Hazardous Waste Report	Department of Toxic Substances Control	Yearly
Conceptual Site Treatment Plan (CSTP) Draft Site Treatment Plan (DSTP) Final Site Treatment Plan (FSTP)	Department of Toxic Substances Control Environmental Protection Agency Department of Energy	As required
Safety Analysis Report	Department of Energy	As required
Contingency Plans	Department of Toxic Substances Control	As required
Closure Plans	Department of Toxic Substances Control	As required
EIR Mitigation Monitoring Annual Report	University of California	Yearly
FFA-CERCLA Reports	Environmental Protection Agency Department of Toxic Substances Control San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board Department of Energy/EM-40	As required

Appendix B. Reports for Regulatory Agencies

Title	Agency	Frequency
Wastewater Discharge/Chemical Storage Permit Application	Livermore Water Reclamation Plant	Yearly
Ground Water Discharges to Sanitary Sewer Annual Self-Monitoring Report	Livermore Water Reclamation Plant	Yearly
Above Ground Petroleum Tank Storage Statement	State Water Resources Control Board	Every 2 years
Arroyo Maintenance Monitoring Report	San Francisco Bay Regional Water Quality Control Board	Annually when there is an exceedance of a receiving water limit
Blue Elderberry Bush Cuttings Report pursuant to Biological Assessment for Fire Trail Grading at Site 300	San Francisco Bay Regional Water Quality Control Board	As required if cutting is needed
WDR 99-086 for Arroyo Las Positas Maintenance; Provision 20: Maintenance Impact Study Results	San Francisco Bay Regional Water Quality Control Board	January 16, 2006

Appendix C.

Errata to 1997 and 1998 Environmental Reports

*Robert J. Harrach
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Protocol for Handling Errata in LLNL Environmental Reports

The advent of readily accessible, electronic documents on the Internet has made the LLNL site annual environmental report (SAER) a truly dual publication with its bound, hard-copy and its Internet electronic forms. These two versions must be fully equivalent and, in fact, the content must be precisely the same, both in their original versions as first presented to the public, and as they are changed (noted as published errata) subsequent to publication.

Revisions to the hard-copy version of LLNL's SAERs up to now have been dealt with by distributing copies of errata information (generally consisting of a list of well-defined corrections) to all identified holders of the original report. Beginning with the present report, hard-copy errata notification is provided in the SAER, rather than by separate mailings.

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) credibility that the Internet version accurately represents each SAER must be 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 electronic and hard copy versions of each SAER must be the same, in the sense that the hard copy version plus its errata, if any, must provide the same information as the current (revised) Internet version.

Presently SAERs covering calendar years 1994 through 1998 can be accessed on the Internet at the address of the LLNL SAER homepage: <http://www.llnl.gov/saer>. Both the main volume and data supplement volume of each individual report can be viewed in its fully corrected, most up-to-date form. A link to an errata section provides a complete record of post-publication changes that have been made.

Appendix C. Errata to 1997 and 1998 Environmental Reports

Record of Changes to SAERs for 1997 and 1998

The following subsections provide a complete record of changes that have been made as of April 2000 in hard-copy (printed, bound) editions of environmental reports covering activities in 1997 and 1998. The information in this section is available on the SAER home page cited above.

Errata for LLNL Environmental Report 1998

In Chapter 2 of LLNL's *Environmental Report 1998*, in Table 2-9 on page 2-27, in the row describing the second off-normal event of February 2, change the quantities "(28 mg/L)" and "(25 mg/L)" to read "(0.28 mg/L)" and "(0.25 mg/L)."

In Chapter 11, in Figure 11-3 on page 11-7, the three data points representing sampling location PIN1 (upper right side of the figure) are mis-plotted. The correct values for 1996, 1997, and 1998, respectively, are 96 Bq/L (2592 pCi/L), 172 Bq/L (4644 pCi/L), and 37.1 Bq/L (1001 pCi/L).

In Chapter 5 of the Data Supplement at the bottom of the ^{22}Na column in Table 5-4 on page 5-10, correct the value to be " $<6.88 \times 10^{-9}$ " instead of " $<6.88 \times 10^{-6}$."

