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Preface

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

To produce a more readable and useful document for our diverse readership—including regulators, scientists and engineers, educators, the media, public interest groups, and interested citizens—we have, as last year, divided this report into two volumes. The first 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 center of data, their spread or variability, and their extreme values. The first 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 protection, compliance self-monitoring, radiological dose assessment, and quality assurance. Information on both the Livermore site and Site 300 are presented in each chapter.

The second volume, supporting Volume 1 summary data, is essentially a detailed data report that provides the individual data points, where applicable. Some summary data are also included in Volume 2, and more detailed accounts are given of sample collection and analytical methods.

Volume 1, which can be read without access to Volume 2, contains all information of interest to most of our readers. Volume 1 will be distributed as usual, but Volume 2 will be sent only upon request; a card for this purpose is included on the last page of Volume 1. Both volumes are available on the Internet at the address of LLNL's home page (http://www.llnl.gov) under the heading "Publications," under the subheadings "Institutional Publications" and "Technical Papers." Alternatively, one can use the address given on the inside front cover of this report.

As in last year's annual report, 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 Bq = 2.7×10^{-11} Ci; 1 Sv = 100 rem). Units are discussed in the introduction of Chapter 13, Radiological Dose Assessment, in Volume 1.

Preface

This document is the responsibility of the Operations and Regulatory Affairs Division of EPD.

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 of LLNL. Special recognition is deserved for the dedication and professionalism of the technicians who carried out environmental monitoring—David Ahre, Paris E. Althouse, Gary A. Bear, David L. Graves, Marion Heaton, Renee Needens, Terrance W. Poole, Donald G. Ramsey, Rebecca J. Ward, Rhonda L. Welsh and Robert Williams—and to the data management personnel—Nina Hankla, Jennifer Clark, Kimberly A. Stanford, and Suzanne Chamberlain. Special thanks also to Judith L. Kelly for secretarial support and collation and distribution of drafts.

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Executive Summary

Robert J. Harrach
Rebecca A. Failor

Introduction

Lawrence Livermore National Laboratory (LLNL), a U.S. Department of Energy (DOE) facility operated by the University of California, 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 multifaceted 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 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. 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 1995, 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 1995, the Environmental Protection Department sampled air, sewage effluent, ground water, surface water, soil, vegetation and foodstuffs, and measured environmental radiation. Over 18,700 environmental samples were taken and analyses were conducted for more than 248,000 analytes. These numbers represent increases of 10% and 5%, respectively, over the previous year.

LLNL's sampling networks undergo constant evaluation; changes are made, as necessary, to ensure adequate, cost effective monitoring of all media potentially affected by LLNL operations. Once samples are collected, they are analyzed for radioactive and nonradioactive substances using standard methods such as analytical procedures approved by the U.S. Environmental Protection Agency

(EPA), special systems such as the continuous monitoring system for Livermore site sewage, or special analytical techniques designed to measure very low levels of radionuclides. Environmental radiation is also measured directly using dosimeters.

The amount of radioactivity released from LLNL during 1995 was slightly less than in 1994 and was below the range of earlier years. The most significant radiological effluent for the Livermore site continues to be tritium, the radioactive isotope of hydrogen. The source of nearly all tritium emissions is Building 331, the Tritium Facility. Reduced operations in the Tritium Facility have led to continually declining emissions in recent years. Tritium values measured in surface water, rain water, and runoff were low in 1995, comparable to levels the previous year and consistent with a generally decreasing historical trend. Measured values for tritium in air and vegetation in 1995 were slightly less than those in 1994. At Site 300, the dominant radioactive effluent is depleted uranium, which contains isotopes with atomic weights 238, 235, and 234 in the weight percentages 99.8, 0.2, and 0.0005, respectively. The primary sources of these emissions were experiments on the firing tables adjacent to Buildings 801 and 851, resulting in estimated releases of the three isotopes that were about 72% of those in 1994 but within the range of variation seen from year to year due to changes in the level of operations at the firing tables.

Air surveillance monitoring was performed for various airborne radionuclides (including particles and tritiated water vapor) and beryllium at locations on the Livermore site, Site 300, throughout the Livermore Valley, and in Tracy. 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. As examples: the concentration of plutonium on air filter samples collected in the Livermore Valley showed a median value of only 0.01% of the federal Derived Concentration Guide (DCG), and on the Livermore site the highest median value for plutonium was 0.02% of the DCG ; median concentrations of tritiated water vapor at Livermore Valley sampling locations showed a highest median value of 0.0006% of the DCG, while the highest median on the Livermore site was 0.05% of the DCG; the highest median concentration of beryllium on the Livermore site perimeter was 0.06% of the limit established by the Bay Area Air Quality Management District.

Discharges of radioactive and hazardous materials to the combined sanitary and industrial sewer at the Livermore site are controlled by limiting the use of those materials, implementing engineering controls, and routing discharged material to retention tanks for later characterization and treatment. Flow-proportional samples of discharged wastewater are regularly collected and analyzed to assure

that LLNL's sewage effluent meets the requirements of the permit granted by the City of Livermore. In addition, effluent is monitored continuously for pH, selected metals, and radioactivity. Should concentrations be detected above warning levels, LLNL's sewer diversion system is automatically activated. The diversion system captures all but the first few minutes of wastewater flow that causes an alarm, thereby protecting the Livermore Water Reclamation Plant (LWRP) and minimizing any required cleanup. In 1995, the Livermore site discharged approximately one million liters per day of wastewater to the City of Livermore sewer system, an amount that constitutes 4.9% of the total flow to the system. During the year, no releases exceeded discharge limits for the release of radioactive materials to the sanitary sewer system, and concentrations of metals in LLNL's sewer effluent were well below discharge limits. There was one discharge above alarm limits in 1995—an alkaline discharge of 3 minutes duration. About 400 liters of effluent was diverted and later returned to the sanitary sewer without incident.

A special study of plutonium in Big Trees Park in the City of Livermore began in 1994. During a 1993 EPA investigation of plutonium in soils in the southeast quadrant of the Livermore site, EPA personnel collected a soil sample at Big Trees Park about two kilometers to the west to serve as a background sample. This soil sample showed plutonium at a higher concentration than expected from global fallout for this region. The park was resampled by EPA, LLNL, and the California Department of Health Services (DHS) in 1995. The results confirmed the finding of plutonium, but all levels are below the EPA's preliminary remediation goal for residential exposure to plutonium. The EPA and DHS concur that there is no regulatory concern or significant impact on human health or the environment.

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 regions. The waters monitored include reservoirs and ponds, streams, rainfall, tap water, storm water runoff, drinking-water supply wells, and ground water monitoring wells. LLNL has two projects under the jurisdiction of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA): the Livermore Site Ground Water Project and the Site 300 Environmental Restoration Program.

Depending on location, the water samples may be analyzed for gross alpha and gross beta radiation, tritium, uranium, and nonradioactive pollutants, including solvents, metals, high explosives, and pesticides and other properties such as total suspended solids, conductivity, and pH. Median activities for gross alpha and gross beta radiation in surface water samples for the Livermore site and Livermore Valley in 1995 were less than 10% of the drinking water maximum contaminant level (MCL). Storm water gross alpha and gross beta were well

below MCLs, with the exception of samples collected December 11 at two influent sampling locations. The sources of these sampling locations are upstream and off the Livermore site; no link to airborne emissions from LLNL has been found. The origin of the elevated readings has not been determined; this investigation is continuing into 1996. Livermore site rainfall has exhibited elevated tritium activities in the past, but during 1995 as in 1994, measurements were far below the MCL established by the EPA for drinking water; the highest activity measured was 10% of the MCL. Tritium values for surface and drinking water samples were less than 0.3% of the drinking water standard.

At Site 300, LLNL routinely monitors 57 ground water wells and, in addition, conducts compliance monitoring associated with known areas of ground water contamination. 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.

Tritium activities in ground water samples from several downgradient wells in the Pit 1 and Pit 7 areas at Site 300 were above the MCL for drinking water in 1995 as noted in previous reports. In the high explosives process area, ground water samples exceeded California drinking water MCLs for arsenic, selenium, nitrate, and trichloroethene. No wells in these areas supply water for agriculture or for human or animal consumption. Off-site water supply wells showed some level of contaminants of concern, but far below drinking water MCLs. All tritium and other radioactivity measurements in off-site surveillance wells showed very low values, equivalent to background. Thus the impact of LLNL operations on ground water beyond Site 300 boundaries is minimal.

Area vegetation and foodstuffs are monitored for their tritium content. The tritium concentrations taken near the Livermore site were greater than those taken from more distant locations. The tritium concentrations were slightly less than those reported in 1994. As in the past, the tritium concentrations in Livermore Valley wines analyzed in 1995 are slightly above those for wines tested from Europe and other locations in California, but were the lowest since this monitoring program began. Even the highest detected value, 6.0 Bq/L (160 pCi/L), represents only 0.8% of the amount California allows in drinking water. This amount is slightly less than the highest value for 1994, 8.0 Bq/L (216 pCi/L).

Radiological Impact Assessment

Radiological dose-assessment modeling, using EPA-mandated computer models, actual LLNL meteorology, population distributions appropriate to the two sites, and 1995 radionuclide inventory and monitoring data, was conducted this past year for each key facility and each new emission point at the Livermore site and Site 300.

The calculated total potential dose for a hypothetical person having the greatest possible exposure at the Livermore site in 1995 was 0.19 µSv (0.019 mrem) from point-source (stack) emissions, and 0.22 µSv (0.022 mrem) from diffuse-source (area) emissions. Summing these contributions yields a total dose of 0.41 µSv (0.041 mrem) for the Livermore site. This total potential dose for 1995 continues the gradual decline in levels seen over the last six years; it is only 17% of the 1990 level.

The calculated total potential dose to a hypothetical person having the greatest possible exposure at Site 300 during 1995 was 0.23 µSv (0.023 mrem). Explosive tests at the Building 801 and Building 851 firing tables accounted for all of the point source dose of 0.20 µSv (0.020 mrem), while a source representing resuspension of LLNL-contributed uranium in surface soils throughout the site was responsible for nearly all of the diffuse sources total of 0.03 µSv (0.003 mrem). This total dose is only about 28% of the previous year's value. Total annual dose levels from Site 300 operations fluctuate from year to year, primarily in response to the total quantity of depleted uranium used in explosives experiments at the Site 300 firing tables.

The doses to the maximally exposed public individual from Livermore site and Site 300 emissions amount to less than 0.5% of the EPA National Emission Standards for Hazardous Air Pollutants (NESHAPs) standard. These doses are a small fraction (about 1/8000) of the doses received by these populations from natural background radiation, not including medical and other anthropogenic sources. Thus, the potential radiological doses from LLNL operations in 1995 were well within regulatory standards and were very small compared to doses from natural background radiation sources.

Environmental Compliance Activities

LLNL works to ensure that its operations have limited environmental impacts and comply with 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 1995.

Both the Livermore site and Site 300 are Superfund sites under CERCLA and are undergoing remedial activities. The primary treatment technology used at the Livermore site to remediate contaminated ground water is pump-and-treat

technology. In 1995, treatment facilities TFA, TFB, TFC, TFD, and TFF at the Livermore site processed hundreds of millions of liters of ground water, removing tens of kilograms of volatile organic compounds (VOCs) plus smaller quantities of dissolved fuel hydrocarbons (FHCs). These efforts at control and remediation have stopped the off-site westward migration of VOC plumes and reduced plume size. Significant progress also occurred at Site 300, where remedial activities are in an earlier stage. All requirements of the Federal Facility Agreements negotiated with DOE and EPA for both sites were met.

A risk-based bioremediation approach for remediating underground contamination from leaking fuel tanks was proposed in 1995 by an LLNL-led team of researchers from LLNL and four University of California campuses. The team found that naturally occurring microbes in the soil and ground water usually can break down most of the fuel hydrocarbons before they reach sources of drinking water. On the basis of this study, the California State Water Resources Control Board is revising its water cleanup policy for fuel leaks, ranking cleanup sites by risk to drinking water sources, selecting cleanup techniques based on risk, and halting pump-and-treat cleanup activities in low-risk cases. As a result, large dollar savings could accrue to the State and to tank owners, and thousands of acres of land could be returned to beneficial use sooner.

Efforts at solid-waste minimization at LLNL in 1995 resulted in reductions of 12.5% and 27.8%, respectively, in the amount of aggregate waste and hazardous waste generated, compared to 1994. The total quantity of potential waste that was diverted from landfills and recycled off site increased 32% over the previous year as a result of recycling programs focused on paper, batteries, ferrous material, tires, and other materials. The Laboratory also made strides in the areas of source reduction and pollution prevention. To cite two examples, in 1995 use of chlorofluorocarbons (CFCs) as degreasing agents, dielectric media, and refrigerants was significantly reduced, and operation of LLNL's Chemical Exchange Warehouse (CHEW), which receives, temporarily stores, tracks, and makes available for reuse excess usable chemicals, won a national award from DOE.

LLNL continues to perform all activities necessary to comply with clean air and clean water requirements. In 1995, the Bay Area Air Quality Management District (BAAQMD) issued or renewed 178 permits to operate for the Livermore site, and two boilers were replaced and two retrofitted to comply with new BAAQMD regulations (Regulation 9, Rule 7). The San Joaquin Valley Unified Air Pollution Control District issued or renewed 41 permits to operate for Site 300. LLNL has permits for underground and above ground 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.

Notification of environmental occurrences at the Laboratory is required under a number of environmental laws, regulations, and DOE orders. LLNL responded to 14 incidents that required federal and/or state agency notification during 1995. None of these caused adverse impact to human health or the environment.

LLNL has one federally listed endangered plant species, *Amsinckia grandiflora* (large-flowered fiddleneck), which is found at Site 300. In 1995, two natural populations and one experimental population of this plant all appeared to be robust. Regarding special-status wildlife species, LLNL's Miniature Optical Lair Explorer (MOLE, a miniature tracked vehicle with a tiny camera that allows subterranean tunnels and animal dens to be explored) was used successfully in 1995 to study burrowing owl and badger dens.

Conclusion

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 current techniques used at the Laboratory for environmental monitoring are very sensitive, allowing detection at extremely low levels of constituents. The combination of surveillance and effluent monitoring, source characterization, and computer modeling show that radiological doses to the public caused by LLNL operations are less than 0.5% of regulatory standards and are about 8000 times smaller than the doses received from background radiation. The analytical results and evaluations generally show a decrease in contaminant levels, reflecting both decreased operations and the commitment of the Laboratory to control pollutants.

In 1995, notable achievements were made in environmental compliance activities related to water, air, waste, and waste reduction. Ground water remediation activities have stopped the westward migration of plumes at the Livermore site; waste minimization efforts have significantly reduced the amount of waste generated in LLNL operations; recycling efforts have diminished the quantity of waste sent to landfills; efforts at waste reduction and pollution prevention have capitalized on a variety of opportunities to reduce or eliminate, recover, or recycle potential pollutants, with a prime example being the reduced use of CFCs and other hazardous organic solvents in Laboratory operations.

In summary, the results of the 1995 environmental programs demonstrate that the environmental impacts of LLNL operations remain minimal and pose no threat to the public or the environment.

1. Site Overview

Rebecca A. Failor
Frank J. Gouveia

Introduction

Climate and geography play primary roles in how the environment is affected by human actions. Dispersal of particles in air, for example, is influenced by wind patterns and rainfall, which in turn are influenced by geographical characteristics. Similarly, the dispersal of ground water is constrained by the particular geology of the site. Thus, data on wind, rainfall, geology, and geographical characteristics are used to help calculate the effects that operations at LLNL might have on the surrounding environment. Some history and a description of these data help us understand how the Laboratory is related to its climatic and geographic setting.

Operations

The mission of LLNL is to serve as a national resource in science and engineering, with a special responsibility for nuclear weapons. Laboratory activities focus on national security, energy, the environment, biomedicine, economic competitiveness, and science and mathematics education. The Laboratory's mission is dynamic and has been broadened 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 8000 personnel.

Location

LLNL consists of two main facilities—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 County (**Figure 1-1**). Each site is unique, requiring a different approach for environmental monitoring and protection.

LLNL was founded in 1952 on the site of 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. Livermore evolved from a small town of fewer than 7000 people at the time the Laboratory began to its present population of about 65,000. The economy diversified from being primarily agricultural 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. The city limits of Livermore are now near LLNL's western boundary.

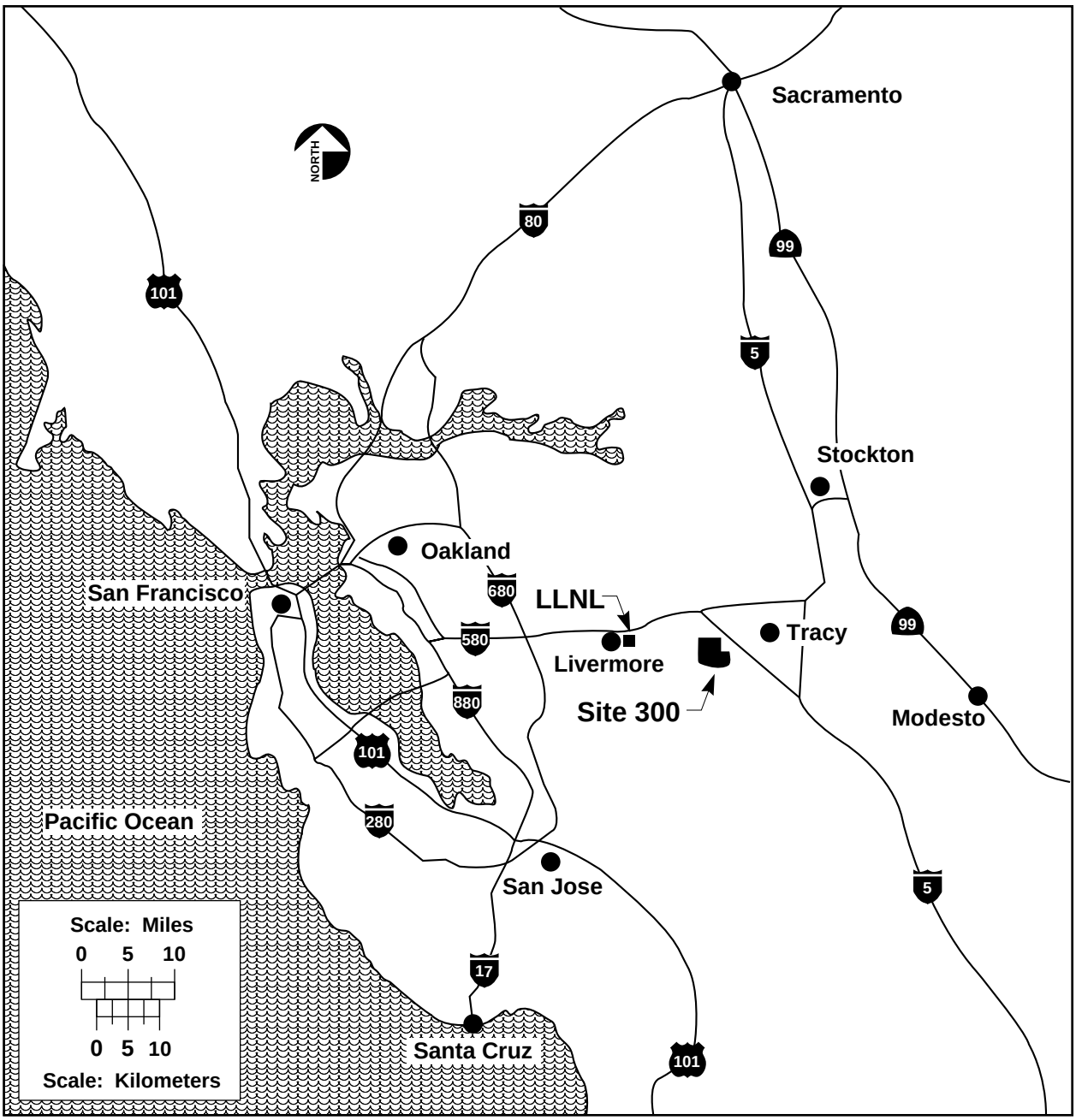

Figure 1-1. Locations of LLNL Livermore site and Site 300.

LLNL's Livermore site occupies an area of 3.28 km^2, including the land that serves as a buffer zone around the site. Immediately to the south is Sandia National Laboratories (SNL)/California, operated by Lockheed-Martin under DOE contract. SNL/California provides research and development associated with nuclear weapons systems engineering, as well as related national security

tasks. Although their primary missions are similar, LLNL and SNL/California are separate facilities, 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. 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 a center for industry.

Site 300, LLNL's Experimental Test Facility, is located 24 km east of the Livermore site in San Joaquin County in the Altamont Hills of the Diablo Range; it occupies an area of 30.3 km^2. It is in close proximity to two other testing facilities: Physics International operates a testing facility that is adjacent and to the east of Site 300, and SRI International operates another facility, 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 northwest of the site. 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 42,000), located 10 km to the northeast.

Meteorology

Meteorological data (including wind speed, wind direction, rainfall, relative humidity, and air temperature) are continuously gathered at both the Livermore site and Site 300. Mild, rainy winters and warm, dry summers characterize the climate of the Livermore Valley. A detailed review of the climatology for LLNL can be found in Gouveia and Chapman (1989). The mean annual temperature for 1995 was 15°C. Temperatures range from –5°C during predawn winter mornings to 40°C during summer afternoons.

Both rainfall and wind exhibit strong seasonal patterns. 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 pattern comes from the south-southwest to westerly direction. These wind patterns are 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

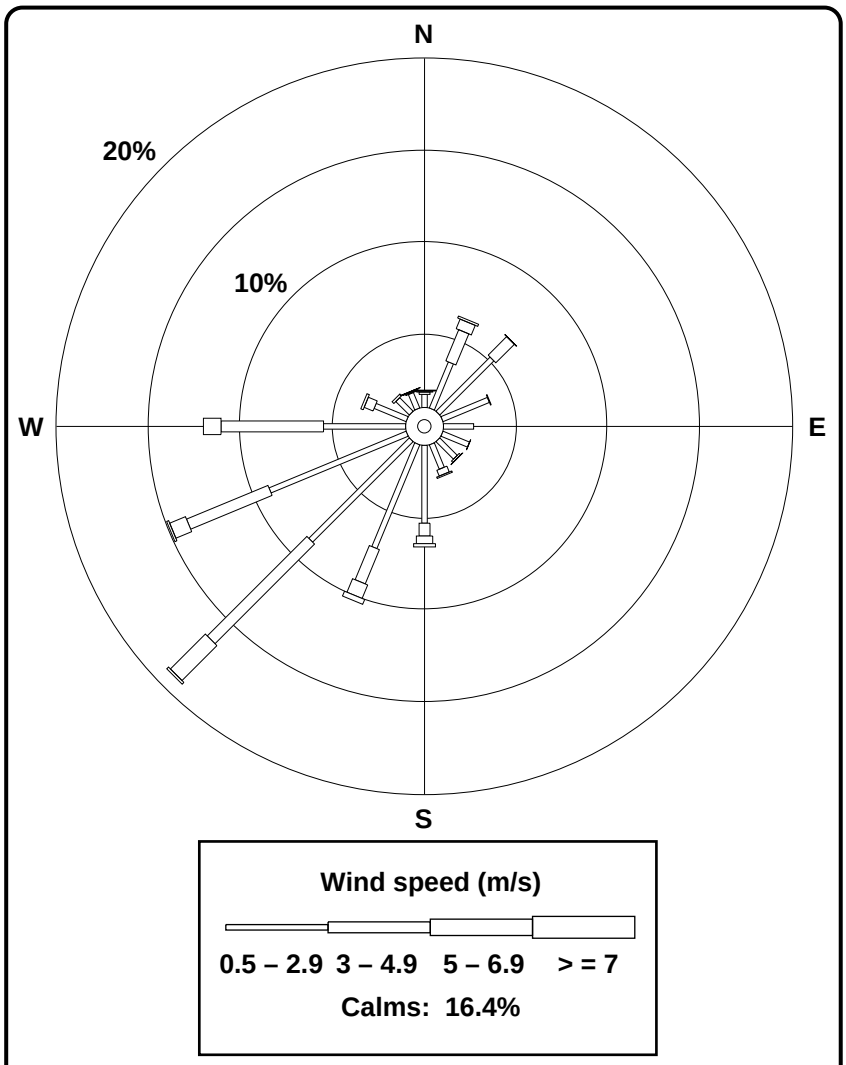

Figure 1-2. Wind rose showing the average annual wind speed, frequency of occurrence, and direction at the Livermore site, 1995.

the warmer months. The highest and lowest annual rainfalls on record are 782 and 138 mm. In 1995, the Livermore site received 522 mm of rain.

The meteorological conditions at Site 300, while generally similar to the Livermore site, are modified by higher elevation and more pronounced 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 these 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 the site result in afternoon temperatures that are typically lower than those for the Livermore site. Rainfall for 1995 was 412 mm.

Table 1-1. Average annual percent frequency of wind direction at different wind speeds measured at 10 m above ground level at the Livermore site, 1995.

Direction	Wind speed (m/s)					
	0.0 – 0.4	0.5 – 2.9	3.0 – 4.9	5.0 – 6.9	≥7.0	Total
NNE	1.03	2.71	1.83	0.56	0.12	6.3
NE	1.03	4.16	1.42	0.02	0.00	6.6
ENE	1.03	2.73	0.04	0.00	0.00	3.8
E	1.03	1.64	0.00	0.00	0.00	2.7
ESE	1.03	1.56	0.00	0.00	0.00	2.6
SE	1.03	1.34	0.11	0.00	0.00	2.5
SSE	1.03	1.43	0.34	0.08	0.00	2.9
S	1.03	4.23	0.70	0.41	0.18	6.6
SSW	1.03	6.10	2.01	0.80	0.28	10.2
SW	1.03	7.72	7.65	2.68	0.14	19.2
WSW	1.03	8.06	4.79	0.93	0.12	14.9
W	1.03	4.46	5.57	0.96	0.00	12.0
WNW	1.03	1.88	0.52	0.14	0.00	3.6
NW	1.03	1.03	0.14	0.00	0.00	2.2
NNW	1.03	0.91	0.06	0.04	0.00	2.1
N	1.03	0.71	0.13	0.06	0.04	2.0
Total[(a)]	**16.5**	**50.7**	**25.3**	**6.7**	**0.9**	**100**

[a] Totals are adjusted for round-off error.

Table 1-2. Average annual percent frequency of wind direction at different wind speeds measured at 10 m above ground level at Site 300, 1995.

Direction	Wind speed (m/s)					
	0.0 – 0.4	0.5 – 4.9	5.0 – 6.9	7.0 – 10.9	≥11.0	Total
NNE	0.04	1.82	0.05	0.00	0.00	1.9
NE	0.04	2.16	0.10	0.00	0.00	2.3
ENE	0.04	2.00	0.06	0.02	0.00	2.1
E	0.04	1.85	0.13	0.13	0.00	2.2
ESE	0.04	2.21	0.50	0.50	0.12	3.4
SE	0.04	3.09	0.37	0.34	0.16	4.0
SSE	0.04	2.43	0.15	0.17	0.12	2.9
S	0.04	3.43	0.64	0.17	0.05	4.3
SSW	0.04	2.05	0.24	0.12	0.02	2.5
SW	0.04	1.86	0.84	1.59	0.29	4.6
WSW	0.04	3.37	4.71	17.46	5.35	30.9
W	0.04	4.14	4.13	2.18	0.10	10.6
WNW	0.04	4.08	1.03	0.49	0.00	5.6
NW	0.04	5.84	1.62	1.75	0.19	9.4
NNW	0.04	4.25	3.02	1.98	1.06	10.4
N	0.04	1.35	1.14	0.24	0.07	2.8
Total[(a)]	**0.7**	**45.9**	**18.7**	**27.1**	**7.5**	**100**

[a] Totals are adjusted for round-off error.

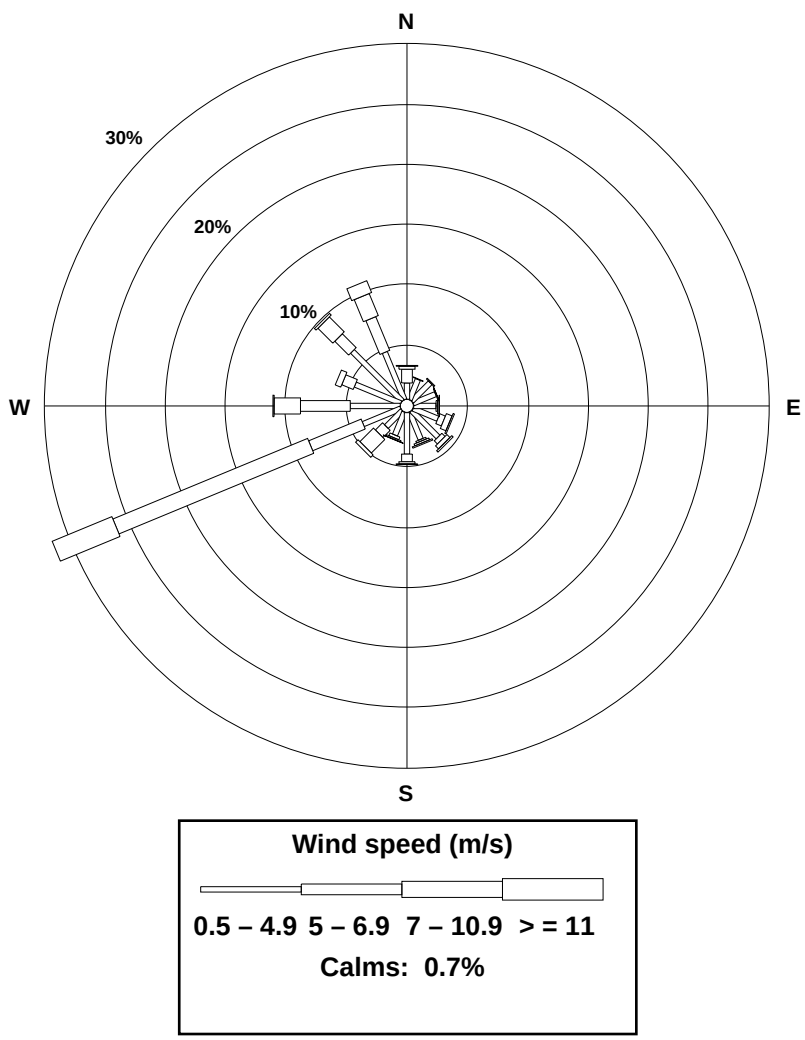

Figure 1-3. Wind rose showing the average annual wind speed, frequency of occurrence, and direction at Site 300, 1995.

Geology

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.

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 150 m above sea level at the southeast corner of the site to approximately 538 m in the northwestern portion.

Hydrogeology

Livermore Site

The hydrogeology and movement of ground water in the vicinity of the Livermore site have been the subjects of several recent and continuing investigations. Detailed discussions of these investigations can be found in 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 RWQCB 1982).

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 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. 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 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 average ground water velocity estimate of 20 m / y (Thorpe et al. 1990). The range in these values reflects the heterogeneity typical of the more permeable of the alluvial sediments that underlie the area.

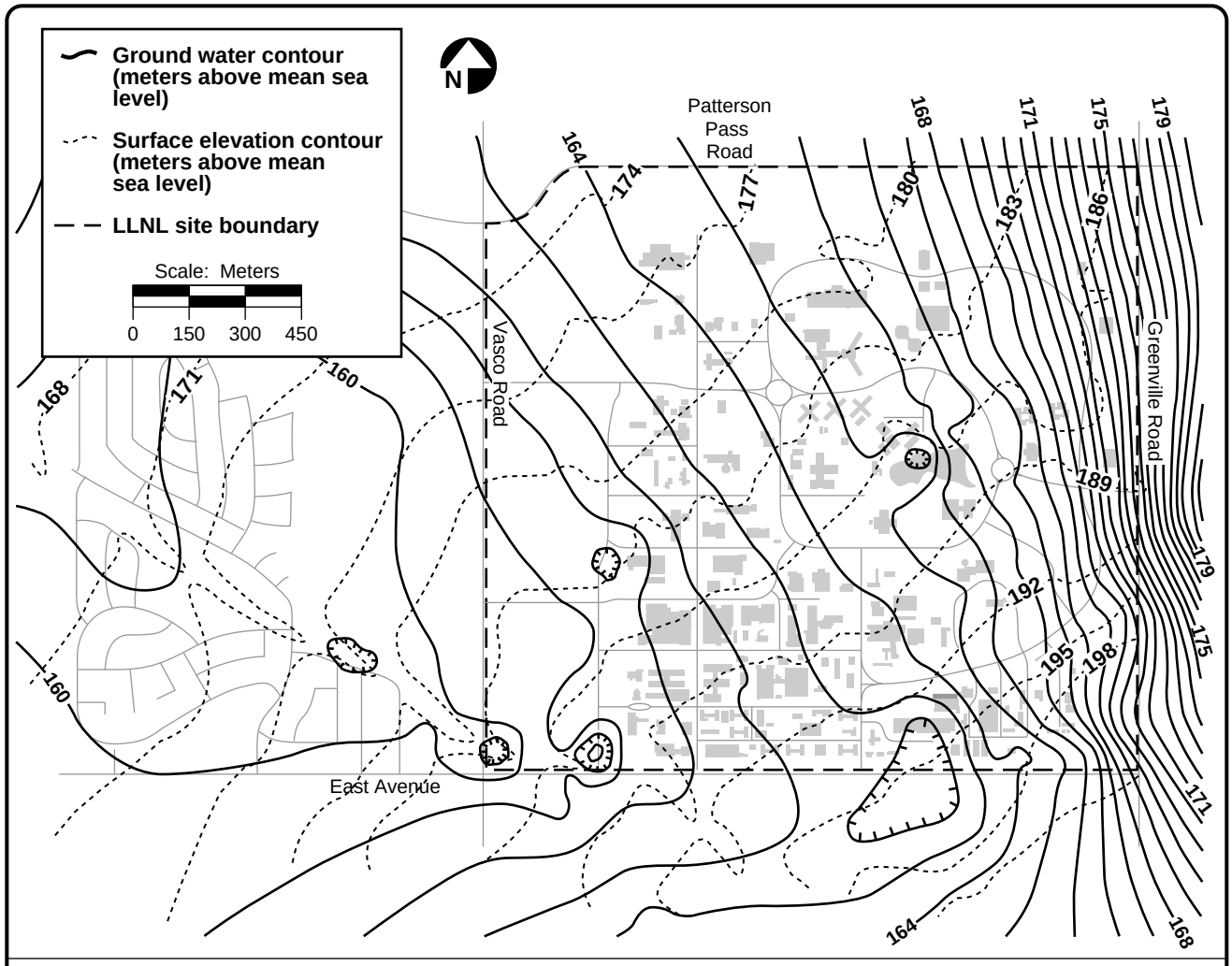

Figure 1-4. Approximate ground water and surface elevation contours, Livermore site and vicinity.

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 northwest 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 sandstone, stratigraphically near the base of the formation, contains confined water. Wells located in the western part of the General Services Area are completed in this aquifer and are used to supply drinking and process water.

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

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

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

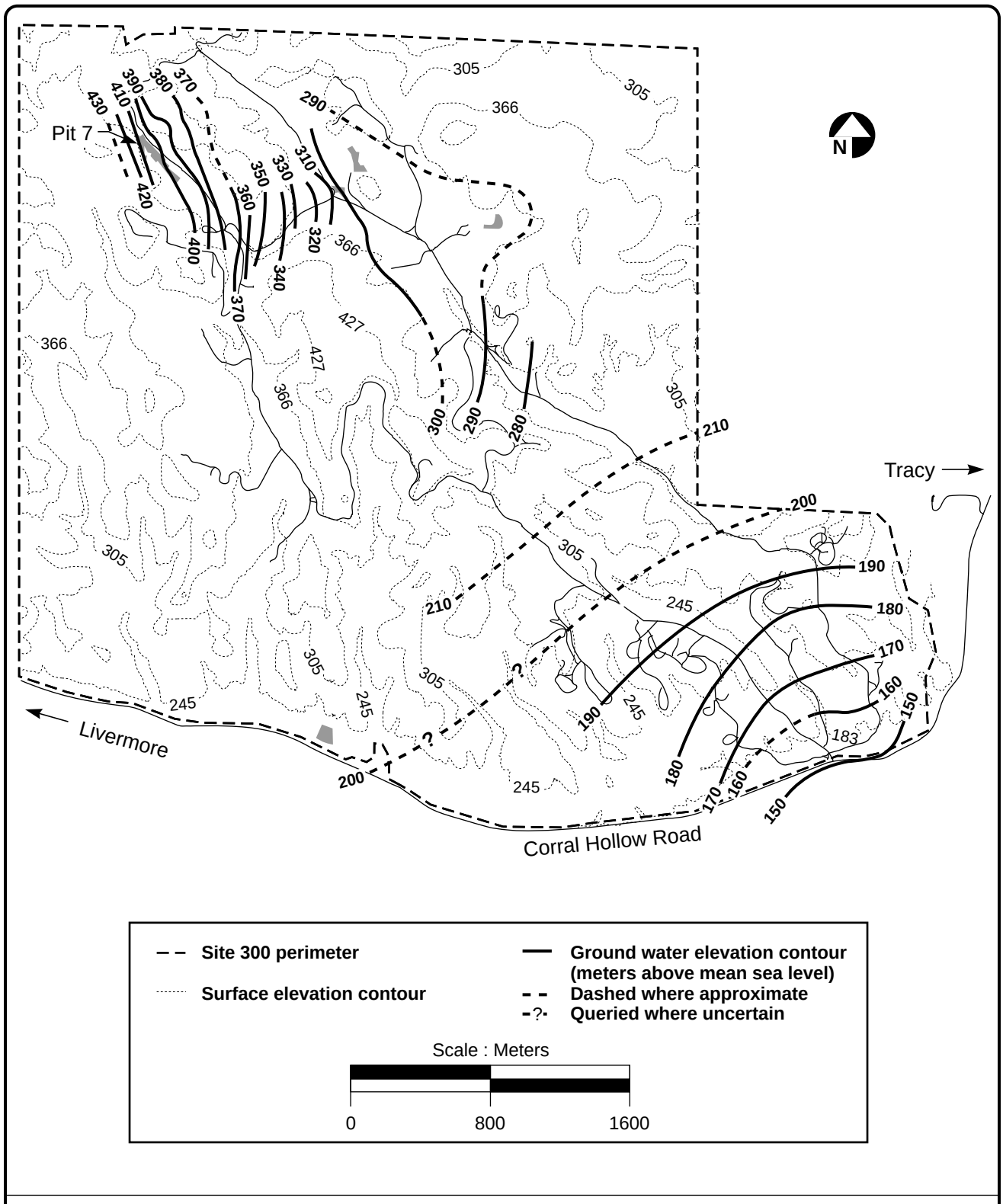

Figure 1-5. Approximate ground water elevations in principal continuous water-bearing zones at Site 300.

Summary

LLNL recognizes the importance of our geology, hydrogeology, climate, and geographical relationship with our neighbors in assessing potential impacts of operations at the Livermore site and Site 300. Each year additional information is gained to allow us to better predict, interpret, and avoid potential impacts. Each environmental medium that is discussed in this document—air, soil, ground water, and 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 medium used to monitor the environment.

2. Compliance Summary

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Introduction

During 1995, Lawrence Livermore National Laboratory (LLNL) participated in numerous environmental activities to comply with federal, state, and local regulations as well as internal requirements and Department of Energy (DOE) orders. Activities related to air, water, waste, waste reduction, community "right to know," and other environmental issues were addressed at the Livermore site and Site 300. Many documents addressing these activities and other environmental issues are available for public viewing at the LLNL Visitors Center and the Livermore and Tracy Public Libraries. A summary of the permits related to environmental activities conducted in 1995 is presented in **Table 2-1**. Details of the wide range of compliance activities are discussed in the following sections.

CERCLA/ SARA, Title I

LLNL has two projects that are under the jurisdiction of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)/ Superfund Amendment and Reauthorization Act (SARA), Title 1. These are the Livermore Site Ground Water Project and the Site 300 Environmental Restoration Program.

Livermore Site Ground Water Project

The Ground Water Project (GWP) complies with provisions specified in a Federal Facility Agreement (FFA) entered into by the 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 (RWQCB). As required by the agreement, the project addresses compliance issues through investigations of potential contamination source areas (such as suspected old release sites, solvent handling areas, and leaking underground tank systems), continued monitoring of ground water, and remediation. The ground water constituents of concern are volatile organic compounds (VOCs), primarily trichloroethylene (TCE) and tetrachloroethylene (PCE). These contaminants are located primarily in the interior of the site but to some extent at the site boundary and beyond, mainly to the west and south of the site. High concentration areas generally correspond to treatment facility locations (see **Figure 2-1**). However, treatment facilities A & B (TFA & TFB) are located at areas of lower concentrations downgradient from high concentration "hot spots" to aid our remediation of contaminated ground water at and beyond the site boundary.

Table 2-1. Summary of permits[a].

Type of permit	Livermore site	Site 300
Air	178 permits (various equipment).	41 permits (various equipment).
Water	WDR Order No. 88-075 for discharges of treated ground water from TFA to percolation pits and recharge basin.	WDR Order No. 93-100 (amended 80-184) for post closure monitoring requirements for 2 Class I landfills.
	WDR Order No. 91-091, NPDES Permit No. CA0029289 for discharges from Livermore site remediation activities and treatment units to surface waters, infiltration trenches, and injection wells.	WDR Order No. 94-131, NPDES Permit No. CA0081396 for discharges of storm water associated with industrial activity and from cooling towers.
	WDR Order No. 95-174, NPDES Permit No. CA0030023 (replaced WDR Order No. 91-13-DWQ as amended by Order No. 92-12-DWQ) NPDES General Permit No. CAS000001) for discharges of storm water associated with industrial activities and low threat non-storm water discharges to surface waters, infiltration trenches, and injection wells.	WDR Order No. 85-188 for operation of septic systems, Class II surface impoundments, and a domestic sewage lagoon.
	WDR Order No. 92-08-DWQ, NPDES General Permit No. CAS000002, Bldg. 132 Site ID No. 2 01S300881 Bldg. DWTF/MWMF Site ID No. 2 01S305140—for discharges of storm water associated with construction activities impacting 2 hectares or more.	WDR Order No. 91-052, NPDES Permit No. CA0082651 for discharges of treated ground water from the eastern General Services Area treatment unit.
Hazardous waste	ISD CA2890012584	Part B CA2890090002
	DTSC Permit No. 2-13640 for disposal of extremely hazardous waste.	Docket HWCA 92/93-031. Open Burning of Explosives Waste.
	Authorization to perform Waste Resin Mixing in Unit CE231-1 and Unit CE443-1 under Conditional Exemption tier.	
Sewer	Discharge Permit Nos. 1250 (95–96), 1508G (95–96), and 1510G (95–96) for discharges of wastewater to the sanitary sewer, discharges of sewerable ground water from TFF, and ground water discharges from restoration treatability studies (in order of numbers as indicated).	
Tanks	Fees paid for 18 underground petroleum and waste storage tanks.	Fees paid for 5 underground petroleum product tanks.
Other	FFA, ground water investigation/remediation; ACEHS medical waste permits for treatment and storage; 1 project completed under Army Corps of Engineers Nationwide Permit, 5 streambed alteration agreements.	FFA ground water investigation/remediation; 4 streambed alteration agreements; 52 registered class V injection wells.

[a] Permit numbers are based on actual permitted units maintained and renewed by LLNL during 1995.

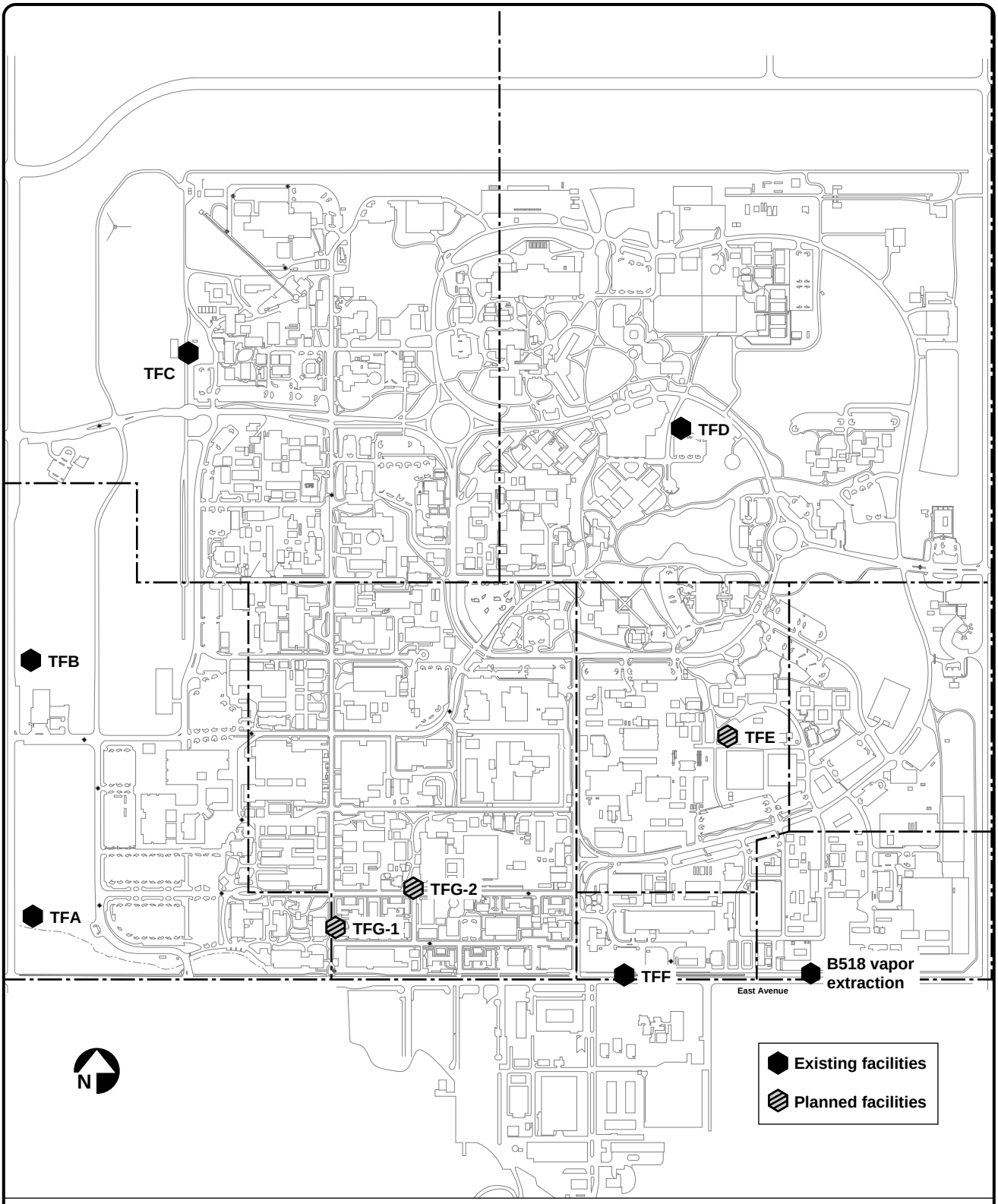

Figure 2-1. Location of existing and planned treatment facilities.

The primary treatment technology employed at the Livermore site to remediate contaminated ground water is ground water pump-and-treat. This technology employs a dense network of ground water extraction wells, monitoring wells, pipelines, and surface treatment facilities. Treatment facility operations and ground water extraction and cleanup activities are discussed in this section.

Required Documentation

In 1995, DOE/LLNL submitted several CERCLA documents for the Livermore site and fulfilled all of the community relation activities required under the National Contingency Plan and FFA. Recipients of these CERCLA documents included EPA, RWQCB, DTSC, Community Work Group Information Repositories, and Tri-Valley Citizens Against a Radioactive Environment (CAREs). The final version of *Remedial Design Report No. 5 for Treatment Facilities G-1 and G-2* (Berg et al. 1995) was issued on March 31, 1995, according to the revised schedule presented in the *Remedial Action Implementation Plan* (Dresen et al. 1993). The draft and draft final *Compliance Monitoring Plan* (Nichols et al. 1996) were issued on schedule on August 30 and December 29, 1995, respectively. As required by the FFA, DOE/LLNL issued the *1994 Ground Water Project Annual Report* (Hoffman et al. 1995) and the January and February 1995 *Ground Water Project Monthly Progress Report* on schedule. In March 1995, the following changes to reporting requirements were implemented by the Livermore Site Remedial Program Managers (RPMs) to reduce the scope and associated costs of document preparation:

- Discontinued monthly progress reports and held RPM meetings monthly. The RPM Meeting Summary now constitutes the monthly report and records all decisions, agreements, noncompliances, if any, and policy changes discussed at RPM meetings.
- Provided self-monitoring data quarterly as an attachment to RPM Meeting Summaries.

In 1995, DOE/LLNL submitted nine RPM Meeting Summaries; the March, June, September, and December summaries included quarterly self-monitoring data (McConachie and Brown 1995a, 1995b, 1995c, 1996).

Treatment Facilities

Treatment Facility A (TFA) has been operating since September 1989. TFA treated more than 270 million liters (ML) of ground water during 1995, removing and destroying approximately 12 kg of volatile organic compounds (VOCs).

Since TFA began operating, about 640 ML have been treated, removing 58 kg of VOCs. (See **Figure 2-1** for the locations of treatment facilities.) Treated waters from TFA are discharged into the recharge basin.

Treatment Facility B (TFB) has been operating since October 1990; TFB treated about 39 ML of ground water in 1995, removing and destroying approximately 3.4 kg of VOCs. More than 125 ML have been treated, removing 12.4 kg of VOCs since TFB began operating. TFB's treated waters are discharged into a drainage ditch at the west perimeter of the site feeding into Arroyo Las Positas.

Treatment Facility C (TFC) has been operating since October 1993. In 1995, a total of 2.7 kg of VOCs was removed from approximately 22 ML of ground water treated at TFC. Treated waters from TFC are discharged into Arroyo Las Positas.

Construction of Treatment Facility D (TFD) began on February 28, 1994, and was completed on July 13, 1994. TFD was activated on July 14, 1994, and operation began on September 15, 1994. In 1995, TFD processed about 7.9 ML of ground water containing about 5.8 kg of VOCs. The treated water was discharged to a storm water drainage channel discharging into Arroyo Las Positas.

During 1995, Treatment Facility F (TFF) extracted and treated ground water for 5 months during business hours only. Ground water extraction ceased at TFF on April 18 for a 6-month biodegradation study and restarted on October 17. The treatment facility was again shut down on December 8 because of storm damage. With regulatory concurrence, extraction and treatment of the residual dissolved fuel hydrocarbons (FHCs) in two hydrostratigraphic units have been temporarily discontinued in favor of a passive bioremediation approach. We will be submitting a Containment Zone (CZ) report for one hydrostratigraphic unit in the TFF Area to the regulatory agencies in early 1996.

During this period, TFF treated approximately 53 ML of ground water containing a volume-weighted average concentration of FHCs of about 1300 parts per billion (ppb). This is equivalent to about 11 L liquid-volume-equivalent of gasoline removed. In addition, TFF extracted about 40 ML of vapor containing a volume-weighted FHC average concentration of about 20 parts per million (ppm) by volume, for about 2.8 L liquid-volume-equivalent of gasoline removed. Therefore, the total liquid-volume-equivalent of gasoline removed from the TFF subsurface during 1995 was about 13.8 L. Treated waters from TFF were discharged into the sanitary sewer.

Treatment Facility 518 (TF518), which began operating on September 25, 1995, treats soil vapor collected from the vadose zone using a vapor extraction system with granulated activated carbon (GAC) canisters to remove the VOCs. A summary of the 1995 activities for TF518 are listed below:

TF518 has removed 19.9 kg of VOC mass from system startup through December 29, 1995. Four new vadose zone wells were installed during 1995. A VOC soil vapor extraction absorption efficiency test (source test) was conducted at TF518 on October 4, 1995. The source test performed better than required, achieving an abatement efficiency of 99.85%. The results of the source test are summarized in a report prepared by Best Environmental, Inc. (Cartner and Thiry 1995).

Two additional treatment facilities, TFE and TFG, were in the design phase in 1995.

Goals and Progress Summary

In summary, our ground water restoration goals are to hydraulically control and prevent further off-site westward migration of VOC plumes and to remediate plumes in both the off-site and on-site areas. The installation and operation of ground water extraction wells has enabled us to stop off-site VOC migration and remove VOC mass from the ground water, which is reducing VOC plume size. Our remedial efforts, which currently utilize detailed hydrostratigraphic analysis of the ground water bearing strata below the site, enable better targeting of specific contaminant plumes with extraction wells and may allow us to reach our cleanup objectives in an estimated 15-20 years rather than our original goal of 50 years.

Community Relations

The Community Work Group (CWG) met three times in 1995 to discuss topics including: treatment facilities G1 and G2 at the Livermore site; tritium monitoring; results of soil sampling for plutonium at Big Trees Park; the Baseline Environmental Management Report; off-site plume capture; DOE budget status; LLNL's Environmental Restoration Division (ERD) organization; and the Compliance Monitoring Plan.

Other community relations activities in 1995 included communications and meetings with a local interest group and other community organizations; public presentations; distributing the *Environmental Community Letter;* maintaining the Information Repositories and the Administrative Record; conducting tours of the site environmental activities; and responding to public and news media inquiries.

Site 300 Environmental Restoration Program

At Site 300, ongoing remedial investigations, feasibility studies, engineering evaluation and cost analyses, and remedial actions are being performed as a part of the Environmental Restoration Program (ERP). Site 300 investigations and remedial actions are conducted under the joint oversight of the EPA, Central Valley RWQCB, and DTSC under the authority of a Federal Facility Agreement (FFA) for the site (there are separate agreements for Site 300 and the Livermore site). Ground water investigations began in 1981 under the regulatory authority of the Central Valley RWQCB. In August 1990, Site 300 was placed on EPA's National Priorities List under CERCLA. In June 1992, the DOE and LLNL negotiated an FFA that describes the ground water and soil investigations to be conducted and specifies reporting due dates. During 1995, LLNL submitted all regulatory documents and performed all actions stipulated in the FFA on or ahead of schedule.

The study areas and major constituents of concern at Site 300 are shown in **Figure 2-2** and include: (1) General Services Area (GSA)—VOCs, primarily TCE, in soil, rock, and ground water; (2) Building 834 Complex—TCE in soil, rock, and ground water; (3) High Explosives (HE) Process Area—VOCs, primarily TCE and high-explosive compounds (primarily HMX [octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine] and RDX [hexahydro-1,3,5-trinitro-1,3,5-triazine] in soil, rock, and ground water); (4) East and West Firing Areas—tritium, depleted uranium, and VOCs (primarily TCE) in soil, rock, and ground water; (5) Pit 6 Area—VOCs (primarily TCE) in soil, rock, and ground water; and (6) Building 832 Canyon Area (formerly called the Building 833 Area)—TCE in soil, rock, and ground water. These study areas roughly correspond to the programmatic areas at Site 300.

Documentation

Before Site 300 was placed on the National Priorities List, several draft remedial investigation and feasibility study reports were completed for the study areas. The draft remedial investigation reports included detailed discussions of the environment, geology and hydrogeology, environmental risk of any chemicals encountered, and assessment of the potential hazard or risk to public health and safety. The draft feasibility study reports included proposals for remedial action alternatives with cost estimates under several conditions, from no action to full remediation. These reports were submitted to regulatory agencies for consideration of appropriate choices for remediation.

In mid-1991, the regulatory agencies requested that LLNL prepare a sitewide remedial investigation report to replace the previously submitted, area-specific, individual draft remedial investigation reports. The *Final Site-Wide Remedial*

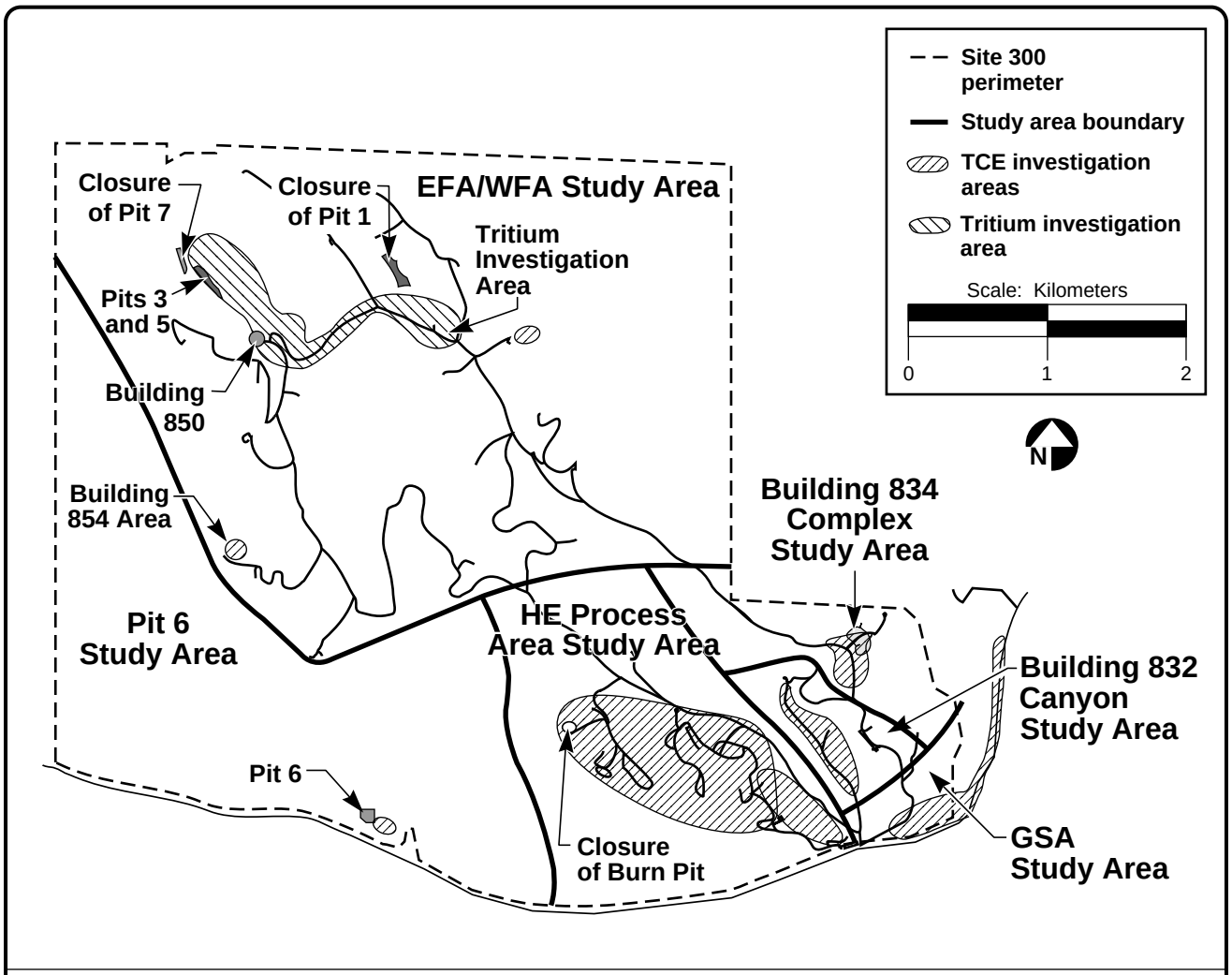

Figure 2-2. Environmental restoration study areas and activities at Site 300.

Investigation Report (Final SWRI report; Webster-Scholten 1994) was submitted to the EPA, Central Valley RWQCB, and DTSC during 1994. The Final SWRI report is organized by study areas, which roughly correspond to the areas covered by the individual remedial investigation reports. It is a thorough compilation of all ground water and soil investigation information for the entire site and contains a detailed assessment of potential human health and ecological hazards or risks resulting from contamination of soil, rock, and ground water. New feasibility study or engineering evaluation/cost analysis (EE/CA) reports have been, or will be, prepared for portions of the individual study areas, termed operable units, where the Final SWRI report or more recent studies indicate that unacceptable potential hazards or risks exist.

During 1995, LLNL submitted to the regulatory agencies the *Final Feasibility Study for the General Services Area Operable Unit* (Rueth and Berry 1995) and the *Final Proposed Plan for the Building 834 Operable Unit* (LLNL 1995a) and the *Draft Proposed Plan for the General Services Area Operable Unit* (LLNL 1995c); the latter reports describe the planned remedial strategies. During 1995, LLNL also submitted to the regulatory agencies the *Final Interim Record of Decision for Building 834* (LLNL 1995b) and the *Draft Evaluation of Remedial Alternatives for the Building 815 Operable Unit of the HE Process Area Study Area* (Madrid and Green-Horner 1995).

In 1995, LLNL made significant progress and is currently finalizing work begun during 1994 with DOE and the regulatory agencies to streamline the Site 300 CERCLA process by reducing the number of documents and by agreeing on a suitable remediation strategy for the two operable units that can be presented in an EE/CA report. Each remedial action would be performed as a CERCLA Removal Action. Prior to finalizing the selection of each Removal Action for these two units, the public would be able to comment at public workshops. This streamlined process is already being applied at Pit 6, where the regulatory agencies will use the Pit 6 Feasibility Study report as an EE/CA and at the Building 815 (HE Process Area study area) and Building 850/Pit 7 Complex (East and West Firing Area study area) operable units. Additional EE/CA reports may be prepared if investigative activities planned at the Building 832 Canyon area and the Building 854, Building 812, and Sandia Test Site areas (East and West Firing Area study area) indicate unacceptable risks or hazards.

General Services Area

This study area is located in the southeastern corner of Site 300. Since 1982, LLNL has conducted an intensive investigation in the GSA and off-site areas to locate VOC release points and to define the vertical and horizontal distribution of VOCs, primarily TCE and PCE, in the soil, rock, and ground water. According to the Final SWRI and *Draft Remedial Investigation* (McIlvride et al. 1990) reports, VOCs in excess of drinking water maximum contaminant levels (MCLs) have been identified in the shallow ground water beneath the GSA in two localities. Two small VOC plumes occur in the central portion of the study area, and one VOC plume occurs in the eastern section in the gravels of Corral Hollow Creek. An air-sparging ground water treatment unit that removes VOCs from the eastern GSA ground water began operation in June 1991 as a CERCLA Removal Action and has been operated throughout 1995. The total volume of water treated here through December 1994 was about 190 ML; 2.9 kg of VOCs were removed from the water. The treated ground water was discharged off site to the Corral Hollow Stream Channel, in accordance with WDR Order No. 91-052 NPDES Permit No. CA0082651. During 1995, an additional 73 ML of ground

water in the eastern GSA was treated to remove approximately 1.4 kg of VOCs. Before cleanup was initiated, this plume extended about 1200 m off site; it now extends only 300 m off site. LLNL estimates that 10 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.

The two VOC ground water plumes in the central GSA are present in alluvium and shallow bedrock and in deeper bedrock. Construction of an air-sparging ground water treatment and vapor extraction unit for a CERCLA Removal Action to remove VOCs from the central GSA ground water and soil vapor was completed in 1993. During 1993, ground water extraction and treatment began. During 1993 and 1994, about 0.90 ML of ground water containing 2.4 kg of VOCs were treated. During 1995, an additional 0.89 ML of ground water containing 0.88 kg of VOCs was treated. The treated ground water was collected and batch discharged in a remote Site 300 canyon, in accordance with substantive requirement agreements issued by the Central Valley RWQCB. Pilot soil vapor extraction and treatment of VOCs began in 1993. During 1993 and 1994, 3000 m^3 of soil vapor were treated with carbon adsorption to remove 7.6 kg of VOCs. During 1995, an additional 180,000 m^3 of soil vapor were treated to remove 17 kg of VOCs. Soil vapor extraction and treatment are ongoing. LLNL estimates that an additional 10 years of soil vapor extraction and 55 years of ground water extraction are required to achieve and maintain ground water VOC concentrations below MCLs at the central GSA.

The *Final Feasibility Study Report for the General Services Area Operable Unit* (Rueth and Berry 1995) defines the extent of ground water contamination and was submitted to the regulatory agencies on October 31, 1995. The *Draft Proposed Plan for the General Services Area Operable Unit* (LLNL 1995c) was submitted on December 15, 1995, and describes the planned remedial strategies for public evaluation.

Building 834 Complex

The Building 834 Complex is located in the eastern portion of Site 300. An isolated, perched water-bearing zone that contains TCE in excess of the MCL of 5 ppb has been defined and reported in the Final SWRI report, *Draft Remedial Investigation and Feasibility Study for the Lawrence Livermore National Laboratory Site 300 Building 834 Complex* (Bryn et al. 1990), and the *Final Feasibility Study Report for the Building 834 Operable Unit* (Landgraf et al. 1994). Techniques have been evaluated and pilot-tested to remove TCE vapor from the vadose zone above the water table and from the shallow perched water. Water was extracted by pumping from ground water extraction wells and from soil vapor extraction wells under vacuum. Pilot remediation began during 1993 at the Building 834

Complex, where about 300 kg of TCE was removed from the unsaturated sediment soil vapor and ground water by extraction and treatment. Ground water has been treated by air sparging. Vapor-phase TCE has been treated by carbon adsorption; successful experiments have been conducted at Building 834 for the breakdown of TCE with ultraviolet-light flash lamps and an electron beam accelerator. During 1993, the pilot extraction system was upgraded in preparation for a CERCLA Removal Action. Proof-of-system testing was conducted during 1994. During 1995, 9700 L of ground water was extracted to treat 0.36 kg of VOCs (primarily TCE) by air sparging. The resulting clean effluent water was misted to air by elevated sprinklers located immediately southeast of the Building 834 Complex. This unique design allows for the rapid evaporation of the clean effluent water and prevents surface erosion and ground water recharge.

During 1995, LLNL submitted the *Final Proposed Plan for the Building 834 Operable Unit* (LLNL 1995a) to the regulatory agencies; this report describes the planned remedial strategies for the public. During 1995, LLNL also submitted to the regulatory agencies the *Final Interim Record of Decision for the Building 834 Operable Unit* (LLNL 1995b). The proposed remedial strategy for the operable unit is ground water and soil vapor extraction and treatment. The interim Record of Decision (ROD) provides for the application of innovative technologies such as surfactants for enhanced removal by soil vapor and ground water extraction.

High Explosives Process Area

During ground water field investigations conducted in the mid-1980s, concentrations of TCE and nitrate above MCLs and concentrations of the high-explosive (HE) compound RDX were discovered in two perched, water-bearing zones within the HE Process Area near Buildings 815 and 817 (Crow and Lamarre 1990; Webster-Scholten 1994). Until 1985, process rinse water from buildings within the HE Process Area was disposed of in unlined lagoons adjacent to the processing buildings. The lagoons were closed and capped with impermeable clay in 1989. Sporadic, but generally low, concentrations of HE compounds, metals, and VOCs were identified in the vadose zone beneath some of the lagoons, but these contaminants have not migrated to the underlying ground water (Webster-Scholten 1994). During 1994, additional investigations were conducted in the study area, and the full extent of the contamination has been determined. The feasibility study for the Building 815 operable unit was replaced by a streamlined *Draft Evaluation of Remedial Alternatives Report* (Madrid and Green-Horner 1995) for the Building 815 Operable Unit, which was submitted to the regulators on December 15, 1995. During 1995 our continued assessment of chemical data indicates that natural attenuation is reducing the extent and maximum concentration of VOCs in the HE Process Area ground

water. The current remedial strategy is on hold pending further well installation, investigation, and modeling of ground water chemistry immediately downgradient (south) of the Building 815 operable unit.

East and West Firing Areas

Debris from explosive tests historically conducted at seven firing tables (Buildings 801, 802, 804, 812, 845, 850, and 851) in this study area in the northern part of Site 300 was disposed of in adjacent unlined landfill pits. These landfill pits are designated Pits 1, 2, 8, and 9 in the East Firing Area (EFA) and Pits 3, 4, 5, and 7, collectively termed the Pit 7 Complex, in the West Firing Area (WFA). In 1981, the Hazardous Waste Assessment study of the hydrology, geology, and ground water chemistry associated with Site 300 landfills was initiated. As part of this project, monitoring wells were installed at the landfills, and a program of periodic ground water monitoring was initiated. In 1984, tritium activities in water from four of the wells rose above the California MCL for drinking water, which is 740 becquerels per liter (Bq/L) (20,000 picocuries per liter [pCi/L]).

A tritium investigation was initiated, and two areas where tritium occurs in ground water above background activities and MCLs were delineated: (1) the Pit 7 Complex and (2) the area encompassing Building 850, Doall Road, and Elk Ravine in the East and West Firing Areas. This area defines the Building 850/Pit 7 Complex Operable Unit. **Figure 2-3** shows the distribution of tritium in ground water for April–May 1995. The Final SWRI report indicates that, at Building 850, tritium was released to the subsurface by percolation of rainfall runoff and dust-control water through contaminated Building 850 firing-table gravels to ground water. In the Pit 7 Complex, tritium was released to ground water from Pits 3 and 5 by heavy winter rains in 1982–1983, 1986–1987, 1991–1992, 1993–94, and the resulting rising water tables. Computer modeling of the transport and fate of the tritium indicates that by the time the tritiated water from sites of known ground water contamination reaches the Site 300 boundary, the tritium will have decayed to near background activities. Details of the remedial investigation for the East and West Firing Areas are discussed in several reports including Taffet et al. (1989) and the Final SWRI report. Past monitoring has also revealed trace amounts of TCE in ground water near the Pit 7 Complex (from Pit 5) and at Building 801. Freon-113 at concentrations significantly below the California maximum contaminant level of 1.2 ppm is present near Pit 1 and is the result of spills at Building 865 (Advanced Testing Accelerator).

During 1995, total uranium activities in excess of the State MCL of 0.74 Bq/L (20 pCi/L) continued to be measured in samples from several ground water monitoring wells at the Pit 7 Complex; several of these wells also yielded samples bearing isotopic ratios indicative of depleted uranium. Conversely,

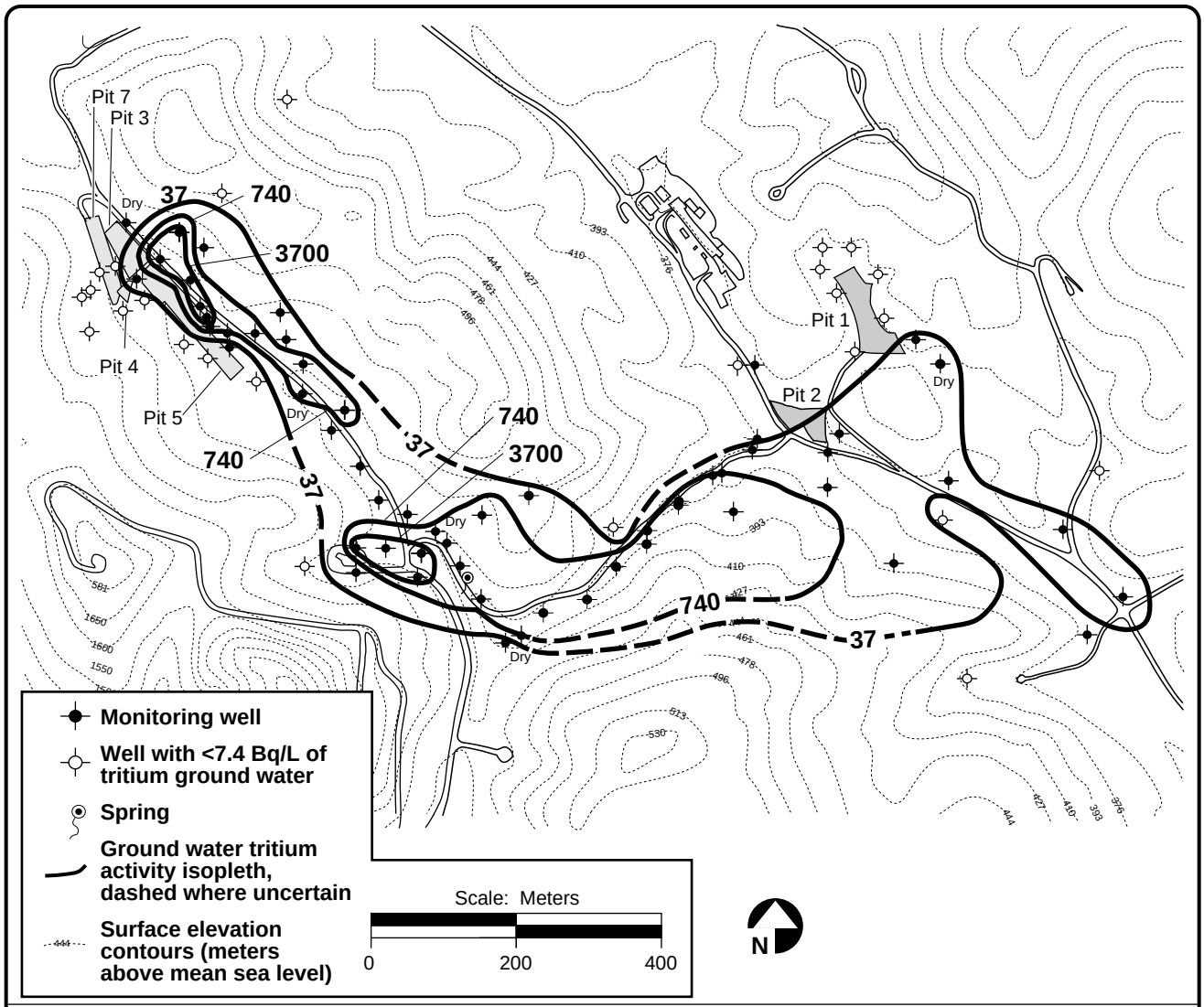

Figure 2-3. Tritium activities (Bq/L) in ground water in the Pit 7 Complex, Building 850/Doall Ravine, and EFA areas, EFA/WFA study area, second quarter, 1995.

samples of ground water from several wells in the area contain uranium activities that exceed the State MCL but bear natural uranium isotopic signatures. Analyses of ground water samples from several wells adjacent to Building 850 also indicate depleted uranium signatures; these samples do not exceed the state MCL for uranium. Additional field work was conducted during 1995 at Building 850 and Pits 3 and 5 to define the nature and extent of uranium isotopes, polychlorinated biphenyls (PCBs), dioxins and furans, and VOCs in soil, rock, and ground water. As a result, we have defined three small plumes of uranium in ground water, emanating from each of Pits 5 and 7 and the Building 850 firing table. Ground water fate and transport modeling indicates that total uranium

activity will be at background levels by the time any depleted uranium-bearing ground water reaches the Site 300 boundary. Although PCBs, dioxins, furans, and depleted uranium were found in soils on the slopes above the Building 850 firing table to a maximum depth of about 1 m, no VOCs or PCBs were detected in surface or subsurface soil and rock collected near Pits 3 and 5. During 1995, these chemical results were integrated into a SWRI Addendum Report for the Building 850/Pit 7 Complex Operable Unit (Taffet et al. 1996). This report was submitted to the regulatory agencies during February 1996 and includes a revised risk assessment for the operable unit. During 1995, LLNL prepared an evaluation of treatment technologies for tritium-bearing ground water (LLNL 1996); this report also was submitted to the regulatory agencies during February 1996. Remedial actions at the operable unit will be carried out as CERCLA Removal Actions. These actions will likely consist of impermeable barriers and subsurface drains designed to keep water out of contaminant sources.

Characterization plans for the Building 854, Building 812, and Sandia Test Site portions of the East and West Firing Areas were submitted to the regulatory agencies during 1994. At the Building 854 Complex, prototype weapons parts have been subjected to environmental stresses. Several large leaks of TCE occurred here in the past. Characterization work began at the Building 854 Complex in the spring of 1995. This work included geological reconnaissance, surface soil sampling, a passive soil vapor survey, monitor well drilling and completion, and borehole-core chemical analysis.

Pit 6 Area

The Final SWRI report and *Draft Remedial Investigation of Landfill Pit 6* (Taffet 1990) discuss the small plume of TCE (in excess of MCLs) in ground water that discharges to the surface at small springs at the southeastern edge of the Pit 6 area. The source of the TCE plume is the southeast corner of the Pit 6 landfill. Because of natural volatilization of affected ground water at the springs, concentrations of VOCs in the plume have declined by over an order of magnitude since 1992. The *Final Feasibility Study Report for the Pit 6 Operable Unit* (Devany et al. 1994) discusses options for remediation in this area. The regulatory agencies have agreed to accept this document as an EE/CA report for a removal action. The removal action includes installation of an impermeable cover, surface drainage diversion system, and several additional monitoring wells. The removal action construction is scheduled for completion by December 1, 1997.

Building 832 Canyon Study Area

Low concentrations of TCE and associated VOCs have been detected in shallow soils and sediments (to a depth of 15 m) beneath the Building 832 Canyon Study

Area (formerly the Building 833 study area). During the remedial investigation of the Building 833 area, VOC concentrations of up to 1800 ppb were detected in ground water samples from two boreholes. Results of the investigation were published in the Final SWRI report and in the *Draft Remedial Investigation of the Building 833 Area* (Webster-Scholten et al. 1991). Although past investigations documented in the Final SWRI report do not indicate risk or hazard above acceptable levels within Building 833, additional investigation began in 1994 at the Building 832 Canyon area. This investigation is scheduled for completion during 1997. Remedial actions will be evaluated if unacceptable risk or hazard is indicated at the Building 832 Canyon area.

Community Relations

The Site 300 CERCLA project maintains proactive communication with the surrounding communities of Tracy and Livermore. Community relations activities conducted during 1995 included continued dialogue with Tri-Valley CAREs, maintenance of the information repositories and administrative records, Site 300 tours for scientists and students from universities and local public schools, support for off-site, private, well-sampling activities, and preparation of a third Site 300 Environmental Restoration fact sheet. This fact sheet will be published during early 1996.

SARA, Title III

Title III of the Superfund Amendment and Reauthorization Act (SARA) of 1986 is known as the Emergency Planning and Community Right-to-Know Act (EPCRA). It requires owners or operators of facilities that have 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, signed by President Clinton on August 3, 1993, directs all federal agencies to comply with the requirements of EPCRA, including the SARA 313 Toxic Release Inventory Program.

Section 302 of EPCRA requires the owner or operator of any facility at which a listed extremely hazardous substance is present in amounts equal to or greater than specified threshold planning quantities to notify the State Emergency Response Commission (SERC), which in California is the Chemical Emergency Planning and Response Commission (CEPRC), that the facility is subject to the emergency planning requirements. Section 303 of EPCRA requires the owner or operator of the facility to designate a facility representative to participate in local emergency planning as a facility emergency response coordinator. LLNL submits Section 302 and 303 information to CEPRC and periodically updates emergency contact information with revised Section 311 submittals described below. In 1995, these updates were submitted to the CEPRC on January 27 and June 20.

Section 304 of EPCRA requires that releases of certain hazardous substances that are not federally permitted must be immediately reported to the SERC and Local Emergency Planning Committee (LEPC). LLNL did not release a hazardous substance requiring notification under Section 304 during 1995.

Section 311 of EPCRA requires the owner or operator of a facility that is required to prepare or have available a Material Safety Data Sheet (MSDS) for a hazardous chemical under the Occupational Safety and Health Act (OSHA) of 1970 to submit an MSDS for each chemical (or a list of such chemicals) to the SERC, LEPC, and local fire department if the amount of the chemical equals or exceeds threshold amounts. LLNL provided two updates to its Section 311 submittals during 1995. **Tables 2-2** and **2-3** identify those chemicals reported by LLNL for the Livermore site and Site 300 under Section 311 during 1995.

Section 312 of EPCRA directs the owner or operator of a facility required to prepare or have available an MSDS for a hazardous chemical under OSHA to prepare and submit an emergency and hazardous chemical inventory form by March 1 of each year if the amount of the chemical equals or exceeds threshold amounts. In California, submittal of chemical inventory information under provisions of California Health and Safety Code Chapter 6.95 (Hazardous Material Release Response Plans and Inventory or "Business Plan") is deemed to meet the requirements of EPCRA Section 312. LLNL has previously submitted separate Business Plans and related chemical inventory information to San Joaquin and Alameda Counties for Site 300 and the Livermore site and updated each of these plans three times during 1995.

Section 313 of EPCRA, the Toxic Release Inventory (TRI) reporting program, requires the owner or operator of certain facilities that manufacture, process, or otherwise use listed toxic chemicals above threshold amounts to submit annually to EPA and designated state officials annual toxic chemical release inventory forms (FORM R) for such toxic chemicals released into the environment. Executive Order 12856 directs federal agencies to report under Section 313 , beginning with reporting year 1994. As required by this Executive Order, LLNL submitted to DOE on June 9, 1995, Form Rs for sulfuric acid and 1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113) for the Livermore site. DOE subsequently submitted the two Form Rs to USEPA and the State of California.

A summary of LLNL compliance with EPCRA in 1995 follows:

EPCRA 302–303: Planning notification	Yes [X]	No [ ]	Not Required [ ]
EPCRA 304: EHS Release notification	Yes [ ]	No [ ]	Not Required [X]
EPCRA 311–312: MSDS/Chemical Inventory	Yes [X]	No [ ]	Not Required [ ]
EPCRA 313: TRI Reporting	Yes [X]	No [ ]	Not Required [ ]

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

Livermore site chemicals	Physical hazards			Health hazards	
	Fire	Pressure	Reactivity	Acute	Chronic
Argon		X		X	
Carbon monoxide		X		X	
Diesel fuel	X				
Ethylene glycol				X	
Freon 11				X	
Freon 12				X	
Freon 113				X	
Gasoline	X				
Helium		X		X	
Hydrofluoric acid		Some containers	X	X	X
Hydrogen peroxide (<52%)			X		
Lead (bricks and ingots)				X	X
Nitric acid	X		X	X	X
Nitrogen		X		X	
Oxygen		X	X		
Paint	X				
Propane	X				
Sodium hypochlorite/bleach				X	X
Stoddard solvent/thinner	X			X	
Sulfuric acid			X	X	X

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

Site 300 chemicals	Physical hazards			Health hazards	
	Fire	Pressure	Reactivity	Acute	Chronic
Chlorine		X		X	
bis (2,2-dinitro-2-fluoroethyl) formal in methylene chloride	—[a]		—[a]	X	X
Diesel fuel	X				
Gasoline	X			X	
High explosives			X		
Lead (bricks)				X	X

[a] Dangerous fire or explosion risk in neat form (solvent evaporates).

ChemTrack

ChemTrack, a computerized chemical inventory system, is an important tool for ensuring compliance with SARA Title III and California Business Plan reporting requirements and improving the overall management of hazardous materials at LLNL. It tracks chemical inventories at LLNL through the use of bar codes, laser scanners, and customized software and enhances LLNL's ability to obtain toxic release information necessary to complete SARA 313 submittals. ChemTrack currently has an inventory of approximately 200,000 chemical containers ranging from 210-L drums to gram-quantity vials. A Business Plan inspection of Site 300 conducted by the San Joaquin Office of Emergency Services on September 21, 1995, found no violations.

In addition, ChemTrack includes a chemical locating service that allows LLNL researchers to find and share chemicals. This minimizes the purchase of new chemicals, thereby reducing procurement costs and the generation of hazardous waste. Also, ChemTrack data is being used by various LLNL organizations to improve emergency response planning and management of Material Safety Data Sheets, to more closely track specific high-hazard chemicals and other regulated substances, and as a screening tool for conducting preliminary hazard analyses of selected LLNL facilities.

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 1995, BAAQMD issued or renewed 178 permits to operate for the Livermore site. Two boilers were replaced at B131 and two boilers were retrofitted in B231, in compliance with BAAQMD Regulation 9, Rule 7. In 1995, SJVUAPCD issued or renewed 41 permits for Site 300.

Inspections

On February 7, 1995, the BAAQMD conducted an inspection of an asbestos removal project at the Livermore site. No deficiencies were noted during the inspection. There were no other air inspections at the Livermore site in 1995. The BAAQMD evaluated the need for other types of inspections based upon the size or amount of air emissions and classified LLNL as an insignificant source since total annual emissions do not exceed regulatory thresholds.

The SJVUAPCD conducted no inspections at Site 300 during 1995. (At Site 300, the interval for annual inspections has been slightly more than 12 months.) An inspection is expected during the spring of 1996.

National Emission Standards for Hazardous Air Pollutants

Demonstration of compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAPs) for radionuclide emissions (Radionuclide NESHAPs, 40 CFR 61, Subpart H) requires that all potential sources of radionuclide air emissions be evaluated to determine the possible effective dose equivalent to the maximally exposed individual member (MEI) of the public. These evaluations include air surveillance monitoring and modeling based on radionuclide inventory data, effluent (source emission) monitoring, or both.

Compliance with two dose limits must be evaluated. First, the sum of all effective dose equivalents to the MEI from all radionuclide emissions to air must not exceed 100 microsieverts per year (μSv / y) (10 millirem per year [mrem / y]). Second, all emission points with the potential for unmitigated emissions resulting in any effective dose equivalent greater than 1 μSv / y (0.1 mrem / y) must have continuous monitoring systems that meet the requirements stated in the regulations.

The *LLNL NESHAPs 1995 Annual Report* (Gallegos et al. 1996) reported to DOE and EPA the total calculated sitewide MEI effective dose equivalents for the Livermore site and Site 300 as 0.41 μSv / y (0.041 mrem / y) and 0.23 μSv / y (0.023 mrem / y), respectively. The reported doses include contributions from both point sources and diffuse sources. Modeling was based on a combination of effluent monitoring data and radionuclide inventory data. The totals are well below the 100 μSv / y (10 mrem / y) dose limits defined by the NESHAPs regulations. The details of these data are included in this report (see Chapter 13). The total calculated 1995 MEI effective dose equivalents for the Livermore site and Site 300 are slightly smaller than those reported for 1994, when the effective dose equivalent values were 0.65 μSv / y (0.065 mrem / y) for the Livermore site and 0.81 μSv / y (0.081 mrem / y) for Site 300.

LLNL is committed to maintain continuous radionuclide emissions monitoring of Building 331, Building 332, and the hardened portion of Building 251; such monitoring already exists in these buildings. Continuous monitoring will also be maintained at six other buildings. Inspections of these sampling systems indicated that representative sampling is being performed.

Clean Water Act and State Programs—Waste Discharge Requirements

Preserving clean water is the subject 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 navigable waterways. In addition, the State of California requires permits, known as Waste Discharge Requirements (WDR) for any discharges of wastes affecting the beneficial uses of waters of the state. The Regional Water Quality Control Boards (RWQCBs) are responsible for issuing and enforcing both permits. The Livermore Water Reclamation Plant (LWRP) requires permits for wastewater

discharges to the city sanitary sewer system. The Army Corps of Engineers (COE) is responsible for work in navigable waterways below the normal high water mark and for controlling dredge and fill operations in waters of the United States. The California Department of Fish and Game (CDFG) under the Fish and Game Code Section 1601 et al. requires streambed alteration agreements for any work that may disturb or impact rivers, streams, or lakes. Finally, the Safe Drinking Water Act (SWDA) requires registration and management of injection wells to protect ground water sources of drinking water.

Ground Water and Surface Water Discharge Permits

WDR Order No. 88-075, issued by the San Francisco Bay RWQCB, pertains to activities undertaken to investigate and remediate contaminants in ground water at the Livermore site. The order allows treated ground water that meets specified standards to be discharged to specified areas on DOE property. LLNL also holds an NPDES permit (CA0029289, WDR Order No. 91-091) for treated ground water discharged to the ground, storm drains, arroyos, injection wells, and infiltration trenches at the Livermore site. The treated ground water is from ground water investigation monitoring wells and ground water treatment facilities. As adopted into the CERCLA Record of Decision, LLNL follows the substantive requirements of CA0029289 as applicable, relevant, and appropriate requirements. The administrative requirements of this permit, including reporting, payment of fees, and permit renewal, are no longer followed. The self-monitoring programs required by this permit and the CERCLA Record of Decision are described in Chapter 14 on Compliance Self-Monitoring. Analytical results are presented in the *LLNL Ground Water Project 1995 Annual Report* (Hoffman et al. 1995a) and *LLNL Ground Water Project Quarterly Reports* (Berg et al. 1995*)* submitted under CERCLA.

The Livermore site also discharges storm water associated with industrial activities and low-threat non-storm water under an NPDES permit (CA0030023, WDR 95-174). LLNL submitted a discharge application to the San Francisco Bay RWQCB in April 1995 for low-threat non-storm water discharges and storm water discharges associated with industrial activities. The NPDES permit was issued in August 1995 allowing discharges of storm water associated with industrial activity and five categories of low-threat discharges (building conduits, equipment sources, building and ground maintenance, fire suppression and other safety systems, and water systems). Upon issuance of the NPDES permit, coverage of storm water discharges associated with industrial activities under the California General Industrial Storm Water Permit (WDR Order No. 91-13-DWQ, as amended by Order No. 92-12-DWQ, NPDES General Permit No. CAS000001) was rescinded.

In addition to storm water discharges associated with industrial activities, LLNL continued construction operations for Building 132 under coverage of the California General Construction Activity Storm Water NPDES Permit. The

Notice of Intent for this project was submitted to the State Water Resources Control Board on September 30, 1992. LLNL also submitted a Notice of Intent on September 29, 1995, for the construction activity associated with non-hazardous permitted portions of the Decontamination and Waste Treatment Facility (DWTF) and Mixed Waste Management Facility (MWMF).

The self-monitoring programs required by these permits and associated analytical results are detailed in Chapters 7 and 14.

Storm water from LLNL's Drainage Retention Basin is discharged under the authority of the CERCLA Record of Decision through reference to WDR Order No. 91-091. The self-monitoring agreement submitted to the San Francisco Bay RWQCB for discharges from the Drainage Retention Basin and associated analytical results are discussed in Chapter 14.

Site 300 discharges storm water associated with industrial activity, routine blow-down water from three cooling towers, and emergency blowdown water from 14 additional cooling towers under NPDES Permit No. CA0081396, WDR Order No. 94-131. Routine cooling tower blowdown discharges from the 14 cooling towers were engineered to percolation pits and discharged to these pits under a Waiver of Waste Discharge Requirements issued by the Central Valley RWQCB on February 6, 1995. In August 1994, LLNL submitted to the Central Valley RWQCB a technical report discussing low-threat non-storm water discharges occurring at Site 300. The Central Valley RWQCB has not yet acted on LLNL's request for an NPDES permit for these discharges but provided written notification to LLNL that these discharges may continue until it issues the permit. LLNL submitted a revision to this technical report on December 1, 1995, indicating that several of the low-threat discharges were engineered to percolation pits and requested a waiver for these discharges and an NPDES permit for the remaining low-threat non-storm water discharges to surface water. The Central Valley RWQCB has not yet acted on these requests. The self-monitoring program for storm water discharges and associated analytical results are detailed in Chapters 7 and 14. The cooling tower self-monitoring program and associated analytical results are detailed in Chapter 14.

A Notice of Termination of coverage for the Site 300 Doall Road project under the general construction activity permit was submitted to the Central Valley RWQCB on February 8, 1995.

Site 300 operates under three additional permits and two substantive requirement agreements issued by the Central Valley RWQCB: WDR Order No. 93-100 pertains to ongoing post-closure monitoring requirements for landfill Pits 1 and 7; WDR Order No. 85-188 is a permit for operation of the domestic sewage lagoon, domestic septic tanks and associated leach fields, and the Class II surface

impoundments for high-explosives rinse waters, chemistry building waste-waters, and photo process rinse waters. A revised report of waste discharge to update WDR Order No. 85-188 was submitted at the request of the Central Valley RWQCB on June 29, 1994. Subsequently, LLNL received a Notice of Violation (NOV) on April 20, 1995, from the Central Valley RWQCB for the unpermitted discharge of wastes to the Class II surface impoundments. (This is reported in the tabulation of Environmental Occurrences **Table 2-5** at the end of this chapter under the date February 10.) As required by the NOV, LLNL submitted an additional Report of Waste Discharge for the operation of the Class II surface impoundments, updating information previously provided to the Regional Board. The Central Valley RWQCB is reviewing the submitted Reports of Waste Discharge and should issue new waste discharge requirements in 1996. We anticipate no further action on the NOV after issuance of the new WDR Order. The self-monitoring programs for WDR Order Nos. 93-100 and 85-188 and associated analytical results reported to the Central Valley RWQCB are described in Chapters 8 and 14.

WDR Order No. 91-052 (NPDES Permit No. CA0082651) is a permit to discharge treated ground water from the eastern GSA ground water treatment facility to Corral Hollow Creek. LLNL submitted a permit application to renew this NPDES permit to the Central Valley RWQCB on February 7, 1996. Two ground water treatment facilities at Site 300 (central GSA and Building 834) operate under substantive requirements issued by the Central Valley RWQCB and agreed to by LLNL as part of the CERCLA process. The substantive requirements for these facilities include proof-of-system and full-scale operation evaluations of the hardware, monitoring of physical properties in the subsurface and influent and effluent chemical concentrations, and regular reporting to the regulatory agencies. The self-monitoring programs for the ground water treatment permit and substantive requirements are also discussed in Chapter 14.

Both the Livermore site and Site 300 are implementing Storm Water Pollution Prevention Plans that were adopted in May 1994. The Storm Water Monitoring Programs were implemented by January 1, 1993, as required by the California General Industrial Activity Permit. The Site 300 Storm Water Monitoring Program was updated July 1994 as required in WDR Order No. 94-131.

Inspections

The San Francisco Bay RWQCB inspected the Livermore site on July 18 and October 25, 1995, to observe LLNL cooling tower heat exchanger operation. On the basis of these inspections, LLNL was able to show wastewater from this operation could be adequately controlled with administrative and minor structural best management practices to ensure discharges did not reach the

storm drainage system. No findings or Notices of Violations (NOVs) resulted from this inspection.

The San Francisco Bay RWQCB staff also visited the Livermore site on September 6, 1995. Various water permitting issues were discussed and a tour was conducted of the areas of streambed work, the Drainage Retention Basin, and the cooling towers.

The Central Valley RWQCB met with LLNL staff on September 12, 1995, to gain a better understanding of LLNL's response to the NOV related to the discharge to Class II surface impoundments, to observe the surface impoundments that were reported leaking in June 1995, and to observe new CERCLA well location sites. The Central Valley RWQCB inspected Site 300 permitted operations on December 19, 1995, to observe repairs made to the Class II surface impoundment liner. No findings or NOVs resulted from these inspections.

Wastewater Permits

A Wastewater Discharge Permit from the LWRP provides for the continued discharge of LLNL sanitary and industrial effluent to the city sewer system. Permit No. 1250 (94-95) was in effect from September 1994 through September 1995, and renewal Permit No. 1250 (95-96) is effective from September 1995 to September 1996. Under the provisions of this permit, LLNL conducts a self-monitoring program at its outfall into the Livermore sewer system. Continuous daily, weekly, and monthly effluent sampling is performed to satisfy permit compliance requirements. The monitoring results of the LLNL effluent are reported monthly to the LWRP. LLNL is seeking an EPA exemption from continued compliance with the Categorical Standards, because we believe the categorical wastewater standards were not written or intended for research and development facilities. Therefore, self-monitoring of categorical processes, as well as writing of semiannual reports, were suspended by the LWRP until further notice.

The self-monitoring program, including a discussion of analytical results for this wastewater discharge, is detailed in Chapters 6 and 14. There were no NOVs for wastewater discharges during 1995.

LLNL renewed two permits issued by the LWRP for discharges of treated ground water to the sanitary sewer during 1995: (1) ground water discharge Permit No. 1508G (95-96) for discharge of sewerable waste from TFF and (2) ground water discharge Permit No. 1510G (95–96) for a sitewide treatability study. Discharges from TFF to the sanitary sewer are monitored quarterly and reported semiannually to the LWRP. Discharges to the sanitary sewer are monitored for the sitewide treatability study and reported annually. These self-monitoring

programs and the associated analytical results documenting compliance with the self-monitoring provisions of these permits are detailed in Chapter 14.

Inspections

LWRP personnel spent 2 days on site during 1995 in May and June. The May visit involved routine inspection and sampling of pretreatment discharges. In July, the LWRP inspectors returned accompanied by the EPA Region IX Enforcement Inspector on a 3-day inspection of LLNL. The inspection was part of a larger EPA audit of the LWRP. No findings or NOVs were issued by the LWRP or the EPA as a result of these inspections.

Streambed Alteration Agreements

California Department of Fish and Game (CDFG) issued five streambed alteration agreements for construction and maintenance projects within arroyos near Livermore site facilities during 1995. On May 22, 1995 , LLNL submitted an application for the Electrical Power Distribution System Retrofits and Upgrades (EPSRU) project to cross Arroyo Las Positas in both the northwest and northeast corners of the site. The agreement for this project is effective June 1, 1995, through June 1, 1996. On May 24, 1995, LLNL submitted an application for work conducted in Arroyo Mocho (located 8.5 miles southeast of LLNL on an easement road off Mines Road, at the 5.65-mile road marker) to repair damage to a utility access road caused by mudslides. The agreement for this project was effective July 1, 1995, through September 1, 1995. On June 9, 1995, LLNL submitted a streambed alteration agreement for emergency work that occurred in Arroyo Seco (covering an area located west of the LLNL southwest entrance off of East Avenue to the Vasco Road crossing) from March 29, 1995, through April 5, 1995, to repair storm damage. The work was conducted on verbal approval provided by the CDFG warden on March 28, 1995. On July 28, 1995, LLNL submitted an application for culvert removal and outfall repairs in Arroyo Las Positas. The culvert was removed at the northeast corner of the site where Arroyo Los Positas enters LLNL and along the east perimeter of the site east of Building 661. Repair on the outfall was conducted at the northeast corner of LLNL, where the arroyo turns north and moves toward Patterson Pass Road.

The streambed alteration agreement for this project was effective July 30, 1995, through September 30, 1995. Finally, an application was submitted on August 10, 1995, for bank stabilization in Arroyo Las Positas to accommodate increased storm water discharge flows as a result of site improvements associated with the construction of Decontamination Waste Treatment Facility and the Mixed Waste Management Facility. The streambed alteration agreement for this project is effective from October 1, 1995, through October 1, 1996.

CDFG issued four streambed alteration agreements for construction and maintenance projects impacting the natural drainage at Site 300. On November 7, 1994, CDFG issued a 5-year maintenance streambed alteration agreement that allows for the removal of vegetation in Corral Hollow Creek. The vegetative growth results from the discharge of treated ground water from the eastern GSA treatment facility (Site 300) and must be removed to prevent flooding of California Department of Forestry property south of the GSA. On May 22, 1995, CDFG issued a 5-year maintenance agreement for work in the LLNL Site 300 drainage channels. A one-time agreement was issued on February 21, 1995, to extend a fire trail across Elk Ravine. On December 8, 1994, a streambed alteration agreement was issued for installation of water monitoring samplers in tributaries to Corral Hollow Creek. The agreement was effective from December 8, 1994, through October 1, 1995.

Inspections

CDFG personnel visited the Livermore site on March 28, 1995, to determine the need for streambed alteration agreements for three projects: (1) utility access road repair work impacting Arroyo Mocho, (2) repair of the Patterson Pass bridge abutment and nearby bank at Arroyo Las Positas, and (3) emergency work in Arroyo Seco. As a result of this visit, the CDFG warden requested that LLNL obtain a streambed alteration agreement for the access road repairs, the warden verbally approved the Arroyo Seco emergency work, provided that an application for an alteration agreement will be filed after the work is completed, and decided that the bridge abutment maintenance did not require an agreement. On June 15, 1995, CDFG personnel inspected the sites of the proposed utility access road repair near Arroyo Mocho and the culvert removal and outfall repairs in Arroyo Las Positas.

CDFG personnel visited the Livermore site on April 12, 1995, to provide guidance on three projects in or near streambeds: debris removal from the Arroyo Seco; North Buffer Zone Channel repairs; and the crossing of Arroyo Mocho to the LLNL Mocho pumping station. The warden agreed with the proposals for the work and asked LLNL to submit an application for a Streambed Alteration Agreement.

CDFG personnel visited Site 300 on May 18, 1995, to determine the need for a streambed alteration agreement for work proposed in the 832 Canyon. CDFG indicated a streambed alteration agreement would be required for the work. The agreement application will be submitted in 1996.

CDFG personnel visited the Livermore site on August 22, 1995, to provide guidance for culvert removal and erosion repair, construction of the Decon-

tamination and Waste Treatment Facility (DWTF) outfall structure, and removal of four culverts near Hertz Hall (Building 661). Different designs for rip-rap at the DWTF outfall were discussed. The warden agreed with LLNL proposals for the work, and suggested that the riprap at DWTF be extended further along the banks to prevent erosion.

No violations were reported by CDGF during these visits.

Nationwide Permits

LLNL notified the Army Corps of Engineers and obtained a waiver of water quality certification from the San Francisco Bay RWQCB for one project discharging dredge or fill materials into navigable waters. On August 11, 1995, LLNL submitted a courtesy notification to the Army Corps of Engineers for maintenance and repair work in Arroyo Las Positas that was considered permitted under Army Corps of Engineers Nationwide Permit (33 CFR, Part 330), pursuant to Section 404 of the Clean Water Act (33 U.S.C. 1344) and Section 10 of the River and Harbors Act of 1899 (33 U.S.C. 403). The provisions of the Nationwide Permit require the project proponent to obtain a Clean Water Act Section 401 water quality certification stating that the project will not violate state water quality standards. On August 9, 1995, LLNL submitted a request for a waiver of Water Quality Certification to the San Francisco Bay RWQCB. The San Francisco Bay RWQCB issued the waiver of the Water Quality Certification on September 19, 1995. No action was required of the Army Corps of Engineers.

Inspections

No inspections were conducted in 1995 by the Army Corps of Engineers.

Injection Wells

In 1995, LLNL registered with EPA for the first time 32 active and 20 inactive Class V injection wells at Site 300. The majority of the active injection wells are septic systems and percolation pits receiving small volumes of process waste, such as boiler blowdown and cooling tower blowdown.

Inspections

No inspections were conducted by EPA in 1995.

Building Drain Repair Project

In 1995, LLNL completed the $2.1 million Building Drain Repair (BDR) project. This project was charged with performing sitewide repairs identified by the Building Drain Investigation Project and prepared necessary documentation to

bring LLNL and Site 300 in compliance with the NPDES Storm Water requirements imposed by the RWQCBs in 1991. Drains discharging to improper destinations were removed or redirected in accordance with currently mandated regulatory requirements. If the discharge was not redirected or removed, it was permitted under provisions mandated by storm water regulatory requirements. Nearly 600 actions were performed at the Livermore site (320 repairs, 196 floor drains stenciled) and Site 300 (77 repairs).

Permit and repair work for the Livermore sitewide storm water permit was approved by the San Francisco Bay RWQCB on August 25, 1995, ahead of the regulatory deadline maintaining regulatory compliance for the site. All requested documentation was submitted and identified repair work was completed by December 22, 1995, maintaining Site 300 regulatory compliance. This work is being driven by the Porter-Cologne Water Quality Control Act and NPDES Stormwater Requirements for Industrial Facilities. Building drain management of over 25,000 drain sources and destinations has now become the responsibility of Plant Engineering's Technical Support Group. All future drain additions and modifications are being tracked with a drain permit system as an infrastructure management function. Environmental drain discharge guidance support will continue to be the responsibility of the Environmental Protection Department.

The BDR project was also responsible for developing guidance and support documentation to aid in future training and facility support. A major cultural shift in peoples' thinking and heightened awareness of cumulative impacts of water-related discharges to ground resulted from project interactions with program staff. The sitewide storm water map for the Livermore facility was updated to better depict storm water infrastructure.

Sanitary Sewer Rehabilitation Project

The $5 million Sanitary Sewer Rehabilitation project was completed in 1995. This project was charged with performing sitewide sewer infrastructure repair activities identified by a 1989 Conceptual Design Report. This report and subsequent closed circuit TV work identified sanitary sewer line deficiencies by a point rating score allowing prioritization of lining, point repair, and manhole rehabilitation activities. This resulted in an 88% reduction in infiltration and improper inflow to the sanitary sewer.

Specifically, this project lined 7300 linear meters of pipe and completed 130 point repairs throughout the facility. Forty-two laterals and 150 cleanouts were installed to allow better access to the sanitary sewer system. Ten new manholes were installed and 50 manholes were lined with fosrock to prevent leakage. The sitewide sanitary sewer map for the Livermore facility was updated to reflect rehabilitated sanitary sewer infrastructure.

Tank Management

LLNL manages its tanks, underground storage tanks (USTs), and aboveground storage tanks (ASTs) through the use of underground tank permits, tank integrity testing, monitoring plans, operational plans, closure and leak documentation, the Tank Upgrade Project, remedial activities, and inspections. Those topics are discussed in the following sections.