Errata for LLNL Environmental Report 1997

In the Executive Summary of LLNL's *Environmental Report 1997*, in the paragraph at the top of page EX-3, add the term "volatile organics" and replace the word "dioxide" with "monoxide" in the parenthetical phrase occurring in the sixth and seventh lines from the top of the page. The phrase should read "(nitrogen oxides, sulfur oxides, volatile organics, particulate matter, carbon monoxide, and lead)."

Raise the order by one of the headings and subheadings in the Geology and Hydrogeology sections in Chapter 1, on pages 1-4, 1-8, and 1-9.

In Chapter 3, correct the caption of Table 3-2 on page 3-10 to say "1993 to 1997" instead of "1990 to 1997."

Similarly, in Chapter 4 on page 4-8, add the term "volatile organics" to the fourth line up from the bottom of the page, so that the parenthetical phrase reads "(nitrogen oxides, sulfur oxides, volatile organics, particulate matter [PM-10], carbon monoxide, and lead)."

Appendix C. Errata to 1997 and 1998 Environmental Reports

In Chapter 12, on page 12-12, correct the phrase starting with the word “annually” in the second line from the top of the page to read “total annual precipitation and annual-average values of the temperature and height of the atmospheric inversion layer.”

On page 12-23 of Chapter 12, in the 11th line from the top of the page, add the omitted prefix “n” so that the quantity reads “190 nCi”.

On page 13-5 of Chapter 13, in footnote b, fifth line up from the bottom of the page, correct the subscripts factor so that it reads $x_1 - x_2$.

On page R-11 of the References section, second line up from the bottom of the page, correct the date to say “1992” instead of “1991.”

In Chapter 8 of the *Data Supplement* on the left-most column of the first row in Table 8-55 on page 8-76, Table 8-57 on page 8-77, and Table 8-58 on page 8-78, correct the phrase “Element (mg/L)” to read “Element ($\mu\text{g/L}$).”

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Glossary

Acronyms and Abbreviations

	%RSD	Percent relative standard deviation.	
A	ACDEH	Alameda County Department of Environmental Health.	
	ACEHS	Alameda County Environmental Health Services.	
	ACL	ambient concentration limit.	
	ACOE	Army Corps of Engineers.	
	ALARA	As low as reasonably achievable.	
	ANOVA	Analysis of variance (see Technical Terms).	
	ANSI	American National Standards Institute.	
	ARB	(California) Air Resources Board.	
	ATSDR	Agency for Toxic Substances and Disease Registry.	
	AVLIS	Advanced Laser Isotope Separation.	
B	AWQC	Ambient water quality criteria.	
	BAAQMD	Bay Area Air Quality Management District. The local agency responsible for regulating stationary air emission sources (including the LLNL Livermore site) in the San Francisco Bay Area.	
	BETX (or BTEX)	Benzene, ethyl benzene, toluene, and xylene.	
	BMP	Best management practice.	
	BOD	Biochemical oxygen demand.	
	Bq	Becquerel (see Technical Terms).	
	BSA	Blanket Service Agreement.	
	C	Cal/EPA	California Environmental Protection Agency.
		CAM	Continuous air monitor.
		CAMP	Corrective Action Monitoring Program.
CAP88-PC		Computer code required by the EPA for modeling air emissions of radionuclides.	
CARB		California Air Resources Board.	
CAREs		(Tri-Valley) Communities Against a Radioactive Environment.	
CCR		California Code of Regulations. Codification of regulations promulgated by the State of California.	
CDFG		California Department of Fish and Game.	
CDHS		California Department of Health Services.	
CDHS-RHB		California Department of Human Services, Radiological Health Branch.	
CEI	Compliance Evaluation Inspection.		
CEPRC	Chemical Emergency Planning and Response Commission.		

Glossary

CEQA	California Environmental Quality Act of 1970. CEQA requires that all California state, local, and regional agencies document, consider, and disclose to the public the environmental implications of their actions.
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980. Administered by EPA, this program, also known as Superfund, requires private parties to notify the EPA after the release of hazardous substances and undertake short-term removal and long-term remediation. If conditions exist that could create the threat of hazardous substances being released, the Act also requires the remediation of those conditions.
CERCLA/SARA	In 1986, the Superfund Amendments and Reauthorization Act (SARA) was enacted, which amended and reauthorized CERCLA for five years at a total funding level of \$8.5 billion.
CES	Chemistry and Materials Science Environmental Services. An LLNL laboratory that analyzes environmental samples.
CFC	Chlorofluorocarbon (see Technical Terms).
CFEST	Coupled Flow Energy and Solute Transport (computer code).
CFF	Contained Firing Facility.
CFR	Code of Federal Regulations. A codification of all regulations promulgated by federal government agencies.
CHP	California Highway Patrol.
Ci	Curie (see Technical Terms).
COC	Constituent of concern.
CRD	Catalytic reductive dehalogenation.
CRMP	Cultural Resource Management Plan.
CRWQCB	California Regional Water Quality Control Board.
CVRWQCB	Central Valley Regional Water Quality Control Board.
CWG	Community Work Group.
D DAP	Discipline Action Plan.
DC	Direct current.
DCG	Derived Concentration Guide (see Technical Terms).
DHS	Department of Health Services.
DL	Detection limits.
DLM	Designated level methodology.
DMP	Detection Monitoring Program.
DO	Dissolved oxygen.
DoD	U.S. Department of Defense.
DOE	U.S. Department of Energy. The federal agency that is responsible for conducting energy research and regulating nuclear materials used for weapons production.
DOE/OAK	DOE Oakland Operations Office.
DOI	U.S. Department of the Interior.
DOT	U.S. Department of Transportation.

	DRB	Drainage Retention Basin. Man-made, lined pond used to capture storm water runoff and treated water at the LLNL Livermore site.
	DTSC	California Environmental Protection Agency, Department of Toxic Substances Control.
	DWTF	Decontamination and Waste Treatment Facility.
E	EA	Environmental Assessment.
	EDE	Effective dose equivalent (see Technical Terms).
	EDO	Environmental Duty Officer.
	EIR	Environmental Impact Report. 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.
	EIS	Environmental Impact Statement. 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.
	EMRL	Environmental Monitoring Radiation Laboratory.
	EOG	Environmental Operations Group.
	EPA	U.S. Environmental Protection Agency. 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.
	EPCRA	Emergency Planning and Community Right-to-Know Act of 1986. EPCRA requires facilities that produce, use, or store hazardous substances to report releases of reportable quantities or hazardous substances to the environment.
	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.
	EST	Environmental support team.
	EWSF	Explosives Waste Storage Facility.
	EWTF	Explosives Waste Treatment Facility.
F	FFA	Federal facility agreement. A negotiated agreement that specifies required actions at a federal facility as agreed upon by various agencies (e.g., EPA, RWQCB, and DOE).
	FONSI	Finding of no significant impact.
	Freon 113	1,1,2-trichloro-1,2,2-trifluoroethane.
	FSP	Facility safety plan.
	FTF	Field tracking forms.
G	g	Gram (see Technical Terms).
	GAC	Granulated activated carbon.