Underground Tank Permits

Underground tanks contain diesel fuel, gasoline, waste oil, and potentially contaminated wastewater; aboveground tanks contain diesel fuel, insulating oil, TCE, and contaminated wastewater. Some of the wastewater systems are a combination of underground storage tanks and aboveground storage tanks. **Table 2-4** tabulates tank status as of December 31, 1995.

Table 2-4. Status of in-service tanks, December 31, 1995.

Tank type	Livermore site			Site 300		
	Permitted	No permits required	Total	Permitted	No permits required	Total
Underground storage tanks						
Diesel fuel	8	0	8	4	0	4
Gasoline	2	0	2	1	0	1
Waste oil	1	0	1	0	0	0
Wastewater	5	37	42	0	10	10
Subtotal	**16**	**37**	**53**	**5**	**10**	**15**
Aboveground storage tanks						
Diesel fuel	0	27	27	0	12	12
Product	0	13	13	0	4	4
Wastewater	7[a]	87	94	0	15	15
Subtotal	**7**	**127**	**134**	**0**	**31**	**31**
TOTAL	**23**	**164**	**187**	**5**	**41**	**46**

[a] These seven tanks are situated at the LLNL Treatment, Storage, and Disposal Facility and are operated under interim status as part of the RCRA Part B permit application.

As a point of clarification, radioactive wastewater tanks are included in the wastewater tanks category. Radioactive wastewater is aqueous waste that contains radionuclides with gross alpha, gross beta, gamma, or tritium levels that are at or above the radiological limits specified in DOE Order No. 5400.5 *Radiation Protection of the Public and the Environment*. Wastewater that contains radionuclides below those specified above can be labeled and managed as radioactive by the programs as a best management practice.

The number of USTs requiring tank operating permit fees during all or part of 1995 at the Livermore site decreased by 10, from 28 in 1994 to 18 in 1995. The 18 tanks for which fees were paid consisted of 8 diesel, 1 waste oil, 2 gasoline and 7 wastewater retention USTs. The 16 permitted USTs noted in **Table 2-4** do not include 2 wastewater retention tanks with which we began the closure process in 1995.

At the end of 1995, Site 300 had a total of five underground petroleum product tanks in service: four diesel storage tanks and one gasoline storage tank. No diesel USTs were closed in 1995. Fees were paid for five tanks during 1995 as noted in **Table 2-4**.

Tank Integrity Testing

Under the tank leak-tightness testing program, single-walled hazardous waste and hazardous product USTs are tested to determine structural integrity in accordance with requirements established in state and federal regulations. The underground portions of tank systems are tested (as a whole or by component parts) using methods that may include precision tests, dye tests, helium-injection detection, and hydrostatic tests. All leak-tightness test results for regulated systems are provided to Alameda County Environmental Health Services or San Joaquin County Public Health Services.

Two diesel USTs and five wastewater retention USTs at the Livermore site and three wastewater retention USTs at Site 300 were tested in 1995 as part of the state and federal requirements for annual testing of single-walled USTs. The new replacement gasoline UST at Site 300 was not tested in 1995 because it is double-walled with continuous leak detection, as are the four diesel USTs.

Closure and Leak Documentation

Closure requirements for hazardous USTs include the preparation and approval of a closure plan for the system, quarterly reports if leaks have been identified, and a report upon completion of closure activities. The closure plans must include a detailed review of the uses of the tank, a sampling plan, a site plan, and other information to verify that no environmental contamination has occurred or, if it has occurred, to ensure its cleanup. Hazardous waste ASTs must also meet regulatory requirements for closure plans, field activities, and closure reports.

A total of 22 closure plans were prepared in 1995 for tank systems (or portions of systems) that were taken out of service, previously removed (but not officially closed), or expected to be removed from service. Four of these closure plans were for regulated hazardous product, hazardous waste, or mixed waste USTs and were submitted to regulatory agencies. (A mixed waste UST stores waste that has the characteristics of both hazardous and radioactive waste.) One closure plan has been approved; the other three are pending approval. The 18 remaining closure

plans were prepared for aboveground hazardous and nonhazardous waste tank systems as a part of LLNL's best management practices. Thirteen of these were approved, and the five remaining are awaiting approval.

Upon completion of closure activities, closure reports for hazardous product, hazardous waste, and mixed waste USTs must be submitted to the regulatory agencies for review and approval. Two closure reports for hazardous product USTs were submitted to regulatory agencies for review in 1995. Both are awaiting approval in 1996. Three additional closure reports were in final review at year end and will be forwarded to regulatory agencies upon completion. Seven closure reports were prepared in 1995 for aboveground hazardous product tanks, two of which were approved as a part of LLNL's best management practices.

In 1995, LLNL submitted unauthorized release (leak)/contamination site reports to the regulatory agencies for three regulated UST systems. All leaks occurred at the Livermore site. Unauthorized release/contamination from a diesel UST was discovered based on soil sample results taken during tank closure. The results indicated diesel contamination. One unauthorized release report was initiated during the removal of a wastewater retention tank system's piping. The third release was identified when contamination was discovered in a soil sample taken from beneath a wastewater retention tank that is in the process of being closed.

Tank Upgrade Project

In fiscal year 1992, LLNL received funding for 4 years to upgrade or close approximately 126 tanks in accordance with existing local, state, and federal tank regulations or to decrease the potential for environmental contamination as the result of a release from a tank or its appurtenances. These tanks include wastewater retention tanks (for nonhazardous, hazardous, mixed, and radioactive waste) and product retention tanks (for petroleum products). In fiscal year 1993, additional funding was granted to provide overflow and spill protection to aboveground oil-filled electrical equipment (e.g., transformers) and additional aboveground petroleum tanks, resulting in a revised total of 214 tanks or transformers being closed or upgraded. In fiscal years 1994 and 1995, the remaining nonhazardous tank systems were dropped from the overall scope, reducing the number of tanks and transformers to 158. As of December 1995, construction was completed for 116 tanks, construction is in progress for 27 tanks, design was completed for 146 tanks, and design is in progress for 12 tanks.

Remedial Activities

Previous Environmental Reports have discussed the leakage of tritiated rinse water from a UST into the Building 292 area subsurface. In 1995, approval was received from the Alameda County regulatory agency to seal the UST in place with concrete. The UST was filled with concrete and the ends of the piping were

sealed on September 6, 1995, and the nearby piezometer UP-292-001 was pressure grouted and sealed in place on September 25, 1995.

The data collected for the Building 292 Area have been incorporated into a vadose-zone computer model to provide estimates of tritiated moisture movement within the subsurface. The model has been verified with experimental results, and work is in progress to assign values to locations where there are no measured data.

Inspections

For every installation and closure of hazardous waste, mixed waste, and hazardous product USTs, there is an inspection in which a representative from Alameda County Environmental Health Services (for the Livermore site) or San Joaquin County Public Health Services (for Site 300) participates. For 1995 there were 13 inspections by the former and no inspections by the latter. No NOVs or notices of deficiency were received as a result of any of these inspections.

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) provides the framework at the federal level for regulating the generation and management of solid wastes, including wastes designated as hazardous. Similarly, the California Hazardous Waste Control Act (HWCA) sets 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 now works solely with the Department of Toxic Substances Control (DTSC) on compliance issues and in obtaining hazardous waste permits.

Hazardous Waste Permits

The Livermore site hazardous waste storage and treatment management units continued to operate under interim status provisions (ISD CA2890012584) while DTSC continued to review and consider the LLNL Part B permit application. Waste management units include container storage, tank storage, and various treatment processes (e.g., wastewater filtration, blending, and size reduction). LLNL also submitted a revised Health Risk Assessment in November 1995 in support of this permitting action.

Work also began in 1995 on the development of a Part B permit application supplement for the Decontamination and Waste Treatment Facility (DWTF), construction of which is slated to begin in September 1997. The DWTF will be constructed in order to consolidate, replace, upgrade, and augment existing LLNL waste management capabilities. In order to become more familiar with

LLNL operations, permitting staff from DTSC visited the Livermore site on March 28, 1996, and toured existing waste management facilities as well as the proposed location of DWTF. The permit application effort will culminate with a submittal to DTSC in June 1996 with an anticipated permit issuance in August 1997.

The Site 300 Building 883 hazardous waste container storage area (CSA) continues to operate under the provisions of the Part B permit (Part B CA28990090002) issued by EPA and DTSC in November 1989, while DTSC considers renewal of the permit. LLNL provided additional information to DTSC in August 1995 to supplement the permit application. Permit renewal is anticipated in early summer of 1996.

Two new facilities were proposed for Site 300, and Part B permit applications were submitted for each facility. Additional information was provided to DTSC in September 1995 to supplement the permit applications. The Explosives Waste Storage Facility (EWSF) augments the storage capability at the Building 883 CSA by providing a separate dedicated facility to store explosives waste. The draft permit for both the EWSF and Building 883 were completed and, if no major issues are identified, should be issued by DTSC as final in early summer of 1996. The other facility is a new open burning/open detonation facility called the Explosives Waste Treatment Facility, EWTF) that will replace the existing Building 829 Open Burn Facility. The Building 829 Open Burn Facility for explosives waste continues to operate under an enforcement order received from DTSC in September 1993. LLNL anticipates issuance of the EWTF permit in fiscal year 1997.

Extremely Hazardous Waste Permit

Permit No. 2-13640 is required, pursuant to 22 CCR 67430.1, to transport extremely hazardous waste to an off-site hazardous waste disposal facility. As a condition of the permit, LLNL must prepare a list of extremely hazardous wastes (including concentration, quantity, packaging, proposed hauler, disposal facility, and proposed method of disposal) and submit it to DTSC two weeks before shipping any such waste. This permit must be renewed annually; the application for renewal was submitted in August 1995.

Inspections of Hazardous Waste Management Facilities

On April 26, 27, and May 9, 1995, Department of Toxic Substances Control (DTSC) Region 2 conducted a Compliance Evaluation Inspection at the Livermore site. The following locations were inspected: four of the five Hazardous Waste Management (HWM) facilities (Areas 612, 514, 233, and 693), five Waste Accumulation Areas (WAAs), 18 workplace accumulation areas (WPAAs), Buildings 141 and 113 aboveground hazardous waste storage tanks, and two conditionally exempt (CE) resin-mixing units. Also on May 9, 1995,

DTSC reviewed the following types of records: inspection logs, hazardous waste manifests, land disposal restriction notifications, annual (facility) reports, stored waste inventory, hazardous waste hauling licenses, interim status documents, hazardous waste facility operating logs, conditionally exempt treatment unit operating logs, contingency plans, and training records.

On May 9, 1995, DTSC held an on-site close-out meeting and delivered a Field Report of Violation identifying no violations and two Tiered Permitting Verification Inspection Reports also identifying no violations. (Although one observation was made during the 3 days of inspection, it was immediately corrected and no violations were cited.) A formal written report of the inspection was issued to LLNL on May 26, 1995.

On November 8 and 9, 1995, DTSC conducted a Compliance Evaluation Inspection of the Site 300 hazardous waste facilities. The following locations were inspected: Building 829 (Existing Open Burn Area), M-3 Waste Accumulation Area (WAA), Building 845 (Proposed Explosives Waste Treatment Facility [EWTF]), RCRA landfill pits 1 and 7, Building 819, Building 883 (Container Storage Area), Building 875 (Maintenance Shop Area and associated WAA), and Building 879 (Motor Pool Area). The following types of records were reviewed: inspections of the Building 883 Container Storage Area and WAAs, hazardous waste manifests, land disposal restriction notifications, contingency and emergency plans, and training records. No violations were noted during the inspection.

Hazardous Waste Reports for 1994 and 1995

Hazardous Waste Management's (HWM's) annual *Hazardous Waste Report—Mainsite* and *Hazardous Waste Report—Site 300* are required under 22 CCR 66264.75. These reports were completed and delivered to EPA on May 30, 1995, by the adjusted deadline. HWM's corresponding biennial reports, which cover 1994 waste-handling information, were completed and submitted to meet DTSC's adjusted April 1, 1995, deadline. The biennial reports are required under 40 CFR 262.41, 264.75, and 265.752.

Both the annual and biennial reports are maintained on file at LLNL and comprise four forms. The Identification and Certification form provides general facility information, including addresses, contacts, and general waste minimization information. The Generation and Management form includes "cradle-to-grave" tracking of each waste stream category. The Waste Received form includes descriptions and quantities of wastes that were received from off-site facilities (Site 300 and the Livermore Airport), and the Process System form includes waste quantities treated by each waste management unit on site.

Hazardous Waste Transport Registration

This registration is required, pursuant to 22 CCR 66263.10, to transport hazardous wastes over public roads (e.g., from one LLNL site to another). Conditions for registration include annual inspections of transport vehicles and trailers by the California Highway Patrol, special training and annual physical examinations for drivers, and annual submission of lists of transport vehicles and trailers to DTSC. The registration was renewed by DTSC in November 1995.

Waste Accumulation Areas

Beginning in January 1995, there were 44 Waste Accumulation Areas (WAAs) at the Livermore site and one WAA at the Livermore Airport. During the year, four WAAs were taken out of service and one WAA was put in service, leaving a total of 41 WAAs at the Livermore site and one WAA at the Livermore Airport. Program representatives conducted inspections at least weekly at all WAAs to ensure that WAAs were operated in compliance with regulatory requirements. In addition, Environmental Protection Department (EPD) personnel conducted biweekly, routine checks at all WAAs to help ensure that programs managed their WAAs and wastes in compliance with state and federal requirements. EPD personnel performed 828 biweekly WAA walkthroughs at the Livermore site and 21 biweekly WAA walkthroughs at the Livermore Airport during 1995. More than 2200 formal WAA inspections were conducted at the Livermore site and 52 at the Livermore Airport WAA. The EPD walkthroughs are informal checks of items such as capacity, labeling, and secondary containment. Formal inspections of these items are conducted by program personnel.

Beginning in January 1995 there were eight WAAs at Site 300. During the year, six WAAs were taken out of service, leaving two WAAs at Site 300. EPD personnel performed 112 biweekly WAA walkthroughs at Site 300 during 1995.

Medical Waste Permit

LLNL generates several types of medical wastes (previously identified as infectious wastes). In July 1991, LLNL registered with the Alameda County Environmental Health Services as a large-quantity generator of medical waste and submitted an application for a medical waste treatment permit for the Livermore site. Site 300 is a small-quantity generator and is therefore exempt from medical waste registration.

The Livermore generator registration and treatment application contained detailed information concerning the management and treatment of medical wastes generated by LLNL's biomedical research, Center for Chemical Forensics, and health services facilities. The registration for medical waste generation is issued annually and is currently valid through July 1996. The treatment permit for steam sterilization at the biomedical facilities was issued in August 1991 and is valid through July 1996.

Inspections

The Alameda County Department of Environmental Health conducted an inspection of LLNL's medical waste generator and treatment facilities at the Livermore site on August 29, 1995. No violations were noted at any of the facilities.

Building Inspections

Formal, detailed building inspections for each LLNL facility are conducted based on a schedule established by the Facility Manager and the appropriate Environmental, Safety and Health (ES&H) Team. The ES&H Teams are made up of environmental, safety, and health discipline specialists who assist LLNL to maintain compliance with ES&H requirements.

The inspections scrutinize handling and management of hazardous and radioactive wastes and waste streams, management and maintenance of WAAs, potential release pathways to the environment (e.g., storm and sanitary sewer drains, air), hazardous product storage areas, wastewater retention tank systems, operating equipment (e.g., vacuum pumps, transformers, capacitors, and baghouses), and laboratory and machine shop areas. An inspection report is prepared for a program or department, and follow-up checks are conducted to ensure implementation of recommendations or corrections. Walkthrough inspections are conducted on an as-needed basis. During 1995, the ES&H teams conducted 211 formal building inspections at the Livermore site. At Site 300, the team conducted 15 formal building inspections. Building inspections include buildings, trailers, and tents. EPD conducted 11 audits of the HWM facilities at the Livermore site and 11 audits of the HWM facilities at Site 300.

Site Evaluations Prior to Construction

Soil and debris from construction sites are evaluated for reuse and disposal. Rubble may be surveyed for radioactivity or analyzed, depending on the outcome of the evaluation. The soil is sampled and analyzed for potential radioactive or hazardous contamination. Soil is reused when possible (depending on analytical results) or disposed of according to established procedures. During 1995, environmental analysts conducted preconstruction site evaluations for 85 construction projects.

Toxic Substances Control Act

The management of polychlorinated biphenyls (PCBs) and asbestos waste are regulated under the Toxic Substances Control Act (TSCA). At LLNL, equipment containing PCBs is used in a totally enclosed manner until the equipment is taken out of service, at which time it is removed to HWM for disposal at an approved site. LLNL also conducts research and development activities using PCBs. Statistics for PCBs compiled in 1995 are kept on file, available for EPA

inspection. The PCB annual report, required under 40 CFR 761.180, is a record of PCB-containing equipment in service, taken out of service, or disposed of during the year. The State of California has also enacted regulatory requirements for PCBs and asbestos wastes. These wastes are reported in the Hazardous Waste Report, which is required by DTSC under 22 CCR 66264.75.

Inspections of Toxic Substances Control Act Facilities

On April 6, 1995, DTSC, on behalf of EPA Region IX, conducted a Toxic Substances Control Act (TSCA) inspection specifically for activities associated with polychlorinated biphenyls (PCBs) covered under 40 CFR 761. The following areas were visited during the inspection: B-517 (High Voltage Group), Building 194 (PCB transformer), Building 365 (BBRP Research and Development Activities, Building 222 (analytical laboratories), Building 625 (PCB storage facility), and Building 693 (PCB storage facility). The following types of records were reviewed: transformer inspection records, storage facility records and inventories, and several annual reports. No violations were determined as a result of this inspection. However, the September 5, 1995, report noted as a potential deficiency that "mixed" PCB containers had been stored for more than one year from their removal from service. The inspector also acknowledged that “there is extremely limited or nearly nonexistent disposal and treatment options” for this type of waste. DOE is working with the EPA and the U.S. Naval Nuclear Propulsion Program to develop a National Federal Facility Compliance Agreement to address this issue. LLNL will comply with the terms of this agreement once it is completed and issued.

National Environmental Policy Act

The National Environmental Policy Act (NEPA—42 U.S.C. 4321 et seq.) established federal policy for protecting environmental quality. The major method for 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 is issued when the 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 more in-depth NEPA review (i.e., preparation of either an EA or EIS). DOE NEPA implementing procedures (57FR15122) identify those categorical exclusions and the eligibility criteria for their application. If a proposed project does not clearly fit one of the exclusion categories, a DOE Action Description Memorandum is prepared to determine which type of assessment document may be needed.

Environmental Assessments/ Analyses Submitted to DOE

In 1995, LLNL prepared 19 categorical exclusion documents for DOE review to comply with NEPA. DOE issued one Finding of No Significant Impact in 1995 for the EA on the Mixed Waste Management Facility (MWMF), submitted earlier for DOE determination. Three draft EAs for proposed projects were submitted to DOE in 1995 for NEPA review and determination.

The 1995 *Draft Project-Specific Analysis for the Contained Firing Facility (CFF)* addressed the potential impacts from construction and operation of a facility that would contain the products of combustion from the testing of explosives at LLNL's Experimental Test Facility at Site 300. DOE is currently reviewing this draft analysis as an appendix to the 1996 *Draft Programmatic EIS for Stockpile Stewardship and Management (*SSM PEIS).

The 1995 *Draft Environmental Assessment for the Decontamination and Waste Treatment Facility* addressed the potential impacts of constructing and operating up-to-date replacement hazardous waste management facilities for handling, storing, disposing of, and treating hazardous, radioactive, and mixed wastes at the Livermore site. DOE is currently reviewing this draft and consolidating public review comments.

In addition, a draft project-specific analysis pertaining to the proposed National Ignition Facility (NIF) was prepared in 1995 by Argonne National Laboratory. Argonne's report addressed the potential impacts of constructing and operating the NIF. The NIF's goal is to achieve fusion ignition in the laboratory for the first time by using inertial confinement fusion (ICF) technology. DOE is currently reviewing this analysis as an appendix to the 1996 *Draft Programmatic EIS for Stockpile Stewardship and Management* (SSM PEIS).

Floodplain Management and Wetland Protection

Executive Orders 11988 (*Floodplain Management)* and 11990 (*Protection of Wetlands*), both dated May 24, 1977, require each federal agency to issue or amend existing procedures to ensure that the agency evaluates the potential effects of any action it may take in a floodplain (Order 11988) and to consider wetland protection in its decision making (Order 11990). DOE's Regulation (10 CFR 1022) outlines procedures for implementing these Executive Orders and states its policy that it should be implemented through existing NEPA review procedures when possible. LLNL applies the requirements of the DOE wetlands/floodplains policy and procedures through the NEPA review process for each proposed LLNL action. In accordance with DOE regulation, a separate public notice and floodplain/wetlands assessment may be required for certain proposed actions and would be prepared if no EA- or EIS-level NEPA documentation incorporating such assessments had been prepared. In 1995, there were no proposed LLNL actions that required such separate DOE assessments.

California Environmental Quality Act

The California Environmental Quality Act (CEQA—California Public Resources Code Sections 21000 et seq.) establishes state policy for protecting environmental quality. The goals of CEQA are achieved by requiring local and state governmental and quasi-governmental agencies to assess the potential environmental impacts of proposed actions for which they may have a decision-making role. This is done through the preparation of an Initial Study (IS), which leads to issuance of a Negative Declaration or a requirement to prepare an Environmental Impact Report (EIR). An EIR may also be prepared directly for projects that may have significant environmental impacts. Exemptions from needing to prepare an IS or EIR are available for certain categories of non-impacting activities.

Initial Studies and Environmental Impact Reports

No Initial Study or EIR documents were prepared by the University of California (UC) in 1995 on proposed projects for which the UC was the decision-making or lead agency.

Mitigation Measures

In November 1992, UC and LLNL made a commitment to implement 67 mitigation measures identified by the 1992 EIS/EIR Environmental Impact Statement and Environmental Impact Report for Continued Operation of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore (U.S. Department of Energy and University of California 1992a,b) and to provide annual reports on their implementation. The measures are being implemented in accordance with the approved 1992 Mitigation Monitoring and Reporting Program. The fiscal year 1994 annual report is dated December 1995; the next annual report will cover fiscal year 1995 activities.

Endangered Species Acts and Sensitive Natural Resources

LLNL must meet 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. For example, in implementing the Mitigation Monitoring and Reporting Program in 1995, biological assessment surveys were performed for special-status species at 32 LLNL project construction (ground disturbance) areas. Presence data for the San Joaquin kit fox (*Vulpes macrotis mutica*), American badger (*Taxidea taxus*), and burrowing owl (*Speotyto cunicularia*) were collected at each project location, and other applicable mitigation measures were implemented when required.

During 1995, no active San Joaquin kit fox dens were discovered, but three potential dens were found. Twelve occupied American badger dens were discovered, and two unoccupied dens were identified. Ten active burrowing owl dens were discovered (six at the Livermore site and four at Site 300), and two potential dens were identified. In addition, one new blue elderberry bush (*Sambucus caerula*) location was delineated at Site 300. One special-status animal

species, not previously known to occur on LLNL property, was observed in 1995: the Western spadefoot toad (*Scaphiopus hammondii)* was observed at Site 300.

In the fall of 1992, LLNL investigators began a project to establish new experimental populations of the large-flowered fiddleneck (*Amsinckia grandiflora*), a federally listed endangered plant species, into a portion of its designated critical habitat at Site 300. The investigators are also studying the causes of the species decline. This work was funded through 1995 by a Laboratory Directed Research and Development grant and is being conducted in collaboration with Mills College, representing the California Department of Fish and Game (CDFG), and UC Davis, with the approval of the U.S. Fish and Wildlife Service.

Researchers from Mills College and UC Davis made numerous trips to Site 300 between October 1994 and May 1995 to work with LLNL personnel on both the experimental and natural populations. The natural populations are located adjacent to the Building 858 Drop Tower (known as the Drop Tower population), and at a site one canyon to the west, which is known as the Draney Canyon population. The experimental populations are located near the Drop Tower natural population. On April 14, 1995, LLNL personnel counted 1114 mature plants in the Drop Tower population. Although this was down from the 1606 plants observed in 1994, it remains a robust population. On April 25, 1995, LLNL personnel counted 27 mature plants in the Draney Canyon population, up from the 16 plants counted in 1994. The census information was provided to the CDFG.

In 1992, artificial seeding was conducted at two locations. In 1993, one of the locations showed promise in sustaining an experimental population, therefore, all subsequent work focused on this location. In 1994, the experimental population at this location had a total of 248 mature plants as a result of additional seeding and transplantation. These plants were allowed to senesce naturally. On April 21, 1995, this population contained 403 naturally established mature plants. This experimental population has apparently successfully established itself and will be counted and managed with the existing two natural populations.

National Historic Preservation Act

The National Historic Preservation Act (NHPA), as amended through 1992, contains two primary sections that apply to federally operated and funded installations such as LLNL: Sections 110 and 106. Section 110 sets forth the broad affirmative responsibilities for balancing agency missions with cultural values. Its purpose is to ensure that historic preservation is fully integrated into federal agency programs. Section 106 (36 CFR 800) requires federal agencies to 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.

Consultation with a variety of agencies and interested parties continued or was initiated in 1995. Building on the consultation process begun in 1994, representatives of the State Historic Preservation Office (SHPO) visited LLNL. After touring some of the archaeological sites at Site 300, discussion focused on possible unique resources at LLNL and methods for resolving both long- and short-term cultural resource compliance issues. In addition, LLNL submitted a draft Programmatic Agreement to the DOE/OAK field office to forward to the SHPO and the Council for comment prior to signing an approved agreement. Native American consultation was initiated with a request for input to the development of a discovery plan to help implement the NHPA, as well as the American Indian Religious Freedom Act, the Native American Graves and Repatriation Act, and the Archaeological Resources Protection Act. Letters were sent to representatives of 12 local Native American groups and tribes identified by the state of California Native American Heritage Commission.

While awaiting finalization of the Programmatic Agreement, policies and procedures for conducting cultural resource management reviews and surveys of proposed projects in accordance with federal and state standards continue to be formalized and instituted into the framework of LLNL program activities.

LLNL participated in the following activities and initiatives in 1995:

- We undertook a major archaeological field survey for the Annual Site 300 Fire Trail Grading Project, which involved surveying approximately 160 km of fire trails at Site 300. Four previously unrecorded isolated historic cultural resources were located. An unrecorded and previously unidentified length of historic telegraph/electric pole was found but is not within the project boundaries. One previously identified site, the residential portion of the Carnegie archaeological site, was found to be within the boundaries of the project. This site will be protected from further impacts while it is undergoing the NHPA Section 106 process. The process will determine the site's eligibility to be listed on the National Register of Historic Places and what effects and impacts, if any, the project has on the resource. If adverse impacts are identified, then appropriate mitigation measures will be determined in consultation with all interested parties.
- Mapping of the residential portion of the Carnegie archaeological site was completed.
- We began installing permanent, surveyed markers for each recorded archaeological site at Site 300. This will not only allow more accurate mapping but will provide higher visibility for site locations to help promote site protection and preservation.

- Seventeen public presentations were performed (as wells as numerous tours and open houses) on the unique cultural resources found at LLNL.
- An oral interview was conducted with a former resident of the Corral Hollow Canyon, where Site 300 and the Carnegie archaeological site are located.

Department of Energy Tiger Team and Tiger Team Progress Assessment

DOE conducted a Tiger Team Assessment of LLNL environmental, safety, and health (ES&H) programs in 1990, and a followup Tiger Team progress assessment in November 1992. In July 1993, LLNL submitted a Draft Action Plan to DOE in response to this assessment. The 58 subtasks covering 24 Areas of Need in this Action Plan were incorporated as an addendum to the original Tiger Team Action Plan.

In 1995, LLNL made significant progress towards completing the 581 subtasks identified in its original seven-year Tiger Team Action Plan. Action items were prioritized and funded within budget constraints. As of December 31, 1995, 91% of these subtasks had been completed, about 1% are on schedule for completion, and 2% are considered late; 33 of the subtasks (the remaining 6%) are not funded or have been canceled because the remaining portion has a low priority based on its cost-to-benefit ratio or because of changes in standards or operations. Of the 58 subtasks in the Progress Assessment Area of Needs, 43 (74%) are complete, 10 are expected to be completed, and 5 will be canceled with no further action. At the end of 1995, LLNL closed the Tiger Team Project Office.

Agreement in Principle Program Activities

DOE established an Agreement in Principle (AIP) Program with the State of California in 1991 to improve openness and information transfer regarding environmental monitoring and impacts at DOE-operated sites in California. Two State agencies were responsible for implementing the State's program; the Department of Health Services had primary responsibility, but delegated to the State Water Resources Control Board responsibility for activities that addressed water resources. During 1995, LLNL cooperated with the State in a colocated direct radiation monitoring program using thermoluminescent dosimeters (TLDs) (see Chapter 12 for a description of LLNL's direct radiation program) and with discussions and data review regarding water monitoring at LLNL's Site 300. In addition, special efforts were initiated by DOE, LLNL, and the State to develop a greater sense of teamwork among all participants of the AIP Program. In late 1995, LLNL was notified that DOE would no longer be funding the California AIP Program. However, we have agreed with the Department of Health Services to maintain the program of colocated TLDs.

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 the spring of 1994, Operations and Regulatory Affairs Division (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 the presence and number of individuals. At LLNL, the San Joaquin kit fox, burrowing owl, and American badger receive special consideration during ground-disturbing activities in order to ensure their protection, if present.

The MOLE was used successfully both on and away from the LLNL site during the 1995 assessment season. The most significant results were obtained on a research trip to a Department of Interior resource conservation area in Idaho. During the trip 22 burrowing owl dens were examined, and the eggs, young, and adults were videotaped in their dens. Numerous other ecological findings accompanied these discoveries, such as the average tunnel length to the nest, underground prey stockpiling for the young, and passive receptivity by the owls to the MOLE vehicle.

MOLE improvements for 1995 included a lowered profile, high-output light emitting diodes (LEDs) for illumination, and a longer tether for more remote viewing of den systems. Use of the MOLE will continue in 1996, and further development of this versatile tool is planned.

Meteorological Tower Upgrades

In response to recent Bay Area Air Quality Management District (BAAQMD) recommendations to monitor meteorological conditions with greater sensitivity, LLNL installed a new set of sensors at the Livermore site during October 1995. The new wind speed and direction sensors respond to much lower wind speeds, which frequently occur at LLNL. The temperature sensors are now housed in fan-aspirated solar shields to more accurately measure temperature when the winds are low. On February 1, 1996, after running the old and new sensors side-by-side for comparative purposes, meteorological monitoring for the site was changed to the new sensors.

10 CFR 834 Proposed Rule

Under the Price Anderson Amendment Acts, 10 CFR 834 is a proposed rule governing radiation protection of the public and the environment. This rule would codify certain aspects of existing DOE orders. LLNL has provided review and comment on many aspects of this proposed regulation. In 1995, guidance for

preparation of the Environmental Radiological Protection Plan required by the rule was drafted by a DOE committee. LLNL provided comments on each version of the guidance that was made available. The proposed rule is expected to be finalized in late-1996.

Necessary and Sufficient Standards

The Necessary and Sufficient Set of Standards Closure Process was developed by the Department Standards Committee of DOE to provide a mechanism for DOE to move to standards-based operations. The Committee commissioned pilot demonstrations to be carried out at selected DOE sites, of which LLNL was one. The scope of the pilot demonstration at LLNL concerned the radiological waste management activities, including low-level waste, transuranic waste, and the radiological component of these types of mixed waste. This scope was chosen to exercise the process on a complex activity at a multiprogrammatic site. The pilot demonstration did not include consideration of the hazardous component of mixed waste; the design and construction of facilities; or institutional activities that are performed at LLNL's Hazardous Waste Management facility on radioactive waste (such as security, radioactive materials accounting and management, emergency response, on-site transportation of waste, and fire safety). Work in these areas where the process was not applied will be done to the existing institutional standards and procedures.

The goals of the pilot demonstration were to consolidate radioactive waste management activities at LLNL under a set of standards that controls risk to workers, the public, and the environment at or below industry accepted levels; reduces costs; increases productivity; and maintains public confidence and protection.

The work of managing radioactive waste was assessed to determine the associated hazards, relative to the safety of the worker, the public, and the environment. The assessment was performed by operational and subject matter experts from the University of California and DOE who work at LLNL. The pilot demonstration members applied their individual and collective judgment and expertise and, working together and with the approval authorities, chose the set of standards and implementing assumptions that will protect the worker, the public, and the environment when the standards are implemented. In general, performance-based standards were chosen except where the standard was a law or rule or in the area of nuclear safety management. With respect to nuclear safety management, both implementing and management standards were chosen.

The approved set of standards and a detailed description of the process for selecting the set can be found in *Environmental Health and Safety Standards for Radioactive Waste Management Activities at Lawrence Livermore National Laboratory*,

February 1996 (UCRL-AR-122882). The contract between DOE and the University of California for the operation of LLNL will be modified to include these standards and the standards will be implemented.

Natural Bioremediation of Underground Fuel Contamination

LLNL led a team of researchers from LLNL and four University of California (UC) campuses in a collaborative study of underground contamination from leaking fuel tanks. The study, performed for the California State Water Resources Control Board (SWRCB), found that, once fuel leak sources have been removed, fuel contamination generally does not spread far from the leak site. Given time, naturally occurring microbes in the soil and ground water will usually break down most of the pollutants before they can reach a source of drinking water. On the basis of this study, the SWRCB is revising its overall ground water cleanup policy, ranking cleanup sites by their risk to drinking water sources and selecting appropriate cleanup techniques based on risk. As a result of the study, the SWRCB offered interim guidance in December 1995 to the State's Regional Water Quality Control Boards to halt pump-and-treat cleanup activities in cases exhibiting low risk to human health or the environment and instead institute monitoring programs to ensure contamination is stable. This risk-based bioremediation approach is expected to save the state and tank owners billions of dollars in cleanup costs and return thousands of acres of land to beneficial use sooner.

Cleanup Process for California's Leaking Underground Fuel Tanks (LUFTs)

As a follow-on to the foregoing item, LLNL is leading a team including UC Davis, UC Santa Barbara, UC Los Angeles, and UC Berkeley, to implement recommendations for a tiered risk-based decision-making approach for the cleanup of leaking underground fuel tanks (LUFTs). The work is performed under a contract with the State Water Resources Control Board (SWRCB). This new approach on LUFT cleanup includes the use of a modification of the American Society for Testing and Materials' Risk-Based Corrective Action (RBCA) decision making process, and the first priority use of natural attenuation for fuel hydrocarbons.

This new approach will be used to streamline and reduce costs for the investigation and cleanup of California's 21,000 leaking underground fuel tanks. This approach will consider the following parameters at each tank site: 1) natural attenuation processes; (2) existing and probable beneficial water uses; (3) source terms; and (4) plume stability. The LUFT team will oversee the demonstration of cost-effective technologies for measuring these parameters at nine U.S. Department of Defense (DoD) military bases in California. DoD LUFT pilot sites will be selected jointly with the SWRCB, and demonstration costs will be paid by the military. The potential cost savings from the implementation of this new approach in California are estimated to be $3 billion.

Cal/EPA Environmental Technology Certification Program

The California Environmental Protection Agency (Cal/EPA), through the Department of Toxic Substances Control (DTSC), has contracted with LLNL to provide performance evaluations for its hazardous waste environmental technology certification program. The program was created for two principal reasons: first, to simplify and expedite the permitting of new technologies for cleanup in California, and, second, to assist California environmental companies to sell their products and services. DTSC is looking toward LLNL as a source of scientific expertise in certain technical areas to (1) evaluate and verify a proponent's technology, and/or (2) to do peer reviews of evaluation reports. The LLNL site is also available as a test bed for private companies to test their technologies for certification.

DTSC reviews each vendor application to determine whether the technology is ready to be certified and estimates the cost of certification. DTSC collects the fee from the vendor, selects members and a chairperson for the teams, and organizes the evaluation and peer review efforts.

The first technology evaluated by LLNL was a field immunoassay system made by OHMICRON for polynuclear aromatic hydrocarbons (PAHs). The second technology is the Ray-O-Vac zinc-manganese rechargeable battery. Other evaluations are in progress.

Environmental Occurrences

Notification of environmental occurrences is required under a number of environmental laws, regulations, and the 5000-series of DOE Orders including DOE Order 5000.3B, *Occurrence Reporting and Processing of Operations Information*, and DOE Order 5484.1, *Environmental Protection, Safety, and Health Protection Information Reporting Requirements*. DOE Order 5000.3B, effective February 22, 1993, provided guidelines to contractor facilities regarding categorization and reporting of environmental occurrences to DOE. The order divides occurrences into three categories: emergencies, unusual occurrences, and off-normal occurrences. DOE Order 232.1, which will replace DOE Order 5000.3B, is pending acceptance by UC Regents. DOE Order 151.1, which will replace the 5500-series DOE Orders, is also pending UC Regents acceptance.

EPD responds to all reports of spills or other environmental occurrences through a well-established reporting process. EPD created a 7-day-a-week, 24-hour-a-day, on-call, rotational position called the Environmental Duty Officer (EDO), who can be reached by pager or by cellular phone at any time. Environmental analysts and the EDO cooperate in providing advice on immediate cleanup and monitoring necessary to protect the environment, in evaluating reporting requirements, and gaining concurrence from LLNL management on the process for notifying local, state, and federal regulatory agencies. The EPD response to environmental occurrences is part of the larger

LLNL On-Site Emergency Response Organization that also includes representatives from Hazards Control, Health Services, Plant Engineering, Public Affairs, Safeguards and Security, and Site 300.

EPD responded to 14 incidents that required agency notification during 1995. Two of the incidents were categorized as unusual occurrences according to the DOE Order 5000.3B implementing procedures. The other incidents were reported as off-normal occurrences. Of the two unusual occurrences, one began as an off-normal occurrence (July 12, 1995), but was later changed to an unusual occurrence (August 7, 1995). None of the incidents, summarized in **Table 2-5**, caused any adverse impact to human health or the environment. Agencies notified of the incidents described above included DOE, Alameda County Health Care Services Agency, San Joaquin County Public Health Services, San Francisco Bay Regional Water Quality Control Board (RWQCB), Central Valley RWQCB, National Response Center, Office of Emergency Services, and Department of Toxic Substances Control (DTSC).

Contributing Authors Acknowledgement

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Table 2-5. Tabulation of environmental occurrences, 1995.

Date[a]	Occurrence category	Description
Jan 18	Off-Normal	The Tank Assessments and Guidance Group (TAGG) received analytical data indicating that soil removed during the removal of underground diesel tank 271-D1U1 was contaminated with 340 mg/kg Total Petroleum Hydrocarbon-Diesel (TPH-D) at the Livermore site. The Alameda County Health Care Services Agency was notified of the release. A written report to outside agencies in a non-routine format meets the requirements for an Off-Normal Occurrence.
Jan 31	Off-Normal	Due to an oversight, the F006 waste code was not included in the LLNL Part A permit application at the Livermore site. The F006 waste code was added for both storage and treatment to the revised LLNL Part A and B permit application, which was submitted to DTSC. However, it was discovered on January 31, 1995 that an F006 waste had been brought to the Hazardous Waste Management (HWM) 612 Facility. As a result, HWM submitted a letter to DTSC notifying them of the incident. A written report to outside agencies in a non-routine format meets the requirements for an Off-Normal Occurrence.
Feb. 10	Unusual	The accidental discharge of a hazardous concentration of 1,2-dichloroethane (DCA) into the Site 300 Class II explosive wastewater surface impoundment was discovered and confirmed during the review of some old analytical reports from retention tank 827-R2A1, dated June 29, 1994. Subsequently the Central Valley RWQCB issued an NOV on April 20, 1995. To minimize the potential for future discharges of waste not compatible with the Site 300 Class II explosive waste-water surface impoundments, the Chemistry and Materials Science Directorate now requires that all wastewater be held pending the receipt and evaluation of analytical data from the samples of the influent waste stream. The National Response Center, Office of Emergency Services, San Joaquin County Public Health Services, Office of Emergency Services, and DTSC were notified. Any occurrence under any agreement or compliance area that requires notification to an outside regulatory agency within four hours or less meets the requirements for an Unusual Occurrence.
March 15	Off-Normal	Approximately 75,000 gallons[b] of potable water was released at Building 132 at the Livermore site when a contractor accidentally hit a fire hydrant causing the rupture of the water line. The main water supply system serving this area was immediately turned off. The quantity of water released violated a provision of LLNL's Waste Discharge Requirement 88-075, which requires notification to the San Francisco Bay RWQCB. A written report to outside agencies in a non-routine format meets the requirements for an Off-Normal Occurrence.
Mar 20	Off-Normal	LLNL personnel observed an oil sheen on water flowing into a storm drain at Site 300. It was determined that the oil sheen originated from the steam cleaning pad operation at Building 879 and that the water in the steam cleaning pad could have been blown over the top of the secondary containment berm by high winds occurring at the time of the release. The Central Valley RWQCB was notified because the sheen had an identifiable source, and it entered a surface water course. A written report to outside agencies in a non-routine format meets the requirements for an Off-Normal Occurrence.
May 5	Off-Normal	A hydraulic hose on a crane ruptured, releasing approximately 31 gallons of hydraulic oil. The Plant Engineering Riggers were operating the LLNL-owned crane on the west side of Building 436 at the Livermore site when the hose ruptured. The spill occurred on asphalt and was quickly contained by spreading Dry-Sorb on the spilled oil. The contaminated material was containerized in 55-gallon drums. A release of any oil greater than 10 gallons and less than 100 gallons meets the requirements for an Off-Normal Occurrence.
June 1	Off-Normal	Shipment papers for a drum of flammable liquid that was shipped to Romic Chemical had not been filled out properly. The drum was mistakenly labeled as a pyrophoric metal. The error was discovered by HWM personnel during a routine quality assurance review on June 1, 1995. Evidence of improper classification of hazardous materials transported offsite meets the requirements for an Off-Normal Occurrence.

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Table 2-5. Tabulation of environmental occurrences, 1995 (concluded).

Date[a]	Occurrence category	Description
June 19	Off-Normal	A 5-gallon carboy, identified as aqueous organics, pH 7, was sent to ENSCO on June 7, 1995. ENSCO's analytical indicated that the aqueous liquid had a pH 14. ENSCO sent a modified Hazardous Waste Manifest to DTSC, which described the discrepancy. Evidence of improper classification of hazardous materials transported off site meets the requirements for an Off-Normal Occurrence.
July 12	Off-Normal	Fourteen soil samples were collected by TAGG from beside Underground Storage Tanks (USTs) 419-R1U4 and 419-R1U5 at the Livermore site. This activity was part of the closure requirements to characterize the surrounding fill material before it was excavated. The samples were analyzed for gross alpha, beta, and tritium. Four samples showed gross alpha activity greater than non-detect, three samples showed tritium greater than non-detect, and two samples showed gross beta greater than non-detect. The Alameda County Health Care Services Agency was notified of the release. A written report to outside agencies in a non-routine format meets the requirements for an Off-Normal Occurrence.
Aug. 7	Unusual	(Upgrade of the July 12 occurrence from Off-Normal to Unusual.) A Notice of Violation was received from the Alameda County Health Care Services Agency by LLNL for failure to submit the Unauthorized Release Contamination Site Report for USTs 419-R1U4 and 419-R1U5, within the five-day period. The report was mailed within the five days, but was not received by Alameda County Health Care Services Agency. Any compliance activity for which a Notice of Violation has been received from the relevant regulatory agency that a site is considered to be in noncompliance meets the requirements for an Unusual Occurrence.
Sept. 20	Off-Normal	Five soil samples were collected by TAGG beneath UST 612-R1U2 secondary containment at the Livermore site as part of the requirements for closure in-place. All five soil samples, collected through a hole drilled in the bottom of the secondary containment, showed tritium above soil background levels of 5 pCi/gm. Sample analysis results ranged from 6.8 pCi/gm to 34 pCi/gm. The Alameda County Health Care Services Agency was notified of the release. A written report to outside agencies in a non-routine format meets the requirements for an Off-Normal Occurrence.
Oct. 25	Off-Normal	Approximately 80,000 gallons of swimming pool water was discharged to ground due to a leak in the swimming pool at the Livermore site. The residual chorine was measured to be between 2 and 3 parts per million. The leak was repaired on September 26, 1995. The San Francisco Bay RWQCB was notified of the release. A written report to outside agencies in a non-routine format meets the requirements for an Off-Normal Occurrence.
Nov. 1	Off-Normal	800 gallons of bulked waste was shipped as California-only regulated waste. The waste was determined to be F-Listed when tested by the off- site treatment facility. The tank and its contents were shipped back to LLNL. It was determined that 55 gallons of F-Listed waste had been bulked with the California-only regulated waste. Evidence of improper classification of hazardous materials transported offsite meets the requirements for an Off-Normal Occurrence.
Nov. 22	Off-Normal	A street sweeper released hydraulic oil throughout the southeast corner of the Livermore site. It was determined that approximately 18 gallons of hydraulic oil was released through a leak in the hydraulic line on the street sweeper. A release of any oil greater than 10 gallons and less than 100 gallons meets the requirements for an Off-Normal Occurrence.

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

b 1 gallon = 3.785 liters. English units are used in this table for consistency with information in the original documentation.

3. Environmental Program Information

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Introduction

LLNL is committed to environmental compliance and accountability. The Environmental Protection Department (EPD) leads efforts in this regard. This chapter begins with a description of the missions and activities of EPD and its three divisions. Then Performance Measures (PMs) used by DOE to evaluate the Laboratory's environmental protection efforts are summarized. The bulk of the chapter is devoted to an account of LLNL's activities in the areas of waste minimization and pollution prevention, where significant progress was made in 1995. Following a brief discussion of spills and EPD environmental training, this chapter concludes with mention of LLNL's "other" environmental programs, i.e., those outside EPD.

Environmental Protection Department

As the Laboratory's environmental support organization, EPD prepares and maintains environmental plans and guidelines, provides environmental guidance and support to Laboratory personnel, informs management about pending changes in environmental regulations pertinent to LLNL, represents the Laboratory in day-to-day interactions with regulatory agencies, and assesses the effectiveness of pollution control programs.

EPD conducts monitoring and performs source evaluations and computer modeling to determine the impact of LLNL operations on humans and the environment. In 1995, 18,700 samples were taken from air, sewage, ground water, surface water, soil, sediments, vegetation, and foodstuff, and more than 248,000 analytes were tested. These numbers represent increases of 10% and 5%, respectively, compared to 1994 values. 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 are 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 EPD's four Environmental Support Teams (ESTs). Each team includes representatives from environmental specialties within the Operations and Regulatory Affairs Division (ORAD), along with a field technician from Hazardous Waste Management Division (HWM). Some teams also include a representative from the Environmental Restoration Division (ERD), the Environmental Safety and Health Teams (ES&H Teams), or the organizations supported by the ESTs. These teams evaluate operations 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 program in evaluating the permit conditions and implementing record keeping requirements.

In 1995, EPD reorganized from four divisions to three by disbanding the Environmental Monitoring and Analysis Division. During this reorganization environmental monitoring activities, compliance activities under the National Emission Standards for Hazardous Air Pollutants (NESHAPs), and water compliance duties were transferred to the Operations and Regulatory Affairs Division (ORAD). Ground water sampling and its associated data management activities were transferred to ERD. Analytical chemistry functions were transferred outside EPD to the Chemistry and Materials Science Directorate.

Operations and Regulatory Affairs Division

The reorganization of EPD in April 1995 added three groups to ORAD. The nine groups that now compose ORAD 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 and provides the liaison between LLNL and regulatory agencies conducting inspections; tracks chemical inventories; prepares National Environmental Policy Act (NEPA) documents and conducts related field studies; oversees wetland protection and flood plain management requirements; coordinates cultural and wildlife resource protection and management; facilitates and provides support for the pollution prevention and recycling programs; teaches numerous environmental training courses; coordinates the tank environmental compliance program; conducts compliance, surveillance, and effluent 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 responds to environmental emergencies and notifies a specially trained Environmental Duty Officer (EDO). EDOs are on duty 24 hours a day and coordinate 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 Hazardous Waste Management (HWM) Division in accordance with state and federal regulations. 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 hazardous waste reports required by the state and federal environmental protection agencies. HWM also prepares waste acceptance criteria documents, safety analysis reports, and various waste guidance and management plans.

Responsible for meeting the requirements of the Federal Facilities Compliance Act (FFC Act), HWM establishes regulations requiring the treatment and disposal of mixed waste. 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 presently certified for disposal). This effort includes a large characterization effort to identify all components of the waste, as well as a certification effort, which will provide the disposal site with appropriate documentation.

Environmental Restoration Division

The Environmental Restoration Division (ERD) was established to evaluate and remediate contaminated soil and ground water resulting from past hazardous materials handling and disposal and from leaks and spills that have occurred at the Livermore site and Site 300, both prior to and during LLNL operations. At both the Livermore site and Site 300, ERD investigates field sites 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.

In dealing with CERCLA compliance issues, ERD plans, directs, and conducts assessments to determine both the impact of such releases on the environment and the restoration activities needed to reduce contaminant concentrations to protect human health and the environment. ERD is responsible for interacting with the community on these issues. Several public meetings are held each year as required in the ERD CERCLA Community Relations Plans. To comply with CERCLA ground water remedial actions at the Livermore site, ERD has designed and constructed six ground water treatment facilities and associated pipeline networks and wells (Chapter 2). At Site 300, ERD has designed and implemented two soil vapor/ground water extraction and treatment systems and one ground water extraction and treatment system. ERD has also capped two inactive mixed-waste landfills. ERD is actively designing, testing, and applying innovative remediation and assessment technologies to contaminant problems at the Livermore site and Site 300. ERD also provides the sampling and data management support for ground water surveillance and compliance monitoring activities.

Performance Measures Summary

Since 1992, the contract for the University of California to manage and operate LLNL for DOE has contained Performance Objectives, Criteria, and Measures. Eight of these Performance Measures evaluated LLNL's environmental protection activities in 1995. The status of these measures is described in this report at the location referenced in **Table 3-1** below.

In their evaluation of LLNL's fiscal year 1995 self-assessment, DOE and UC reported that LLNL met or exceeded all of the environmental performance measures for the reporting period. Data for calendar year 1995 will be included in the annual self-assessment and evaluation conducted August through October 1996.

Table 3-1. DOE environmental protection performance measures.

P.M. designator	Performance measure	Location in this report
1.1.b	Radiation Protection of the Public Public radiation doses to the maximally exposed individual from DOE operations will be measured or calculated and controlled to assure that applicable Federal limits are not exceeded. An effective ALARA program shall be in place to manage dose to the public.	Ch. 13: Radiological Dose Assessment; section on Radiological Doses From Air Emissions.
1.1.g	Process Waste Minimization Jointly, DOE and the Laboratory selected 3 of 5 process waste streams that were the highest generators of waste (hazardous, low-level waste, transuranics or mixed) for 1993 generation data. These 3 waste streams shall continue, at a minimum, to be reduced annually by an average of 5%. Annually, beginning in 1995, the Laboratory will review the previous year's waste generation for the purpose of proposing new waste streams to be added to this performance measure. Progress on new waste streams will initially be tracked to specific milestones agreed upon with the local DOE office. Once the waste minimization efforts are implemented the wastes will at a minimum be reduced annually by an average of 5%, but a larger reduction target will be negotiated for the first implementation year.	This chapter, section on Waste Minimization and Pollution Prevention Performance Measures.
1.1.h	Solid Waste Minimization The Laboratory will decrease annually the aggregate weight of all waste generated sitewide.	This chapter, section on Waste Minimization and Pollution Prevention Performance Measures.
1.1.i	Source Reduction and Pollution Prevention The Laboratory will annually evaluate and prioritize a site-specific number of pollution prevention opportunities and establish milestones/metrics that allow the measurement of progress for each opportunity.	This chapter, section on Waste Minimization and Pollution Prevention Performance Measures.
2.1.a	Tracking and Trending of Findings and Violations The number of validated environmental violations and findings resulting from inspections by regulatory agencies and formal audits will be tracked and trended. A downward trend is expected for each category from the 1993 base year. Changes in regulatory procedures after the 1993 base year that increase or decrease the level of occurrence reporting shall be brought to the attention of UC and DOE as soon as possible and adjustments made to the base year figure, as appropriate.	In Chapter 2, under the heading or subheading "Inspections," by subject area.
2.1.b	Tracking and Trending of Environmental Releases Reportable occurrences of environmental releases exceeding regulatory or permitted levels imposed by local, state or federal agencies will be determined and trended. A downward trend is expected. Changes in regulatory procedures after the 1993 base year that increase or decrease the level of occurrence reporting shall be brought to the attention of UC and DOE as soon as possible and adjustments made to the base year figure, as appropriate.	All releases are described in the list of Environmental Occurrences in Ch. 2, Table 2-5.