Glossary

	GBq	Gigabecquerel. 1×10^9 Becquerel.
	GENMIN	General mineral site of analyses performed on ground water samples.
	GFI	Ground fault interrupt.
	GSA	General Services Area (LLNL Site 300).
	GTU	GAC treatment unit.
	GWP	Ground Water Project.
	GWMPM	Ground Water Project Management Program.
	GWTF	Ground Water Treatment Facility.
	GWTS	Ground Water Treatment System.
	Gy	Gray (see Technical Terms).
H	HCAL	Hazards Control Department's Analytical Laboratory.
	HCD	Hazards Control Department.
	HE	High explosives. Materials that release large amounts of chemical energy when detonated.
	HEPA	High-efficiency particulate air (filter). (See also Technical Terms.)
	HMX	Cyclotetramethyltetramine, a high-explosive compound. Also referred to as octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine.
	HPGe	High-purity germanium.
	HSD	(Tukey-Kramer) honestly significant difference (test).
	HSU	Hydrostratigraphic unit.
	HT	Tritiated hydrogen gas. (See also tritium in Technical Terms.)
	HTO	Tritiated water and water vapor (See also tritium in Technical Terms.)
	HWCA	(California) Hazardous Waste Control Act. This legislation specifies requirements for the management of hazardous wastes in California.
	HWM	Hazardous Waste Management Division of the Environmental Protection Department at LLNL.
I	ICRP	International Commission on Radiological Protection. An international organization that studies radiation, including its measurement and effects.
	IMS	Instrumented membrane system.
	IQR	Interquartile range (see Technical Terms).
	ISD	Interim status document.
	ISMS	Integrated safety management system.
	ITRC	Environmental Council of States Interstate Technology and Regulatory Cooperation.
	IWS	Integration work sheet.
J	JON	Judgement of Need.
L	LEPC	Local Emergency Planning Committee.
	LLNL	Lawrence Livermore National Laboratory.
	LOEC	Lowest observed effect concentration.
	LOS	Limits of sensitivity.

LSM	Liter of soil moisture.
LUFT	Leaking underground fuel tank.
LWRP	Livermore Water Reclamation Plant. The City of Livermore's municipal wastewater treatment plant, which accepts discharges from the LLNL Livermore site.
M	
MAPEP	Mixed Analyte Performance Evaluation Program.
MCL	Maximum contaminant level in drinking water established by EPA or DTSC.
MDC	Minimum detectable concentration.
MDL	Minimum detection limit.
MEI	Maximally exposed individual member of the public.
ML	Megaliter. 10^6 liters.
mL	Milliliter. 10^{-3} liter = 1 cm^3 .
MOLE	Miniature Optical Lair Explorer.
MPN	Most probable number.
mR	Milliroentgen. 10^{-3} roentgen.
mrem	Millirem. 10^{-3} rem.
MRP	Monitoring and Reporting Program.
MSDS	Material safety data sheet.
mSv	Millisievert. 10^{-3} sievert.
MTBE	Methyl tertiary-butyl ether.
N	
NCR	Nonconformance Report.
NCRP	National Council on Radiation Protection.
NEPA	National Environmental Policy Act. This federal legislation, enacted in 1969, requires all federal agencies to document and consider environmental impacts from federally funded or approved projects. DOE is responsible for NEPA compliance at LLNL.
NESHAPs	National Emission Standards for Hazardous Air Pollutants. These standards are found in the Clean Air Act and set limits for hazardous air pollutants.
NHPA	National Historical Preservation Act.
NIF	National Ignition Facility.
NIST	National Institute for Standards and Technology. The federal agency, formerly known as the National Bureau of Standards, responsible for reference materials against which laboratory materials are calibrated.
NOEC	No observed effect concentration.
NOV	Notice of Violation.
NPDES	National Pollutant Discharge Elimination System. This federal regulation, under the Clean Water Act, requires permits for discharges into surface waterways.
NPDESMETALS	Suite of metal analysis performed on ground water samples required under NPDES.
NPL	National Priorities List.