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Table 3-1. DOE environmental protection performance measures (concluded).

P.M. designator	Performance measure	Location in this report
2.2.a	Regulatory Commitments All funded regulatory consent agreement milestones will be met. If such milestones cannot be met, the Laboratory must inform the University and DOE in writing at the earliest possible time before the milestone passes and seek written concurrence from the appropriate regulatory agency on a revised schedule.	In Ch. 2, section on Livermore Site Ground Water Project, Required Documentation, and section on Site 300 Environmental Restoration Program, Documentation.
5.1.a	Regulator Satisfaction At least once per year, the Laboratory will interview key external regulators utilizing a pre-established and consistently used customer survey questionnaire.	Questionnaires were delivered to two agencies in 1995: BAAQMD and DTSC. Results will be analyzed by DOE and UC in 1996.

DOE Pollution Prevention Goals

The Department of Energy embraces pollution prevention as its strategy to reduce the generation of all waste streams and thus minimize the impact of Departmental operations on the environment. Preventing pollution also reduces risks to the health and safety of workers and the general public, and saves scarce budget dollars. To demonstrate the Department's commitment to pollution prevention, DOE set the following goals, relative to 1993 as a baseline year, to be achieved by December 31, 1999:

For routine operations:

- Reduce the generation of radioactive waste by 50%.
- Reduce the generation of low-level mixed waste by 50%.
- Reduce generation of hazardous waste by 50%.
- Reduce the generation of sanitary waste by 33%.
- Reduce total releases and transfers for treatment and disposal of EPCRA 313 toxic chemicals by 50%.

For all operations, including cleanup/stabilization activities:

- Divert for recycling 33% of sanitary wastes.

For affirmation procurement:

- Increase procurement of EPA-designated, recycled products to 100% except where they are not available competitively at a reasonable price or do not meet performance standards.

Waste Minimization and Pollution Prevention Awareness Plan

In order to implement LLNL's Waste Minimization Policy, EPD provides technical guidance to LLNL programs to help them plan pollution prevention projects and select and design waste-reduction technologies and equipment. These ongoing efforts identify substitutes for hazardous materials used in experimentation in order to reduce the quantity of hazardous waste generated at LLNL; they also identify areas where research and development efforts are necessary to develop suitable alternatives to materials and processes that produce waste.

LLNL prepared a Waste Minimization and Pollution Prevention Awareness (WMPPA) Plan, which meets the requirements of (1) DOE Orders 5820.2A and 5400.1; (2) RCRA, Sections 3002(b) and 3005(h); and (3) Title 22 of the California Code of Regulations. This Plan is reviewed annually and updated every 3 years; it was last updated and submitted to the DOE in July 1994. The Plan reviews past and current waste minimization activities and states the objectives of LLNL's waste minimization and pollution prevention efforts.

The strategies proposed in the WMPPA Plan are being implemented by two actions. The first action is to develop specific ways for the programs to prevent pollution, conserve resources, and minimize waste generation. This action includes creating incentives for pollution prevention; developing specific goals and schedules for waste minimization activities; promoting the use of nonhazardous materials; substituting, reformulating, modifying, managing, and/or recycling waste materials to achieve minimal adverse effects; targeting policies, procedures, or practices that may present barriers to waste minimization; and integrating and coordinating waste generators' and waste managers' activities on waste minimization issues.

A primary way that this action is currently being implemented is through the use of Pollution Prevention Opportunity Assessments (PPOAs). These PPOAs provide a systematic methodology for identifying cost-effective pollution prevention projects for which funding is requested. In addition, the PPOAs identify technology gaps or improvements to existing technology that may reduce pollution. The net effect of conducting PPOAs has been to increase the awareness of LLNL programs to pollution prevention opportunities.

A second action implementing the strategies proposed in the WMPPA Plan is to enhance communication of waste minimization goals and ideas. This involves developing and implementing employee pollution prevention awareness and occupational training programs, collecting and exchanging waste minimization information through technology transfer outreach and educational networks, and developing mechanisms for disseminating current technical information.

These efforts are included in periodic publications, such as EPD's *Waste Matters*, LLNL's *Newsline*, and DOE's *Pollution Prevention Advisor*; booths at the April 1995 LLNL Earth Day Fair and at the October 1995 LLNL Energy Fair; continuation of basic guidance through environmental training courses; and development of a "home page" for the dissemination of pollution prevention information on the Internet. In addition, LLNL has developed two pollution prevention video tapes for use in new employee orientation, environmental training, and small-group discussions.

LLNL provides reports on waste minimization, pollution prevention, and recycling to DOE, the State of California, and local agencies when requested. Two of the major efforts in 1995 were a report on waste generation and waste minimization progress for 1994, as requested by DOE for both the Livermore site and Site 300, and the Source-Reduction Evaluation Review and Plan Summary, an update to the California Senate Bill 14 (SB14) reports. Additionally, the University of California Contract 48, Appendix F, Performance Measures require waste minimization tracking and reporting on a quarterly basis.

Waste Minimization/ Pollution Prevention Performance Measures

LLNL's waste minimization and pollution prevention strategies have evolved over the last decade from ones focused on reactive measures (abatement, treatment, cleanup, and monitoring) to proactive ones of waste minimization and pollution prevention. LLNL's successes in waste reduction and pollution prevention are well illustrated by the accomplishments described in this and the following section on "Other Significant Pollution Prevention and Waste Management Accomplishments."

LLNL operated under three waste minimization / pollution prevention Performance Measures in 1995, falling under the headings Process Waste Minimization, Solid Waste Minimization, and Source Reduction and Pollution Prevention.

Process Waste Minimization

As indicated in **Table 3-1**, DOE and the Laboratory jointly selected three of five process waste streams that were the highest generators of waste (hazardous waste, low-level waste, and mixed waste) for 1993 generation data. LLNL successfully met the goal of reducing the three agreed-upon process waste streams by an average of 5% per year. LLNL and DOE have agreed on the waste streams to be reduced next year and the percentage reduction. Tracking of two more waste streams (from the uranium enrichment operations) may be added to the performance measure next year.

Process Waste Streams

During 1995, LLNL continued efforts to reduce the three process waste streams that were first selected for reduction in 1993. These were contaminated gravel and debris from the firing tables at Site 300, spent aqueous coolant from the Engineering machine shop, and aqueous liquids from the Plant Engineering paint shop.

Gravel from Firing Tables

A gravel washer has been utilized to recondition used gravel that had been generated by operations on the firing tables in previous years. To date the gravel washer has processed 60,000 kg of used gravel and produced 52,000 kg of reusable gravel; a recovery rate of 87%. This recovery rate may increase when the most recent gravel is processed because of improvements in presorting. The gravel washer and the gravel reuse effort are considered to be successful by both DOE and LLNL. The waste from explosive testing has been reduced from over 253,000 kg of mixed waste in 1989 to 54,000 kg of low-level waste in 1995.

Machine Shop Coolant

Throughout 1995, tests were performed on semisynthetic and synthetic coolants to replace the current coolant used in machine shops. To date, three machines are now using the semisynthetic and three machines the 100% synthetic coolants. Because LLNL is still improving the way the machining coolant is handled, DOE and LLNL have agreed to continue to track this waste stream in 1996. Engineering has installed a product recovery unit that recovers about 80% of the low-level coolant for reuse.

Aqueous Liquids from the Paint Shop

In 1995, no aqueous waste was generated from the paint shop, and a micro-separator performed as expected; this waste will not be tracked in 1996. Hazardous aqueous waste from the paint shop was reduced from about 12,000 kg in 1993 to zero in 1995.

Solid Waste Minimization

Through extensive efforts in 1995 to reduce the amount of waste generated and to recycle unwanted material rather than disposing of it as waste, LLNL was able to achieve a 12.5% reduction in the amount of waste disposed in 1994. In 1995,

for the second year, material going to the landfill was accurately measured using a consistent method. The nature of the waste generated in 1995 is directly comparable to that generated in 1994.

The aggregate waste generated in 1995 was about 2.5 million kg versus 2.9 million kg in 1994, a 12.5% reduction (**Figure 3-1)**.

One of the major contributions to this achievement was a reduction of 115,000 kg in the nonhazardous (compacted) waste disposed of at the sanitary landfill. This change was due in part to the sitewide cardboard recycling program.

Hazardous waste generated during 1995 was 334,000 versus 463,000 kg in 1994 (27.8% reduction).

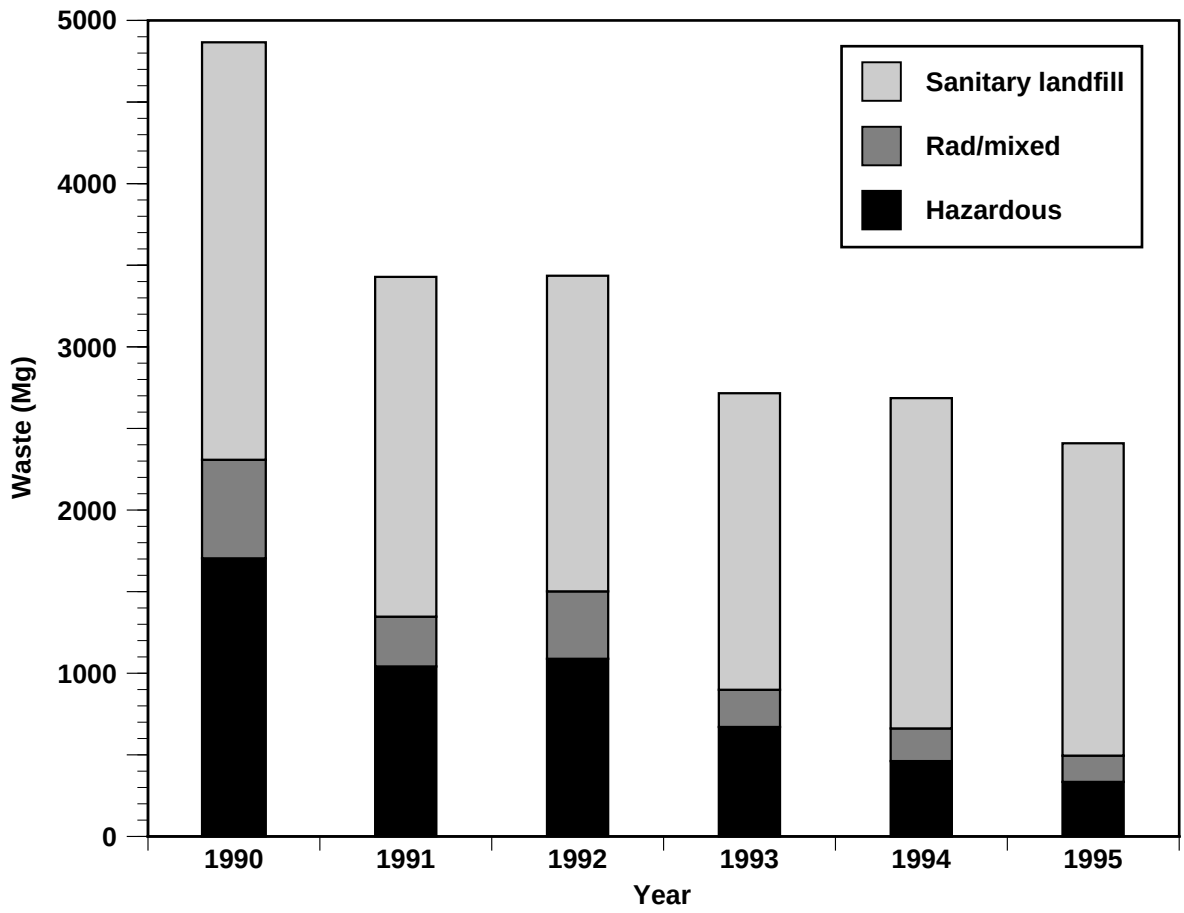

Figure 3-1. Yearly quantities of solid waste generated at LLNL.

Although not part of this performance measure, LLNL did have an increase in the amount of decontamination and decommissioning waste produced. The increase from 199 to 583 tons was due to the demolition of Building 435 cooling towers and the removal of contaminated soil from Building 404. The equipment from the cooling tower demolition, such as heat exchangers, pumps, piping, and valves, was sold as scrap metal. In addition, LLNL shipped some accumulated low-level certified waste for off-site disposal. Since this waste was generated in previous years it was not included in the total for 1995 radioactive waste generated.

Diverted Waste

The total quantity of potential waste that was diverted from the landfills and recycled off site was 3.1 million kg for calendar year 1995 verses 2.3 million kg for calendar year 1994: a 32% increase in the quantity diverted. LLNL achieved these impressive figures as a result of recycling programs focused on office paper, batteries, ferrous material, cardboard, newspaper, magazines, and tires.

The amount of hazardous material shipped off site for recycling by the Hazardous Waste Management Division decreased from 381,000 to 284,000 kg. Asphalt removed from the Livermore site, which was previously taken to the landfill, is now used as road base in road construction at the landfill. The amount of asphalt reused in this fashion was 622,000 kg in calendar year 1995.

Table 3-2 summarizes the recycling activity. In this table, the line entitled Donation, Utilization, and Sales includes ferrous and nonferrous metals, copper, tires, magazines and newspaper, all of which are recycled. The term “paper” includes office paper and baled paper from the hammermill. Office paper includes recycled white and colored paper.

Source Reduction and Pollution Prevention

The Laboratory surveyed its operations for opportunities related to source reduction and pollution prevention in 1995. Annually, effective with fiscal year 1996, the Laboratory will continue 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.

NOx Reduction

Oxides of nitrogen (NOx) account for about half of the total toxic gas emissions from LLNL (see Chapter 5). Boilers continue to be the most significant source of air pollutant emissions, accounting for over 60% of all NOx.

Table 3-2. Recycling summary in kilograms of material.

	Weight (kg)		
Recycled items	**1993**	**1994**	**1995**
Hazardous waste management	80,739	381,018	283,949
Donation, Utilization, and Sales (DUS)	1,087,714	1,104,044	1,289,109
Wood	380,110	488,065	368,317
Cardboard	40,823	46,266	136,985
Asphalt	NA	NA	622,329
Toner cartridges	NA	2721	1814[a]
Paper	355,616	283,949	334,751
Batteries	22,680[b]	23,587	34,473
Total	**1,967,300**	**2,329,650**	**3,071,727**

NA = Not available.

[a] Weight has been estimated based on volume.

[b] Prior to 1994, LLNL recycled only “wet” type batteries.

Four boilers were scheduled to be either replaced or retrofitted with low NOx burners. Two boilers in Building 231 were retrofitted with low NOx burners in December 1995. The effort to replace the other two boilers (Building 131) continued into 1996.

LLNL has looked at additional boilers for potential replacement. Boilers that use 1.5 megawatts or more of power provide a major opportunity for further NOx reductions. LLNL has identified 13 boilers in the 1.5 megawatt or greater range that could be retrofitted or replaced with low NOx burners. However, their replacement is not required under law, and their retrofitting costs are estimated to exceed 1 million dollars. Since boilers represent such a large portion of the air emissions, these smaller boilers are the most likely candidates for future replacement or retrofitting.

Toxic Reporting Inventory information

LLNL has been active in reducing its use of ozone-depleting chemicals. Use of chlorofluorocarbons (CFCs) for degreasing applications in Engineering’s main machining facilities was reduced to less than 4 L/y. Other CFC degreasing operations in Chemistry and Materials Science, Lasers, and Engineering are being studied, with the aim of totally eliminating CFC usage.

The largest CFC usage at LLNL continues to be as dielectric and coolant media. Most of this use has been in Laser Isotope Separation applications, in which the

dielectric properties of CFC 113 are important. The program has, however, reengineered some electrical components to allow mineral oil to be substituted for CFCs, and is also testing other chemicals as possible replacements.

Plant Operations employs CFCs as refrigerants and is actively replacing or retrofitting refrigeration units with alternative, non-ozone-depleting chemicals.

Other Significant Pollution Prevention and Waste Management Accomplishments

A major part of LLNL's efforts to reduce waste has been to reduce hazardous organic solvents (such as CFCs as discussed above or halogenated hydrocarbons) that are disposed of as liquid hazardous waste or that may evaporate into the air. To date, approximately 25 shops or laboratories on site have converted to environmentally friendly chemicals in their cleaning operations.

A contamination analysis sensor is currently being developed to measure the cleaning performance of different solvents in near-real time, which will help redesign cleaning processes to be more efficient and present fewer environmental risks. The sensor will be field tested in the aerospace and electronics industry in the coming year, and a patent is pending.

LLNL won a national award from DOE in 1995 for its success in recycling hazardous material and for the operation of its Chemical Exchange Warehouse (CHEW). LLNL continues to operate CHEW to receive, temporarily store, and track excess usable chemicals in order to make them available to other users. By reusing chemicals, the hazardous waste stream is lessened, thereby reducing chemical procurement and disposal costs.

LLNL is procuring a recycling unit for its ethanol laser dye solution, and its CFC 113 recycling unit will be upgraded and brought online. Recycling this dielectric coolant on site will increase the amount of recovered coolant compared to previous off-site recycling. Carbon dioxide cleaning is becoming the cornerstone cleaning technology for LLNL's National Ignition Facility. Work continues to evaluate the use of carbon dioxide snow and pellet sprays for precision cleaning of optics, electronics, and other assemblies. After cleaning, the carbon dioxide sublimates, leaving no solvent waste. The Laser Program has also replaced paper protective clothing with washable clothing and is now laundering this on site instead of disposing of the used paper clothing as low-level waste. Lasers Directorate is using an additional ethanol recycling unit on the Nova project, where ethanol is used with optics processing.

Many LLNL programs and directorates have recently implemented significant pollution prevention technologies. For example, the Electronics Engineering Department has improved pollution control at its Rapid Prototype Facility (RPF), one of several on-site electronics fabrication facilities. Aqueous solvents and alter-

native cleaning equipment have decreased air emission and hazardous waste sources. Plant Engineering has replaced a CFC degreaser in its instrument shop with a triple-rinse aqueous system, cutting CFC use by 1500 L/y. The Chemistry and Materials Science Directorate has recycled acetone in aerogel fabrication, purchased oil-less vacuum pumps to eliminate used vacuum pump oil as a hazardous waste, and replaced a toluene-based cocktail used in low- level radioactive sample analysis with a nonhazardous aqueous-based scintillation cocktail.

Other EPD waste management highlights include the following:

- Completed sampling and characterization of over 250 drums of depleted uranium and repackaged approximately 60 drums for shipment to the Scientific Ecology Group.
- Shipped 74 boxes of mixed waste to Envirocare of Utah, our first mixed waste shipment to a commercial disposal facility.
- Completed real-time radiography of approximately 920 drums of radioactive waste.
- Significantly increased the speed (up to a factor of 30) of the Total Waste Management System database by moving it to a far more powerful computer system.

Spill Reporting

The Federal government and the State of California have several distinct statutory and regulatory provisions that require responsible persons to report releases or threatened releases of hazardous materials or pollutants into the environment. DOE has also established various Orders that require reporting of incidents to DOE Headquarters. Applicable rules, regulations, and DOE Orders are summarized below in **Table 3-3**. These provisions have varying requirements as to the types of releases that must be reported, the timing of the report or notification (immediate and follow-up), the content of the report (e.g., source of the release, nature of the material, and the quantity released), and the particular agencies that must be notified. Many releases must be reported under more than one provision, and compliance with one provision will not necessarily satisfy another applicable provision.

Under authority of the *San Francisco Bay Water Quality Control Plan*, the San Francisco Bay RWQCB requires a report of all releases to the ground or surface waters that are not specifically allowed in permits. LLNL followed a reporting procedure established by the San Francisco Bay RWQCB that identifies the types of spills that must be reported, and when the spills are considered to be of so little consequence that records can be kept on file and noted in the routine quarterly reports. If a spill of a reportable quantity of material occurs or the material is not contained, the appropriate agencies are contacted immediately.

Table 3-3. Laws, regulations, and DOE Orders that include spill reporting requirements.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or "Superfund Act"
Superfund Amendments and Reauthorization Act (SARA)
Toxic Substance Control Act (TSCA)
The Federal Water Pollution Control Act, or Clean Water Act
Resource Conservation and Recovery Act (RCRA)
Resource Conservation and Recovery Act "Underground Storage Tanks"
California Hazardous Waste Control Law, California Code of Regulations, Title 22, Division 4.5
California Hazardous Waste Control Law, California Code of Regulations, Title 23, Chapter 16, Underground Tank Regulations
California Hazardous Waste Control Law, California Health and Safety Code, Division 20, Chapter 6.95, Business Plan
California Hazardous Waste Control Law, California Health and Safety Code, Division 20, Chapter 6.67, Aboveground Petroleum Storage Act
California Hazardous Waste Control Law, California Health and Safety Code, Division 20, Chapter 6.8, Hazardous Substance Account Act
Porter-Cologne Water Quality Control Act, California Water Code, Division 7, Chapter 4
Industrial Waste Water Discharge
Federal and State Clean Air Acts
Department of Energy Orders
Atomic Energy Act

Response to Spills and Other Environmental Emergencies

All spills and leaks (releases) that are potentially hazardous to the environment are investigated and evaluated. The release response process includes identifying the release, shutting off the source (if 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-days-a week, 24-hours-a-day, on-call rotational position entitled the Environmental Duty Officer (EDO). Specialized EDO training includes simulated accidents to provide the staff with the experience of working together

to resolve environmental issues within the regulatory structure. 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 (EA) assigned to support their program area. The EOG EA 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 the DOE. The EDO and the EOG EA also notify and consult with program management, and have 7-days-a-week, 24-hours-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 possibly the Fire Department. 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 3-4**.

LLNL's Other Environmental Programs

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.

In 1995, LLNL formed its Council on Energy and Environmental Systems to coordinate and direct the Lab's wide range of environmental research activities. To develop a core mission area of global ecology, a two-year position was established creating a Director of Energy and Environmental Systems, to develop and integrate our research in these areas.

Table 3-4. EPD training courses.

Administrative Operations Pollution Prevention*	Air Source Management
Diversity Training*	Environmental Duty Officer Briefings
Environmental Law and Regulation	General Awareness/Familiarization
Hazardous 90-Days Waste Retention Tank Management*	General Requisition Briefing*
Hazardous Waste Generation and Certification	Hazardous Waste Sampling
Hazardous Waste Transportation	Identification of Hazardous Material
Labeling of Packages	Land Disposal Restriction*
Low-Level Waste Certification Overview	Low-Level Waste Generation and Certification
Low-Level Waste Generation and Certification of Encapsulated Uranium Waste*	Marking of Packages
Overview of Environmental Law and Regulation	Packaging Operations
Placarding: Hazardous Waste Transport	Pollution Prevention for Facility Design
Radioactive Materials	RCRA Facility Management
RCRA Operations	Requisition Training*
Safety	SARA/OSHA Refresher Training
SARA/OSHA Supervisory Training	SARA/OSHA Training 40 Hour
Separation for Highway Transport	Shipping Papers
TRU Waste Generation and Certification	Unique Moves
Waste Accumulation Area Operations	

*New training classes in 1995.

As part of this effort an Industrial Ecology Program was established, whose goals are to:

- Support and develop multidisciplinary programs, which create the scientific and technological basis for achieving an environmentally and economically efficient, and sustainable, global economy. Work with the DOE and others to develop an integrated, science-based program that addresses the future environmental, energy, and economic security of the Nation.
- Encourage and contribute to the development of responsible, technically and scientifically valid, cost-effective environmental laws, regulations, standards, practices, and methodologies.
- Promote the conservation of raw materials and other natural resources: Eliminate or reduce waste and emissions; recycle and reuse materials, components, and products; and purchase recycled products.

- Integrate applicable environmental considerations into our research and development activities, business decisions, and planning activities, including decisions on projects, products, processes, and purchases.
- Research, develop, and exploit environmentally and economically efficient technology and technological systems and analysis tools as a principal means of implementing this policy.
- Utilize a lifecycle, systems-based approach in implementing this policy.

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. These 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 less hazardous chemicals in many of their processes, and Education Program's efforts to enhance environmental education, to name just a few.

4. Air Monitoring

Paula J. Tate
Joel H. White

Introduction

Air surveillance monitoring is performed 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. LLNL complies with local, state, and federal environmental air quality laws and DOE regulations including 40 CFR 61, the National Emissions Standards for Hazardous Air Pollutants (NESHAPs) section of the Clean Air Act and DOE Orders 5400.1, *General Environmental Protection Program*, and 5400.5, *Radiation Protection of the Public and the Environment*. 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. Other laws governing air quality include 22 CCR 67264.700 and 66265.710, Environmental and Compliance Monitoring, and the California Air Toxics "Hot Spots" Information and Assessment Act of 1987 (AB2588). In general, LLNL analyzes for most constituents at levels that are far below regulatory standards in order to determine any environmental impact.

LLNL monitors ambient air to determine if airborne radionuclides or hazardous materials are being released by Laboratory operations, what the concentrations are, and what the trends are in the LLNL environs. In our air monitoring, particles are collected on filters and vapor is chemically trapped 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, at off-site locations throughout the Livermore Valley, and at an off-site location in Tracy. Point sources as well as diffuse, or nonpoint sources, are monitored to fulfill NESHAPs requirements.

Methods

For air surveillance monitoring, two networks monitor the air particulates in the environs of the Livermore site; and one network monitors particulates in the environs of Site 300, including one sampler in the city of Tracy. All these networks use continuously operating, high volume samplers located as shown in **Figures 4-1, 4-2,** and **4-3**. The Livermore site perimeter network consists of six samplers at the perimeter and two at areas of special interest (diffuse sources). The Livermore Valley network consists of samplers located in all wind directions. For the purposes of data analysis, samplers located in the least prevalent wind directions (FCC, FIRE, HOSP, RRCH, and ERCH) are considered to be upwind or background and four samplers located in the most prevalent

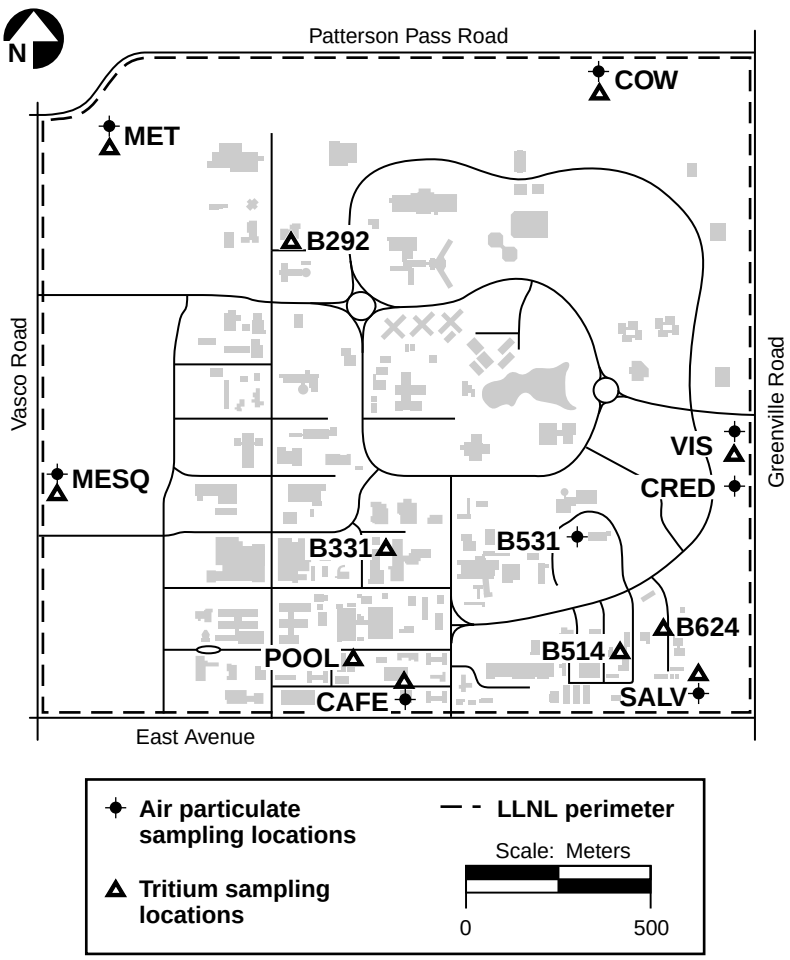

Figure 4-1. Air particulate and tritium sampling locations, Livermore site, 1995.

directions (PATT, ZON7, TANK, and ALTA) are considered downwind. An additional sampler is located in an area of special interest (LWRP) because of a plutonium release to the sanitary sewer system in 1967 (see Results section below). These air samplers are positioned to provide reasonable probability that any significant concentration of radioactive particulate effluents from LLNL operations will be detected should it occur.

One of the sampling locations, ERCH, was removed from service in October of 1995 because of logistical problems at the location, and will not be replaced at this time. The geographical details of the particulate sampling locations are outlined in a procedure in Appendix A of the *Environmental Monitoring Plan* (Tate et al. 1995).

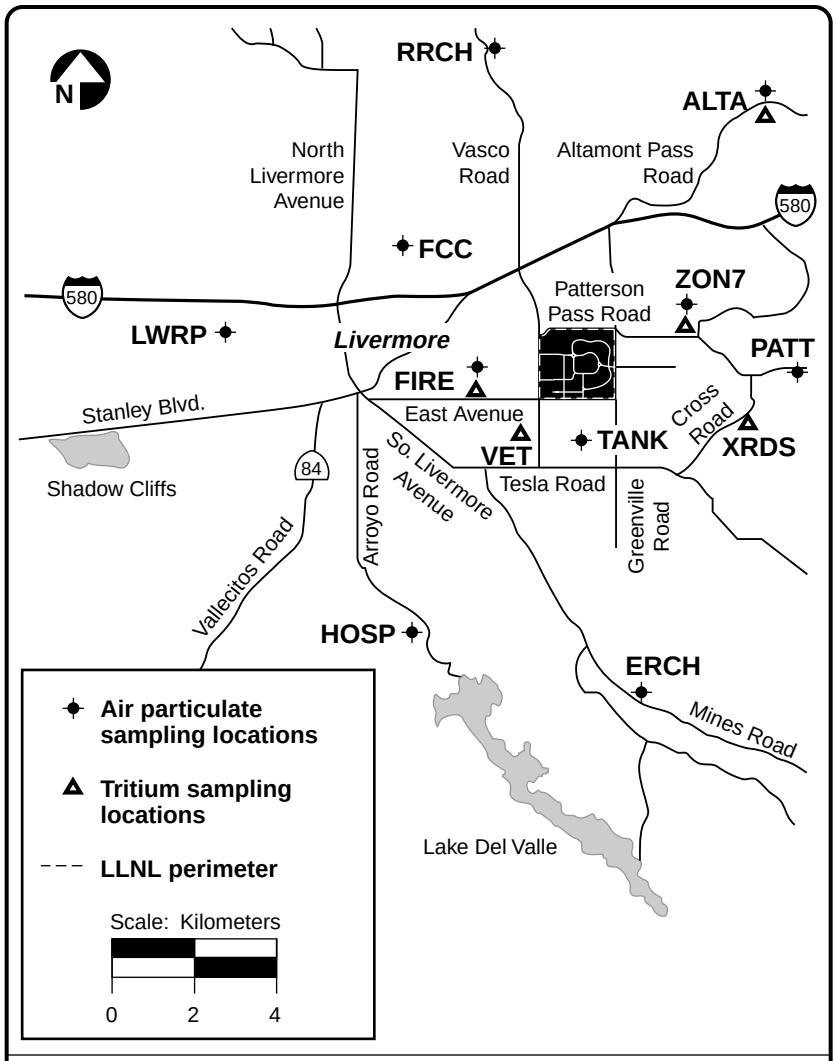

Figure 4-2. Air particulate and tritium sampling locations, Livermore Valley, 1995.

LLNL also maintains 11 continuously operating airborne tritium samplers on the Livermore site (**Figure 4-1**) and 5 samplers in the Livermore Valley (**Figure 4-2**). Four of the Livermore site locations (B331, B292, B514, and B624) monitor diffuse tritium emissions. The tritium sample locations are detailed in Appendix A of the *Environmental Monitoring Plan*(Tate et al. 1995).

Particulate filters are changed each week at all locations, and tritium samples are changed every two weeks. Duplicate quality control samplers are operated for 2 months in parallel with the permanent sampler at a given site, and samples are analyzed to confirm results.

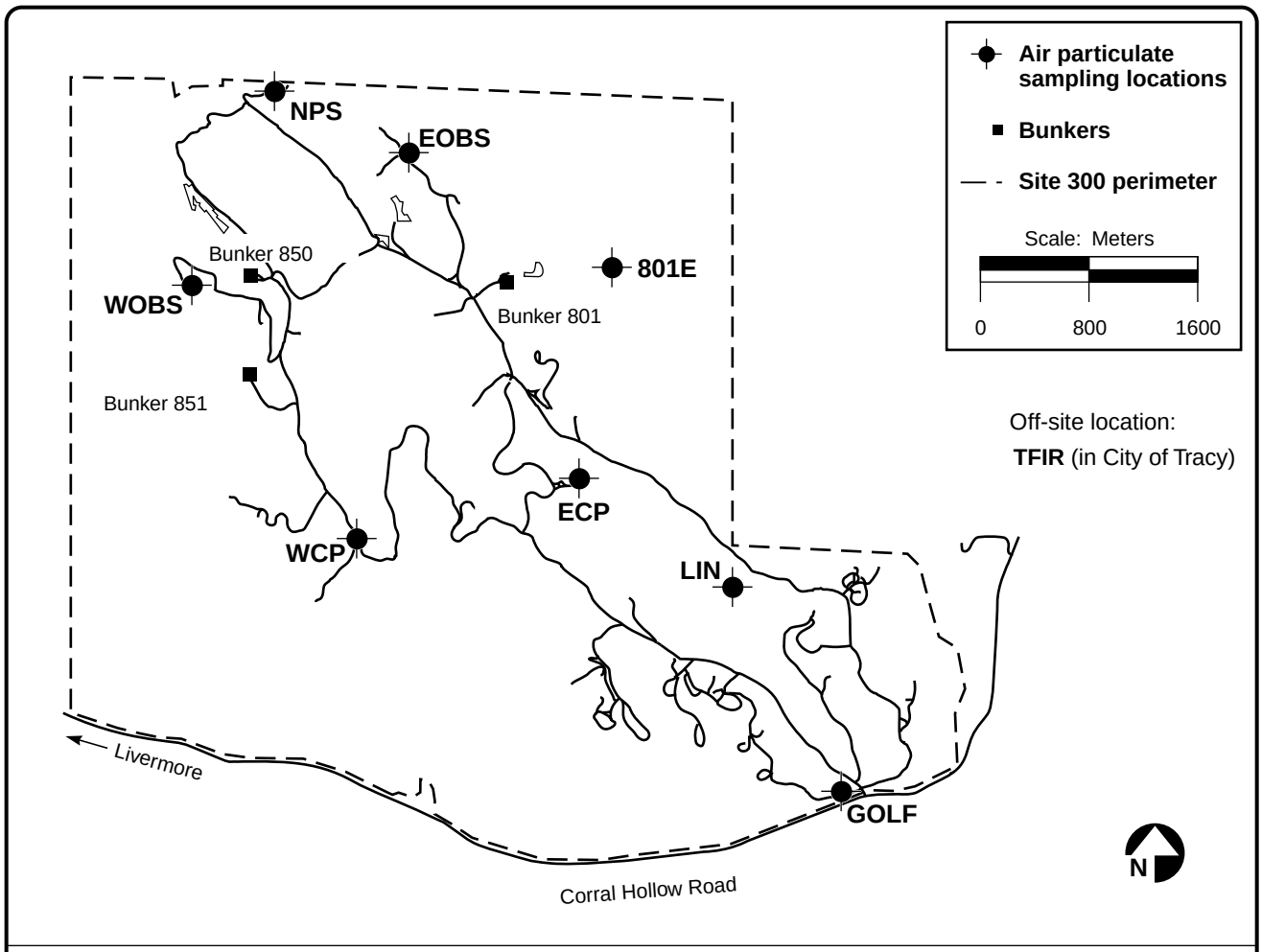

Figure 4-3. Air particulate sampling locations, Site 300, 1995.

As outlined in the *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. All analytical results are reported as a measured concentration per volume of air, or at the minimum detection limit (MDL) when no activity is detected. In all cases, the MDL is more than 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*. Further details of the surveillance monitoring methods are included in Volume 2, Chapter 4.

Results

This section discusses the air monitoring results at the Livermore site and at Site 300.

Livermore Site

Airborne Radioactivity

Table 4-1 summarizes the monthly gross alpha and gross beta results for the LLNL perimeter, Livermore Valley, and Site 300 sampling locations. Medians, interquartile ranges (IQR), and maximum values for each network are included. (See Volume 2, Tables 4-1 and 4-2 for detailed location results for all networks for gross alpha and gross beta concentrations.) The monthly median gross alpha and gross beta concentrations are plotted in **Figures 4-4** and **4-5**, respectively. The gross beta results are slightly higher during the fall and winter, which is a similar pattern to the 1992, 1993, and 1994 data; however, the maximum values have decreased possibly because of the decrease in global fallout.

The gross alpha data are much more variable because of the nature of the standard analytical method capabilities, and most of the data are at or below the detection limit of the method.

Typical gross alpha activity (median value) for the LLNL perimeter network is 2.2×10^{-13} Bq / mL (6.0×10^{-24} Ci / mL); for the upwind Livermore Valley stations the value is -1.1×10^{-11} Bq / mL (-3.0×10^{-22} Ci / mL); and for the downwind Livermore Valley stations the value is -4.1×10^{-12} Bq / mL (-1.1×10^{-22} Ci / mL). 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 4.1×10^{-10} Bq / mL (1.1×10^{-20} Ci / mL); for the upwind Livermore Valley stations the value is 3.7×10^{-10} Bq / mL (1.0×10^{-20} Ci / mL);. and for the downwind Livermore stations the value is 3.9×10^{-10} Bq / mL (1.0×10^{-20} Ci / mL). These values are similar to those obtained from previous monitoring data during the past several years. 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 Chernobyl reactor accident in 1986.

Gamma-emitting radionuclide concentrations in air that contribute to the activity in the Livermore site perimeter samples are summarized in **Table 4-2**. (See Volume 2, Table 4-4 for monthly gamma data.) Of the nuclides tabulated, ^{7}Be, ^{40}K, ^{226}Ra, ^{228}Ra, and ^{228}Th occur naturally. The primary source of ^{137}Cs is long-term global fallout and fallout resuspension.

Table 4-1. Gross alpha and gross beta in air particulate samples summarized by month, 1995.[a]

	Gross alpha (Bq/mL)			Gross beta (Bq/mL)		
	Median	Interquartile range	Maximum	Median	Interquartile range	Maximum
LLNL perimeter						
Jan	-1.7×10^{-11}	3.4×10^{-11}	2.4×10^{-11}	2.3×10^{-10}	2.8×10^{-10}	1.1×10^{-9}
Feb	-3.2×10^{-11}	4.6×10^{-11}	7.2×10^{-11}	7.0×10^{-10}	4.4×10^{-10}	1.9×10^{-9}
Mar	4.6×10^{-12}	2.9×10^{-11}	6.8×10^{-11}	2.6×10^{-10}	2.6×10^{-10}	9.5×10^{-10}
Apr	-9.7×10^{-12}	4.0×10^{-11}	1.1×10^{-10}	2.5×10^{-10}	1.9×10^{-10}	5.4×10^{-10}
May	-9.5×10^{-12}	3.3×10^{-11}	8.3×10^{-11}	2.6×10^{-10}	1.5×10^{-10}	5.7×10^{-10}
June	1.3×10^{-11}	2.3×10^{-11}	8.3×10^{-11}	2.3×10^{-10}	2.7×10^{-10}	5.3×10^{-10}
July	-1.6×10^{-11}	5.5×10^{-11}	6.4×10^{-11}	2.6×10^{-10}	1.9×10^{-10}	4.9×10^{-10}
Aug	-1.8×10^{-11}	5.4×10^{-11}	6.2×10^{-11}	4.9×10^{-10}	1.7×10^{-10}	9.1×10^{-10}
Sept	1.5×10^{-11}	8.2×10^{-11}	6.9×10^{-11}	7.7×10^{-10}	5.8×10^{-10}	1.1×10^{-9}
Oct	4.6×10^{-11}	8.3×10^{-11}	1.6×10^{-10}	8.1×10^{-10}	2.6×10^{-10}	2.0×10^{-9}
Nov	3.1×10^{-11}	5.9×10^{-11}	1.5×10^{-10}	7.4×10^{-10}	3.9×10^{-10}	1.7×10^{-9}
Dec	-2.4×10^{-11}	6.4×10^{-11}	6.0×10^{-11}	4.5×10^{-10}	6.5×10^{-10}	2.4×10^{-9}
Livermore Valley upwind						
Jan	-1.8×10^{-11}	2.6×10^{-11}	7.1×10^{-11}	2.1×10^{-10}	1.5×10^{-10}	4.3×10^{-10}
Feb	-2.3×10^{-11}	3.9×10^{-11}	5.6×10^{-11}	6.8×10^{-10}	5.0×10^{-10}	2.0×10^{-9}
Mar	-3.1×10^{-12}	5.0×10^{-11}	5.5×10^{-11}	2.2×10^{-10}	1.6×10^{-10}	6.9×10^{-10}
Apr	-1.1×10^{-11}	5.1×10^{-11}	9.0×10^{-11}	2.0×10^{-10}	1.2×10^{-10}	5.0×10^{-10}
May	-9.9×10^{-12}	6.0×10^{-11}	5.1×10^{-11}	2.2×10^{-10}	1.9×10^{-10}	5.6×10^{-10}
June	-8.0×10^{-12}	4.0×10^{-11}	5.9×10^{-11}	1.3×10^{-10}	1.4×10^{-10}	4.3×10^{-10}
July	-7.5×10^{-12}	5.8×10^{-11}	7.2×10^{-11}	2.6×10^{-10}	1.6×10^{-10}	5.0×10^{-10}
Aug	-2.8×10^{-11}	4.0×10^{-11}	2.2×10^{-11}	4.5×10^{-10}	1.3×10^{-10}	7.0×10^{-10}
Sept	-9.9×10^{-12}	4.1×10^{-11}	1.0×10^{-10}	6.6×10^{-10}	6.0×10^{-10}	1.2×10^{-9}
Oct	3.9×10^{-11}	4.7×10^{-11}	1.2×10^{-10}	7.7×10^{-10}	3.3×10^{-10}	1.1×10^{-9}
Nov	1.6×10^{-11}	8.9×10^{-11}	1.2×10^{-10}	7.2×10^{-10}	2.9×10^{-10}	1.7×10^{-9}
Dec	-1.6×10^{-11}	6.5×10^{-11}	3.9×10^{-11}	4.6×10^{-10}	5.7×10^{-10}	2.1×10^{-9}

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Table 4-1. Gross alpha and gross beta in air particulate samples summarized by month, 1995[a] (concluded).

	Gross alpha (Bq/mL)			Gross beta (Bq/mL)		
	Median	Interquartile range	Maximum	Median	Interquartile range	Maximum
Livermore Valley downwind						
Jan	-1.4×10^{-11}	3.6×10^{-11}	3.0×10^{-11}	1.9×10^{-10}	1.8×10^{-10}	4.8×10^{-10}
Feb	-5.6×10^{-11}	6.5×10^{-11}	3.1×10^{-11}	6.7×10^{-10}	4.2×10^{-10}	1.7×10^{-9}
Mar	-1.1×10^{-12}	3.6×10^{-11}	4.8×10^{-11}	2.8×10^{-10}	2.1×10^{-10}	8.1×10^{-10}
Apr	3.3×10^{-13}	4.8×10^{-11}	3.5×10^{-11}	2.5×10^{-10}	1.2×10^{-10}	5.9×10^{-10}
May	-9.9×10^{-12}	3.9×10^{-11}	4.9×10^{-11}	2.8×10^{-10}	1.9×10^{-10}	4.7×10^{-10}
June	4.9×10^{-12}	5.2×10^{-11}	4.9×10^{-11}	2.4×10^{-10}	1.6×10^{-10}	4.4×10^{-10}
July	-1.3×10^{-11}	6.6×10^{-11}	5.2×10^{-11}	2.7×10^{-10}	1.4×10^{-10}	5.8×10^{-10}
Aug	-2.0×10^{-11}	7.0×10^{-11}	1.2×10^{-10}	4.4×10^{-10}	1.4×10^{-10}	6.6×10^{-10}
Sept	-3.1×10^{-11}	6.4×10^{-11}	8.4×10^{-11}	6.2×10^{-10}	5.4×10^{-10}	10.0×10^{-10}
Oct	3.4×10^{-11}	7.9×10^{-11}	1.2×10^{-10}	7.3×10^{-10}	3.9×10^{-10}	1.2×10^{-9}
Nov	4.0×10^{-11}	4.0×10^{-11}	1.2×10^{-10}	6.0×10^{-10}	5.1×10^{-10}	1.4×10^{-9}
Dec	-2.3×10^{-11}	5.5×10^{-11}	4.0×10^{-11}	3.6×10^{-10}	5.0×10^{-10}	2.4×10^{-9}
Site 300						
Jan	-1.2×10^{-11}	2.9×10^{-11}	3.1×10^{-11}	1.6×10^{-10}	1.9×10^{-10}	5.3×10^{-10}
Feb	-2.3×10^{-11}	4.1×10^{-11}	4.9×10^{-11}	5.8×10^{-10}	2.6×10^{-10}	1.0×10^{-9}
Mar	-1.5×10^{-11}	4.3×10^{-11}	5.1×10^{-11}	2.8×10^{-10}	4.3×10^{-10}	1.9×10^{-9}
Apr	-1.8×10^{-11}	3.4×10^{-11}	6.9×10^{-11}	2.2×10^{-10}	2.0×10^{-10}	5.1×10^{-10}
May	1.8×10^{-11}	4.4×10^{-11}	1.5×10^{-10}	2.8×10^{-10}	1.7×10^{-10}	5.5×10^{-10}
June	7.7×10^{-12}	4.3×10^{-11}	1.1×10^{-10}	2.1×10^{-10}	3.3×10^{-10}	7.1×10^{-10}
July	4.4×10^{-12}	3.8×10^{-11}	9.3×10^{-11}	2.8×10^{-10}	1.4×10^{-10}	5.4×10^{-10}
Aug	-2.6×10^{-11}	6.4×10^{-11}	6.1×10^{-11}	5.2×10^{-10}	1.2×10^{-10}	8.4×10^{-10}
Sept	2.3×10^{-12}	7.4×10^{-11}	1.5×10^{-10}	7.1×10^{-10}	3.1×10^{-10}	1.2×10^{-9}
Oct	4.3×10^{-11}	5.5×10^{-11}	1.6×10^{-10}	7.1×10^{-10}	3.2×10^{-10}	1.0×10^{-9}
Nov	3.5×10^{-11}	6.3×10^{-11}	2.0×10^{-10}	7.4×10^{-10}	6.0×10^{-10}	1.9×10^{-9}
Dec	-1.8×10^{-11}	5.0×10^{-11}	1.2×10^{-10}	4.9×10^{-10}	5.3×10^{-10}	1.7×10^{-9}

[a] Negative values indicate that the activity of the background is greater than that of the sample.

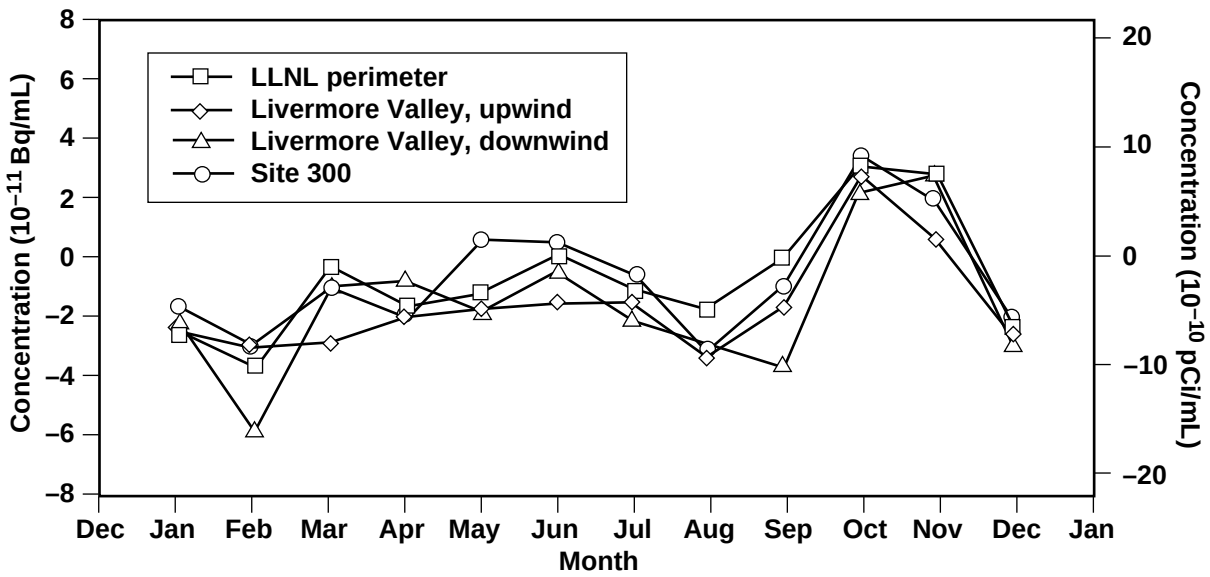

Figure 4-4. Monthly median gross alpha concentrations in particulate air samples from LLNL perimeter, Livermore Valley, and Site 300 sampling locations, 1995.

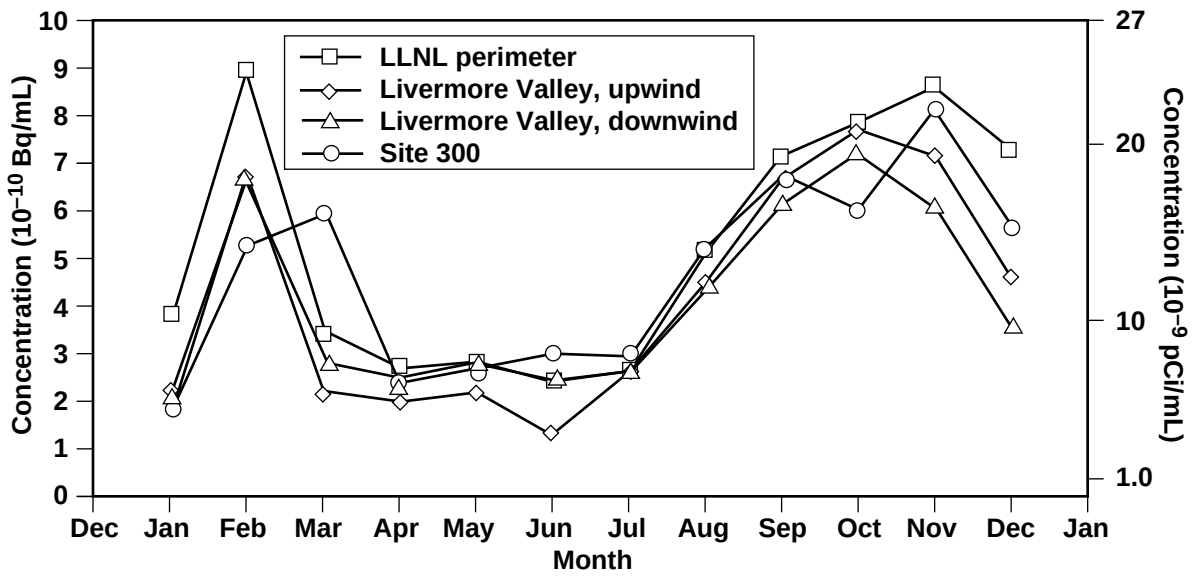

Figure 4-5. Monthly median gross beta concentrations in particulate air samples from LLNL perimeter, Livermore Valley, and Site 300 sampling locations, 1995.

Table 4-2. Gamma activity in air particulate samples, Livermore site perimeter and Site 300, 1995.

	(10^{-9} Bq/mL)	(10^{-12} Bq/mL)					
	^{7}Be	^{40}K	^{137}Cs	^{22}Na	^{226}Ra	^{228}Ra	^{228}Th
Livermore perimeter							
Median	4.4	<11.3	<0.2	<0.3	<0.5	<1.4	<0.6
Interquartile range	1.3	<23.4	—[a]	—[a]	—[a]	—[a]	—[a]
Maximum	6.6	41.4	1.3	0.6	3.0	3.2	2.3
Median fraction of DCG[b]	3.0×10^{-6}	$<3.4 \times 10^{-7}$	$<1.2 \times 10^{-8}$	$<6.8 \times 10^{-9}$	$<1.3 \times 10^{-5}$	$<1.3 \times 10^{-5}$	$<4.0 \times 10^{-4}$
Site 300							
Median	4.5	<5.8	<0.2	<0.5	<0.4	<0.6	<0.4
Interquartile range	1.8	<17.5	—[a]	<0.24	—[a]	—[a]	—[a]
Maximum	7.2	34.9	0.5	0.8	2.2	2.3	1.9
Median fraction of DCG[b]	3.0×10^{-6}	$<1.7 \times 10^{-7}$	$<1.0 \times 10^{-8}$	$<1.4 \times 10^{-8}$	$<1.0 \times 10^{-5}$	$<5.6 \times 10^{-6}$	$<2.7 \times 10^{-4}$
DCG[b] (Bq/mL)	1.5×10^{-3}	3.3×10^{-5}	1.5×10^{-5}	3.7×10^{-5}	3.7×10^{-8}	1.1×10^{-7}	1.5×10^{-9}

a No measure of dispersion calculated. See Chapter 15, Quality Assurance.

b Derived Concentration Guide.

In addition to providing baseline data on global fallout, analysis of these radionuclides enables LLNL to monitor the containment of the small inventories of mixed fission products and radiochemical tracers used at LLNL. The Derived Concentration Guides (DCGs) for these radionuclides are also shown in **Table 4-2**. 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 on Radiological Dose Assessment provides an explanation of this and other units of dose.) Finally, the fraction of the DCGs is presented. These values demonstrate that levels of gamma activity present in air at the Livermore site perimeter are low.

Table 4-3 shows the detection frequency, median, IQR, maximum, and fraction of DCG for concentration of plutonium on air filter samples collected in the Livermore Valley. (See Volume 2, Table 4-6 for monthly data.) The highest off-site median concentration of ^{239}Pu occurred at the Livermore Water Reclamation Plant (LWRP). Soils near the LWRP contain some detectable plutonium, principally resulting from sludge-spreading operations following an estimated 1.2×10^{9} Bq (32 mCi) release to the sewer in 1967 (see Chapter 10, Soil and

Table 4-3. Plutonium activity in air particulate samples (in 10^{-15} Bq/mL), 1995.

Sampling location[a]	Median	Interquartile range	Maximum	Median fraction of DCG[b]
Livermore Valley downwind locations				
ALTA	9.4	14.6	118.0	1.3×10^{-5}
PATT	6.1	14.1	61.4	8.2×10^{-6}
TANK	7.3	14.0	22.5	9.9×10^{-6}
ZON7	6.0	6.2	43.7	8.1×10^{-6}
Livermore Valley upwind locations				
ERCH[c]	9.3	7.0	13.2	1.3×10^{-5}
FCC	3.7	7.0	13.3	4.9×10^{-6}
FIRE	0.9	16.7	45.5	1.2×10^{-6}
HOSP	2.2	8.1	10.8	3.0×10^{-6}
RRCH	1.4	5.4	20.1	1.8×10^{-6}
Special interest				
LWRP	12.8	21.8	132.0	1.7×10^{-5}
LLNL perimeter				
SALV	22.0	14.0	544.0	3.0×10^{-5}
MESQ	22.7	10.0	38.5	3.1×10^{-5}
CAFE	24.5	23.4	49.6	3.3×10^{-5}
MET	22.7	23.4	273.0	3.1×10^{-5}
VIS	22.9	17.8	105.0	3.1×10^{-5}
COW	35.1	50.0	758.0	4.8×10^{-5}
Diffuse on-site sources				
B531	136	494	1062	1.8×10^{-4}
CRED	7.9	14.9	29.9	1.1×10^{-5}
Site 300	4.8	1.9	12.2	6.5×10^{-6}
Tracy	3.7	10.7	14.8	5.2×10^{-6}

a See **Figures 4-1, 4-2,** and **4-3** for sampling locations.

b DCG = 7.4 x 10^{-10} Bq/mL (2 x 10^{-14} µCi/mL) for ^{239}Pu activity in air.

c Station was discontinued in October because of logistical problems.

Sediment Monitoring). Resuspension of these soils probably accounts for the slightly higher average ^{239}Pu in air concentrations observed. However, the median observed value is <0.0001 of the DCG.

Table 4-3 also shows the concentrations of airborne ^{239}Pu on air filters from the LLNL perimeter locations. (See Volume 2, Table 4-7 for the detailed location monthly data.) The highest concentration was registered at location COW in June 1995; the concentration value is reported as 7.6×10^{-13} Bq / mL (2.1×10^{-23} Ci / mL), which represents 0.001 of the DCG. This concentration may be due to the construction activities in the area, which included significant grading and dirt movement, thereby increasing the resuspension probability. The median concentration at location COW is 3.5×10^{-14} Bq / mL (9.5×10^{-25} Ci / mL), which is just slightly higher than the previous year. Other locations that may have been impacted by higher concentrations for a single month because of construction activities in their vicinity included SALV and MET; however, the median concentrations at all LLNL site perimeter locations were similar to those in 1994.

Figure 4-6 shows the annual median concentrations of ^{239}Pu for locations SALV (on site) and FCC (off site) from 1982 to 1995. Location FCC represents a typical upwind background location, and SALV represents the perimeter location having the highest annual average for most of this 13-year period. The higher values in the past at SALV may be attributed to historical activities at LLNL; improvements in operational processes in the immediate work area have contributed to the observed downward trend of the data.

In June 1991, two air particulate sampling locations (B531 and CRED) were added as part of a special study to investigate the somewhat elevated levels of plutonium in air and surface soil in the southeast quadrant of the Livermore site (see Chapter 10, Soil and Sediment Monitoring, for general background on this study). These sampling locations are now part of our routine monitoring network and provide data for diffuse source dose assessments. **Table 4-3** shows the median concentrations of airborne ^{239}Pu at these two locations. (See Volume 2, Table 4-8 for monthly data.) The median concentration of 1.4×10^{-13} Bq / mL (3.7×10^{-24} Ci / mL) at location B531 is higher than the median concentration for any of the other air particulate sampling locations but is still only 0.0002 of the DCG.

The median ^{235}U and ^{238}U concentrations in air samples from the Livermore site perimeter are shown in **Table 4-4**. (See Volume 2, Table 4-10 for monthly data.) The maximum measured concentrations of ^{238}U are less than 0.0005 of the DCG (DOE Order 5400.5). All ^{235}U / ^{238}U median ratios are as expected for naturally occurring uranium; however, monthly data in Volume 2 shows some unexpected

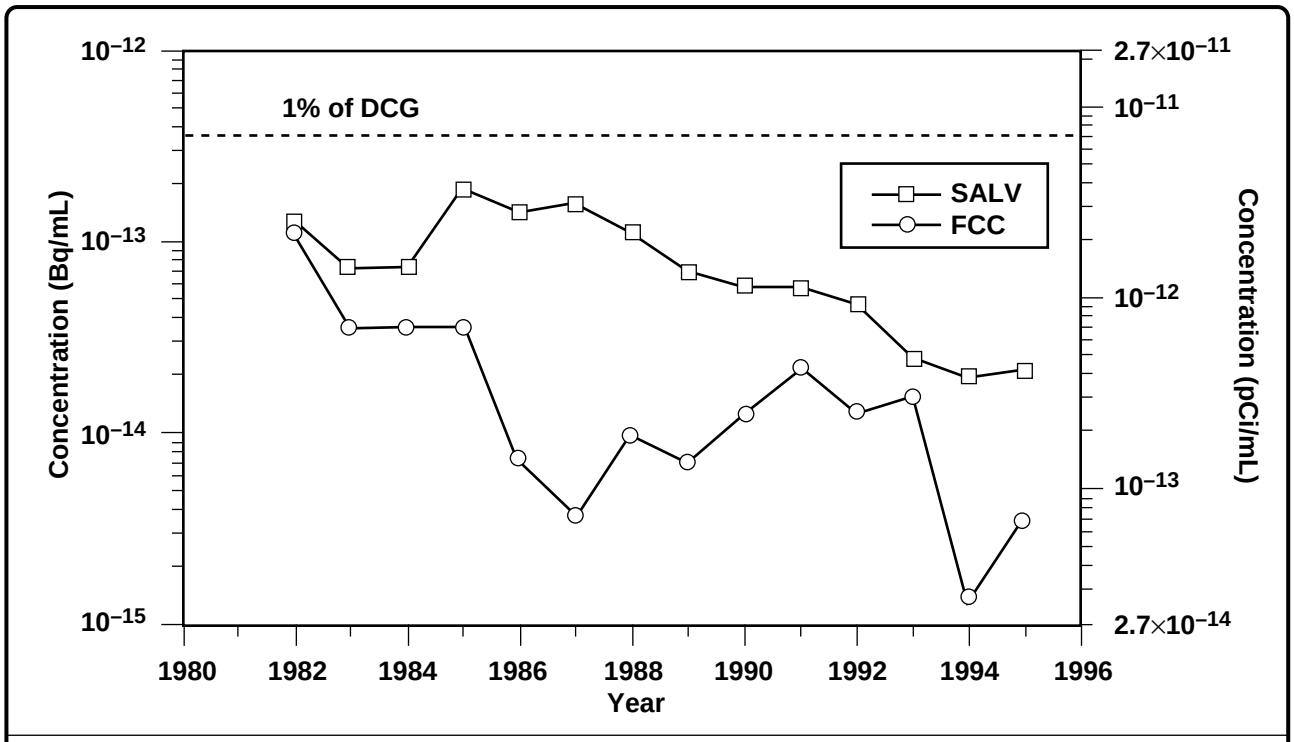

Figure 4-6. Median plutonium concentrations in air particulate samples at two locations, SALV and FCC, 1982–1995 (DCG = 7.4×10^{-10} Bq/mL).

$^{235}U/^{238}U$ ratios, indicating other than natural uranium around the Livermore site perimeter. While no significant environmental impact stems from the observed ratios, their cause is not known but may be attributed to construction activities near the sampling locations causing increased resuspension of historical contamination and an increase in the mass loading of the filters.

Table 4-5 shows the median concentrations of tritiated water vapor for the Livermore Valley sampling locations. (See Volume 2, Table 4-12 for biweekly data for each location.) The highest annual median concentration was observed at location ZON7. At approximately 2.2×10^{-8} Bq/mL (5.9×10^{-19} Ci/mL), this concentration represents 0.000006 of the DCG. The highest biweekly concentration was observed in January at VET. If it were a yearly average, this concentration, 3.6×10^{-7} Bq/mL (9.7×10^{-18} Ci/mL), would be 0.0001 of the DCG. The 1995 tritium values generally are similar to those reported last year.

Table 4-5 also shows the median concentrations of tritiated water vapor that were observed at the Livermore site perimeter sampling locations. (See Volume 2, Table 4-13 for biweekly data.) The highest annual median concentration was observed at location POOL, which was 1.4×10^{-7} Bq/mL (3.8×10^{-18} Ci/mL), or 0.00004 of the DCG.

Table 4-4. Uranium activity in air particulate samples, 1995.

Sampling location[a]	^{238}U[b] [10^{-5} μg/m^3]	^{235}U[c] [10^{-7} μg/m^3]	$^{235}U/^{238}U$[d] [10^{-3}]
LLNL perimeter			
SALV			
Median	4.1	2.9	7.28
Interquartile range	5.8	4.3	0.28
Maximum	13.9	10.3	—[e]
Median fraction of DCG	1.40×10^{-4}	6.20×10^{-6}	
MESQ			
Median	4.5	3.2	7.3
Interquartile range	4.4	3.2	0.23
Maximum	13.4	9.9	—[e]
Median fraction of DCG	1.50×10^{-4}	6.80×10^{-6}	
CAFE			
Median	4.5	3.3	7.24
Interquartile range	4	2.9	0.29
Maximum	14.2	10.5	—[e]
Median fraction of DCG	1.50×10^{-4}	7.10×10^{-6}	
VIS			
Median	2.8	3.4	7.36
Interquartile range	3.9	3.7	0.92
Maximum	12.1	16	—[e]
Median fraction of DCG	9.50×10^{-5}	7.10×10^{-6}	
COW			
Median	5.5	4.1	7.25
Interquartile range	10.3	6.7	0.29
Maximum	19.4	143	—[e]
Median fraction of DCG	1.80×10^{-4}	8.70×10^{-6}	
MET			
Median	3.7	2.7	7.28
Interquartile range	5.5	4.4	0.39
Maximum	14.3	10.5	—[e]
Median fraction of DCG	1.22×10^{-4}	5.60×10^{-6}	
Site 300 (composite)			
Median	4.2	2.7	6.1
Interquartile range	6.6	4.1	2.2
Maximum	14.5	10.3	—[e]
Median fraction of DCG	1.40×10^{-4}	5.70×10^{-6}	

a See **Figures 4-1** and **4-3** for sampling locations.

b Derived Concentration Guide (DCG) = 0.3 μg/m^3 for ^{238}U activity in air.

c Derived Concentration Guide (DCG) = 0.047 μg/m^3 for ^{235}U activity in air.

d Naturally occurring uranium has a $^{235}U/^{238}U$ ratio of 7.1 X 10^{-3}.

e Maximum not computed for $^{235}U/^{238}U$ ratio; maximum for each isotope may not occur in same month.

Table 4-5. Tritium in air samples (in 10^{-9} Bq/mL), 1995.

Sampling location[a]	Detection frequency	Median	IQR[b]	Maximum	Median fraction of DCG[c]	Median dose (mSv)[d]
Livermore Valley						
ZON7	17/23	22.1	<37.7	318.9	6.0×10^{-6}	4.7×10^{-6}
ALTA	8/22	<15.3	—[e]	24.1	$<4.1 \times 10^{-6}$	3.3×10^{-6}
FIRE	11/25	<16.0	<23.5	74.0	$<4.3 \times 10^{-6}$	3.4×10^{-6}
XRDS	6/25	<13.1	—[e]	87.7	$<3.6 \times 10^{-6}$	2.8×10^{-6}
VET	16/25	21.7	<35.6	357.1	5.9×10^{-6}	4.7×10^{-6}
Livermore perimeter						
SALV	26/26	78.6	85.3	558.7	2.1×10^{-5}	1.7×10^{-5}
MESQ	19/25	32.3	<39.2	141.0	8.7×10^{-6}	6.9×10^{-6}
CAFE	26/26	77.5	81.6	555.0	2.1×10^{-5}	1.7×10^{-5}
MET	20/26	<39.2	—[e]	148.4	$<1.1 \times 10^{-5}$	8.4×10^{-6}
VIS	26/26	73.8	48.7	373.7	2.0×10^{-5}	1.6×10^{-5}
COW	24/26	61.2	35.3	392.2	1.7×10^{-5}	1.3×10^{-5}
POOL	25/25	143.9	142.1	921.3	3.9×10^{-5}	3.1×10^{-5}
Diffuse on-site sources						
B292	24/24	128.4	76.1	359.3	3.5×10^{-5}	2.8×10^{-5}
B331	25/25	1931.4	4780.4	43660.0	5.2×10^{-4}	4.1×10^{-4}
B514	25/25	152.1	85.5	525.4	4.1×10^{-5}	3.3×10^{-5}
B624	25/25	921.3	762.2	3540.9	2.5×10^{-4}	2.0×10^{-4}

a See **Figures 4-1** and **4-2** for sample locations.
b Interquartile range.
c DCG = 3.7×10^{-3} Bq/mL (1×10^{-7} μCi/mL).
d 1 mSv = 100 mrem.
e Interquartile range not calculated. See Chapter 15, Quality Assurance.

Diffuse sources of tritium on the Livermore site are monitored at air tritium sampling locations B331, B292, B514, and B624. **Table 4-5** shows the median concentrations of tritiated water vapor for these sampling locations. (See Volume 2, Table 4-14 for biweekly data.) The highest median concentration was observed at location B331. This concentration was 1.9×10^{-6} Bq/mL (5.2×10^{-17} Ci/mL) and represents 0.0005 of the DCG. The highest biweekly tritium concentration, 4.4×10^{-5} Bq/mL (1.2×10^{-15} Ci/mL), was observed in August. If it were a yearly average, this concentration would represent 0.01 of the DCG. The median concentration at the B331 sampling location is almost three times higher than in previous years.

The B331 location is near the Tritium Facility (Building 331), in which 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 a waste accumulation area before being sent to Hazardous Waste Management facilities. During 1995, outgassing from such waste processing released an estimated 0.15×10^{12} Bq/L (4 Ci) of tritium to the atmosphere outside of Building 331.

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 consists of several areas where waste containers that are outgassing tritium are stored outdoors. The 1995 median concentrations at B292 and B624 are similar to the median concentrations in 1994.

The B292 location is near an underground retention tank that had previously leaked and the B514 sampling location is in a hazardous waste management area where tritium-contaminated waste is treated.

Beryllium in Air

The median concentrations of airborne beryllium for the Livermore site perimeter sampling locations are shown in **Table 4-6**. (See Volume 2, Table 4-15 for monthly data.) The highest value of 54.8 pg/m^3 occurred in the October composite at location SALV. The median concentration for this location is 0.0006 of the monthly ambient concentration limit of 10,000 pg/m^3 established by the Bay Area Air Quality Management District (BAAQMD) and the EPA.

Figure 4-7 is a plot of the median beryllium concentration at the Livermore site perimeter from 1974 through 1995. The overall median concentration was calculated to be 0.002 of the ambient concentration guide. Unless there is a change in LLNL's operations, it is expected that the beryllium levels will remain unchanged.

Site 300

Airborne Radioactivity

Most gross alpha determinations at Site 300 were at or near the analytical limit of detection for the method. **Table 4-1** shows the monthly gross alpha and gross beta detection frequency, median, IQR, and maximum for sampling locations at Site 300. (See Volume 2, Table 4-3 for monthly data.) The monthly median gross alpha and gross beta concentrations are shown in **Figures 4-4** and **4-5**. The Site 300 gross beta results show a similar pattern to those found at the Livermore site. Typical gross alpha activity is -5.8×10^{-12} Bq/mL (-1.6×10^{-23} Ci/mL), or below the detection limit.

Table 4-6. Beryllium in air particulate samples (in pg/m^3), Livermore site perimeter and Site 300, 1995.

Sampling location[a]	Detection frequency	Median	Interquartile range	Maximum
Livermore perimeter				
SALV	12/12	6.1	10.3	54.8
MESQ	12/12	7.0	8.3	25.6
CAFE	12/12	8.0	10.9	23.5
MET	12/12	8.1	11.6	47.5
VIS	12/12	5.2	8.4	23.7
COW	12/12	9.5	11.8	34.2
Site 300				
EOBS	12/12	5.9	7.2	44.7
ECP	12/12	4.9	6.8	33.7
WCP	12/12	4.1	7.0	38.6
LIN	12/12	7.2	12.2	21.6
GOLF	12/12	6.1	8.4	20.0
TFIR	12/12	11.9	16.4	73.9
NPS	12/12	5.7	8.5	29.0
WOBS	12/12	4.4	11.6	57.1
801E	12/12	11.6	12.6	43.5

[a] See **Figures 4-1** and **4-3** for sampling locations.

Typical gross beta activity is 4.1×10^{-10} Bq / mL (1.1×10^{-20} Ci / mL). The primary sources of observed gross alpha and gross beta activity are naturally occurring radioisotopes of uranium and thorium and their decay products, and any residual fallout from atmospheric weapons testing and the Chernobyl reactor accident (1986).

Table 4-2 lists the annual median activities, IQR, the fraction of the DCG, as well as the DCGs, of gamma-emitting radionuclides in samples from Site 300 and Tracy. (See Volume 2, Table 4-5 for monthly data.) All these radionuclides were measured at concentrations significantly below the DCGs. Of the nuclides tabulated, ^{7}Be, ^{40}K, ^{226}Ra, ^{228}Ra, and ^{228}Th are naturally occurring. The primary source of ^{137}Cs normally is long-term global fallout and resuspension.

Table 4-3 shows the median concentration of ^{239}Pu on air-filter samples collected from Site 300. (See Volume 2, Table 4-9 for monthly data.) The highest concentration of ^{239}Pu was observed in the October composite at a level of 1.2×10^{-14} Bq / mL (3.2×10^{-25} Ci / mL), or 0.00002 of the DCG. **Table 4-5** shows the median concentration of ^{238}U, ^{235}U, and the ^{235}U / ^{238}U ratio on air samples from Site 300. (See Volume 2, Table 4-11 for monthly data.) The highest

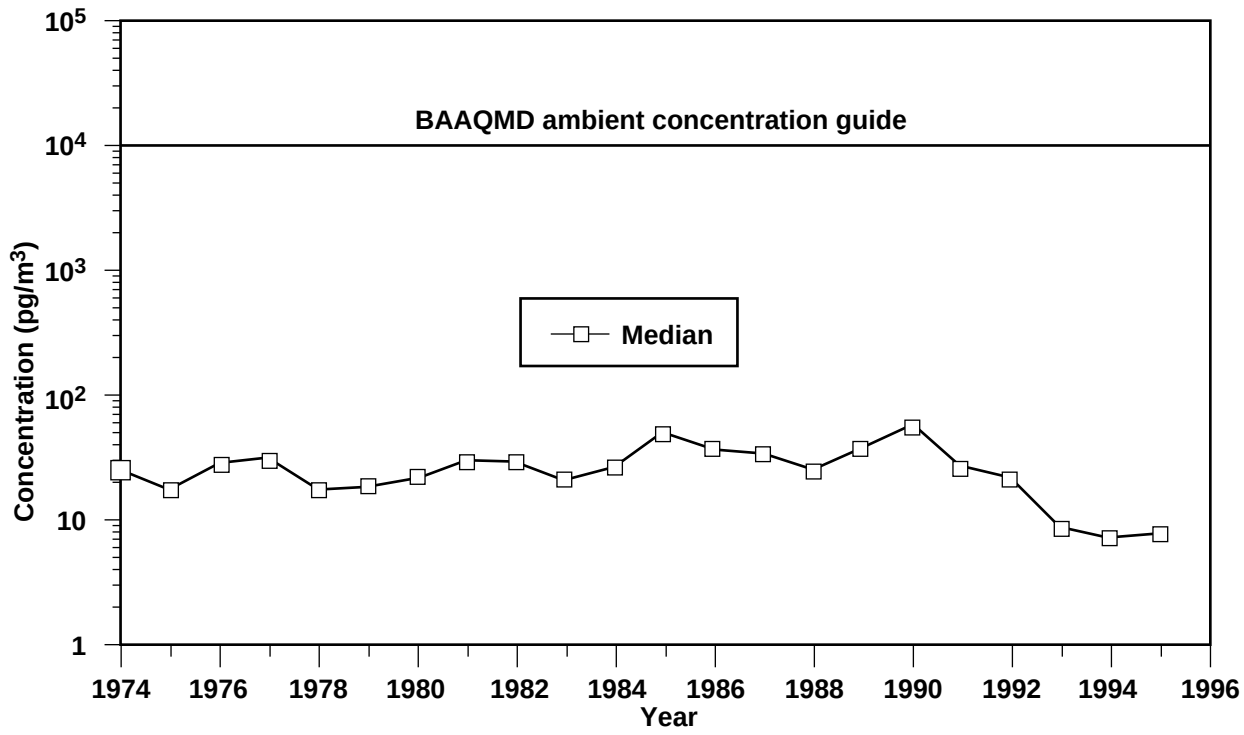

Figure 4-7. Median concentration of beryllium in air particulate samples, Livermore site perimeter, 1974 to 1995.

concentration of ^{238}U was observed in the October composite at a level of 1.5×10^{-4} µg / m^3 (0.0005 of the DCG). The highest concentration of ^{235}U was observed in the October composite at a level of 1.0×10^{-6} µg / m^3 (0.00002 of the DCG). No other significant differences between locations or samples were noted. The overall levels were essentially the same as those reported in previous years.

The ratio of ^{235}U to ^{238}U can be used to identify the source of the uranium. Both ^{235}U and ^{238}U occur naturally in the area, but only 0.7% of the naturally occurring uranium is ^{235}U, and the remainder is almost entirely ^{238}U. Because Site 300 operations use depleted uranium that contains very little ^{235}U, it follows that if the ratio remains constant and near 0.7% (within the limit of sampling and analytical error), then the ^{238}U measured is from natural sources. The $^{235}U / ^{238}U$ ratios in January and February are slightly less than expected for natural sources, which may be a result of the increased variability in the measurements at the reported values. The deviations from the natural ratio in March, May, June, and August indicate some impact from operations at Site 300. The median concentration of ^{238}U for 1995, however, is only 0.00014 of the DCG (DOE Order 5400.5).

Beryllium in Air

The detection frequency, median, IQR, and maximum concentrations of airborne beryllium for the Site 300 sampling locations are shown in **Table 4-6**. (See Volume 2, Table 4-16 for monthly data.) The highest beryllium concentration of

73.9 pg/m^3 occurred in October at location TFIR. The concentration median for this location is 0.0006 of the federal ambient concentration limit, which is 10,000 pg/m^3.

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 concentration in ambient air in 1995. Radionuclide concentrations in air at the Livermore site and in the Livermore Valley are well below levels that would cause concern to the environment or public health according to existing regulatory standards.

The diffuse tritium sources at B292, B331, B514, and B624 have a localized effect; no elevated tritium concentrations were detected at the site perimeter or off site.

The concentrations of radionuclides measured around Site 300 and in the City of Tracy were well below all standards and, except for uranium isotopes, reflect background or naturally occurring levels of these chemicals. (See Chapter 13, Dose Assessment, for discussion of estimated dose from these data.) The $^{235}U/^{238}U$ ratios in October and December are less than the ratio of naturally occurring concentrations of these isotopes, which suggests that LLNL-introduced depleted uranium is present in air samples from Site 300. These kinds of results can occur when tests using depleted uranium are conducted at Site 300.

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 Central Valley typically contains 10 to 100 μg/m^3 of particulates. Using a value of 50 μg/m^3 for an average dust load and 1 ppm for beryllium content of dust, an airborne beryllium concentration of 50 pg/m^3 can be calculated. The overall annual medians for the Livermore site and Site 300 are 7.1 pg/m^3 and 6.2 pg/m^3, respectively. These data are well below standards and do not indicate the presence of a threat to the environment or public health.

5. Air Effluent Monitoring

Arthur H. Biermann
Paula J. Tate

Introduction

Air effluent emissions from facility operations are assessed 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. LLNL complies with local, state, and federal environmental air quality laws and DOE regulations previously discussed in Chapter 4. In general, LLNL analyzes for most constituents at levels that are far below regulatory standards in order to determine any environmental impact. Air surveillance measurements (see Chapter 4) are also made to assess environmental impact.

Assessment of air effluent emissions is performed by monitoring emissions and/or evaluating potential emissions. Currently, the air effluent sampling program measures only radiological emissions. LLNL has operations with the potential for nonradiological discharges; however, permits for these operations are obtained through local agencies having enforcement authority for the Clean Air Act, and stack monitoring is not required. The agencies governing LLNL compliance are EPA Region IX, 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.

Historically, monitoring of radionuclide air effluents at LLNL has been implemented according to the DOE ALARA (as low as reasonably achievable) policy. This policy is meant to ensure that DOE facilities have the capabilities consistent with the types of operations to monitor routine and nonroutine radiological releases, so that the dose to members of the public can be assessed and that doses are ALARA. The more recent National Emission Standards for Hazardous Air Pollutants (NESHAPs) 40 CFR 61, Subpart H regulations require that monitoring of facility radionuclide air effluents must be performed if the potential off-site dose equivalent is greater than 1 μSv/y (0.1 mrem/y), as calculated using the EPA-mandated air dispersion dose model and assuming no emission control devices. Air effluent monitoring provides the actual source term for modeling to ensure that the NESHAPs standard, 100 μSv/y (10 mrem/y) total site effective dose equivalent, is not exceeded. Discharges that have a potential to release radionuclides from operations but that are not monitored are also evaluated according to the NESHAPs regulations.

A wide variety of radioisotopes are used for research purposes at LLNL, including transuranics, biomedical tracers, tritium, mixed fission products, and others. 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 transuranic aerosols. The air effluent sampling systems described in this chapter apply to stationary and point source discharges. Sampling methods to evaluate LLNL diffuse sources are described in Chapter 4, Volume 2.

LLNL conducts air effluent monitoring at atmospheric discharge points of some facilities to determine the actual emissions from individual facilities and to confirm the operation of emission control systems. Air monitoring involves measurement of particles collected on filters or of vapor chemically trapped on a collection medium. Concentrations of various airborne radionuclides (including particles and tritiated water vapor) are measured at the Livermore site. Point sources as well as diffuse, or nonpoint sources, are monitored to fulfill NESHAPs requirements.

Methods

For air effluent monitoring, LLNL maintains 103 radionuclide samplers on air exhausts at 9 facilities at the Livermore site (see **Figure 5-1**). These systems are listed in **Table 5-1** along with the analytes of interest, the type of sampler, and the number of samplers and discharge points monitored. Sampling for particles containing radionuclides is conducted in eight of the facilities; sampling for tritium is conducted in one facility. All sampling systems operate continuously. Samples are collected weekly or biweekly depending on the facility. Air samples for particulate emissions are extracted downstream of high efficiency particulate air (HEPA) filters and prior to the discharge point to the atmosphere. Particles in the extracted air are 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 have real-time monitors at discharge points to provide faster notification in the event of a release of radioactivity. Further details of LLNL air effluent sampling systems are included in Chapter 4 of the *Environmental Monitoring Plan* (Tate et al. 1995).

The need for continuous air effluent monitoring at other air discharge points that can potentially release radionuclides to the atmosphere is evaluated according to the NESHAPs regulations. The evaluation is based on estimated releases using radionuclide inventories specific to individual discharge points and does not take into account reduction by emission control systems (according to the regulations). The most recent NESHAPs evaluation for LLNL operations is reported in the LLNL NESHAPs 1995 Annual Report (Gallegos et al. 1996). Many of the existing sampling systems now in place (**Table 5-1**) are not required by law; however, LLNL has continued to operate these systems as a best management practice.

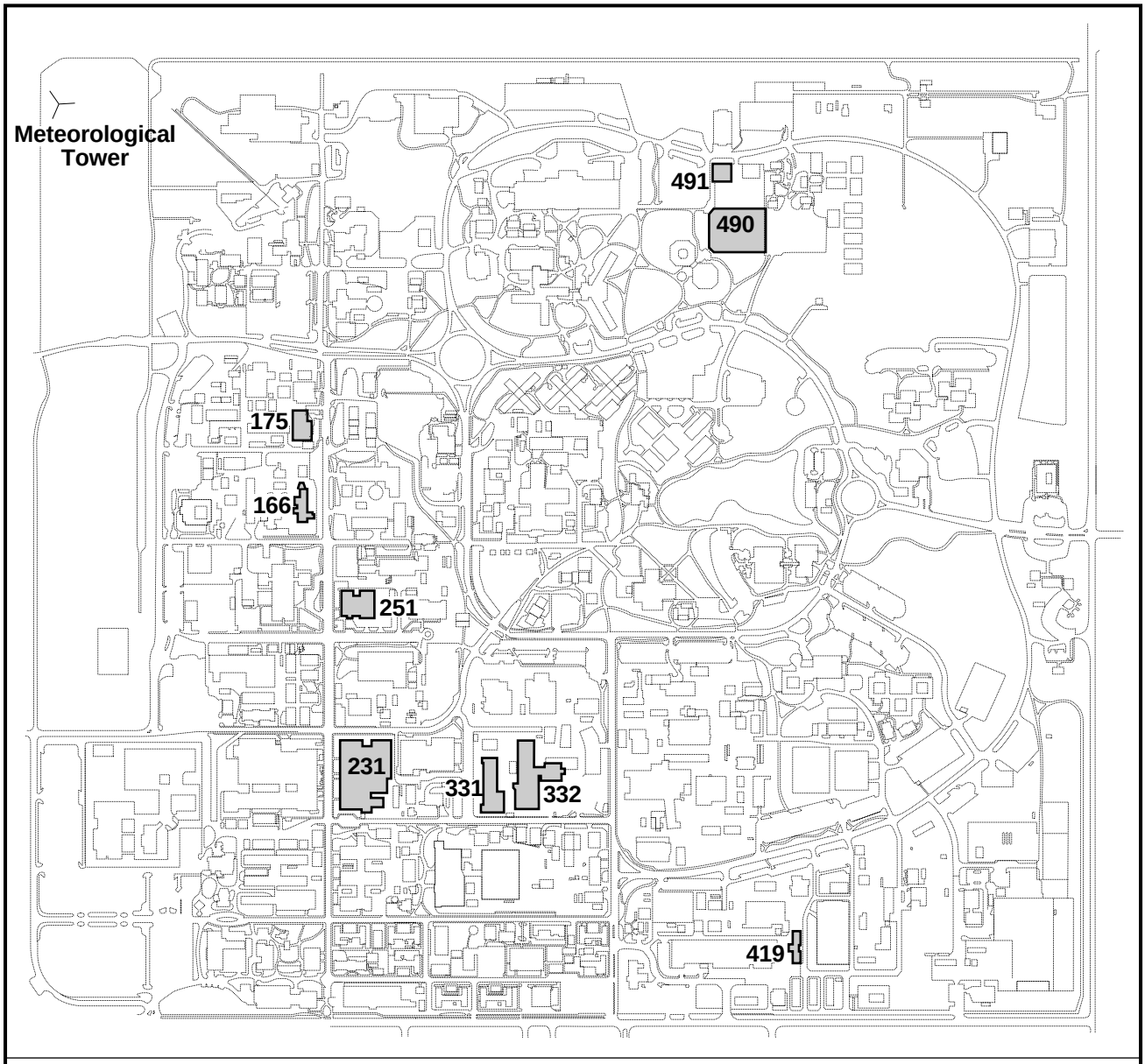

Figure 5-1. Buildings at the LLNL site having air monitoring systems for effluent gas streams.

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 these data, the BAAQMD and the SJVUAPCD have ranked LLNL as a low-risk facility. Each year LLNL completes a review of the air toxics inventory and updates the annual permit. Currently, nonradiological emissions (with the exception of beryllium) are permitted through the local air districts and air toxics monitoring is not required.

In 1995, a new radiological sampling system was installed in Building 166 to monitor emissions from glove-box operations. The system was installed based on a NESHAPs assessment of operations involving uranium that were begun in early 1995. In addition, 8 new filter type samplers were installed, 4 in the Building 251 hardened area and 4 in Building 332 as part of improvements made to LLNL sampling systems. Release points where these samplers were installed had existing sampling systems; the added samplers provide increased sampling capabilities.

All analytical results are reported as a measured concentration per volume of air, or at 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 air sample.

Table 5-1. Air effluent sampling locations and systems.

Building	Facility	Analytes	Sample type	Number of samplers	Number of discharge points
166	Pyrochemistry demonstration facility	Gross α, β on particles	Filters	1	1
175	MARS	Gross α, β on particles	Filters	6	6
231	Vault	Gross α, β on particles	Filter	1	1
251	Heavy elements				
	Unhardened area	Gross α, β on particles	Filters	44	55[a]
	Hardened area	Gross α, β on particles	CAM[b]	4	4
		Gross α, β on particles	Filters	4	4
331	Tritium	Tritium	Ionization chamber[b]	4	4
		Gaseous tritium and tritiated water vapor	Molecular sieves	4	2
332	Plutonium	Gross α, β on particles	CAM[b]	12	11
		Gross α, β on particles	Filters	16	11
419	Decontamination	Gross α, β on particles	Filters	2	2
490	Laser isotope separation	Gross α, β on particles	Filters	4	4
491	Laser isotope separation	Gross α, β on particles	Filters	1	1

Note: “CAM” denotes Eberline continuous air monitors.

a Alternate blower system measured by the same sampler.

b Alarmed systems.

Results: Measured Emissions

This section discusses the air effluent monitoring results at the Livermore site.

Livermore Site

Radioactive Air Emissions

Actual measurements of air radioactivity and effluent flow are the basis for reported emissions from continuously monitored sources. LLNL facilities that have continuously monitored discharge points are Buildings 166, 175, 231-vault, 251, 331, 332, 419, 490, and 491.

Tritium emissions from operations at the Tritium Facility (Building 331) account for nearly all the radioactive discharges to the atmosphere from monitored facilities. In 1995, operations there released a total of 3.4×10^{12} Bq (92 Ci) of tritium, or approximately 97% of the tritium released from the Livermore site. Of this, approximately 2.3×10^{12} Bq (63 Ci) were released as tritiated water (HTO). The remaining tritium released, 1.1×10^{12} Bq (29 Ci), was elemental tritium gas. The highest single weekly stack emission from the facility was 1.4×10^{11} Bq (3.8 Ci), of which 5.6×10^{10} Bq (1.5 Ci) was tritiated water. The potential dose from tritium gas is approximately 25,000 times lower than the dose from a comparable release of tritiated water. Therefore, the tritiated hydrogen gas did not contribute significantly in calculations of the overall tritium dose. Building 331 tritium emissions over the period 1981 to 1995 are shown in **Figure 5-2**. Reduced operations in the facility have lead to continuing declining emissions in the latter years.

For most of the continuously sampled discharge points having the potential for particulate radionuclide releases, sample results are below the MDC of the analysis. Sometimes as few as 1 or 2 samples (out of 25 to 50 per year) have concentrations greater than the MDC. Generally, these few samples having results above the MDC are only marginally above the MDC. Use of zero values for this type of data can be justified based on facility knowledge, the use of multiple-stage HEPA filters in all significant release pathways, and alpha-spectroscopy-based isotopic analyses of selected air-sampling filters. These isotopic analyses have demonstrated the presence of naturally occurring radionuclides, such as radon daughters, e.g., polonium, on air-sampling filters. In addition, because of exhaust configurations at some facilities, the monitoring systems sometimes sample air from the ambient atmosphere in addition to the HEPA-filtered air from facility operations, which gives rise to background atmospheric radioactivity being collected. Because of these considerations, the emissions from such facility operations are reported as zero. Furthermore, even

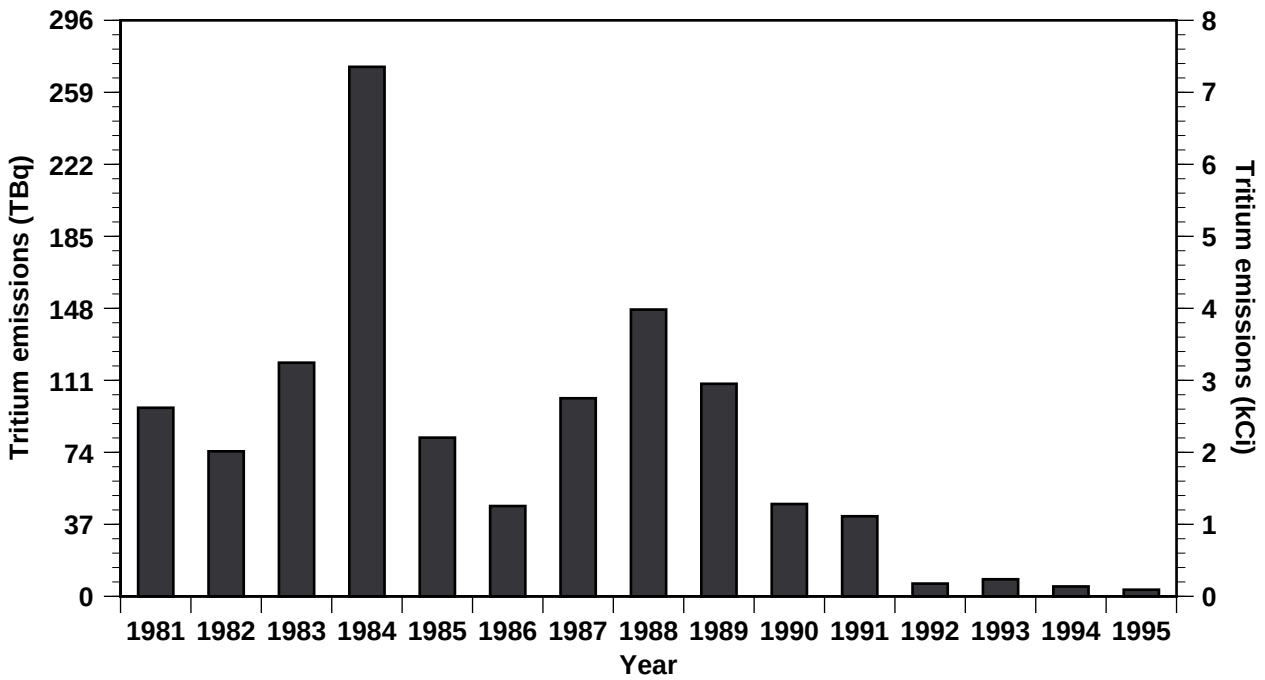

Figure 5-2. Tritium Facility emissions between 1981 and 1995.

if the MDC values were to be used in calculations of the emission estimates for these facilities, an extremely conservative approach, the total dose to a member of the public attributable to LLNL activities should not be significantly affected.

In 1995, samples from three emission points at two facilities, Buildings 251 (Unhardened Area) and 419, yielded gross alpha results greater than the MDC on a majority of the samples collected throughout the year. We use gross alpha as the primary indicator of potential emissions for operations, such as those at Buildings 251 and 419, that involve the use of transuranic materials. The gross alpha monitoring concentrations for these buildings ranged from 7.0×10^{-6} Bq / m^3 (1.9×10^{-16} Ci / m^3) to 2.3×10^{-4} Bq / m^3(6.2×10^{-15} Ci / m^3). Because of the number of samples with values above the MDC, we have taken a conservative approach and reported gross alpha and gross beta measurements as actual emissions. The gross alpha and gross beta emissions for Building 251 were determined to be 6.9×10^2 Bq / y (1.9×10^{-8} Ci / y) and 7.4×10^3 Bq / y (2.0×10^{-7} Ci / y), and the gross alpha and gross beta emissions derived from the measured concentrations for Building 419 were 8.7×10^3 Bq / y (2.3×10^{-7} Ci / y) and 8.5×10^4 Bq / y (2.3×10^{-6} Ci / y). Emissions for Building 251 here are less than those reported in the *LLNL NESHAPs 1995 Annual Report* (Gallegos et al. 1996) because subsequent investigation of the greater than MDC emissions for the sampler warranted correction to the data. **Table 5-2** lists a summary of

radioactive emissions for 1995. We have not confirmed these to be actual facility emissions by isotopic analysis, so it is possible that these, too, are due to naturally occurring, or background, radioactivity, as discussed above. In any case, the radiological dose from the emissions at these facilities is far less than the dose due to other Livermore site emissions.

Table 5-2. Measured radioactive air effluent emissions for 1995 for the Livermore site.

Tritium			
Building	**Facility**	**Elemental, HT (Bq)**	**Tritiated water, HTO (Bq)**
B331	Tritium	1.1×10^{12}	2.3×10^{12}

Gross alpha and gross beta			
Building	**Facility**	**Gross alpha (Bq)**	**Gross beta (Bq)**
B251	Heavy Element	6.9×10^{2}	7.4×10^{3}
B419	Decontamination	8.7×10^{3}	8.5×10^{4}
Total	**Livermore site**	$\mathbf{9.4 \times 10^{3}}$	$\mathbf{9.2 \times 10^{4}}$

Radioactive effluent concentrations from individual discharge points at these facilities are reported in Chapter 5 of Volume 2. Activity concentrations are comparable to the concentrations of gross alpha and gross beta activities as measured by LLNL air surveillance samplers and reported in Chapter 4.

Site 300

Radioactive Air Emissions

Currently, there is no air effluent monitoring of facilities at Site 300. Air surveillance monitoring is performed for Site 300, and results are reported in Chapter 4.

Results: All Potential Sources

This section discusses the evaluation of all sources of radionuclide emissions to air at the Livermore site and Site 300. All discharge points having a potential to release radionuclides to the air are evaluated according to 40 CFR 61, Subpart H of the NESHAPs regulations. This evaluation, performed on an annual basis, uses radionuclide 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. Results for 1995 have been published in *LLNL NESHAPs 1995 Annual Report* (Gallegos et al. 1996).

Estimates of emissions are also made for nonradioactive effluents.

Livermore Site Radioactive Emissions

All Potential Sources of Radioactive Air Emissions

An abbreviated isotope summary of measured and calculated emissions for 1995 is presented in **Table 5-3.** There were 45 buildings involved in the evaluation of emissions; these buildings, their operations, and effective dose equivalents to a member of the public are listed in Chapter 13 (Radiological Dose Assessment). The total estimated release from both point and diffuse sources for all isotopes used was 3.9×10^{12} Bq (105 Ci). Tritium emissions from both point and diffuse sources account for 94% of the total estimated emissions. Primary diffuse sources include tritium storage areas at Building 331, Hazardous Waste Management operations at Buildings 514 and 612, contaminated soil near Building 292, and contaminated soil in the southeast quadrant of the site. The diffuse tritium sources at Buildings 292, 331, 514, and 624 have a localized effect; no elevated tritium concentrations were detected at the site perimeter or off site (See Chapter 4). Operations involving tritium at facilities other than the Tritium Facility had estimated releases totaling 1.05×10^{11} Bq (2.8 Ci) during 1995. These releases were assumed conservatively to be HTO.

A complete isotope listing of calculated emissions appears in Volume 2, Table 5-1. The radioactive atmospheric emissions from these Livermore site operations during 1995 are generally lower than previous years.

Site 300 Radioactive Emissions

All Potential Sources of Radioactive Air Emissions

The estimated radioactive air emissions from Site 300 for 1995 are presented in **Table 5-4.** The total estimated release from both point and diffuse sources was 4.1×10^{10} Bq (1.1 Ci). Point sources, which included explosives testing operations at Buildings 801 and 851, accounted for 87% of the total estimated emissions at Site 300. The remaining 13% of the emissions were from diffuse sources and included subsurface tritium contamination and resuspension of uranium in

contaminated soil. Both types of contamination are from previous explosives testing. Details of the calculations and assumptions involved in obtaining the estimates are contained in the LLNL NESHAPs 1995 Annual Report (Gallegos, 1996).

Table 5-3. Calculated radioactive air emissions from the Livermore site for 1995.

Radionuclide[a]	Calculated emissions[b] (Bq)	Radionuclide	Calculated emissions[b] (Bq)
^{3}H (HTO)[c]	2.6×10^{12}	^{228}Th	1.6×10^{3}
^{238}U	5.4×10^{5}	^{237}Np	4.8×10^{2}
^{234}U	2.6×10^{5}	^{242}Pu	4.1×10^{2}
Gross alpha[c,d]	2.1×10^{4}	^{238}Pu	3.7×10^{2}
^{13}N	1.6×10^{11}	^{32}P	1.9×10^{7}
^{63}Ni	1.1×10^{9}	^{243}Am	8.2×10^{1}
^{235}U	1.4×10^{4}	^{239}Pu	7.1×10^{1}
^{241}Am	2.7×10^{3}	Gross beta[c,d]	1.0×10^{5}
^{15}O	8.5×10^{10}	^{3}H (HT)[c]	1.1×10^{12}
Total			$\mathbf{3.9 \times 10^{12}}$

a Radionuclides have been ordered by weighting the emissions according to the inhalation dose rate conversion factor for the isotope.

b Calculated emissions are estimates made according to NESHAPs 40 CFR 61, Subpart H except those noted as measured. Values are considered to be conservative.

c Includes measured emissions from continuously monitored facilities.

d Gross alpha and gross beta activities are reported in inventories where specific isotopic content is not determined.

Table 5-4. Calculated radioactive air emissions from Site 300 for 1995.

Radionuclide[a]	Calculated emissions[b] (Bq)
^{238}U	2.0×10^{9}
^{234}U	1.9×10^{8}
^{235}U	2.6×10^{7}
^{3}H (HTO)	3.8×10^{10}
Total	$\mathbf{4.1 \times 10^{10}}$

a Radionuclides have been ordered by weighting the emissions according to the inhalation dose rate conversion factor for the isotope.

b Calculated emissions are estimates made according to NESHAPs 40 CFR 61, Subpart H. Values are considered to be conservative.

Nonradioactive Effluents

The Livermore site currently emits approximately 100 kg/day of criteria air pollutants (nitrogen oxides, sulfur oxides, particulate matter (PM10), carbon monoxide, and lead). 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).

The estimated releases from exempt and permitted sources of air pollutants at the Livermore site can be compared to the most recent estimated 1994 daily release of air pollutants for the entire Bay Area. For example, the total emissions of oxides of nitrogen released in the Bay Area is approximately 4.4×10^5 kg / day compared to an estimate for LLNL releases of 56 kg / day for the Livermore site (0.00013 of total Bay Area emissions). The BAAQMD estimate for reactive organic emissions is 7.5×10^5 kg / day, versus Livermore site's estimated releases of 25 kg / day (0.00003 of total Bay Area emissions) in 1995. **Table 5-5** lists the estimated Livermore site 1995 total airborne releases for criteria pollutants.

Certain operations at Site 300 require permits from San Joaquin Valley Unified Air Pollution Control District. The total estimated air emissions during 1995 from operations (permitted and exempt air sources) at Site 300 are given in **Table 5-5**. Criteria sources at Site 300 include a gasoline dispensing operation, open burning, paint spray booths, and soil vapor extraction.

Table 5-5. Nonradioactive air emissions, Livermore site and Site 300, 1995.

Pollutant	Estimated releases (kg/day)	
	Livermore site	Site 300
Organics/volatile organics	25	1.3
Oxides of nitrogen	56	0.60
Carbon monoxide	9.6	0.40
Particulates (PM10)	8.4	2.3
Oxides of sulfur	7.2×10^{-1}	2.5×10^{-2}

Environmental Impact

Radioactive air effluents from the Livermore site and Site 300 operations for 1995 are well below levels which should cause concern to the environment or public health according to existing regulatory standards. The doses to the hypothetical maximally exposed members of the public due to measured and potential air emissions, as reported in Chapter 13 (Radiological Dose Assessment), are 0.41 µSv (0.041 mrem) for the Livermore site and 0.23 µSv (0.023 mrem) for Site 300. When compared to the NESHAPs standard of 100 µSv / y (10 mrem / y) and dose from naturally occurring radiation, the estimated doses due to the LLNL radionuclide air emissions reported here are minimal. Nonradioactive air effluents, which are also very small compared to emissions in surrounding areas, are well below standards and do not indicate threats to the environment or public health.

6. Sewage Monitoring

Jennifer M. Larson

Introduction

In 1995, the Livermore site discharged approximately 1.0 million liters (ML) per day of wastewater to the City of Livermore sewer system, an amount that constitutes 4.9% of the total flow to the system. This volume includes wastewater generated by Sandia National Laboratories/California (SNL/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. In 1995, SNL/California generated approximately 14% of the total flow discharged from the Livermore site. The wastewater contains sanitary sewage and industrial effluent and is discharged in accordance with permit requirements and the City of Livermore Municipal Code.

The effluent is processed 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 the treated effluent 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 Quality 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.

Administrative and engineering controls at the Livermore site effectively 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 for inappropriate discharges. Retention tanks are used to collect wastewater from processes that might release contaminants in quantities sufficient to disrupt operations at the LWRP. Finally, to verify the success of training and control equipment, wastewaters are 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.

To ensure the integrity of the wastewater collection system, LLNL has pursued an aggressive assessment and rehabilitation program. (See Chapter 2, Compliance

Summary, for details.) Begun in 1992 and completed in 1995, the program tested all known building drains to determine their points of discharge. The identified deficiencies, considered to be illicit connections, were classified and corrected; major deficiencies were immediately remedied. Finally, preparatory to relining with a synthetic sock, the major laterals of the sanitary sewer system were videotaped and evaluated. Major line failures were repaired. In addition, the retention tank infrastructure at LLNL is undergoing comprehensive evaluation and rehabilitation (see Tank Management, Chapter 2).

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

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 (as mentioned above), selected 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. The monitoring system provides a continuous check on sewage control and, since July 1990, automatically notifies the LWRP in the event that contaminants are detected. Trained staff respond to all alarms to evaluate the cause.