Glossary

	NRC	Nuclear Regulatory Commission. The federal agency charged with oversight of nuclear power and nuclear machinery and applications not regulated by DOE or the Department of Defense.	
O	OBT	Organically bound tritium.	
	OEHHA	Office of Environmental Health Hazard Assessment.	
	OJT	On-the-job training.	
	ORAD	Operations and Regulatory Affairs Division of the Environmental Protection Department at LLNL.	
	OSHA	Occupational Safety and Health Administration.	
	OSP	Operational safety plan.	
	OU	Operable unit.	
P	P2	Pollution Prevention.	
	PA	Programmatic agreement.	
	PCB	Polychlorinated biphenyl.	
	PCE	Perchloroethylene (or perchloroethene). Also called tetrachloroethylene (or tetrachloroethene).	
	pCi	Picocurie. 1×10^{-12} Ci.	
	PeerRP	Peer Review Panel.	
	PEIS	Programmatic Environmental Impact Statement.	
	PHA	Public Health Assessment.	
	pHMS	pH Monitoring Station.	
	PM	Performance measure.	
	PMCL	Primary maximum contaminant level.	
	POTW	Publicly owned treatment works.	
	ppb	Parts per billion. 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.	
	ppm	Parts per million. 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.	
	ppmv	Parts per million by volume.	
	PPOA	Pollution Prevention Opportunity Assessment.	
	PRG	Preliminary remediation goal.	
	PTU	Portable treatment unit.	
	Q	QA	Quality assurance (see Technical Terms).
		QC	Quality control (see Technical Terms).
R	R	Roentgen (see Technical Terms).	
	RAIP	Remedial Action Implementation Plan.	
	RCRA	Resource Conservation and Recovery Act of 1976. RCRA is a program of federal laws and regulations that govern the management of hazardous wastes. RCRA is applicable to all entities that manage hazardous wastes.	

RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine. A high-explosive compound.
RFG	Reformulated gasoline.
RHB	Radiological Health Branch.
RL	Reporting limit.
RML	Radiological Measurements Laboratory.
RMMA	Radioactive Materials Management Area.
ROD	Record of Decision.
ROI	Return on investment.
RPM	Remedial Project Manager.
RWQCB	Regional Water Quality Control Board. 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.

S

SAA	Streambed Alteration Agreement.
Sandia/California	Sandia National Laboratories, California.
SAR	Safety analysis report.
SARA	Superfund Amendment and Reauthorization Act of 1986 (see CERCLA/SARA).
Scfm	Standard cubic feet per minute.
SDF	Sewer Diversion Facility.
SE	Standard error.
SERC	State Emergency Response Commission.
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board. The local agency responsible for regulating stationary air emission sources (including the Livermore site) in the San Francisco Bay Area.
SHPO	(California) State Historic Preservation Office.
SI	Système International d'Unités. An international system of physical units. Units of measure in this system include meter (length), kilogram (mass), kelvin (temperature), becquerel (radioactivity), gray (radioactive dose), and sievert (dose equivalent).
Site 300	LLNL's Experimental Test Site, located approximately 24 km east of the Livermore site.
SJCHD	San Joaquin County Health District. The local agency that enforces underground-tank regulations in San Joaquin County, including Site 300.
SJVUAPCD	San Joaquin Valley Unified Air Pollution Control District. The local agency responsible for regulating stationary air emission sources (including Site 300) in San Joaquin County.
SL	Statistical limit.
SMCL	Secondary maximum contaminant level.
SME	Subject matter expert.
SMS	Sewer Monitoring Station.

Glossary

SOV	Summary of violations.
SPCC	Spill Prevention Control and Countermeasure.
STAR	Sample tracking and receiving (computer system).
STP	Site Treatment Plan.
STU	Solar tracking unit.
Sv	Sievert. (See Technical Terms.)
SVE	Soil vapor extraction.
SVOC	Semivolatile organic compound.
SVRA	State Vehicular Recreation Area.
SWAT	Solar-powered water activated-carbon treatment.
SWDA	State Water Drinking Act.
SW-MEI	Sitewide maximally exposed individual member of the public (see Technical Terms).
SWPPP	Storm Water Pollution Prevention Plan.
SWRCB	(California) State Water Resources Control Board.
SWRI	(LLNL) Site-wide Remedial Investigation (Report).
T	
TBOS	Tetrabutyl orthosilicate.
TBq	Terabecquerel. 1×10^{12} Becquerel.
TCE	Trichloroethene (or trichloroethylene).
TDI	Technology Deployment Initiative.
TDS	Total dissolved solids. The portion of solid material in a waste stream that is dissolved and passed through a filter.
TLD	Thermoluminescent dosimeter. A device used to measure external beta or gamma radiation levels. TLDs contain a material that after exposure to beta or gamma radiation emits light when processed and heated.
TNT	Trinitrotoluene.
TOC	Total organic carbon. The sum of the organic material present in a sample.
TOX	Total organic halides. The sum of the organic halides present in a sample.
TRU	Transuranic waste.
TSCA	Toxic Substances Control Act.
TSS	Total suspended solids.
TWMS	Total Waste Management System.
U	
UC	University of California.
USEC	U.S. Enrichment Corporation.
USFWS	U.S. Fish and Wildlife Service.
UST	Underground storage tank.
UV	Ultraviolet light.
V	
VOC	Volatile organic compound. 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.