Two major upgrades were made to the continuous monitoring system in the first quarter of 1995. First, the monitoring system computer was replaced and a redesigned sewer monitoring software system implemented. The new computer is markedly faster, more reliable, and serviceable; the new software is cohesively structured and well-documented. Secondly, the mechanical aspects of the monitoring system were redesigned: plumbing was reorganized and brought up to waste handling standards, the floor layout was reconfigured, the floor was graded and sealed, and extraneous equipment was removed from the facility.

The mechanical upgrade reduces accidental contact with sensitive equipment and facilitates cleaning and maintenance of the continuous monitoring system.

On the basis of the continuous monitoring data, during 1995 there was one release of a corrosive contaminant above the warning levels (see the Environmental Impact section of this chapter) and no releases of metallic or radioactive contaminants that warranted a sewer diversion (see below). This single release is consistent with the results for 1994 and 1993, when one and no such releases, respectively, were detected, and contrasts markedly with the results for 1991 and 1992, when 15 and 13 such releases, respectively, were detected.

In 1991, LLNL completed construction of a diversion system that is automatically activated when the monitoring system sounds an alarm. The diversion system ensures that all but the first few minutes of the affected wastewater flow is retained at LLNL, thereby protecting the LWRP and minimizing any required cleanup. 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 the liquid is not hazardous or after the contamination level is adjusted, depending on analytical results), shipped for off-site disposal, or treated at LLNL's Hazardous Waste Management Facility. All diverted sewage in 1995 was returned to the sanitary sewer.

In 1991, LLNL completed the implementation of a system of 10 satellite monitoring stations that operates in conjunction with the sewer monitoring system (**Figure 6-1**). The satellite monitoring stations are positioned at strategic locations within the main sewer system to help pinpoint the on-site area from which a release might have originated. Each station consists of an automatic sampler that collects samples on a time-proportional basis. If there is a release, these samples are analyzed. However, early in 1994, all but two (86B and 51A) of the satellite monitoring stations were taken off line pending ergonomic reengineering of the equipment used during routine maintenance. In 1995, one satellite monitoring station (163A) was restored to operation. This satellite monitoring station is located at the point of discharge of SNL/California wastewater to the LLNL collection system. The low level of unacceptable releases to the sewer has lowered the priority for this reengineering.

Radioactivity in Sewage

Determination of the total radioactivity released from tritium, alpha emitters, and beta emitters is based either on the measured radioactivity in the effluent or on the limit of sensitivity, whichever is higher (see **Table 6-1**). The 1995 combined releases of tritium and alpha and beta sources were 5.4 GBq (0.15 C i). The total is based on the results shown in **Table 6-1**, reduced by reported SNL/California tritium releases of 0.9 GBq (0.02 Ci). The annual mean concentration of tritium in LLNL sanitary sewer effluent was 0.014 Bq/mL (0.38 pCi/mL).

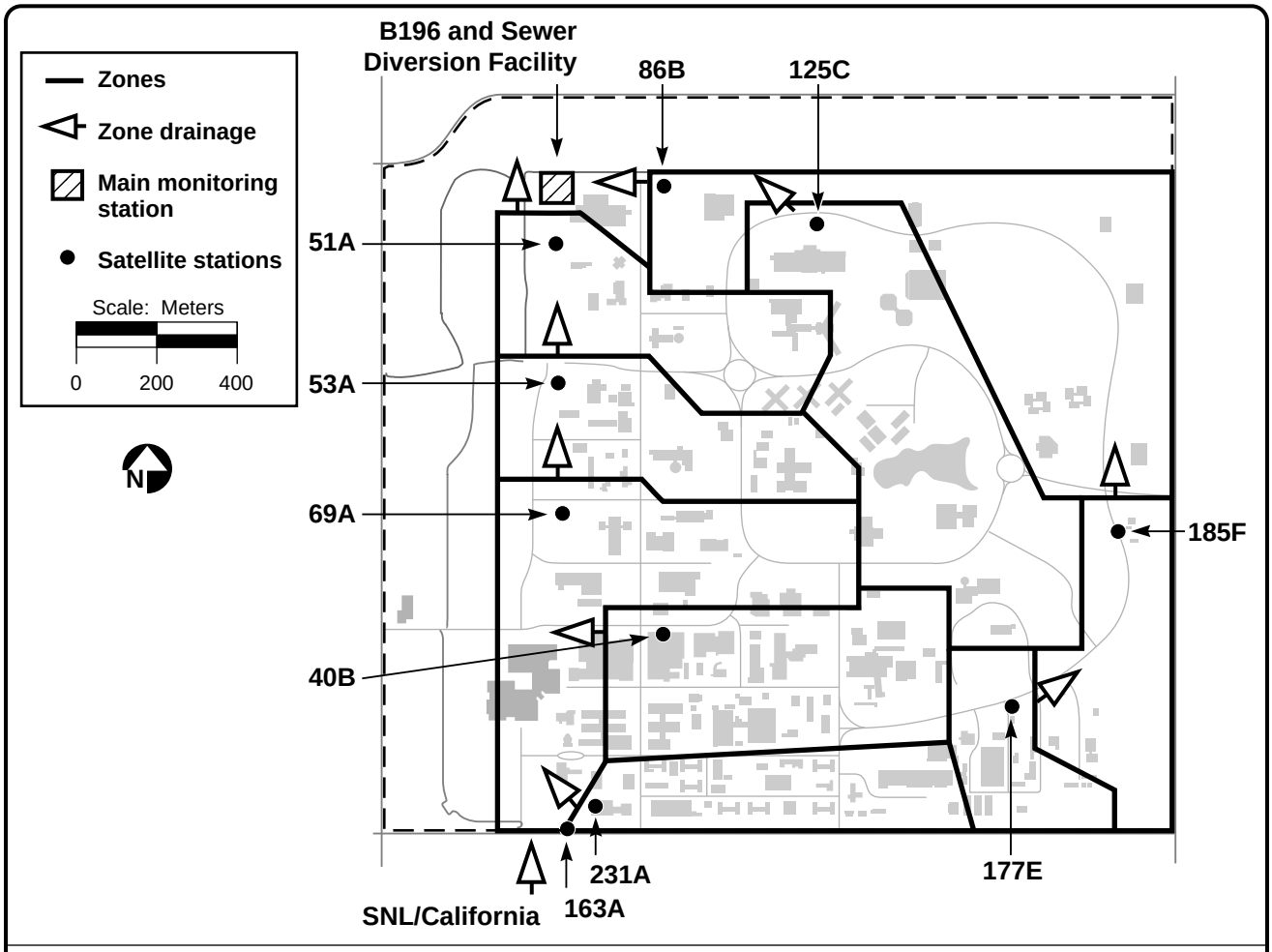

Figure 6-1. Sewer monitoring network.

Table 6-1. Estimated total radioactivity in sanitary sewer effluent, LLNL, 1995.

Radioactive emitter	Estimate based on effluent concentration (GBq)[a]	Limit of sensitivity (GBq)[a]
Tritium	6.0[b]	3.9
Alpha sources	0.065	0.062
Beta sources	0.24	0.066

a GBq = 10^9 Bq or 0.027 Ci.

b 6.0 GBq includes 5.1 GBq from LLNL plus 0.9 GBq from SNL/California.

Table 6-2. Various radionuclides in sanitary sewer effluents, LLNL and LWRP, 1995.

Month	^{3}H (mBq/mL)		^{137}Cs (μBq/mL)		^{239}Pu (nBq/mL)		^{239}Pu (mBq/dry g)
	LLNL	LWRP	LLNL	LWRP	LLNL	LWRP	LWRP sludge[a]
January	24 ± 1	1.9 ± 1.2	0.9 ± 0.4	<0.3	217 ± 46	0.73 ± 8.47	
February	8.4 ± 2.2	3.6 ± 3.6	1.7 ± 0.4	<0.6	134 ± 38	9.25 ± 9.66	
March	6.1 ± 5.0	3.0 ± 3.0	1.0 ± 0.4	<0.6	143 ± 30	0.00 ± 6.48	0.82 ± 0.08
April	5.1 ± 3.7	–2.3 ± –2.3	1.3 ± 0.4	<0.5	130 ± 32	3.63 ± 6.96	
May	12 ± 3	–0.20 ± –0.20	1.2 ± 0.5	<0.5	995 ± 162	19.3 ± 19.3	
June	13 ± 5	2.0 ± 2.0	1.3 ± 0.5	<0.5	392 ± 70	13.7 ± 10.4	0.51 ± 0.05
July	5.3 ± 3.9	0.053 ± 0.053	1.4 ± 0.5	<0.7	223 ± 56	3.41 ± 3.92	
August	11 ± 4	1.7 ± 1.7	2.4 ± 0.4	<0.4	496 ± 80	7.5 ± 11.1	
September	14 ± 4	–0.94 ± –0.94	1.9 ± 0.5	0.5 ± 0.2	932 ± 116	2.86 ± 9.66	0.74 ± 0.09
October	16 ± 4	–0.61 ± –0.61	1.5 ± 0.5	<0.7	214 ± 54	–1.3 ± 12.0	
November	8.3 ± 3.4	2.2 ± 2.2	7.2 ± 0.6	1.3 ± 0.5	181 ± 43	4.55 ± 7.03	
December	3.3 ± 3.3	0.13 ± 0.13	4.8 ± 0.6	0.6 ± 0.3	1110 ± 130	3.66 ± 7.51	0.82 ± 0.08
Median	**10**	**0.90**	**1.4**	**<0.6**	**220**	**3.64**	**0.78**
Interquartile range	**7**	**2.3**	**0.8**	**—[b]**	**434**	**5.59**	**0.14**
			pCi/mL[c]				**pCi/dry g[c]**
Median	**0.26**	**0.024**	**3.9×10^{-5}**	**$<1.5 \times 10^{-5}$**	**6.0×10^{-6}**	**9.9×10^{-8}**	**0.021**
Interquartile range	**0.20**	**0.063**	**2.1×10^{-5}**	**—[b]**	**1.2×10^{-5}**	**1.5×10^{-7}**	**0.004**
			Annual total discharges by radioisotope				
	^{3}H[d]		**^{137}Cs**		**^{239}Pu**		**Total[d]**
Bq/y	**5.1×10^{9}**		**7.5×10^{5}**		**1.2×10^{5}**		**5.1×10^{9}**
Ci/y[c]	**0.14**		**2.0×10^{-5}**		**3.2×10^{-6}**		**0.14**
			Fraction of limit				
DOE	**3.9×10^{-5}**		**3.7×10^{-6}**		**9.0×10^{-7}**		**3.8×10^{-5}**
10 CFR	**0.028**		**2.0×10^{-5}**		**—**		**—**

Note: Radionuclide results are reported ±2σ; see Chapter 15, 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 Livermore Sanitary Landfill.

b Because of the large number of nondetections, the interquartile range is omitted. See Chapter 15, Quality Assurance.

c 1 Ci = 3.7×10^{10} Bq.

d Not including SNL/California discharges of 0.9×10^{9} Bq (0.024 Ci). Does not include gross alpha and beta results shown in **Table 6-1**.

The concentrations of ^{239}Pu, ^{137}Cs, and tritium measured in the sanitary sewer effluent from LLNL and LWRP are presented in **Table 6-2**. The tritium numbers are based on the flow-weighted average of the individual daily sample results for a given month. The plutonium and cesium numbers are the direct result of analysis of monthly composite samples of LLNL and LWRP effluent, and quarterly composites of LWRP sludge. At the bottom of the table, the total activity released is given by radioisotope. This was calculated by multiplying each sample result by the total flow volume over which the sample was collected, and summing up over all samples. The total activity released for each radioisotope is a conservative value; the limit of sensitivity was used in the calculation when the limit of sensitivity was greater than the actual activity reported. Also included in the table are fractions of DOE and 10 CFR limits, discussed in the Environmental Impact section of this chapter.

The historical trend in the monthly average concentration of tritium is shown in **Figure 6-2**. Also included in the figure is the DOE tritium limit (370 Bq / mL), discussed in the Environmental Impact section of this chapter. The trend plot in **Figure 6-2** indicates a well-controlled tritium discharge, one well below the DOE tritium limit and not necessarily driven by a decreasing trituium inventory at the Livermore site.

Figure 6-3 shows the average monthly plutonium and cesium concentrations in sewage since 1985. The annual mean concentration of ^{137}Cs was 2.1 μBq / mL (5.7×10^{-5} pCi / mL); the annual mean ^{239}Pu concentration was 0.33 μBq / mL (8.9×10^{-6} pCi / mL).

Nonradioactive Pollutants in Sewage

Table 6-3 presents monthly average metal concentrations in LLNL's sanitary sewer effluent. The averages were obtained by a flow-proportional weighting of the results from analysis of the weekly composite samples and the 24-hour composites collected each month. Each result was weighted by the total flow volume for the period during which the sample was collected. The results are quite typical of the values seen during previous years, with the exception of arsenic. The arsenic results are discussed below in the Environmental Impact section.

Results of monthly monitoring for metals and other physical and chemical characteristics of the sanitary sewer effluent are provided in **Table 6-4**. Note that—although the samples were analyzed for bromide, carbonate alkalinity (as $CaCO_3$), hydroxide alkalinity as ($CaCO_3$), the full suite of polychlorinated biphenyls, the full suite of organochlorine pesticides, beryllium, cadmium, and cyanide—those analytes were not detected in any sample acquired during 1995, and so are not presented in the table. The results are quite typical of those seen in previous years.

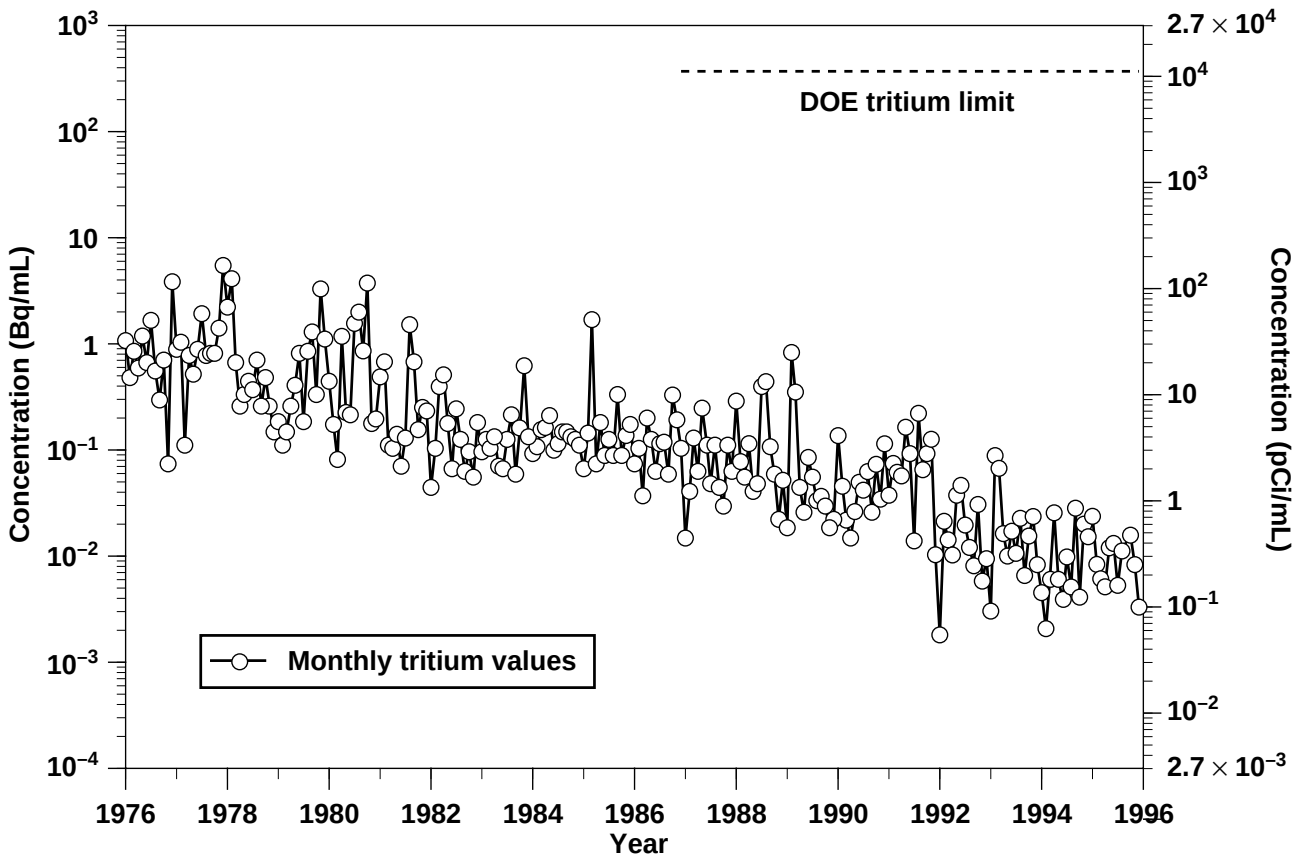

Figure 6-2. Historic trend in tritium concentration in LLNL sewage.

Environmental Impact of Radioactivity in Sewage

During 1995, no inadvertent releases exceeded any discharge limits for release of radioactive materials to the sanitary sewer system.

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 applied by Title 17 of the California Code of Regulations. As a federal facility, LLNL is formally exempt from the requirements of state regulations but follows those requirements under the guidance of DOE. Title 17 contained a limit on discharges of radioactivity in sewage of 37 GBq (1 Ci) each year; it also listed limits on the daily, monthly, and annual concentration for each specific radionuclide.

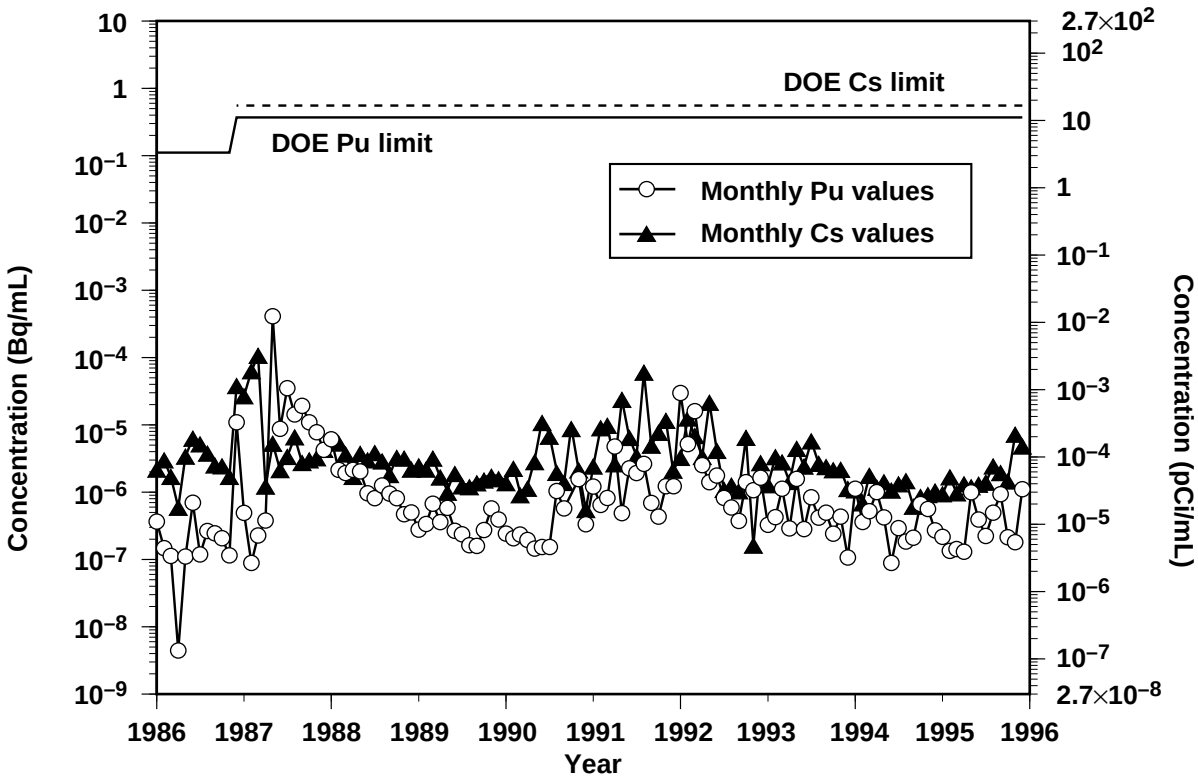

Figure 6-3. Historical trends in plutonium and cesium concentrations in LLNL sewage.

In 1994, the discharge requirements previously found in Title 17 were changed to correspond to the requirements in Title 10 of the Code of Federal Regulations, Part 20. Title 10 contains a limit for the total discharge activity of tritium (185 GBq or 5 Ci), carbon-14 (37 GBq or 1 Ci), and all other radionuclides combined (37 GBq or 1 Ci); in addition, it specifies that the discharge material must be soluble and lists limits on monthly concentrations.

Table 6-5 summarizes the discharge requirements of Title 10. Because Title 10 permits and therefore applies to only soluble discharges, and because the plutonium in LLNL effluent is in the insoluble form, there is no applicable discharge requirement for ^{239}Pu. This assumption is supported by our experience during the sewer system evaluation, when increased cleaning led to higher plutonium concentrations in LLNL sewage (Gallegos et al. 1992a). This indicates that the bulk of plutonium discharged is liberated from deposits on the sewer pipes, which are, by their nature, insoluble.

Table 6-3. Metals discharged to sanitary sewer system (in mg/L), 1995 summary.

Month	Ag	Al	As	Be	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn
January	0.012	0.37	0.0045	<0.00050	<0.0050	0.013	0.08	1.1	0.0013	0.0063	0.009	0.16
February	0.014	0.27	0.0032	<0.00050	<0.0050	0.013	0.11	0.9	0.00043	0.0062	0.017	0.22
March	0.013	0.61	0.0043	<0.00050	<0.0050	0.010	0.09	1.2	0.00071	0.0065	0.014	0.22
April	0.011	0.42	0.0025	<0.00050	<0.0050	0.010	0.10	1.2	0.00027	0.0062	0.014	0.18
May	0.018	0.37	0.0020	0.00057	<0.0050	0.011	0.11	1.4	0.00036	0.0092	0.027	0.21
June	0.020	0.31	0.0029	<0.00050	<0.0050	0.010	0.08	1.0	0.00046	0.0050	0.010	0.18
July	0.012	0.35	0.0025	<0.00050	<0.0050	0.014	0.12	1.1	0.00053	0.0052	0.018	0.35
August	0.017	0.53	0.0032	<0.00050	<0.0050	0.014	0.14	1.2	0.00043	0.0065	0.025	0.24
September	0.010	0.48	0.0021	<0.00050	<0.0050	0.015	0.16	1.4	0.00072	0.0053	0.025	0.22
October	0.010	0.59	0.0023	<0.00050	<0.0050	0.014	0.12	1.4	0.00064	0.0065	0.022	0.23
November	0.011	0.59	0.0024	<0.00050	<0.0050	0.014	0.09	1.3	0.00034	0.0089	0.016	0.23
December	0.007	1.2	0.0048	<0.00050	<0.0020	0.013	0.16	1.6	0.00024	0.0086	0.038	0.35
Median	**0.012**	**0.45**	**0.0027**	**<0.00050**	**<0.0050**	**0.013**	**0.11**	**1.2**	**0.00045**	**0.0064**	**0.017**	**0.22**
IQR	**0.004**	**0.22**	**0.0011**	**—[a]**	**—[a]**	**0.003**	**0.03**	**0.3**	**0.00030**	**0.0011**	**0.011**	**0.03**
DCL[b]	**0.2**	**—[c]**	**0.06**	**—[c]**	**0.14**	**0.62**	**1.0**	**—[c]**	**0.01**	**0.61**	**0.2**	**3.0**
Fraction of DCL	**0.06**	**—[c]**	**0.05**	**—[c]**	**0.04**	**0.02**	**0.11**	**—[c]**	**0.04**	**0.01**	**0.09**	**0.07**

a Because of the large number of nondetects, the interquartile range could not be calculated for these analytes. See Chapter 15, Quality Assurance.

b Discharge Concentration Limit (City of Livermore Ordinance 13.32).

c No established limit for analyte.

Table 6-4. Positively detected parameters in LLNL sanitary sewer effluent, 1995.

Positively detected parameter	Detection[a] frequency	Minimum	Maximum	Median	IQR[b]
Composite sample parameters (mg/L)					
Oxygen demand					
Biochemical oxygen demand	12/12	90	340	210	80
Chemical oxygen demand	11/11	60	530	180	320
Solids					
Total settleable solids (mL/L/h)	12/12	5	34	26	7
Total dissolved solids	12/12	170	470	255	95
Total suspended solids	12/12	22	410	215	120
Volatile solids	12/12	44	110	81	24
Anions					
Nitrate (as N)	3/11	<0.1	1.1	<0.5	—
Nitrate (as NO_3)	3/11	<0.5	<5	<0.5	—
Nitrite (as N)	1/11	<0.2	<1.5	<0.5	—
Nitrite (as NO_2)	1/11	<0.5	<5	<0.8	—
Chloride	11/11	30	78	49	31
Sulfate	11/11	16	66	22	27
Alkalinity					
Total alkalinity (as $CaCO_3$)	11/11	130	290	190	53
Bicarbonate alkalinity (as $CaCO_3$)	11/11	130	290	190	53
Nutrients					
Ammonia nitrogen (as N)	11/11	0.3	48	37	12
Total Kjeldahl nitrogen	10/10	36	65	45	17
Total phosphorus (as P)	11/11	1.1	8.2	4.4	3.1
Organic carbon					
Total organic carbon (TOC)	11/11	29	78	45	22
Total metals					
Aluminum	11/12	<0.2	1.4	0.65	0.33
Arsenic	4/12	<0.002	<0.005	<0.002	—
Calcium	12/12	9.4	35	14	12
Chromium	8/12	<0.01	0.027	0.018	0.010
Copper	12/12	0.067	0.16	0.13	0.050
Iron	12/12	0.36	2.7	1.4	0.45

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Table 6-4. Positively detected parameters in LLNL sanitary sewer effluent, 1995 (concluded).

Positively detected parameter	Detection[a] frequency	Minimum	Maximum	Median	IQR[b]
Lead	12/12	0.01	0.054	0.023	0.017
Magnesium	12/12	2	16	3.3	5.2
Mercury	10/12	<0.0002	0.0076	0.00062	0.00037
Nickel	8/12	<0.005	0.013	0.0061	0.0024
Potassium	12/12	12	24	18	2.5
Selenium	2/12	<0.002	<0.005	<0.002	—
Silver	5/12	<0.005	0.019	<0.010	—
Sodium	12/12	25	140	42	21
Zinc	12/12	0.12	0.57	0.23	0.090
Grab sample parameters					
Volatile organic compounds (μg/L)					
Acetone	10/12	<40	290	95	110
Bromodichloromethane	3/12	<1	3.2	<1	—
Chloroform	12/12	5.3	26	10	5.2
Dibromochloromethane	1/12	<1	1.4	<1	—
Methylene chloride	3/12	<1	1.8	<1	—
Semivolatile organic compounds (μg/L)					
Benzyl alcohol	6/12	<20	1100	<27	32
Bis(2-ethylhexyl)phthalate	5/12	<10	<100	<11	—
m- and p-Cresol	1/12	<10	<100	<10	—
Phenolics (mg/L)					
Total recoverable phenolics	12/12	0.017	0.52	0.027	0.021
Oil and grease (mg/L)					
Total oil and grease (average)	12/12	11	34	20	12

a 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).

b Where the detection frequency is less than 50%, the interquartile range is omitted.

Table 6-5. Sewer discharge release limits for ^{3}H, ^{137}Cs, and ^{239}Pu.

	^{3}H	^{137}Cs	^{239}Pu
10 CFR 20 concentrations used to establish release limits (Bq/mL)	370	0.37	NA[a]
10 CFR 20			
Monthly	185[b]	11	—
Yearly	185[b]	37[c]	—
DOE annualized discharge limit for application of BAT[d] (Bq/mL)	370	0.56	0.37

a 10 CFR 20 imposes a discharge limit for soluble ^{239}Pu released. Evidence supports the insolubility of LLNL's plutonium discharges. Refer to the Environmental Impact section of this chapter.

b 10 CFR 20 imposes a 185-GBq (5-Ci) limit for the tritium radiation released.

c 10 CFR 20 imposes a 37-GBq (1-Ci) combined limit on the total of all radiation released (excluding tritium and ^{14}C, which have separate 10 CFR 20 limits of 185 GBq and 37 GBq, respectively); i.e., the total release of all isotopes must not exceed 37 GBq. If a total of 37 GBq of a particular isotope were released during the year, this would require that no other isotopes be released.

d The DOE annualized discharge limit for application of Best Available Technology (BAT) is five times the Derived Concentration Guide (DCG; ingested water) for each radionuclide released.

Table 6-5 also includes the total activity that could have been discharged by LLNL during a given period (monthly and annually) using 10 CFR 20 concentrations with the annual cap and assuming the 1995 average monthly flow rate. As the table shows, the Title 10 concentration limits for tritium for facilities such as LLNL that generate wastewater in large volumes are overridden by the limit on total tritium activity (18.5 Gbq) dischargable during a single year. In 1995, the total LLNL tritium release was 2.8% of the corresponding Title 10 limit. Total LLNL releases (**Table 6-1**), in the form of alpha and beta emitters (excluding tritium), were 0.82% of the corresponding Title 10 limit.

DOE has also established criteria for the application of Best Available Technology to protect public health adequately and minimize degradation of the environment. These criteria (the Derived Concentration Guides, or DCGs) limit the concentration of each specific radionuclide that is discharged to publicly owned treatment works. If a measurement of the monthly average concentration of a radioisotope exceeds its concentration limit, LLNL would be required to improve discharge control measures until concentrations were again below the DOE limits. **Table 6-5** presents the DCGs for the specific radioisotopes of most interest at LLNL.

The annual average concentration of tritium in LLNL sanitary sewer effluent was 0.000038 (that is, 0.0038%) of the DOE DCG (and the Title 10 limit); the annual average concentration of ^{137}Cs was 3.8×10^{-6} of the DOE DCG (and 5.7×10^{-6} of the Title 10 limit); and the annual average ^{239}Pu concentration was 8.9×10^{-6} of the DOE DCG. The combined discharges were therefore 4.3×10^{-6} of the DCG.

As discussed earlier in this section, when calculating the contribution from plutonium, the plutonium in LLNL effluent is assumed to be in the insoluble form (the DCG for soluble forms of plutonium is 70 times less than the DCG for insoluble plutonium).

LLNL also compares annual discharges against 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 1995, a total of 6.0 GBq (0.16 Ci) of tritium was discharged to the sanitary sewer. This is the combined release from the Livermore site and from SNL/California, whose records account for 0.9 GBq (0.02 Ci) of this amount; LLNL therefore released 5.1 GBq (0.14 Ci), an amount that is well within environmental protection standards and is comparable to the amount reported in 1994. Moreover, the total tritium released by LLNL in 1995 (and 1994) is less than the range reported in the past.

Table 6-6. Radioactive liquid effluent releases from the Livermore site, 1986–1995.

Year	Liquid effluents (GBq)	
	^{3}H	^{239}Pu
1986	74	5.5×10^{-4}
1987	52	2.6×10^{-2}
1988	56	8.1×10^{-4}
1989	59	1.8×10^{-4}
1990[a]	25	2.3×10^{-4}
1991	32	6.1×10^{-4}
1992	8	1.9×10^{-3}
1993	12.6	2.6×10^{-4}
1994	6.9	1.9×10^{-4}
1995	6.0	1.2×10^{-4}

[a] The 1990 DOE Order 5400.5 required compliance with legally applicable local and state regulations such as California Title 17, which mandated a 37 GBQ (1 Ci) limit.

Figure 6-3 summarizes the ^{239}Pu monitoring data over the past 10 years. The historical levels observed since 1986 average 2 µBq/mL (6×10^{-5} pCi/mL), with the exception of a peak in 1987. Even this peak is well below the applicable DOE DCG. Historically, levels generally are six-millionths (0.000006) of that limit. 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 plutonium concentration observed in 1995 sludge (**Table 6-2**), 0.78 mBq/dry g (0.02 pCi/dry g), is more than 600 times lower than the proposed EPA guideline for unrestricted use of soil (480 mBq/dry g).

As first discussed in the *Environmental Report for 1991* (Gallegos et al. 1992a), 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 is related to sewer cleaning with new, more-effective equipment. During 1993, as utility personnel worked to complete an assessment of the condition of the sewer system, cleaning activity around the site was less extensive, resulting in slightly lower plutonium and cesium concentrations in LLNL effluent. During 1994, in conjunction with the installation of the synthetic sock lining in the sewer system, the cleaning activity around the site was more extensive than in 1993. However, by the end of 1993, the new sewer cleaning equipment had been used on LLNL's entire sewer system; this was reflected in 1994 by the continuation of the slightly lower plutonium and cesium concentrations that were observed in the 1993 effluent. The 1995 plutonium and cesium concentrations are comparable to 1994 concentrations except for the final two months of 1995 cesium concentrations, pictured in **Figure 6-3** and reported in **Table 6-2**. These two slightly elevated cesium values are not indicative of a trend towards increased concentrations; data for January and February 1996 reflect a return to the concentration levels reported for the majority of 1995.

Environmental Impact of Nonradioactive Liquid Effluents

Table 6-3 presents monthly average metal concentrations in LLNL's sanitary sewer effluent. At the bottom of the table, the annual average concentration for each metal is compared to the discharge limit. The metals that approached closest to the discharge limits were copper and lead at 11% and 9%, respectively.

Although well below discharge limits, the slightly elevated arsenic levels first seen in 1992 continued through 1995. First discussed in the *Environmental Report for 1993* (Gallegos et al. 1994), the elevated arsenic levels were the subject of an extended investigation during 1993. While arsenic occurs naturally in Livermore site ground water (see Chapter 9), the 1993 study concluded that the presence of arsenic in the sewer was associated with the ground water cleanup at the gas pad along the southern border of the site. The gas pad cleanup operation was continued in 1994, and the slightly elevated arsenic levels of 1993 continued in 1994. During 1995, the gas pad cleanup operations were reduced and the slightly elevated arsenic levels were seen less frequently.

The continuous monitoring system detected one inadvertent discharge during 1995 (as compared to 1, 0, and 13 such discharges in 1994, 1993, and 1992, respectively); this incident was reported to the LWRP. Specifically, on January 23, 1995, the continuous monitoring system detected a brief alkaline discharge above alarm limits. The maximum pH was 10.7, as compared to a pH of 10.0, the effluent pollutant limit for alkalinity contained in LLNL's sewer permit. The estimated duration of the incident was 3 minutes. The Sewer Diversion Facility was activated and approximately 1000 gallons of effluent was

diverted during the three-minute incident. (Uncontained pH releases above the effluent pollutant limit could disrupt treatment plant operations or cause the treated wastewater to exceed allowable concentration limits for discharge to the San Francisco Bay.) Later analysis of the diverted effluent showed that the average pH of 10.1 was sufficiently low to allow release of the wastewater back to the sanitary sewer. This incident did not represent a threat to the integrity of the operations at the LWRP.

For the year as a whole, the monitoring data reflect the success of LLNL's discharge control program in preventing any significant impact on the operations of Livermore's treatment plant. The results demonstrate good compliance with the effluent pollutant limitations of LLNL's sewer permit, and are generally consistent with values seen in the past.

7. Surface Water Monitoring

Erich R. Brandstetter
Richard A. Brown

Introduction

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 first two locales, LLNL monitors reservoirs and ponds, the LLNL swimming pool, rainfall, tap water, and storm water runoff. At Site 300 and vicinity, surface water monitoring encompasses rainfall 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, oil and grease, metals, minerals, anions, and a wide range of organic compounds. In addition, a fish bioassay is performed annually for storm water entering and leaving the Livermore site via the Arroyo Las Positas pathway.

Surface water monitoring is driven by the requirements in the *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. Department of Energy, 1991) and DOE Orders 5400.1, General Environmental Protection Program, and 5400.5, Radiation Protection of the Public and the Environment. LLNL also complies with the Federal Clean Water Act and changes in Section 402 of this Act, which led to LLNL's revision of the storm water monitoring program during 1993. In addition, LLNL's National Pollutant Discharge Elimination System (NPDES) Permit (NPDES No. CA0030023, WDR 95-174) for the Livermore site contains specific monitoring requirements.

Rainwater monitoring is called for in DOE Order 5400.1, which states:

> "Representative meteorological data are required at DOE facilities to support environmental monitoring activities. This information is essential to characterize atmospheric transport and diffusion conditions in the vicinity of the DOE facility and to represent other meteorological conditions (e.g., precipitation, temperature, and atmospheric moisture) that are important to environmental surveillance activities such as air quality and radiation monitoring."

Water Sampling Methods

A description of water sampling methods for surface water and rainfall follows.

7. Surface Water Monitoring

Surface Water

Surface and drinking water near the Livermore site and in the Livermore Valley are sampled at locations shown in **Figure 7-1** according to procedures set out in Appendix A of the *Environmental Monitoring Plan* (Tate et al. 1995). Sampling locations DEL, ZON7, DUCK, ALAG, SHAD, and CAL are surface water sources; BELL, GAS, PALM, and ORCH are drinking water outlets. LLNL samples these locations quarterly for gross alpha, gross beta, and tritium. The on-site swimming pool and drinking water sources POOL and TAP are also sampled, as described above, for gross alpha, gross beta, and tritium. POOL is sampled monthly, TAP quarterly.

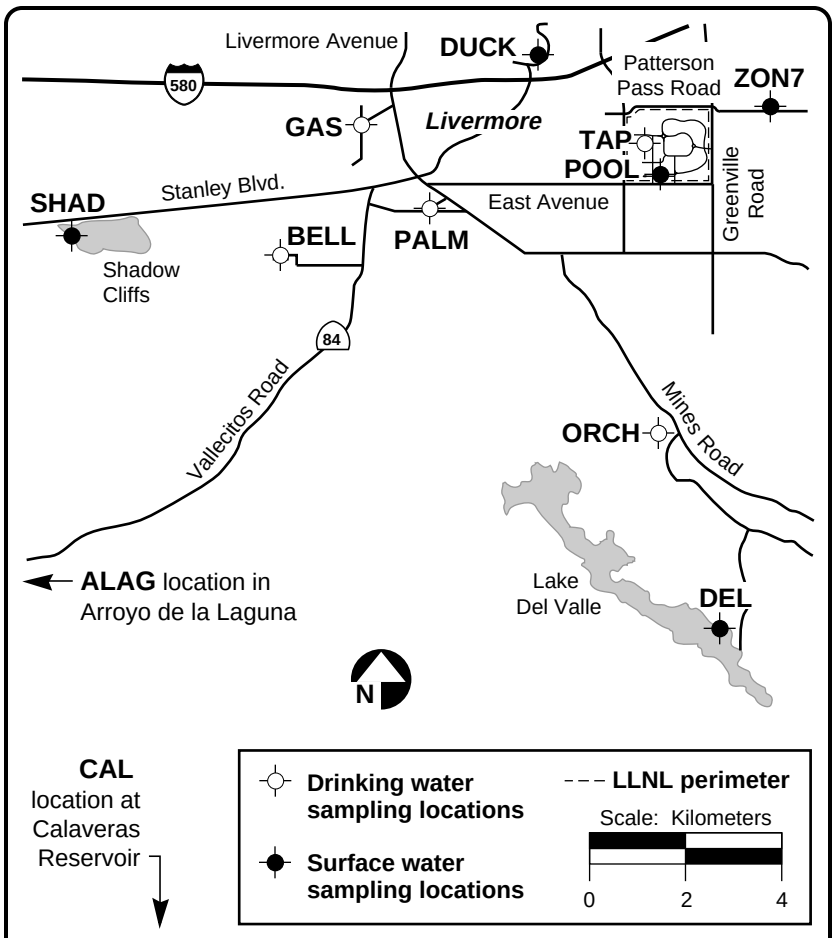

Figure 7-1. Surface and drinking water sampling locations, Livermore Valley, 1995.

Rainfall

Rainfall is sampled for tritium according to written procedures in Appendix A of the *Environmental Monitoring Plan* (Tate et al. 1995). The tritium activity measured in rainfall in the Livermore Valley results primarily from atmospheric emissions of tritiated water vapor (HTO) from stacks at LLNL's Tritium Facility (Building 331), and SNL/California's former Tritium Research Laboratory. The B343 rain sampling location is near the Tritium Facility (Building 331), in which LLNL personnel have reduced operations in recent years and performed significant inventory reduction and cleanup activities. HTO emissions resulted from various continuing cleanup activities at both facilities. The total measured atmospheric emission of HTO from these facilities in 1995 was 5.1 TBq, equal to 140 curies (Ci). Of this amount, LLNL released 2.3 TBq (63 Ci)(see Chapter 5).

The rain sampling station locations are shown on **Figure 7-2.** The fixed stations are positioned around the two main HTO sources so as to record a wide spectrum of tritium activities in rainfall, from the maximum expected down to background levels.

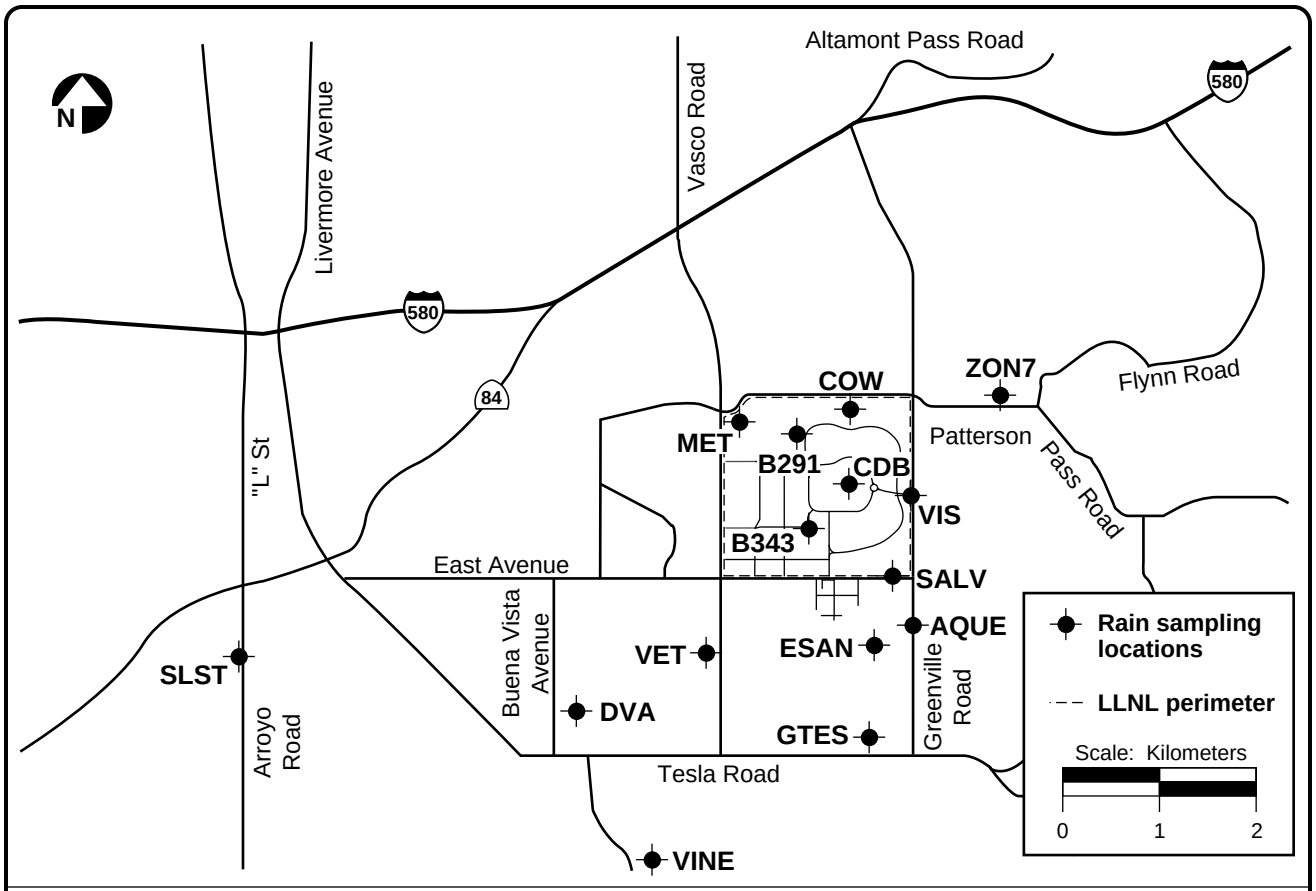

Figure 7-2. Rain sampling locations, Livermore site and Livermore Valley, 1995.

Winds measured at LLNL during rain events are predominantly from the southwest quadrant and totaled 49% of the 1995 wind field. Winds from the northwest, northeast, and southeast quadrants counted for 16, 21, and 14%, respectively, during rain events. One station, SLST, located west-southwest of LLNL, is utilized to determine upwind background levels of tritium activity in rainfall (**Figure 7-2**). Station MET is located on site at the meteorological tower. Nine additional rain sampling locations were designed to monitor rainfall close to the primary sources. Stations were placed at various compass directions to provide adequate coverage of wind directions expected during rain events. A new rain sampling station southwest of LLNL (VET) was established in October 1994 to provide an off-site location that would be downwind during the 21% of the rain events in which wind is from the northeast quadrant (**Figure 7-2**). Three additional rain sampling stations in existence prior to 1993—VINE (nearly 3 km south-southwest of the southwest corner of LLNL), BVA (2 km southwest of LLNL), and GTES (about 1.8 km south of the southeast corner of LLNL)—were reinstituted in 1995. These locations were reinstitued to determine the extent of tritium activity in rainfall to the southwest of LLNL and SNL/California.

One central location is used to collect rainfall for tritium activity measurements at LLNL's Experimental Test Site (Site 300) (**Figure 7-3**). Rain samples are collected monthly from Site 300 during the rainy season. Over the past 24 years, 155 measurements of rainfall samples collected at this location give a maximum tritium activity of only 9.1 Bq/L (250 pCi/L), a median of 2.3 Bq/L (62 pCi/L), with a standard deviation of 2.1 Bq/L (57 pCi/L). The tritium activity measured in rainfall at Site 300 has been indistinguishable from atmospheric background over the past 24 years.

Storm Water

Storm water runoff monitoring provides a broad measure of the efficacy of LLNL operational procedures that prevent, contain, and remediate inadvertent spills of hazardous wastes or products onto the ground at the Livermore site and Site 300. LLNL first monitored storm water runoff at the Livermore site in 1975. This monitoring network, originally designed to detect pesticides, expanded in 1990 to cover new locations and additional water quality parameters (i.e., radioactivity, metals, and additional organic compounds). Additional changes during 1993 complied with the National Pollutant Discharge Elimination System General Industrial Activities Storm Water Permit (NPDES General Permit). In October 1993, also in response to the NPDES General Permit, LLNL established a new storm water monitoring program at Site 300. In 1995, the San Francisco Bay Region Water Quality Control Board issued a Waste Discharge Requirements and National Pollutant Discharge Elimination System (NPDES) Permit (NPDES No. CA0030023, WDR 95-174) for the Livermore site, which replaced coverage

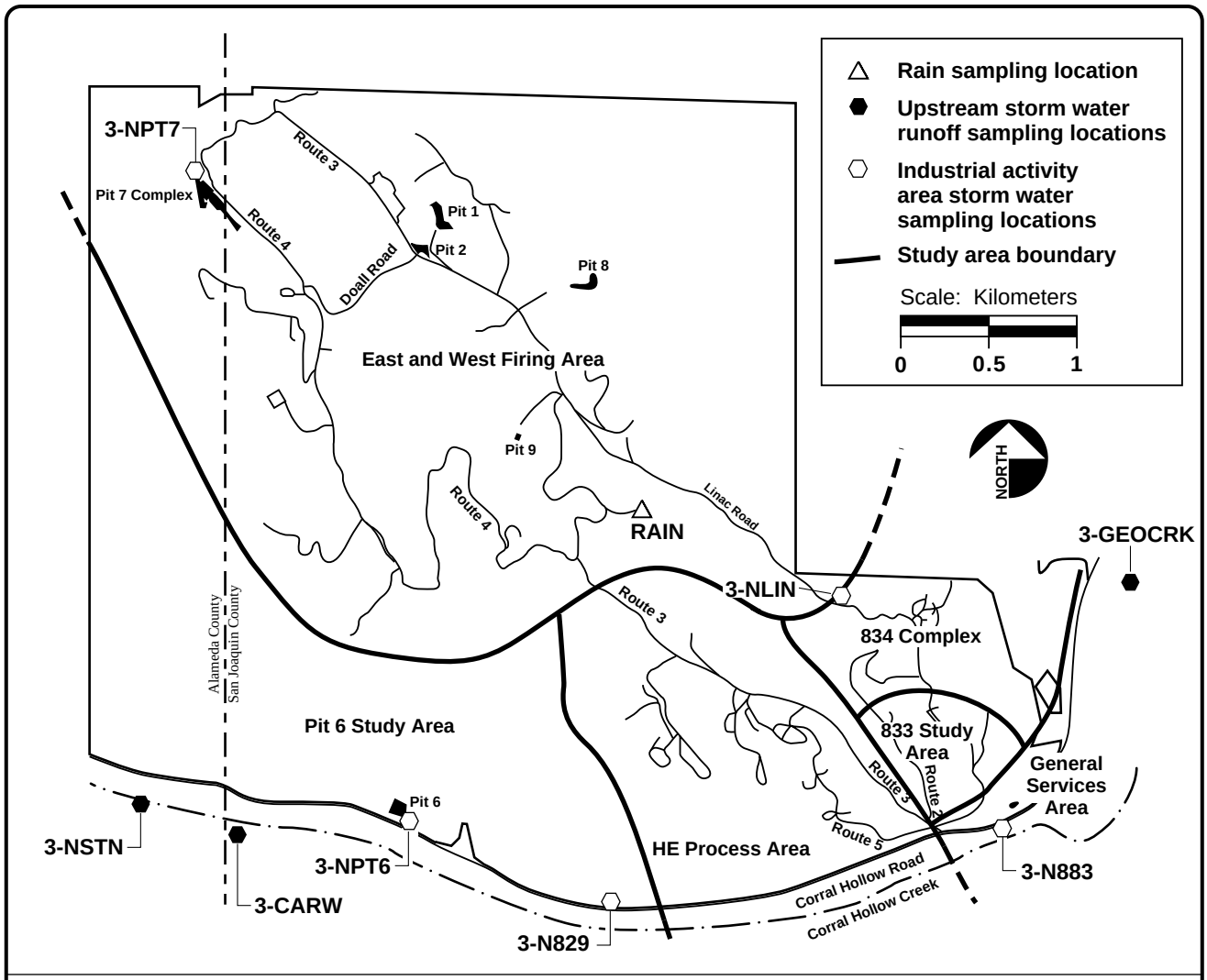

Figure 7-3. Rain and storm water runoff sampling locations, Site 300 and vicinity, 1995.

under the Statewide General NPDES Permit for Storm Water Discharges Associated with Industrial Activities (Order No. 91-13-DWQ). The new permit includes specific monitoring and reporting requirements. The current list of analyses requested for storm water samples is given in **Table 7-1**. Flow patterns at the site are such that storm water at sampling locations includes components from other sources, such as neighboring agricultural land, parking lots, and landscaped areas. Because of this, and because a wide range of activities is conducted at the Livermore site, it is necessary to analyze storm water for a wide range of constituents at the Livermore site. In contrast, storm water at Site 300 is sampled at locations that target specific activities, and a smaller range of analyses is sufficient.

Table 7-1. Requested analyses for storm water samples.

Livermore site	Site 300
pH	pH
Total suspended solids	Total suspended solids
Specific conductance	Specific conductance
Oil and grease	Total organic carbon
Total organic carbon	Gross alpha and beta
Gross alpha and beta	Tritium
Tritium	Uranium
Chemical oxygen demand	Total organic halides
General minerals	Explosives
Anions	
Metals	
Organochlorine pesticides – EPA Method 608	
Chlorinated pesticides – EPA Method 615	
Volatile organics – EPA Method 624	
Semivolatile organics – EPA Method 625	
Fish bioassay (fathead minnow)	

About one-fourth of the storm water runoff generated within the Livermore site drains into the Drainage Retention Basin, or DRB (**Figure 7-4**), a lined depression turned into a man-made lake through the collection of runoff. The DRB discharges to a culvert that leads to Arroyo Las Positas. The remainder of the site drains either directly or eventually into two arroyos by way of storm sewers and ditches. The two arroyos drain from east to west. Arroyo Seco cuts across the southwestern corner of the site. Arroyo Las Positas, diverted from its natural course, follows the northeastern and northern boundaries of the site and exits the site at the northwest corner.

In 1995, the Livermore site storm water sampling network consisted of nine locations (**Figure 7-4**). Six locations characterize storm water either entering (influent: ALPE, ALPO, GRNE, and ASS2) or exiting (effluent: WPDC and ASW) 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.

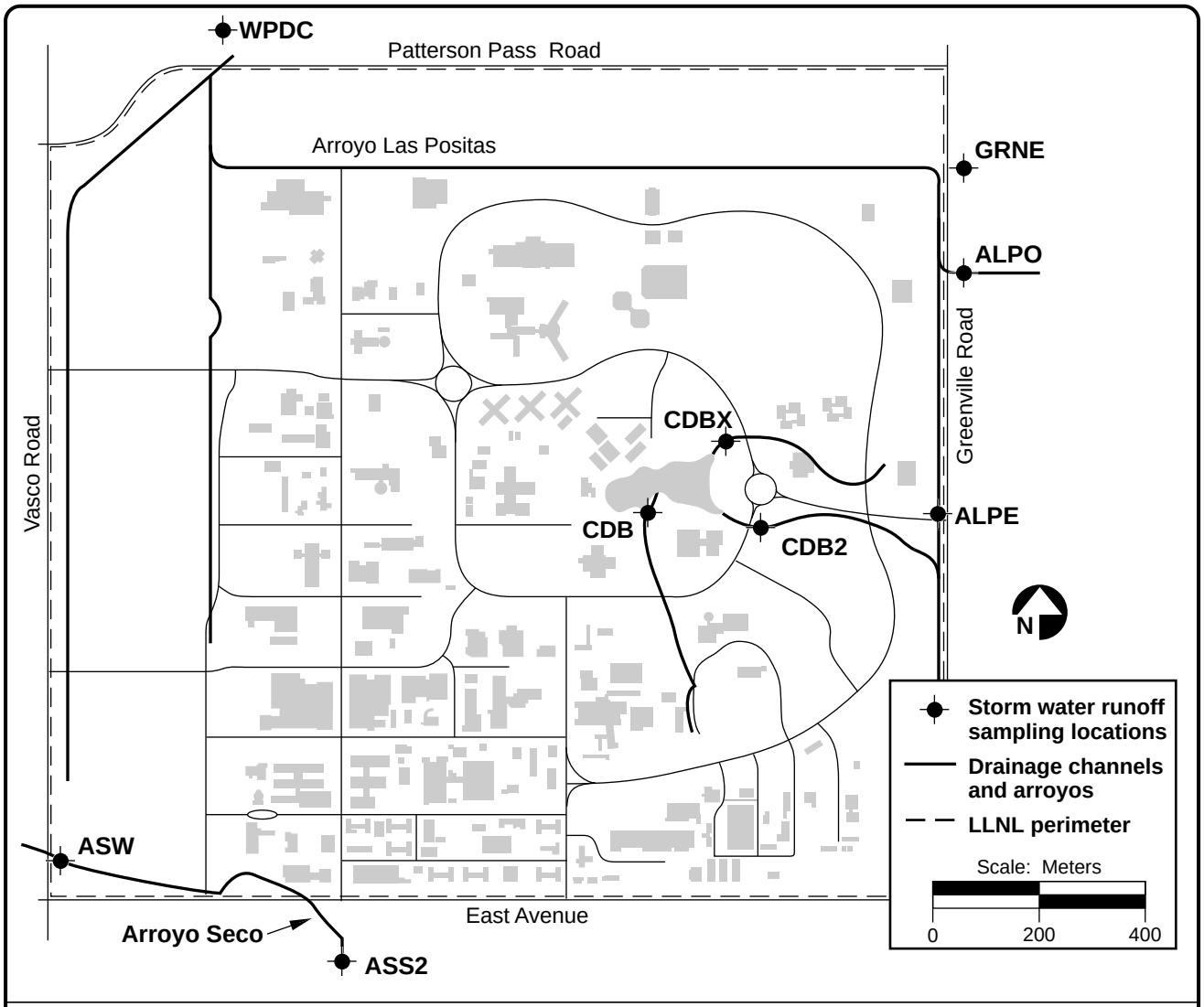

Figure 7-4. Storm water runoff sampling locations, Livermore site and vicinity, 1995.

The Site 300 storm water sampling network began in 1994 with six locations and expanded to nine locations in 1995 (**Figure 7-3**). Location CARW was added to further characterize background conditions in Corral Hollow Creek, along with existing location NSTN. Location GEOCRK was formerly reported in Chapter 8 (Routine Ground Water Monitoring at Site 300) because there is a spring upgradient of the location, which contributes water representative of ground water. GEOCRK was transferred to storm water monitoring in order to utilize the location to characterize runoff in Corral Hollow Creek downgradient of Site 300. The remaining five locations were selected to characterize ways in which storm water runoff could potentially be affected by specific Site 300 activities.

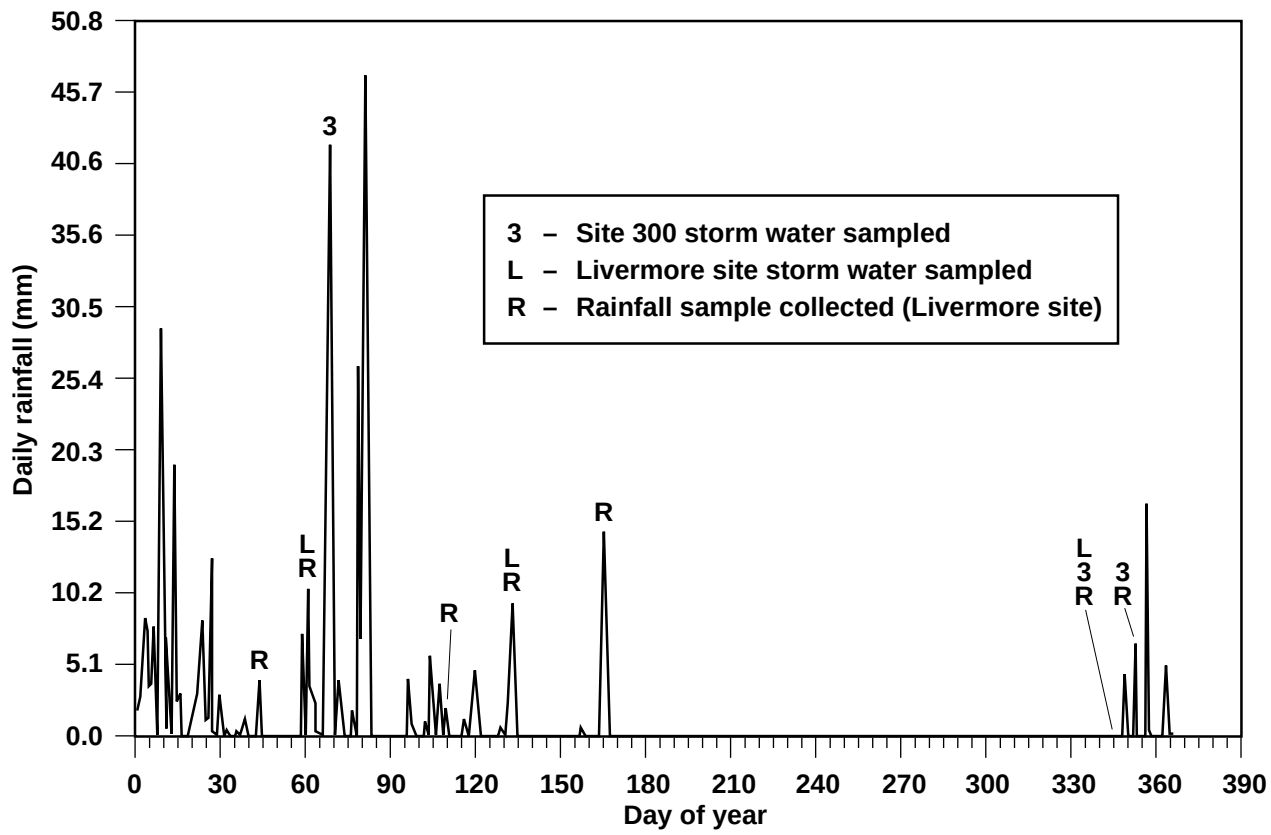

Figure 7-5. 1995 rainfall and sampling events. (Rainfall data were not available for the December 11 storm event.)

Storm water was sampled on five dates during 1995. **Figure 7-5** shows sampling dates overlaid on a plot of daily rainfall. LLNL obtained samples from all six Livermore site locations on March 2, May 13, and December 11. Samples were collected from some Site 300 locations on March 9, December 11, and December 18. Typically, a given 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.

Results

This section presents the monitoring results for surface water, drinking water, and storm water at the Livermore site, Livermore Valley, and Site 300 and vicinity.

Livermore Site and Livermore Valley Radioactivity in Surface Water

Gross Alpha and Gross Beta

Median activities for gross alpha and gross beta radiation in surface water samples are generally less than 10% of the drinking water maximum contaminant levels (MCLs): 0.56 Bq/L (15 pCi/L) for gross alpha and 1.85 Bq/L (50 pCi/L) for gross beta. However, the maximum activity detected for gross alpha (0.38 Bq/L; 10.3 pCi/L) at location ORCH was slightly more than 50% of the MCL (see **Table 7-2**). Detailed data are in Volume 2, Table 7-1). Historically, gross alpha and gross beta radiation has fluctuated about the laboratory detection limits with no trends apparent. At these very low levels, the error measurements are nearly equal to the measured values so that no trends are apparent in the data. **Figure 7-6** shows gross beta radiation in surface and drinking water since 1988.

Storm water gross alpha and gross beta samples are listed in **Table 7-3**. Because there were only three storm events sampled at each site in 1995, the entire data set is presented. Storm water gross alpha and gross beta were below MCLs, except for samples collected December 11 at influent locations ALPO and GRNE. Because ALPO and GRNE are influent locations, the gross alpha and gross beta sources for these Livermore site locations were upstream and off the site (see **Figure 7-4**). The origin of this off-site source for alpha and beta radiation is unknown.

In order to investigate possible sources for the December 11 ALPO and GRNE gross alpha and gross beta, 1995 air particulate gross alpha and gross beta sampling was examined in detail. Air particulate sampling locations ZON7 and PATT are in the area upgradient of storm water location GRNE. If either of these locations exhibited abnormally high gross alpha or gross beta levels, it would indicate a source via the air pathway. **Figure 7-7** compares ZON7 and PATT monthly median air particulate gross alpha with the monthly median for all Livermore Valley locations. All values are very low, near the detection limit of the method. Thus, although the gross alpha level PATT is slightly higher than the Livermore Valley median in November, it is within the variation expected at such low levels. **Figure 7-8** is the same plot for air particulate gross beta. The ZON7 and PATT locations exhibit the same pattern as the Livermore Valley median, with no large deviations, and are slightly less than the Livermore Valley median for September through December. Investigation of these locations indicated that there is no pattern in the 1995 air particulate gross alpha and gross beta sampling that would tie the ALPO and GRNE results to airborne emissions from LLNL (see Chapter 4, Air Monitoring).

Contemporaneous storm water gross alpha and gross beta measurements at WPDC (the LLNL outfall location) were at levels (**Table 7-3**) typical for that location and less than one-third of the MCL.

Table 7-2. Radioactivity in surface water runoff (Bq/L) at Livermore site, 1995.[a]

	No. of samples	Tritium	Gross alpha	Gross beta
Surface waters only[b]	24			
Median		1.22	0.03	0.15
Minimum		0.13	–0.09	0.04
Maximum		2.19	0.25	0.85
Interquartile range		1.22	0.08	0.16
With POOL[c]	54			
Median		0.77	0.03	0.14
Minimum		0.13	–0.09	0.02
Maximum		8.92	0.38	0.85
Interquartile range		1.36	0.08	0.15
Without POOL[d]	44			
Median		0.61	0.04	0.11
Minimum		0.13	–0.09	0.02
Maximum		2.19	0.38	0.85
Interquartile range		0.82	0.07	0.08
POOL only[e]	10			
Median		5.88	0.01	0.19
Minimum		2.33	–0.06	0.14
Maximum		8.92	0.35	0.31
Interquartile range		2.29	0.07	0.10
Offsite drinking waters only[f]	16			
Median		0.56	0.03	0.11
Minimum		0.34	–0.03	0.04
Maximum		0.88	0.38	0.66
Interquartile range		0.19	0.08	0.16
Onsite TAP only[g]	4			
Median		0.45	0.06	0.031
Minimum		0.38	0.02	0.015
Maximum		0.82	0.08	0.12
Interquartile range		0.16	—[h]	—[h]

a MCL = 740 for tritium, 0.56 for gross alpha, and 1.85 for gross beta.

b Locations: DEL, ZON7, DUCK, ALAG, SHAD, and CAL.

c All locations.

d All locations except POOL.

e Location: POOL only.

f Location: BELL. GAS, PALM, and ORCH.

g Location: TAP only.

h Insufficient data to calculate.

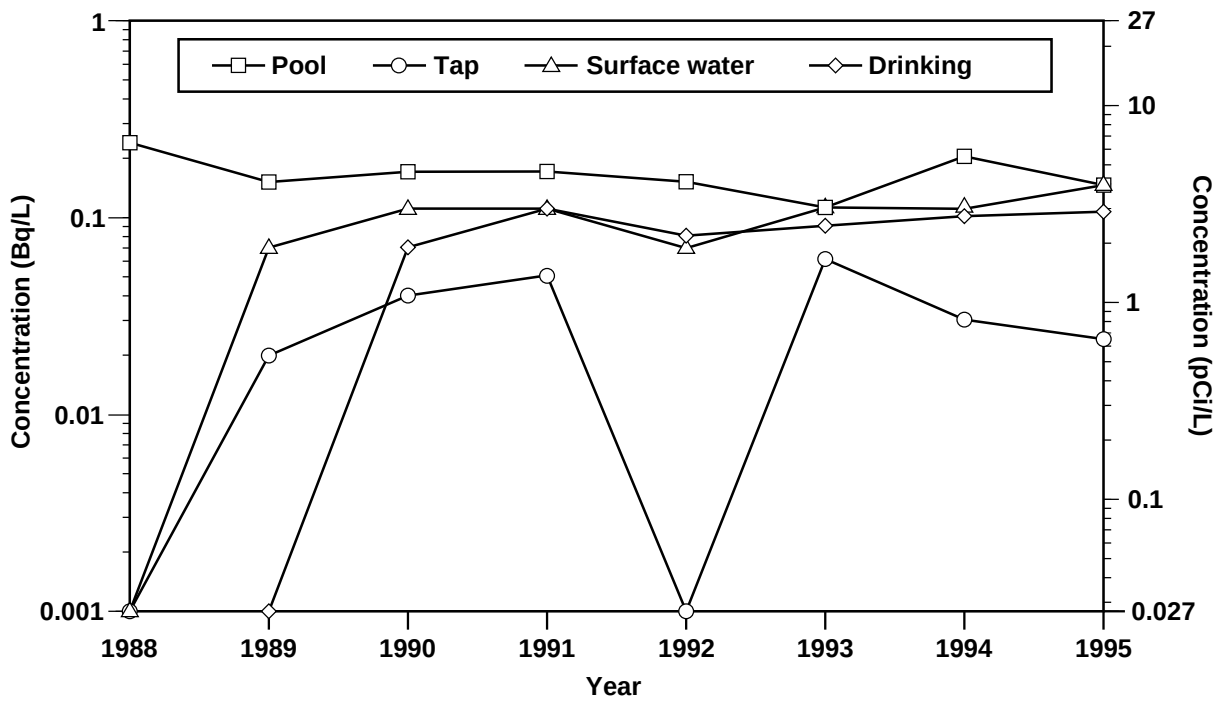

Figure 7-6. Annual median gross beta in surface and drinking water, 1988 to 1995.

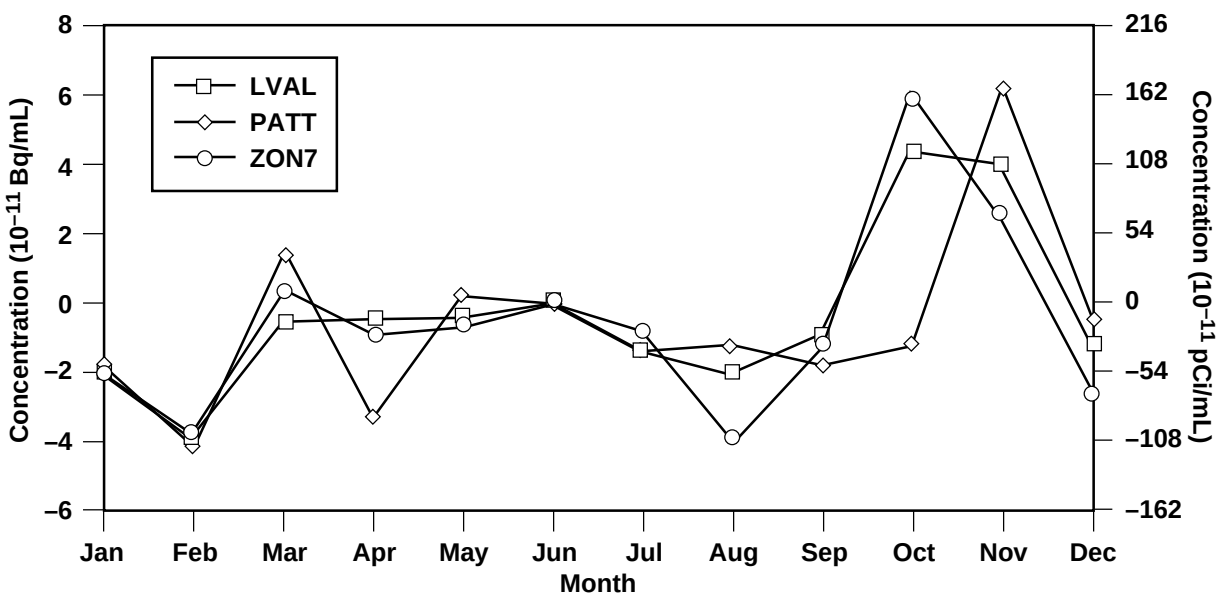

Figure 7-7. Monthly median gross alpha in particulate air samples for 1995, comparing ZON7 and PATT location with Livermore Valley medians (LVAL is the median of all Livermore Valley locations).

Table 7-3. Radioactivity in storm water runoff (Bq/L) at Livermore site, 1995.

Location	Date	Tritium	Gross alpha	Gross beta
ALPE	Mar 2	51.10 ± 3.06	0.10 ± 0.02	0.29 ± 0.01
	May 13	2.42 ± 1.83	0.11 ± 0.07	0.207 ± 0.06
	Dec 11	6.14 ± 2.48	0.11 ± 0.08	0.35 ± 0.07
ALPO	Dec 11	5.77 ± 2.46	0.96 ± 0.47	0.74 ± 0.26
	Dec 11	—[a]	0.65 ± 0.34	1.13 ± 0.30
ASS2	Mar 3	4.74 ± 1.77	0.09 ± 0.01	0.24 ± 0.01
	May 13	<1.77	0.10 ± 0.05	0.23 ± 0.06
	Dec 11	6.59 ± 2.49	0.08 ± 0.06	0.25 ± 0.06
ASW	Mar 2	38.10 ± 2.78	0.14 ± 0.01	0.23 ± 0.01
	May 13	<1.70	0.04 ± 0.03	0.10 ± 0.05
	Dec 11	9.92 ± 2.60	0.11 ± 0.09	0.43 ± 0.08
CDB	Mar 2	18.30 ± 2.27	0.12 ± 0.01	0.23 ± 0.01
	May 13	<1.77	0.03 ± 0.03	0.10 ± 0.05
	Dec 11	3.65 ± 2.39	0.06 ± 0.04	0.11 ± 0.05
CDB2	Mar 3	28.80 ± 2.48	0.08 ± 0.01	0.19 ± 0.01
	May 13	12.50 ± 2.18	0.07 ± 0.05	0.19 ± 0.06
	Dec 11	9.32 ± 2.58	0.09 ± 0.07	0.30 ± 0.07
GRNE	Mar 2	14.20 ± 2.15	0.12 ± 0.01	0.22 ± 0.01
	May 13	<1.82	0.15 ± 0.08	0.27 ± 0.07
	Dec 11	3.06 ± 2.38	2.41 ± 1.07	1.89 ± 0.70
	Dec 11	—[a]	2.44 ± 1.00	2.26 ± 0.74
WPDC	Mar 2	16.90 ± 2.14	0.10 ± 0.01	0.18 ± 0.01
	May 13	3.30 ± 1.86	0.11 ± 0.06	0.26 ± 0.06
	Dec 11	3.61 ± 2.39	0.17 ± 0.11	0.37 ± 0.09

MCL = 740 for tritium, 0.56 for gross alpha, and 1.85 for gross beta.

[a] Sample reanalyzed for gross alpha and bata only.

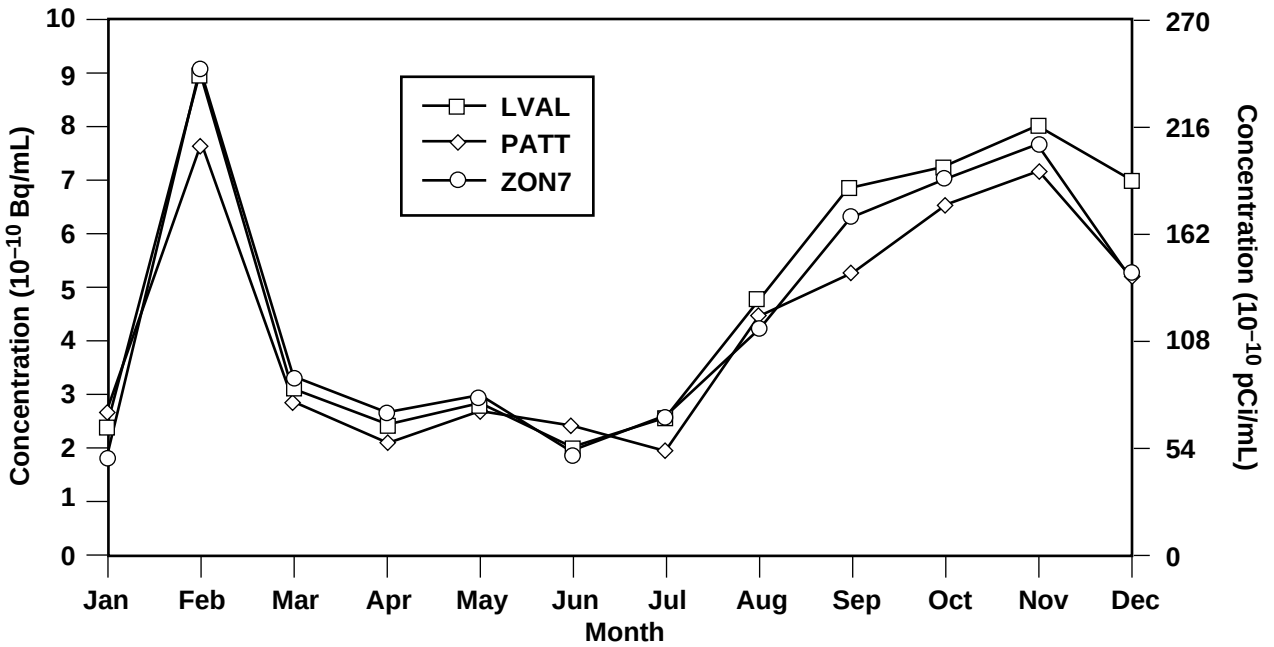

Figure 7-8. Monthly median gross beta in particulate air samples for 1995, comparing ZON7 and PATT locations with Livermore Valley medians (LVAL is the median of all Livermore Valley locations).

The two samples (ALPO and GRNE) for which gross alpha and gross beta were above the MCL were reanalyzed, which confirmed the original results (see **Table 7-3**). In addition, the samples were analyzed for uranium isotopes. Naturally occurring uranium was present in the samples, but not in sufficient quantities to fully account for the gross alpha and gross beta results. These samples were all high in sediments, so it was suspected that the gross alpha and gross beta could be attributed to the sediments, not the liquid portion of the storm water runoff. To investigate this, 1996 samples and selected Site 300 1995 samples were filtered, and the liquid and solid phases analyzed separately. Because of sample volume limitations, this was not done with the 1995 Livermore site samples. Data from 1996 samples confirmed that the greater than typical sediment load caused the high gross alpha and gross beta results. Also, all historical gross alpha and gross beta data were plotted against total suspended solids (TSS) in **Figure 7-9.** This figure shows a clear relationship between gross alpha and gross beta and TSS. Thus, these samples do not indicate that some new source has contributed to increased environmental gross alpha and gross beta radiation, but rather, only that more sediments are being transported in these storm events at these locations. Furthermore, the gross alpha and gross beta in the solid phase is at expected levels. In addition (see **Table 7-4**), the sediment portions of the samples were analyzed for thorium, plutonium, and uranium isotopes (alpha emitters) and potassium isotopes (beta

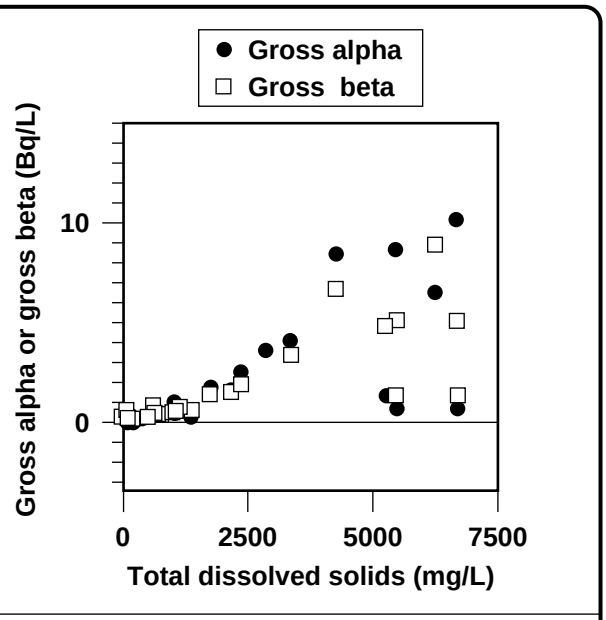

Figure 7-9. Relationship of storm water gross alpha and gross beta to total suspended solids.

Table 7-4. Analysis of sediments from ALPO and GRNE samples for radionuclides (Bq/L).

	Samples	
	ALPO	**GRNE**
Total uranium	0.08 ± 0.01	0.10 ± 0.01
Total plutonium	$5.1 \times 10^{-4} \pm 3.2 \times 10^{-3}$	$4.9 \times 10^{-4} \pm 1.7 \times 10^{-3}$
Total thorium	0.1 ± 0.05	0.744 ± 0.0679
Potassium-40	0.165 ± 0.008	0.90 ± 0.045

emitters). Since other analyses have indicated that the majority of the gross alpha and gross beta activity is contributed by the solid phase of the samples, only the solid phase was analyzed. Plutonium levels were extremely low, less than 5×10^{-4} Bq/L (0.014 pCi/L). Thorium and uranium were present at higher levels, yet not high enough to account for all of the gross alpha and gross beta. However, uranium or thorium decay produces a chain of daughter products that also produce alpha and beta radiation. These daughter products are not observed in the isotopic analyses, but can be calculated from the known uranium and thorium concentrations. When this calculation is performed, approximately 70% of the gross alpha and gross beta radiation is accounted for. Thus, within

the accuracy of the analytical methods, the apparent high levels of gross alpha and gross beta radiation observed in these storm water samples can be attributed to high sediment loads (due to erosion typical to the region) and naturally occurring levels of potassium, thorium, and uranium, along with their daughter products, carried in that sediment. There is no indication of an anthropogenic source of the gross alpha and gross beta levels.

Figures 7-10 and **7-11** show the historical trend in storm water gross alpha and gross beta, respectively. In these figures and other storm water historical trend figures in this chapter, all available data for the influent and effluent locations of the two runoff pathways through the LLNL site have been aggregated. Also, data have been aggregated on a wet season basis—that is, October of one year through May of the next—rather than on a calendar year basis. Thus, data on storm plots labeled 1994/1995 represent October 1994 through May 1995, and data labeled 1995 represent October through December 1995. The 1995 points represent a partial wet season, pending collection of 1996 data, and are based on only one sampling event for each location. Finally, plots include all available storm water influent and effluent data for each constituent. The gross alpha and gross beta data show no discernible pattern; the high gross alpha influent value for 1995 is due to the December ALPO and GRNE results discussed above.

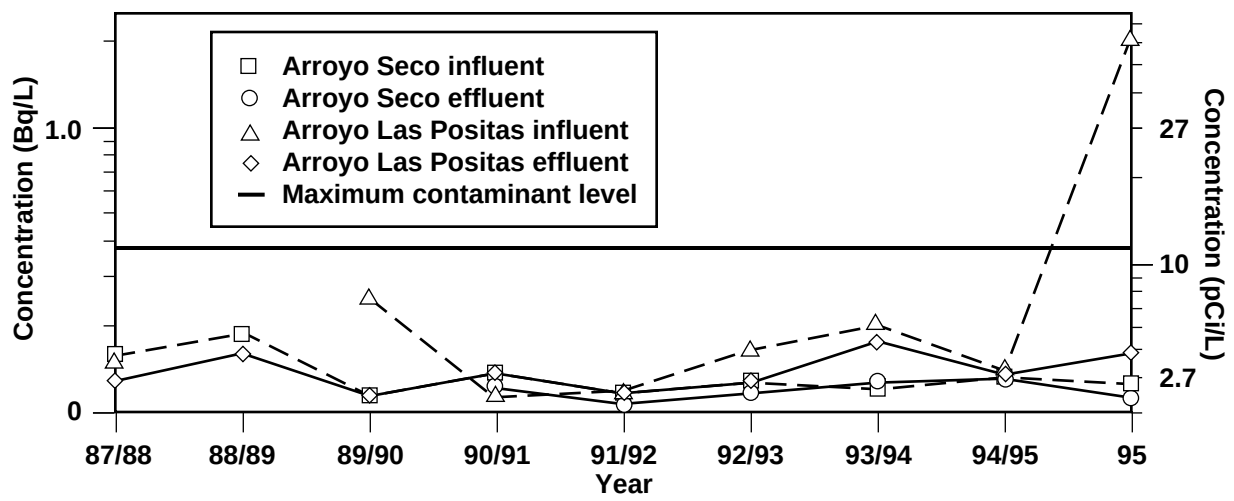

Figure 7-10. Annual median gross alpha in LLNL storm water.

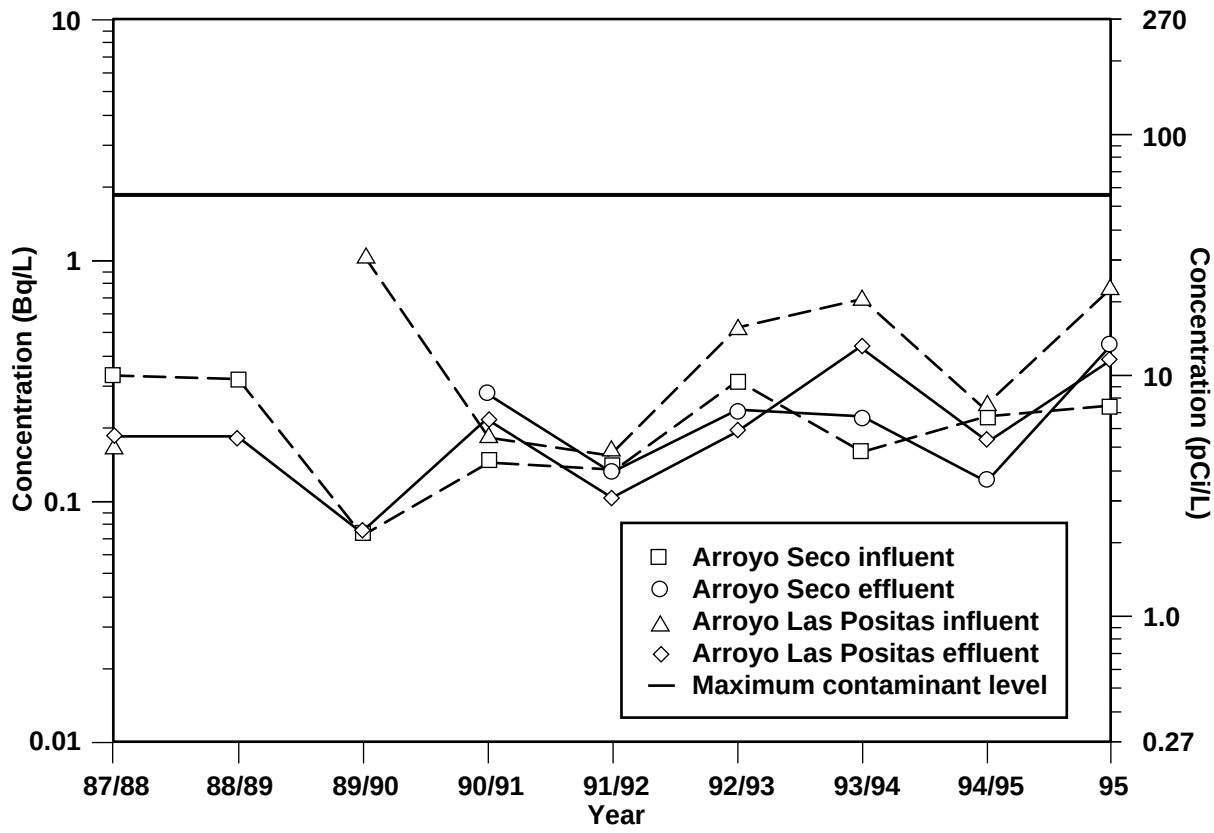

Figure 7-11. Annual median gross beta in LLNL storm water.

Tritium

Median tritium activity was 0.61 Bq/L (16.6 pCi/L) and the maximum tritium activity was 2.19 Bq/L (59.2 pCi/L) at surface and drinking water locations in the Livermore Valley, less than 0.3% of the drinking water MCL (**Table 7-2**). Water in the LLNL swimming pool had the highest median value (**Figure 7-12**) and individual measurement. The median activity for tritium at POOL for 1995 was 5.88 Bq/L (159 pCi/L), compared to 4.51 Bq/L (122 pCi/L) in 1994, with both values less than 1% of the drinking water MCL. The highest single observation for POOL was 8.92 Bq/L (241 pCi/L), which is slightly higher than 5.96 Bq/L (161 pCi/L) maximum detected in 1994.

Tritium activities in the POOL have decreased from 1988 (the beginning of tritium monitoring) to 1994, with a very slight increase in 1995 (**Figure 7-12**). The overall decrease in tritium activities has been most marked since 1991, the last year in which there were significant tritium emissions from Building 331, the

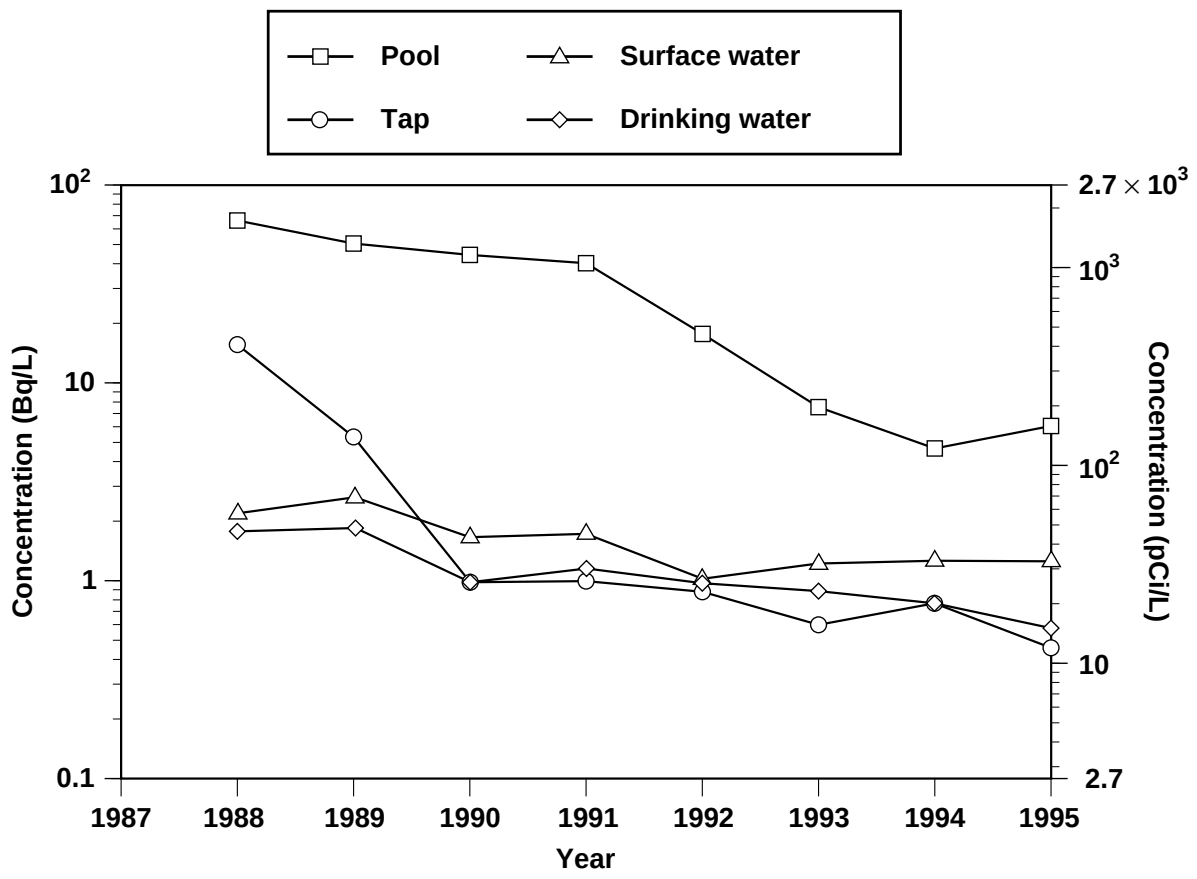

Figure 7-12. Annual median tritium in surface and drinking water, 1988 to 1995.

Tritium Facility, located near the POOL. Median tritium activities in the on-site drinking water have also decreased with time since 1988. Tritium in the off-site surface waters and drinking waters has decreased very gradually (**Figure 7-12**).

Tritium activities measured in rainfall at the LLNL site and vicinity are shown in **Table 7-5** The Livermore site rainfall has exhibited elevated tritium activities in the past (Gallegos et al., 1994). During 1995, however, measurements of tritium activity in rainfall were all far below the 740 Bq/L (20,000 pCi/L) Maximum Contaminant Level (MCL) established by the federal EPA for drinking water. Rainfall samples were collected on February 15, March 2, April 19, May 13, June 16, December 11, and December 12, 1995 (see **Figure 7-5**). The highest overall activity was 72.89 Bq/L (1970 pCi/L) measured on April 19 near Building 343, just to the north of the on-site Tritium facility. This value is approximately 10% of the MCL for tritium. The highest off-site activity measured was 55.87 Bq/L

Table 7-5. Tritium activities in rainfall (in Bq/L) for the Livermore site and Livermore Valley.[a]

Location	Median	Minimum	Maximum	Interquartile range	Number
On-site					
B343	22.42	4.92	72.89	26.29	7
B291	10.54	2.19	19.35	10.91	7
CDB	9.84	2.17	24.46	10.34	7
VIS	5.22	2.29	12.91	6.50	7
COW	4.85	1.82	9.36	5.75	7
SALV	3.70	1.75	31.45	9.82	7
MET	2.29	1.97	7.96	0.87	6
On-site summary:	6.84	1.75	72.89	10.78	48
Off-site					
ESAN	4.81	1.79	55.87	29.00	7
ZON7	2.20	1.75	8.44	3.08	7
AQUE	2.10	1.72	28.34	11.41	7
SLST	2.08	1.68	2.80	0.27	7
GTES	1.77	1.64	2.78	0.26	5
VINE	1.92	1.67	9.55	3.24	7
BVA	1.89	1.64	17.06	0.32	7
VET	1.83	1.61	20.68	4.07	6
Off-site summary:	2.05	1.61	55.87	3.03	53
Overall summary	2.78	1.61	72.89	7.07	101

[a] MCL = 740 Bq/L.

(1510 pCi/L). This activity was recorded in a sample collected from station ESAN on March 2, 1995. This station is 0.3 km east of the former Tritium Research Laboratory at SNL/California and 1.1 km southeast of LLNL's Building 331.

As expected, the stations in the prevailing downwind directions and closest to the sources showed the highest median tritium activities in rain. These were stations B343 (**Table 7-5**) and CDB for the LLNL Building 331 sources and stations ESAN, and AQUE for the source at SNL/California. The most distant downwind station, ZON7, had a higher median tritium activity than the median for AQUE, which is within 1 km of the SNL/California tritium source. The lowest median tritium activities for 1995 were located at off-site stations: VET established in October 1994 and new station BVA generally upwind of both tritium facilities. Another new station, VINE, also showed low tritium activities.

Tritium activity in rainfall at the Livermore site has trended downward during the past 6 years. This decrease mirrors the downward trend in total HTO emissions from LLNL's Tritium Facility and SNL/California's former Tritium Research Laboratory. These trends are shown in **Figure 7-13**. Values for the median rain tritium activity shown in **Figure 7-13** are derived from the six on-site rain sampling locations (B343, B291, CDB, SALV, VIS, and COW) that historically have given the highest activities. A nearly seven-fold decrease in total HTO emissions has occurred since 1991, from 34.9 TBq (943 Ci) down to 5.1 TBq (137 Ci; 1 TBq = 10 Bq). This decrease is mirrored by a nearly tenfold decrease in median tritium activity measured in rainfall on site at LLNL (65.9 Bq/L down to 8.5 Bq/L, or 1780 pCi/L down to 230 pCi/L).

As with tritium levels in rainfall, tritium levels in storm water runoff were low; the overall median was 6.0 Bq/L (172 pCi/L), or less than 1% of the drinking water MCL (**Table 7-3**). The highest tritium activity measured in storm water runoff during 1995 was 51.1 Bq/L (1380 pCi/L) at location ALPE, less than 7% of the drinking water MCL. The historical trend (**Figure 7-14**) indicates generally decreasing tritium levels in storm water from the 1988/89 to 1991/92 season, after which the curve is relatively flat.

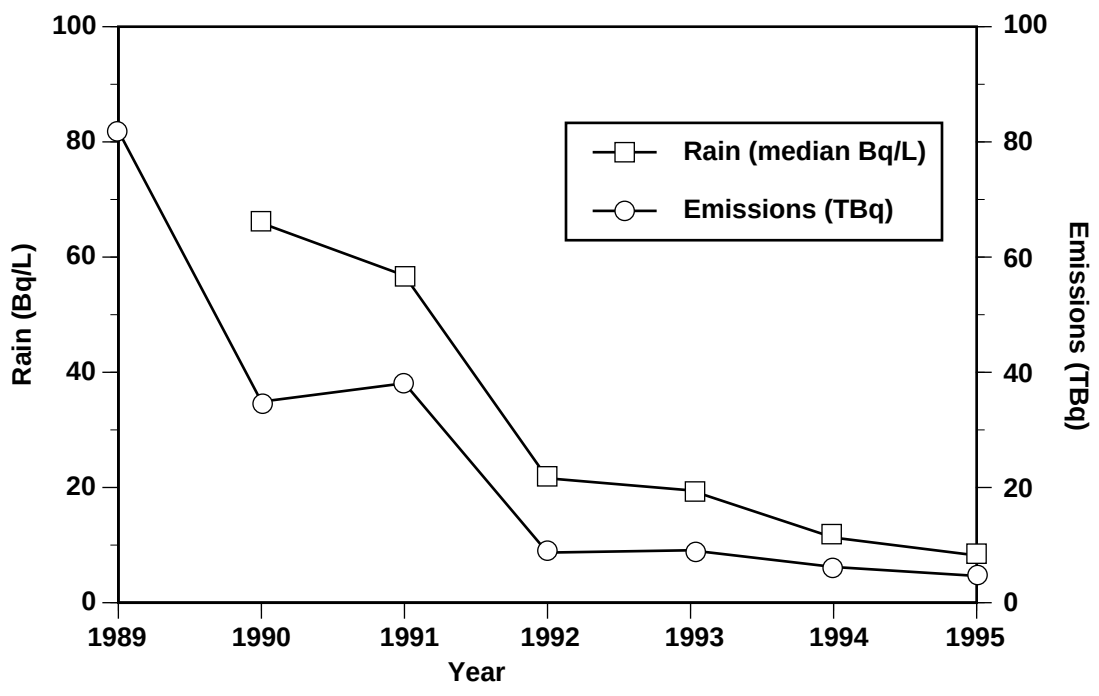

Figure 7-13. Trends of median tritium activity in rain and total stack emissions of HTO by LLNL and SNL/California, 1989 to 1995.

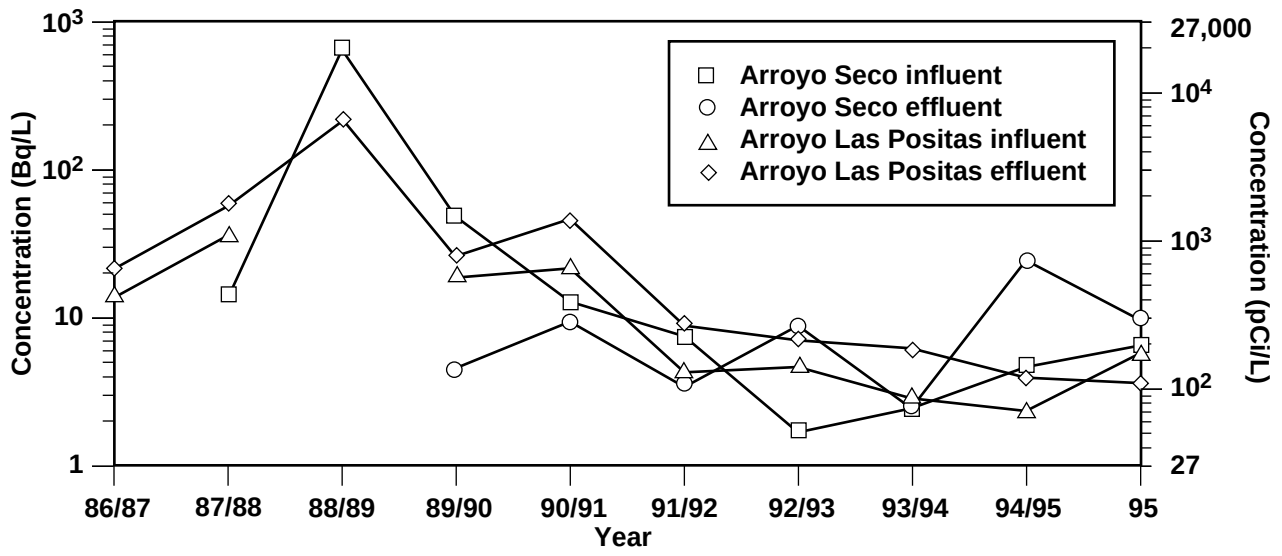

Figure 7-14. Annual median tritium concentrations in LLNL storm water.

Livermore Site and Livermore Valley, Nonradioactive Pollutants in Storm Water

There are currently no numeric criteria that place limits on storm water effluent. The EPA established in the multisector permit benchmark values for 41 parameters, but stressed that these concentrations are not intended to be interpreted as effluent limitations. Rather, they are levels that the EPA has used to determine if storm water discharge from any given facility merits further monitoring. Other water quality criteria were also compared to LLNL storm water analysis results. However, these criteria were defined for other purposes, and therefore not directly applicable to storm water effluent. Nevertheless, use of a broad range of criteria can help ensure high quality in LLNL storm water effluent. Storm water sample results for the Livermore site were compared with criteria listed in *The Water Quality Control Plan, San Francisco Bay Basin Region* (San Francisco Bay RWQCB 1995) and results for Site 300 were compared to criteria listed in *The Water Quality Control Plan* (*Basin Plan)* for the California Regional Water Quality Control Board Central Valley Region (Longley et al. 1994), both newly approved in 1995. Criteria in the Basin Plans include surface water quality objectives for the protection of aquatic life and water quality objectives for waters designated for use as domestic or municipal supply or agricultural supply. These criteria include, by reference, California Maximum Contaminant Levels (MCLs) for drinking water. In addition, results were compared to EPA MCLs and Ambient Water Quality Criteria (AWQC), as well as California AWQC. Finally, comparison was made with criteria listed in the State-level California Inland Surface Waters Plan and California Enclosed Bays

and Estuaries Plan, althoughthese plans were invalidated by a court decision. Criteria not specifically listed in the Basin Plans were obtained from *A Compilation of Water Quality Goals* (Marshack 1995).

This year, as required by LLNL's new NPDES permit (WDR 95-174, NPDES No. CA0030023), an annual fish bioassay was initiated. There are two tests involved in the fish bioassay. In the acute test, 96-hour survival of Fathead Minnow (*Pimephales promelas*) in undiluted storm water collected from location WPDC is observed. The Regional Board has set a criteria of 20% survival compared to the control as an acceptable level. The testing laboratory provides water to use in the control sample. In addition, in agreement with Regional Board guidance, upgradient water from influent locations ALPO, ALPE, and GRNE is used as controls. If fewer than 20% of the fish survive in the WPDC effluent storm water than survive in the control in two consecutive tests, LLNL is required to perform a toxicity reduction evaluation in order to identify the source of the toxicity. In the chronic test, storm water dilutions of 0 (no effluent storm water), 1, 3, 10, 30, and 100% (undiluted storm water) are used to determine a dose-response relationship, if any. No criteria have been set for this test; this test is being performed for information purposes only. In this year's acute toxicity test, 90% survival was observed. In the chronic test, survival rates were 90, 98, 100, 55, 93, and 85% for the dilutions of 0, 1, 3, 10, 30, and 100%, respectively. Because the low survival at the 10% dilution did not continue at the higher concentrations, no dose-response could be developed. The testing laboratory did not provide an explanation for the anomalous result at the 10% level.

Table 7-6 lists nonradioactive constituents found above comparison criteria in Livermore site storm water. In this summary, generally only the most stringent criteria are presented. Complete storm water results are presented in Table 7-4, Volume 2, including all information in **Table 7-6** except criteria.

Chromium was detected above the California Inland Surface Waters Plan AWQC (0.016 mg/L) in a number of samples. In one case (ASW on 12/11/95), the effluent value (0.034 mg/L) was slightly higher than the influent value (ASS2, 0.028 mg/L). A plot of historical annual median chromium concentrations (**Figure 7-15**) indicates that chromium concentrations have been gradually increasing since 1992/1993 at both influent and effluent locations, but there is no indication that LLNL is contributing to this increase.

Table 7-6. Storm water nonradioactive parameters exceeding selected comparison criteria.

Constituent	Criteria value (mg/L)	Criteria source	Date	Location	Concentration (mg/L)
Barium	1.0	CA PMCL	12/11/95	GRNE	1.5
				CDB2	1.0
Cadmium	0.005	EPA PMCL	12/11/95	CDB2	0.95
	0.0159[a]	Benchmark			
Chromium	0.016[b]	Inland Plan AWQC	3/2/95-3/3/95	ALPE	0.017
	0.05	EPA PMCL		GRNE	0.016
				CDB2	0.021
				WPDC*	0.017
			5/13/95	ASS2	0.018
				GRNE	0.026
				CDB2	0.017
				WPDC*	0.025
			12/11/95	ASS2	0.028
				ASW*	0.034
				ALPE	0.044
				ALPO	0.05
				GRNE	0.2
				CDB2	1.0
				WPDC*	0.047
Copper	0.027	EPA AWQC[c]	3/2/95	CDB	0.028
	0.0636	Benchmark[a]		WPDC*	0.031
			12/11/95	ALPO	0.06
				GRNE	0.09
				CDB2	1.0
				WPDC*	0.029
Iron	0.3	EPA PMCL	3/2/95	ASS2	4.0
	1.0	Benchmark		ASW*	2.0
				ALPE	6.4
				GRNE	7.4
				CDB	6.2
				CDB2	8.3
				WPDC*	7.9
			5/13/95	ASS2	8.4
				ASW*	2.5
				ALPE	5.0
				GRNE	14.0
				CDB	2.8

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Table 7-6. Storm water nonradioactive parameters exceeding selected comparison criteria (continued).