	VPP	Voluntary Protection Program.
	VTF	Vapor treatment facilities.
W	WAA	Waste accumulation area. 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.
	WDR	Waste Discharge Requirements. Issued by the California Regional Water Quality Control Board.
	WGMG	Water Guidance and Monitoring Group.
	WQO	Water quality objective.
	WSS	Work Smart Standards.
	WTF	Working task force.
Z	Zone 7	Alameda County Flood Control and Conservation District, Zone 7.

Technical Terms

A	Absorbed dose	The amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material. 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, it is the level of pollutants which, if exceeded, requires regulatory action.
	Aerosol	A gaseous suspension of very small particles of liquid or solid.
	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. It is not considered to include the air immediately adjacent to emission sources.
	Analyte	The specific component that is being measured in a chemical analysis.
	Anion	A negatively charged ion, for example Cl ⁻ .
	ANOVA	Analysis of variance. A test of whether two or more sample means are statistically different.
	Aquifer	A saturated layer of rock or soil below the ground surface that can supply usable quantities of ground water to wells and springs. Aquifers can 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. In this method, the sample is vaporized and its light absorbance measured.
B	Barcad	Device that samples water in a well. Water, collected in a discrete water-bearing zone, is forced to the surface by pressurized nitrogen.

Glossary

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	A measure of the amount of dissolved oxygen that microorganisms need to break down organic matter in water. It is used as an indicator of water quality.
C	
Categorical discharge	Discharge from a process regulated by EPA rules for specific industrial categories.
Chlorofluorocarbon (CFC)	A compound that has fluorine and chlorine atoms on a carbon backbone. Freons are common CFCs.
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.
Chlorocarbon	A compound of carbon and chlorine, or carbon, hydrogen, and chlorine, such as carbon tetrachloride, chloroform, and tetrachloroethene.
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.
Cosmic radiation	Radiation with very high energies, originating outside the earth's atmosphere. Cosmic radiation 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.
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).

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.” A “de minimis level” would be a level that is so inconsequential that, by definition, it cannot be cause for concern.
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. Dose equivalent is 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 ground water flow from a designated area; analogous to downstream.
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.
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. Federal facilities are subject to the same requirements as other responsible parties once placed on the Superfund National Priorities List.
Federal Register	A document published daily by the federal government containing notification of government agency actions. The Federal Register contains notification of EPA and DOE actions, including notification of EPA and DOE decisions concerning permit applications and rule-making.
G	
Gamma ray	High-energy, short-wavelength, electromagnetic radiation emitted from the nucleus of an atom. Gamma radiation frequently accompanies the emission of alpha or beta particles.
Gram	The standard metric measure of weight approximately equal to 0.035 ounce.

Glossary

	Gray	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.
	Ground water	All subsurface water.
H	Half-life (radiological)	The time required for one-half the radioactive atoms in a given amount of material to decay. 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	Wastes exhibiting any of the following characteristics: ignitability, corrosivity, reactivity, or EP-toxicity (yielding toxic constituents in a leaching test). In addition, EPA has listed as hazardous other wastes that do not necessarily exhibit these characteristics. Although the legal definition of hazardous waste is complex, the term more generally refers to any waste that EPA believes could pose a threat to human health and the environment if managed improperly.
	HEPA filter	A high-efficiency particulate air filter used to capture particulates in an air stream. A HEPA filter is a throwaway, extended-media, dry type filter with a rigid casing enclosing the full depths of the pleats. HEPA filter collection efficiencies are at least 99.97% for 0.3 micrometer diameter particles.
	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. Inorganic compounds include metals, salts, and various carbon oxides (e.g., carbon monoxide and carbon dioxide).
	In situ	A term that can be used to refer to the treatment of contaminated areas in place, i.e., without excavation or removal, as in the in situ treatment of soils through biodegradation of contaminants on site.
	Interim status	A legal classification that applies to hazardous waste incinerators or other hazardous waste management facilities that were under construction or in operation by November 19, 1980, and can meet other interim status requirements. Interim status facilities may operate while EPA considers their permit application.
	Interquartile range (IQR)	The distance between the top of the lower quartile and the bottom of the upper quartile. The IQR 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	Liter	The SI measure of capacity approximately equal to 1.057 quart.
	Less than detection limits	A phrase indicating that a chemical constituent was either not identified or not quantified at the lowest level of sensitivity of the analytical method being employed by the laboratory. Therefore, the chemical constituent either is not present in the sample, or it is present in such a small concentration that it cannot be measured by the analytical procedure.
	Low-level waste	Waste defined by DOE Order 5820.2A. Low-level waste 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	The maximally exposed individual is 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.
	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 the uppermost "completion" is accessible from the surface, making physical sample-taking possible (as opposed to Barcads), and is referred to as a well.
	Mixed waste	Waste that has the properties of both hazardous and radioactive waste.
N	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).
	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. It covers in detail the procedures followed at a facility to protect human health and the environment.
	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. Generally used to measure the elevation of the water table in a small, nonpumping well.
	Pliocene	Geological epoch of the Tertiary period, starting about 12 million years ago.
	PM-10	Fine particulate matter with an aerodynamic diameter equal to or less than 10 microns.
	Point source	Any confined and discrete conveyance (e.g., pipe, ditch, well, or stack).
	Pretreatment	Any process used to reduce a pollutant load before it enters the sewer system.

Glossary

	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. Quality factor is 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. It is the quantity of energy imparted by ionizing radiation to a unit mass of matter such as tissue. One rad equals 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.
	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.” It is 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.
	Risk assessment	The use of established methods to measure the risks posed by an activity or exposure. In the present context, risk assessments evaluate: (1) the relationship between exposure to radioactive substances and the subsequent occurrence of health effects; and (2) the likelihood for that exposure to occur.
	Roentgen	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 describing the procedures used to collect, handle, and analyze ground water samples. The plan details quality control measures that are implemented to ensure that sample-collection, analysis, and data-presentation activities meet the prescribed requirements.
	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. This is the product of the absorbed dose (gray), quality factor (Q), distribution factor, and other necessary modifying factors. One sievert equals 100 rem.
Sitewide Maximally Exposed Individual (SW-MEI):	The sitewide maximally exposed individual member of the public is defined as the 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.
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.
T	
Tritium	The radioactive isotope of hydrogen, containing one proton and two neutrons in its nucleus. It decays at a half-life of 12.3 years by emitting a low-energy beta particle.
Transuranic waste	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.
Tukey-Kramer HSD test	The Tukey-Kramer honestly significant difference test, a statistical technique for testing differences among group means.
U	
Unsaturated zone	That portion of the subsurface in which the pores are only partially filled with water. The direction of water flow is vertical in this zone; which is also referred to as the vadose zone.
V	
Vadose zone	The partially saturated or unsaturated region above the water table that does not yield water to wells.
W	
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. It is the level to which a well that is screened in the unconfined aquifer would fill with water.

Glossary

Weighting factor A value used to calculate dose equivalents. It is tissue-specific and 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. Zone 7 is the water management agency for the Livermore-Amador Valley with responsibility for water treatment and distribution. Zone 7 is also responsible for management of agricultural and surface water and the ground water basin.

Reader Survey and Data Supplement Order Form

Our goal in providing this report is to give you a clear accounting of the range of environmental activities we undertake, the methods we employ, and the degree of accuracy of our results. It is important that the information we provide is easily understood, is of interest, and communicates LLNL's efforts to protect human health and the environment and to comply with environmental regulations. We would like to know from you whether we are successful in these goals. Your comments are welcome.

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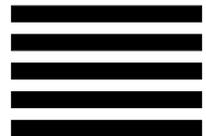
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