Constituent	Criteria value (mg/L)	Criteria source	Date	Location	Concentration (mg/L)
Iron (continued)				CDB2	6.7
				WPDC*	12.0
			12/11/95	ASS2	8.4
				ASW*	11.0
				ALPE	14.0
				ALPO	22.0
				GRNE	120.0
				CDB	1.6
				CDB2	2.2
				WPDC*	18.0
Lead	0.015	EPA PMCL 10%[d]	12/11/95	CDB2	1.1
	0.05	Inland Plan Drinking Water			
	0.0816[a]	Benchmark			
	0.11[c]	EPA AWQC			
Manganese	0.5	EPA SMCL	12/11/95	CDB2	1.1
	1.0	Benchmark		GRNE	1.9
Nickel	0.1	EPA PMCL	12/11/95	ALPE	0.18
	1.417[a]	Benchmark		ALPO	0.35
				GRNE	0.28
				CDB2	1.0
Nitrate (as N)	10	EPA PMCL	3/2/95	ASS2	4.1
	0.68[e]	Benchmark		ASW*	2.5
				ALPE	6.7
				GRNE	31.0
				CDB	6.4
				CDB2	2.9
				WPDC*	4.0
Nitrate (as NO_3)	45	EPA PMCL	5/13/95	ASS2	3.6
	3.01[f]	Benchmark		ALPE	17.0
				GRNE	11.0
			12/11//95	ASS2	<5.0
				ASW*	<5.0
				ALPE	4.3
				ALPO	4.8
				GRNE	9.2
				CDB	4.4
				CDB2	<5.0
				WPDC*	<5.0

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Table 7-6. Storm water nonradioactive parameters exceeding selected comparison criteria (continued).

Constituent	Criteria value (mg/L)	Criteria source	Date	Location	Concentration (mg/L)
pH	6.5-8.5	EPA SMCL	3/2/95	CDB	6.4
	6.0-9.0	Benchmark	3/9/95	N883*	6.2
			5/13/95	CDB	6.5
			12/18/95	N829*	8.7
				NLIN	8.8
Silver	0.0082[c]	EPA AWQC	12/11/95	ALPO	0.011
	0.0318[a]	Benchmark		CDB2	0.81
Specific conductance (μmhos/cm)	900	CA SMCL	3/2/95	ALPE	910
Total alkalinity	>20	EPA AWQC	3/2/95	ASW*	10
				CDB	9.5
				CDB2	17
				WPDC*	10
			5/13/95	ASS2	19
				ASW*	12
				CDB	7.6
				CDB2	19
				WPDC*	18
			12/11/95	ASS2	11
				ASW	11
				CDB	11
				CDB2	17
Total suspended solids	100	Benchmark	3/9/95	NLIN*	6600
				NPT7*	160
				NSTN	1300
				CARW	20,000
			5/13/95	ALPE	120
				GRNE	150
				WPDC*	210
			12/11/95	ASS2	210
				ASW*	310
				ALPE	200
				ALPO	1000
				GRNE	2300
				CDB2	210
				WPDC*	400
				NPT7*	100

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Table 7-6. Storm water nonradioactive parameters exceeding selected comparison criteria (concluded).

Constituent	Criteria value (mg/L)	Criteria source	Date	Location	Concentration (mg/L)
Total suspended solids (continued)			12/18/95	N829*	5200
				NLIN*	6200
				NPT6*	2800
Zinc	0.174	EPA AWQC[c]	3/2/95	GRNE	0.26
	0.117	Benchmark		CDB	0.16
					0.26
				CDB2	0.14
				WPDC*	0.19
			5/13/95	CDB	0.14
				WPDC*	0.14
			12/11/95	ASS2	0.13
					0.37
				ASW	0.13
				ALPO	0.12
				GRNE	0.4
				CDB	0.14
					0.18
				CDB2	1.0
				WPDC	0.21
2,4-D	0.070	EPA PMCL	3/2/95	ALPE	0.12
			5/13/95	GRNE	17,000
				ALPE	1000

[a] Hardness-dependent benchmark values are calculated using an assumed hardness of 100 mg/L.

[b] This value assumes all chromium is Cr (VI).

[c] Value is hardness-dependent; calculated based upon receiving water hardness of 164 mg/L.

[d] The MCL for lead includes this “Action Level,” to be exceeded in no more than 10% of samples.

[e] Benchmark is for nitrate plus nitrite as N.

[f] In order to compare benchmark to data, benchmark for nitrate plus nitrite as N was converted to equivalent value for nitrate as NO_3.

*Effluent locations.

Abbreviations:

AWQC — Ambient Water Quality Criteria for the protection of freshwater aquatic life.

Bay Plan — California Enclosed Bays and Estuaries Plan (this Plan was invalidated by a court decision).

Benchmark — EPA storm water benchmark value.

Drinking Water — Criteria for water with designated use as drinking water.

Inland Plan — California Inland Surface Waters Plan (this Plan was invalidated by a court decision).

San Francisco Plan — Water Quality Control Plan, San Francisco Bay Basin Region.

PMCL —- Primary Maximum Contaminant Level.

SMCL — Secondary Maximum Contaminant Level.

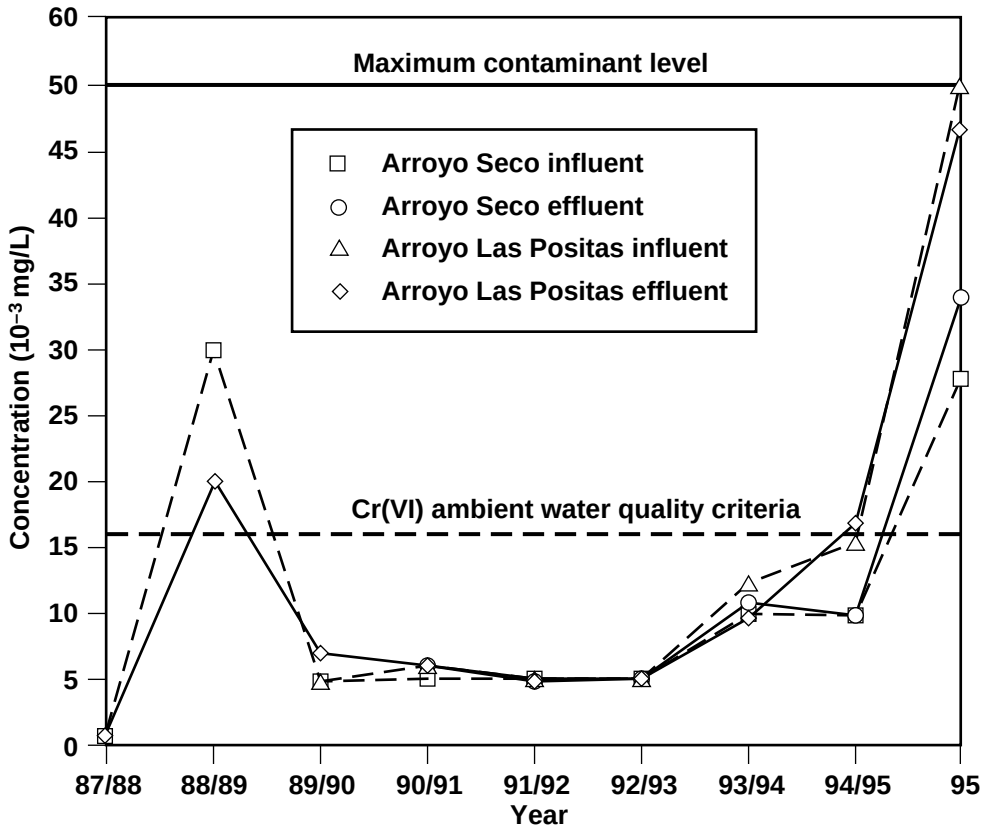

Figure 7-15. Annual median total chromium concentrations in LLNL storm water.

Copper was detected above the EPA AWQC (0.27 mg/L) in four samples, including one instance at effluent location WPDC (0.034 mg/L) in which influent locations were below the criteria. However, only two samples, influent location GRNE (0.09 mg/L) and onsite location CDB (1.0 mg/L), were above the benchmark value (0.0636). Historically, annual median copper concentrations (Figure 7-16) were reduced dramatically in the 1992/1993 season from early measurements (0.85 and 0.97 mg/L). Since then, annual median concentrations have shown little change, although there are indications that copper concentrations are increasing slightly.

Iron was detected above the MCL and benchmark values in every sample. Because past, annual median iron concentrations have virtually all been at the detection limit of 0.1 mg/L, a historical plot is not shown. All the values were obtained through a test method that was applied to iron in storm water for the first time beginning in 1995. The new test method produces higher iron concentrations for two reasons. First, with the previous test method, samples

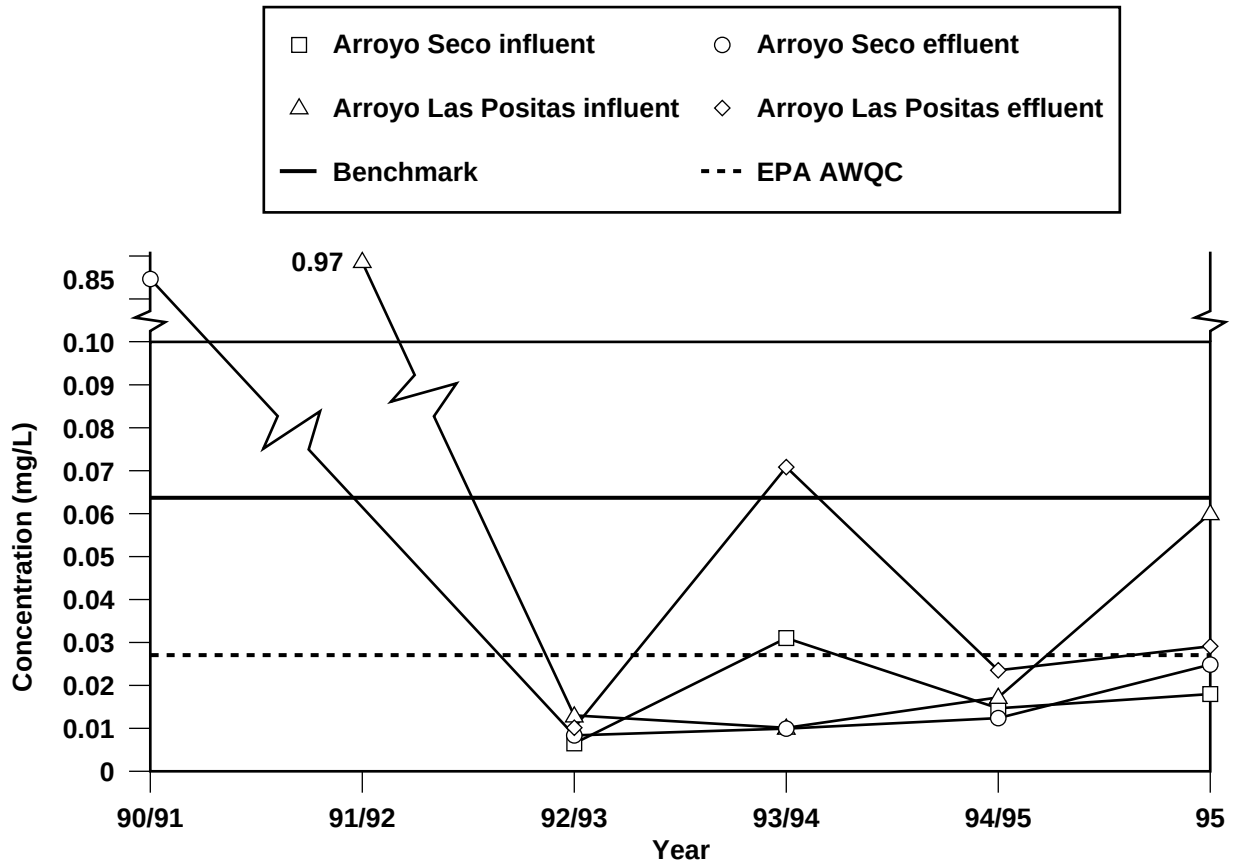

Figure 7-16. Annual median copper concentrations in LLNL storm water.

with high sediment loads were filtered. Second, the new test method incorporates a "digestion" procedure that extracts the metals from the suspended solids.

Thus, the difference between these two methods is that the previous method measured primarily dissolved metal, whereas the new method additionally measures the contribution of the sediments carried in the storm water.

At one location and on two dates pH was 6.4 and 6.5, at or below the EPA secondary MCL. Overall, annual medians at both influent and effluent locations have been within the MCL bounds (**Figure 7-17**). In the Arroyo Seco pathway, the pH has been very slightly lower at the effluent point than at the influent point, though for the 1995 data point, influent and effluent pH were the same. In the Arroyo Las Positas pathway, median pH has been from 0.7 to 1.05 lower at the effluent point than it is at the influent point. However, the difference between influent and effluent has decreased every year, indicating an improvement in LLNL storm water quality.

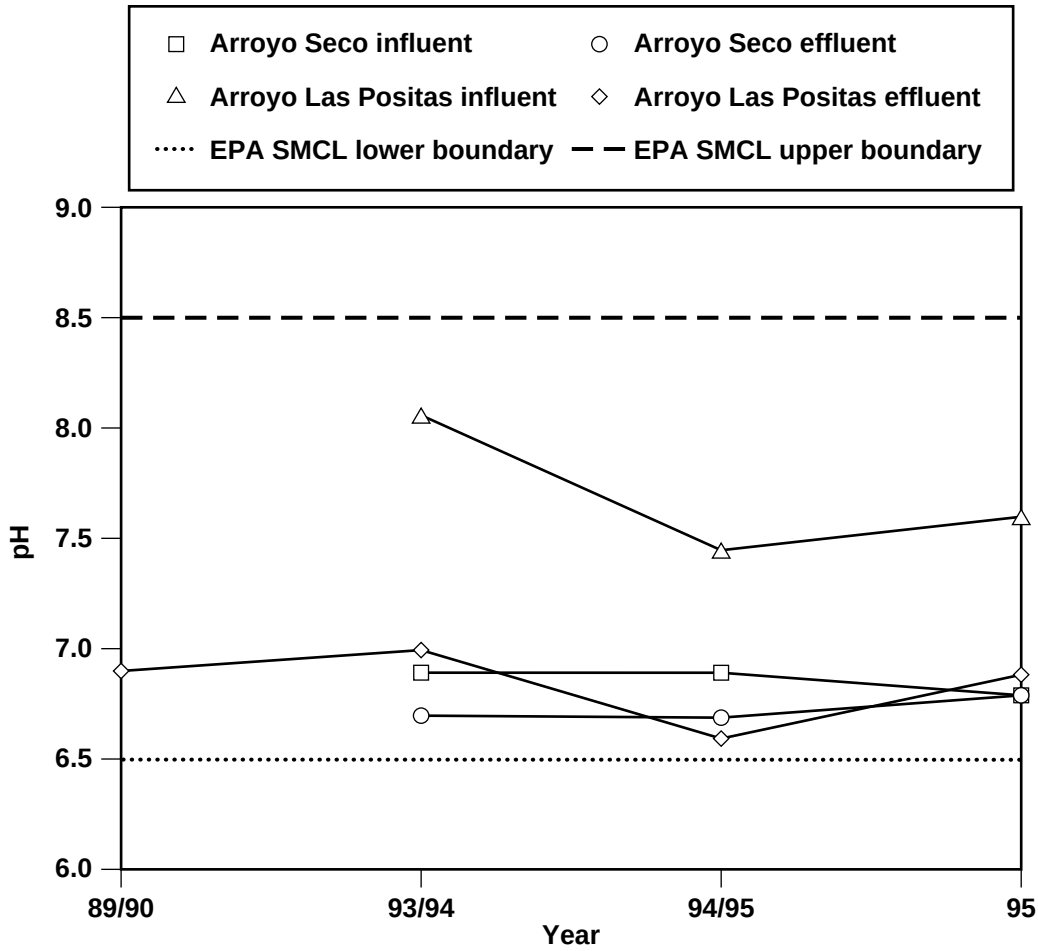

Figure 7-17. Annual median pH of LLNL storm water.

Total suspended solids (TSS) were frequently above the benchmark value (100 mg/L). No other criteria were found for TSS. However, TSS levels were primarily due to the natural, upgradient TSS. In general, annual median effluent TSS closely tracks influent TSS (**Figure 7-18**). With the exception of the 1995 Arroyo Las Positas pathway, annual median effluent TSS never differed from influent TSS by more than 100 mg/L. The high influent Arroyo Las Positas TSS can most likely be attributed to a road construction project (not conducted by LLNL) in the vicinity of the influent points.

Zinc was frequently above the AWQC (0.174 mg/L) and/or the benchmark (0.117 mg/L) values, although there was only one case (5/13/95 WPDC, at 0.14 mg/L) in which an effluent value above criteria could not be attributed to a corresponding influent value. Thus, the source of zinc seems to be primarily off site and/or naturally occurring There seems to be a gradual increase in zinc

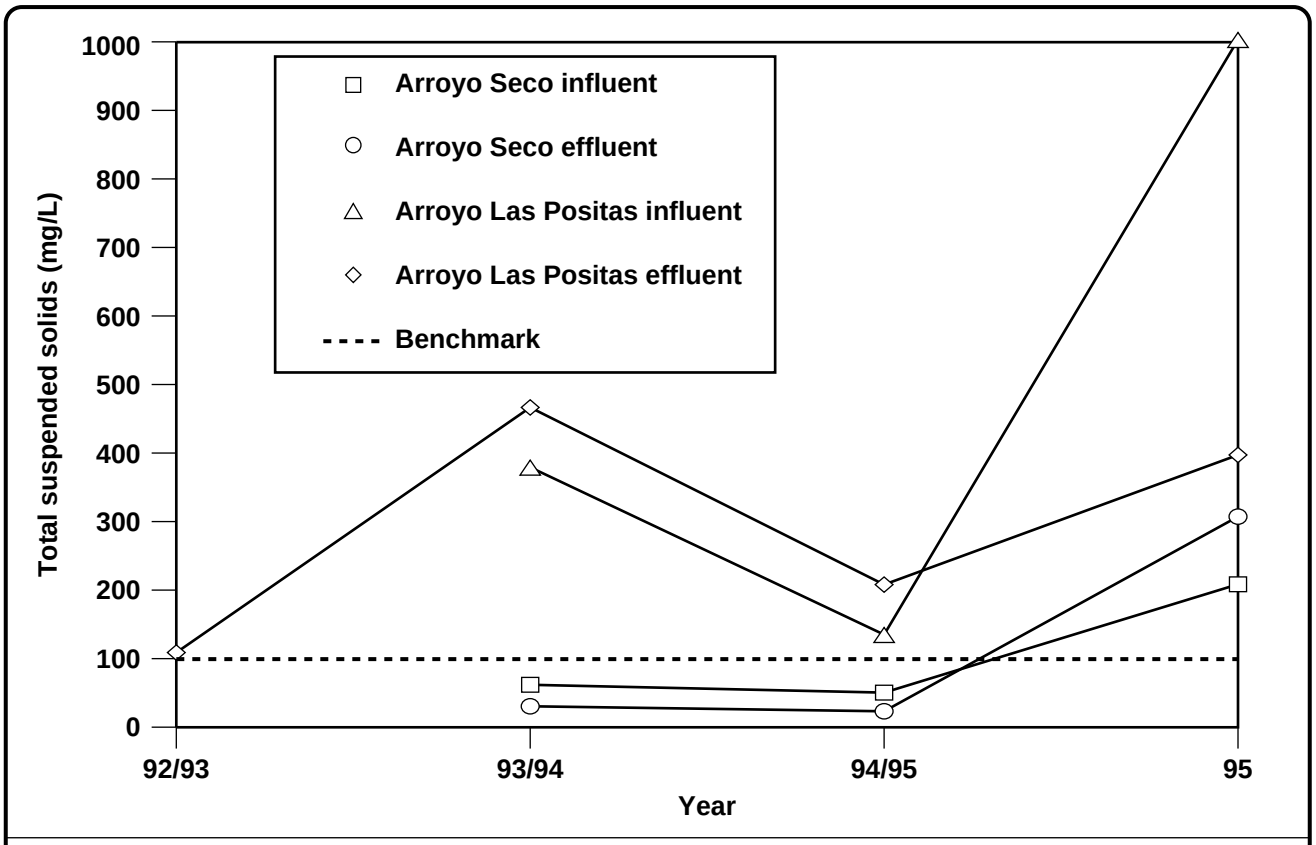

Figure 7-18. Annual median total suspended solids in LLNL storm water.

concentrations since the 1992/1993 season (**Figure 7-19)**, with Arroyo Seco effluent somewhat less than influent, and Arroyo Las Positas effluent slightly greater than influent.

Chromium, copper, and zinc are common constituents in urban runoff (**Table 7-7**); in one study (Salomons et al. 1995), zinc and copper were the most frequently detected constituents in urban runoff. All three elements have been linked with automobile metal corrosion and emissions; copper and zinc concentrations have been correlated with traffic volume, and one study showed a zinc concentration of 0.37 mg/L in highway runoff. In addition, zinc is released from automobile tires (Salomons et al. 1995.). Thus, it is likely that these types of nonindustrial sources are contributing metals to storm water runoff.

Whereas most criteria are a maximum level, the AWQC for total alkalinity as $CaCO_3$ (20 mg/L) is a minimum. Storm water samples frequently had alkalinities below this level. In addition, for two of the three sampling events, alkalinity was lower at the Arroyo Las Positas effluent point than at any of the

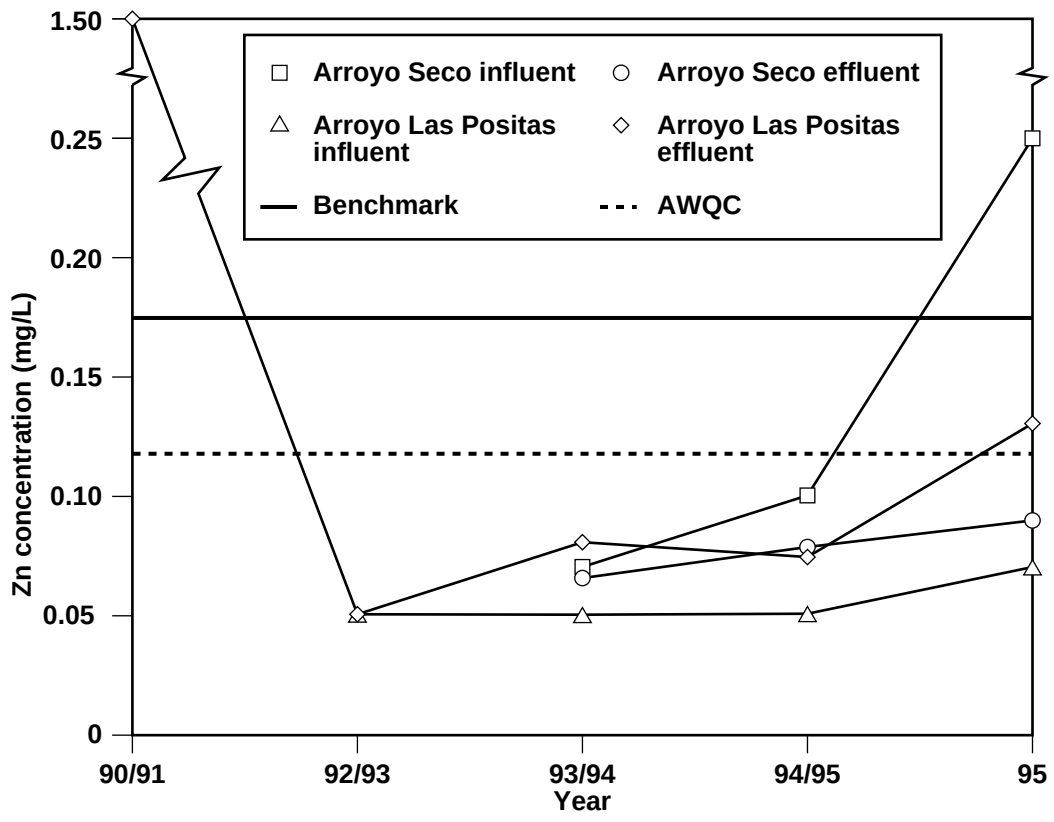

Figure 7-19. Annual median zinc concentrations in LLNL storm water.

Table 7-7. Concentrations (mg/L) of priority pollutants in runoff from urban source areas (from Salomons et al.1995).

	Source area					
Constituent	**Roofs**	**Parking**	**Storage**	**Streets**	**Vehicle service**	**Landscaped area**
Chromium	0.007–0.51	0.018–0.31	0.06–0.34	0.0033–0.03	0.019–0.32	0.1–0.25
Copper	0.017–0.9	0.02–0.77	0.03–0.3	0.015–1.25	0.0083–0.58	0.08–0.3
Zinc	0.1–1.58	0.03–0.15	0.066–0.29	0.058–0.13	0.067–0.13	0.032–1.16

influent points. The historical plot (**Figure 7-20**) indicates no obvious trends in alkalinity. However, it does show that, for the Arroyo Las Positas pathway, effluent alkalinity is generally 10-30 mg/L lower than influent alkalinity.

A number of measurements, barium, cadmium, lead, manganese, nickel, nitrate, silver, specific conductance, and 2,4-D (2,4-dichlorophenoxy acetic acid), were above comparison criteria. However, no exceedences at effluent points were higher than at influent points, indicating an off site or possibly naturally occurring source. Furthermore, with the exception of nitrate, each of these constituents exceeded criteria in at most four samples. Other organic constituents detected in 1995 were chloroform and 2,4,5-T (one detection each). Chloroform was below criteria, and no criteria were found for 2,4,5-T (2,4,5-trichlorophenoxy acetic acid).

Site 300 Radioactivity in Surface Water

Rainfall at the semiarid Site 300 was only sufficient to provide a total of four samples. The samples were collected during the first, second, and fourth quarters of 1995. The measured tritium activities were 0.37 Bq/L, 2.21 Bq/L, 2.16 Bq/L, and 2.17 Bq/L (9.9, 59.8, 58.5, and 58.6 pCi/L), respectively. These activities are indistinguishable from atmospheric background activity.

Tritium was only detected in one 1995 Site 300 storm water runoff sample location, NLIN, on December 18, at 2.98 Bq/L, about 0.4% of the MCL (**Table 7-8**). On March 9, gross alpha was above its MCL (0.56 Bq/L or 15 pCi/L) at locations CARW, NLIN, and NSTN. Gross beta on the date was above its MCL (1.86 Bq/L or 50 pCi/L at locations CARW and NLIN. The remaining sample from these locations was filtered, and the solid and liquid phases reanalyzed separately. The recount was somewhat lower than the original result and showed that nearly all of the gross alpha and gross beta was due to the greater-than-typical sediment loads and not to increased environmental gross alpha and gross beta radiation (**Table 7-9**). On December 18, gross alpha and/or gross beta were above MCLs at locations N829, NPT6, and NPT7. In this case, recounts confirmed the initial results. Uranium isotopic analysis showed the presence of naturally occurring uranium in all the March 9 and December 18 samples, but not enough to account for the gross alpha and gross beta. Because of budget limitations, one sample (December 18, NLIN) was selected for isotopic analysis. As in the case of the Livermore site samples, the plutonium level was extremely low (1.16×10^{-4} Bq/L or 31.4×10^{-4} pCi/L); uranium, thorium, and potassium levels (0.39, 1.70, and 35.9 Bq/L, respectively) were higher, but not enough higher to account for all the observed gross alpha and gross beta; and calculated daughter product emissions accounted for the majority of the gross alpha and gross beta.

Table 7-8. Radioactivity in storm water runoff at Site 300 (in Bq/L), 1995.

Location	Date	Tritium	Gross alpha	Gross beta
CARW	Mar 9	<1.62	33.82 ± 1.30	21.50 ± 0.67
	Mar 9[a]		6.857 ± 2.916	9.916 ± 5.720
N829	Mar 9	<1.56	0.13 ± 0.01	0.17 ± 0.01
	Dec 18	<2.31	1.26 ± 1.18	4.85 ± 1.07
	Dec 18[a]		3.885 ± 1.517	5.439 ± 1.110
N883	Mar 9	<1.61	0.12 ± 0.01	0.15 ± 0.01
	Dec 11	<1.99	0.07 ± 0.06	0.15 ± 0.06
NLIN	Mar 9	<1.55	10.10 ± 0.44	5.07 ± 0.22
	Mar 9[a]		2.658 ± 0.987	3.737± 2.049
	Dec 18	2.98 ± 2.38	6.59 ± 3.29	8.99 ± 2.52
	Dec 18[a]		7.955 ± 2.923	7.955 ± 1.998
NPT6	Dec 18	<2.33	3.66 ± 2.29	8.47 ± 2.41
	Dec 18[a]		3.589 ± 2.22	9.065 ± 1.85
NPT7	Mar 9	<1.57	0.13 ± 0.01	0.18 ± 0.01
	Dec 11	<2.02	0.07 ± 0.05	0.15 ± 0.06
NSTN	Mar 9	<1.64	1.50 ± 0.07	1.27 ± 0.04
	Mar 9[a]		0.15 ± 0.21	0.59 ± 0.19

Location	Date	Uranium-234	Uranium-235	Uranium-238
CARW	Mar 9	0.0078 ± 0.0041	0.0041 ± 0.0033	0.0044 ± 0.0030
	Mar 9			
N829	Mar 9	0.0118 ± 0.0063	0.0048 ± 0.0044	0.0118 ± 0.0067
	Dec 18	0.19 ± 0.02	0.0148 ± 0.0048	0.19 ± 0.02
N883	Mar 9	0.0070 ± 0.0037	0.003 ± 0.0025	0.0059 ± 0.0033
	Dec 11	0.0073 ± 0.0037	0.0014 ± 0.0016	0.0042 ± 0.0024
NLIN	Mar 9	0.56 ± 0.10	0.06 ± 0.0148	0.52 ± 0.09
	Dec 18	0.378 ± 0.0322	0.0189 ± 0.0063	0.45 ± 0.04
NPT6	Dec 18	0.163 ± 0.0189	0.0115 ± 0.0048	0.21 ± 0.02
NPT7	Mar 9	0.0130 ± 0.0052	0.0004 ± 0.0011	0.0096 ± 0.0044
	Dec 11	0.0141 ± 0.0052	0.0031 ± 0.0030	0.0085 ± 0.0041
NSTN	Mar 9	0.11 ± 0.02	0.0048 ± 0.0033	0.11 ± 0.02

[a] Recount performed for gross alpha and gross beta only.

Table 7-9. Activities of liquid and solid components of Site 300 storm water runoff samples (Bq/L).

	CARW	NLIN		NSTN
	(Mar 9)	Mar 9	Dec 12	(Mar 9)
Gross alpha	6.86 ± 2.92	2.66 ± 0.987	3.59 ± 2.22	0.738 ± 0.536
Gross alpha (solid phase)	6.85 ± 2.92	2.43 ± 0.981		0.6549 ± 0.529
Gross alpha (liquid phase)	0.0119 ± 0.016	0.228 ± 0.110		0.0829 ± 0.083
Gross beta	9.92 ± 5.72	3.74 ± 2.05	9.07± 1.85	1.032 ± 0.182
Gross beta (solid phase)	8.954 ± 5.661	2.4568 ± 1.987		0.492 ± 0.039
Gross beta (liquid phase)	0.962 ± 0.821	1.28 ± 0.500		0.540 ± 0.178
Uranium (solid phase)			0.39 ± 0.0295	
Plutonium (solid phase)			$1.16 \times 10^{-4} \pm 2.30 \times 10^{-3}$	
Thorium (solid phase)			1.70 ± 0.123	
Potassium-40 (solid phase)			0.132 ± 0.00666	

Site 300 Nonradioactive Pollutants in Storm Water

Three pH readings in Site 300 storm water runoff (**Table 7-10**) were outside of the MCL range (6.5 to 8.5); a pH of 6.2 was measured on March 2 at location N883, and pH of 8.7 and 8.8 were measured on December 18 at locations N829 and NLIN, respectively. In addition, TSS was often above the benchmark value (100 mg/L). This can readily be attributed to naturally occurring sediment loads in storm water runoff. Total suspended solids at background locations ranged as high as 20,000 mg/L, with a 94/95 median of over 10,000 mg/L, compared to a maximum effluent TSS of 6600 mg/L. All other nonradioactive constituents and parameters were below comparison criteria.

Environmental Impact

Tritium activities in all off-site drinking waters (as well as the on-site TAP location) were well below the drinking water MCL; they were within the range of the estimated background levels (background ranges from 3–4 Bq/L). The potential impact of such levels of tritium in drinking water supplies was estimated by determining the effective dose equivalent (EDE). Appendix B presents the method to calculate dose. Of all off-site drinking waters measured, the maximum tritium activity, 0.88 Bq/L (23.8 pCi/L), occurred at location ORCH (a drinking water source on private property near LLNL) sampled on January 13, 1995. The EDE to an adult who ingested 2 L of water at this concentration per day for 1 year would be 0.011 µSv (1.1 µrem), which is approximately 0.001% of the DOE standard allowable dose of 1.0 mSv/y (100 mrem). All other off-site waters, if ingested at the 2 L/day rate, would result in even lower EDEs.

Table 7-10. Site 300 storm water runoff, nonradioactive parameters, 1995.

Location	Storm date	Total organic halides (mg/L)	Total organic carbon (mg/L)	Total suspended solids (mg/L)	pH	Specific conductance (μmhos/cm)	HMX[a] (μg/L)	RDX [a] (μg/L)	TATB[a] (μg/L)	TNT[a] (μg/L)
CARW	Mar 9	0.13	13	20,000	7.5	700				
N829	Mar 9	<0.02	1.5	99	6.6	17	—[b]	—[b]	—[b]	—[b]
	Dec 18	0.04	5.3	5200	8.7	85	<20	<30	<70	<30
N883	Mar 9	—[b]	2	33	6.2	14				
	Dec 11	0.014	20	9	6.5	62				
NLIN	Mar 9	<0.02	8.9	6600	8.3	190				
	Dec 18	0.041	8.2	6200	8.8	120				
NPT6	Dec 18	0.028	4.4	2800	7.3	27				
NPT7	Mar 9	0.022	2.4	160	8.1	69				
	Dec 11	<0.01	5	100	8.1	72				
NSTN	Mar 9	0.16	6.5	1300	7.8	870				

[a] Analysis performed for location N829 only.

[b] Sample not collected due to field technical error.

The environmental impact of tritium measured in rainfall samples from LLNL, SNL/California, the Livermore Valley, and Site 300 was negligible. The highest tritium activity measured in a 1995 rainfall sample was 72.9 Bq/L (1970 pCi/L). This activity is less than 10% of the 740 Bq/L limit established for drinking water by the federal EPA. The EDE if an adult were to ingest 2 L of this rain per day for 1 year would be approximately 0.001 mSv (0.1 mrem), which is 0.1% of the DOE standard allowable annual dose of 1.0 mSv (100 mrem).

The environmental impact of tritium measured in storm water effluent from LLNL and Site 300, was also negligible. The highest tritium activity measured in a 1995 runoff effluent sample was 16.9 Bq/L (456 pCi/L). This activity is less than 2.5% of the 740 Bq/L limit established for drinking water by the federal EPA. The EDE if an adult were to ingest 2 L of this water per day for 1 year would be approximately 0.2 μSv (0.02 mrem), which is 0.02% of the DOE standard allowable annual dose of 1.0 mSv (100 mrem). The data from waters sampled during 1995 and the estimated potential maximal dose demonstrate a minimal impact of LLNL operations on valley waters resulting from releases of tritium to the atmosphere.

Three Site 300 effluent samples contained gross alpha and/or gross beta above MCL criteria, but this was attributed to high TSS. Storm water effluent also contained levels of chromium, copper, iron, nitrate, TSS, and zinc that were, at times, above their respective water quality criteria. In addition, pH was at times outside of the MCL range, and alkalinity was at times below the minimum AWQC. Although some 1995 storm water results were above criteria, there is no evidence that indicates any impact to off-site biota.

8. Routine Ground Water Monitoring at Site 300

Eric Christofferson

Introduction

The LLNL Experimental Test Site (Site 300) is located in the Altamont Hills, about 12 km southwest of the City of Tracy. Routine ground water monitoring at Site 300 includes both surveillance and compliance monitoring. LLNL routinely monitors 56 ground water wells at Site 300 in addition to Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) monitoring associated with areas of known ground water contamination (see Chapter 2 for a summary of CERCLA activities at Site 300). Ground water monitoring at Site 300 includes the analyses of samples taken from water supply wells and from wells constructed for monitoring purposes only.

Sampling of well waters follows standard operating procedures (SOPs) that minimize the effects of sampling on analytical results (Dibley and Depue 1995). Analytical results are reviewed by a Quality Control (QC) chemist and passed to the responsible water analyst. The analyst compares the results with historical data and predicted trends for each well. If unpredicted increases are observed that violate permitted limits, the analyst alerts LLNL management to the potential problem. Because LLNL requires its analytical laboratories to follow stringent quality control procedures, unpredicted results can often be traced to analytical errors or to typographical errors. Sampling is often repeated to confirm unusual results. In most instances, abrupt increases in the concentration, or the activity, of a constituent in ground water samples are not confirmed by repeated sampling and analysis.

Area-wide surveillance monitoring of ground water at Site 300 utilizes 34 wells and 1 spring. Four of the wells are fitted with a total of 10 Barcad sampling devices that monitor multiple water-bearing zones. Ground water surveillance monitoring is required by U.S. Department of Energy (DOE) Orders 5400.1 and 5400.5. DOE provides additional direction on radiological effluent monitoring in *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. Department of Energy 1991). For ground water surveillance purposes, LLNL determines the number and locations of sampling wells, the constituents to be monitored, the frequency of sampling, and the analytical methods to be used. This allows LLNL to design a comprehensive, cost-effective monitoring program.

Little flexibility is available to LLNL for compliance monitoring of ground water at Site 300, where requirements are specified in two Waste Discharge Requirement (WDR) Orders, issued by the California Central Valley Regional

Water Quality Control Board (RWQCB), and in post-closure monitoring and reporting plans. The WDRs and post-closure plans specify the wells to be monitored, the constituents to be measured, the frequency of measurements, the analytical methodology to be used, and the frequency and form of required reports. The Site 300 compliance monitoring data that are summarized in this chapter were previously submitted to the DOE, the Central Valley RWQCB , and other interested federal agencies and individuals in four quarterly reports and one annual report for year 1995 (Christofferson and MacQueen 1995a, 1995b, 1995c, 1996a, and 1996b). The extensive compliance monitoring data were not tabled again for this report.

Potential contaminants to ground waters were monitored in the vicinity of two landfills, known as Pit 1 and Pit 7, that were closed under the Resource Conservation and Recovery Act (RCRA), and similar monitoring continued during 1995 in the vicinity of two active surface impoundments, where process water is evaporated. The primary objective of compliance monitoring is the early detection of any release of chemicals to ground water from the closed landfills, or from the active process-water evaporation ponds. Compliance monitoring is accomplished by obtaining ground water samples quarterly from 22 monitoring wells and analyzing the samples for specific constituents of concern (COCs) and general contaminant indicator parameters. Typically, quantitative analyses are conducted for those COCs known to have been buried in a particular landfill or contained in process waters that are evaporated in the surface impoundments.

Networks of ground water monitoring wells that are sampled quarterly are the primary means for detecting the release of chemicals from the closed landfills, whereas wells form a tertiary tier of release detection around the process-water surface impoundments. Primary release detection there consists of weekly visual inspections for leachate flow at the outfalls of perforated pipes installed in a layer of sand confined between each impoundment ' s two liners. Each impoundment has an inner impermeable liner of high density polyethylene (HDPE) and an outer impermeable liner of compacted clay. Secondary release detection there consists of quarterly remote operation of lysimeters installed beneath the outer clay liners. It is unlikely that process water from either impoundment could reach the lysimeters, because it would have to breach both liners. However, if this unlikely event did occur, the network of monitoring wells in the vicinity of the evaporation ponds provides a tertiary release detection system and a means of estimating the environmental impact on the ground water.

Surveillance monitoring of ground water at Site 300 uses samples taken from on-site and off-site wells. Depending on their location and purpose, wells are sampled monthly, quarterly, or annually. Ground water samples from wells

are routinely measured for general contaminant indicators, gross radioactivity, radioisotopes, toxic metals, and a wide range of organic chemicals. Typically, surveillance monitoring involves more COCs than does compliance monitoring.

Compliance Ground Water Monitoring at Site 300

Compliance ground water monitoring at Site 300 is governed specifically by two WDR permits, 85-188 and 93-100, (Central Valley RWQCB 1985; 1993) and a RCRA post-closure monitoring and reporting plan (Rogers / Pacific Corporation 1990). Compliance monitoring involves analyses of water samples drawn from 22 wells associated with two RCRA-closed landfills (17 wells) and two active process water impoundments (5 wells). **Figure 8-1** shows the locations of the closed landfills (Pit 1 and Pit 7), the two process water surface impoundments, and the on-site and off-site wells used for surveillance monitoring purposes. A complete description of the stratigraphy and hydrogeologic conditions at Site 300 can be found in the *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300* (Webster-Scholten 1994), hereafter referred to as the Final SWRI report. A brief description of the monitored areas and their associated wells follows.

Pit 1 Area

Figure 8-2 locates Pit 1, monitoring wells, an adjacent closed landfill identified as Pit 2, and the Advanced Test Accelerator (ATA) Building 865 area. Pit 1 lies in the upper part of the Elk Ravine drainage area at an average elevation of 330 m above sea level. Although the test site is a semiarid locale, intense rainfall does occur. In order to combat erosion, rain runoff from the pit cap and surrounding area is collected in a concrete channel that encircles the pit. The outfall is at the southwest corner of Pit 1 where surface runoff flows to Elk Ravine. Subsurface water flow beneath Pit 1 is east-northeasterly and generally follows the dip of the underlying sedimentary rocks. Of eight designated Pit 1 compliance monitoring wells, Wells K1-01C and K1-07 are hydrologically upgradient from Pit 1, Wells K1-02B, K1-03, K1-04, and K1-05 are downgradient; and Wells K1-08 and K1-09 are cross-gradient to this RCRA-closed landfill. Pit 2 was closed before RCRA became effective. Pit 2 is hydrologically upgradient from Pit 1 with respect to subsurface water flow, but it is downslope from Pit 1 with respect to rain runoff into Elk Ravine. The ATA Building 865 area is hydrologically upgradient from Pit 1 monitoring wells K1-05, K1-08, and K1-09 with respect to ground water flow.

The eight Pit 1 monitoring wells are completed near the contact between the Tertiary Neroly Formation lower blue sandstone member and the underlying mid-Miocene Cierbo Formation consisting of claystones and siltstones. The Tertiary Neroly and Cierbo sedimentary rock formations contain the main water-bearing strata beneath the test site.

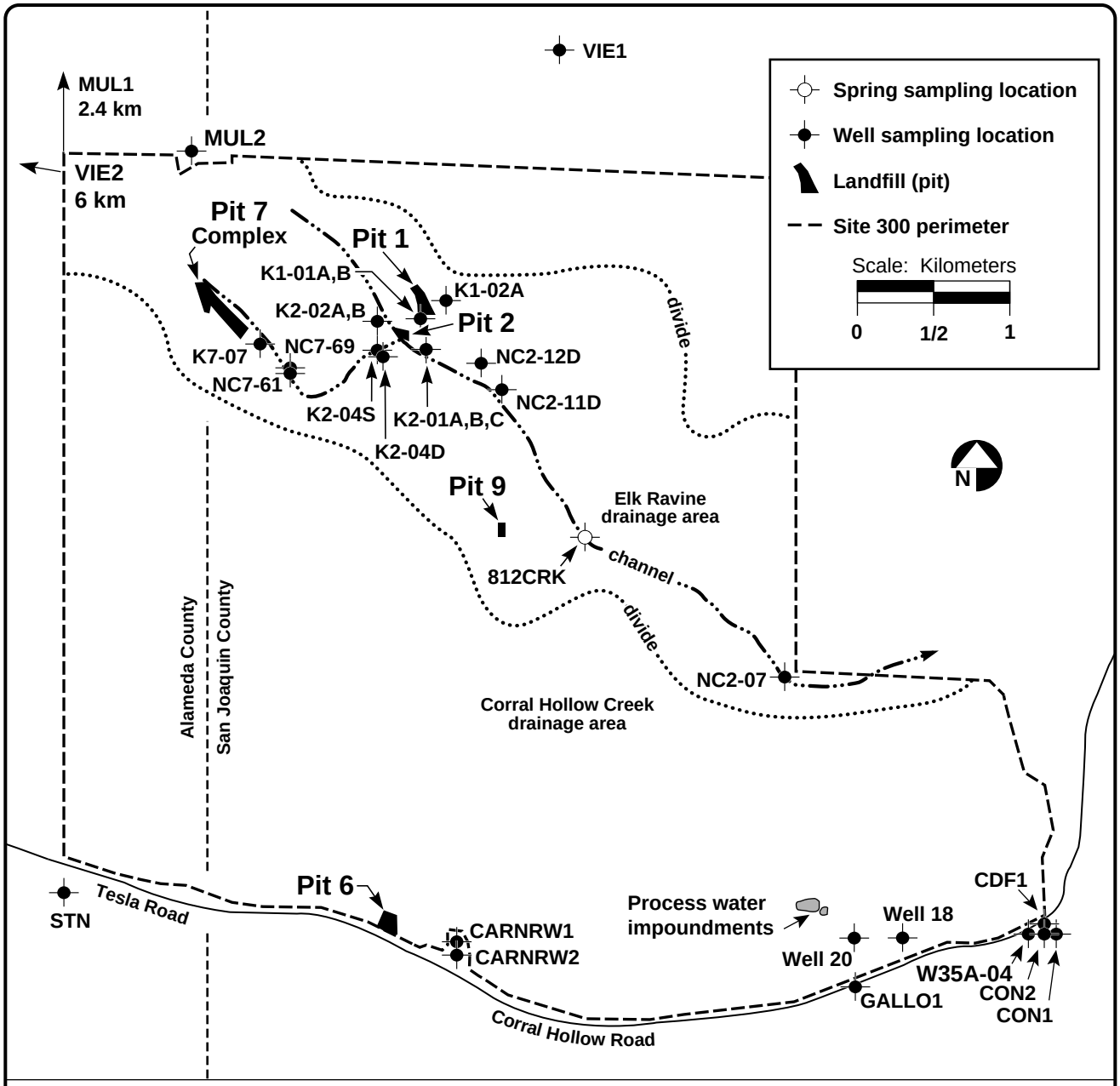

Figure 8-1. Site 300 surveillance wells, spring, impoundments, and closed landfills (pits).

Pit 1 ground water samples were analyzed for constituents fulfilling the requirements of WDR Order No. 93-100 and a post-RCRA-closure monitoring plan (Rogers / Pacific Corporation 1990). Measurements were performed for water table elevation; total dissolved solids (TDS); specific conductance; temperature; pH; metals; high-explosive (HE) compounds (cyclotetramethyl-tetramine [HMX], hexahydro-1,3,5-trinitro-1,3,5-triazine [RDX], and

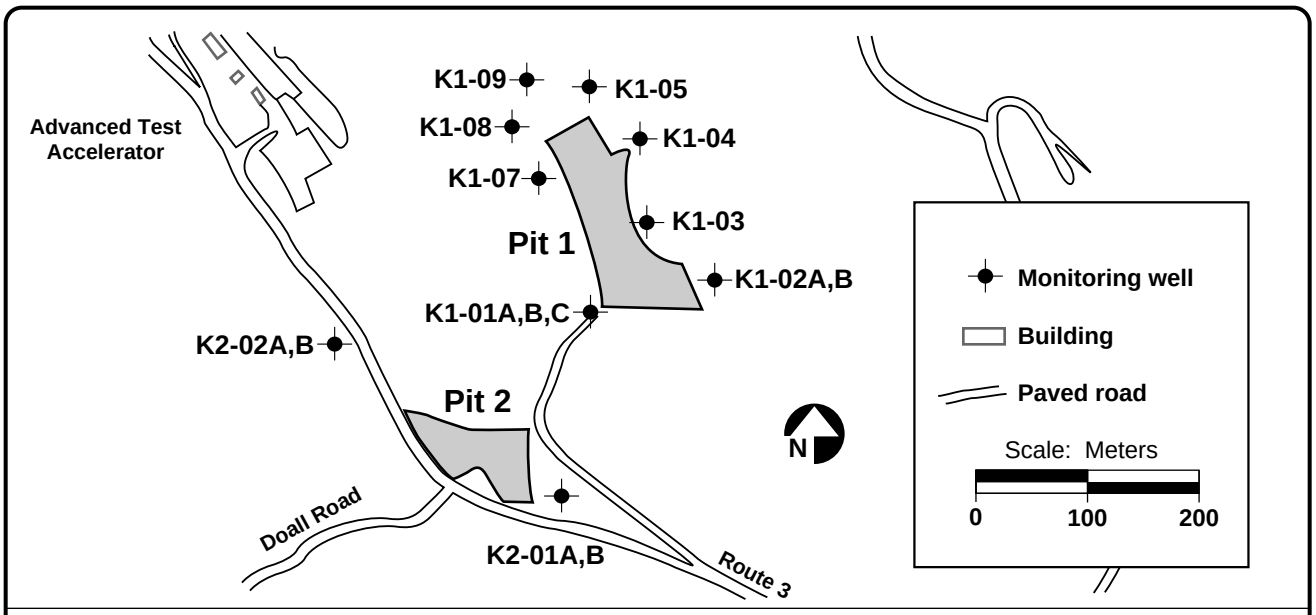

Figure 8-2. Pit 1 compliance wells and Pit 2 surveillance wells.

trinitrotoluene [TNT]); general minerals; total organic carbon (TOC); total organic halides (TOX); radioactivity (gross alpha and gross beta); the radioisotopes tritium (^{3}H), radium (^{226}Ra), uranium (^{234}U, ^{235}U, and ^{238}U), and thorium (^{228}Th and ^{232}Th); herbicides and pesticides (EPA Methods 615 and 608); purgeable organic compounds (EPA Method 624); and extractable organic compounds (EPA Method 625).

Pit 7 Complex Area

Nine designated compliance wells monitor the Pit 7 Complex that consists of three pre-RCRA-closed landfills (Pits 3, 4, and 5), and one RCRA-closed landfill (Pit 7; **Figure 8-3**). The complex of closed landfills is in the Pit 7 Complex Valley, which occupies the uppermost reach of the Elk Ravine drainage area. The average elevation of the pit complex is 425 m. To combat erosion in this area of high relief and to reduce local ground water recharge, rain runoff from the Pit 7 cap is collected in several diversion channels made of concrete. Pit 7 is nearly encircled by a diversion channel that collects rain runoff from the pit cap and directs it southeasterly into the Elk Ravine drainage system. A second diversion channel was constructed on the west side of Pit 7. Runoff entering this northerly directed channel develops on the hillside immediately to the west of the Pit 7 landfill. Subsurface water can flow in two directions through this area. With sufficient seasonal rainfall, a shallow, unconfined, southeastward flow can develop in the unconsolidated surficial Quaternary valley-fill deposits. The predominant ground water flow, however, follows the east-northeasterly dip of

the underlying Tertiary sedimentary rocks of the Neroly and Cierbo formations. With respect to Pit 7 and the predominant flow direction, Well K7-06 is upgradient, Wells K7-09 and K7-10 are cross-gradient, and Wells K7-01, K7-03, NC7-25, NC7-26, NC7-47, and NC7-48 are downgradient. Wells K7-01, K7-10, and NC7-26 are completed in the lower blue sandstone of the Tertiary Neroly Formation that underlies much of the Pit 7 Complex. The remaining wells are completed within the claystones and sandstones of the mid-Miocene Cierbo Formation.

Pit 7 ground water samples were analyzed for constituents fulfilling the requirements of WDR Order No. 93-100 and the monitoring plan for the post-RCRA closure. Measurements were performed for water table elevation; TDS; specific conductance; temperature; pH; metals; general minerals; the radioisotopes tritium (^{3}H), radium (^{226}Ra), uranium (^{234}U, ^{235}U, and ^{238}U), and thorium (^{228}Th and ^{232}Th); HE compounds (HMX, RDX, and TNT); and a wide range of organic chemicals.

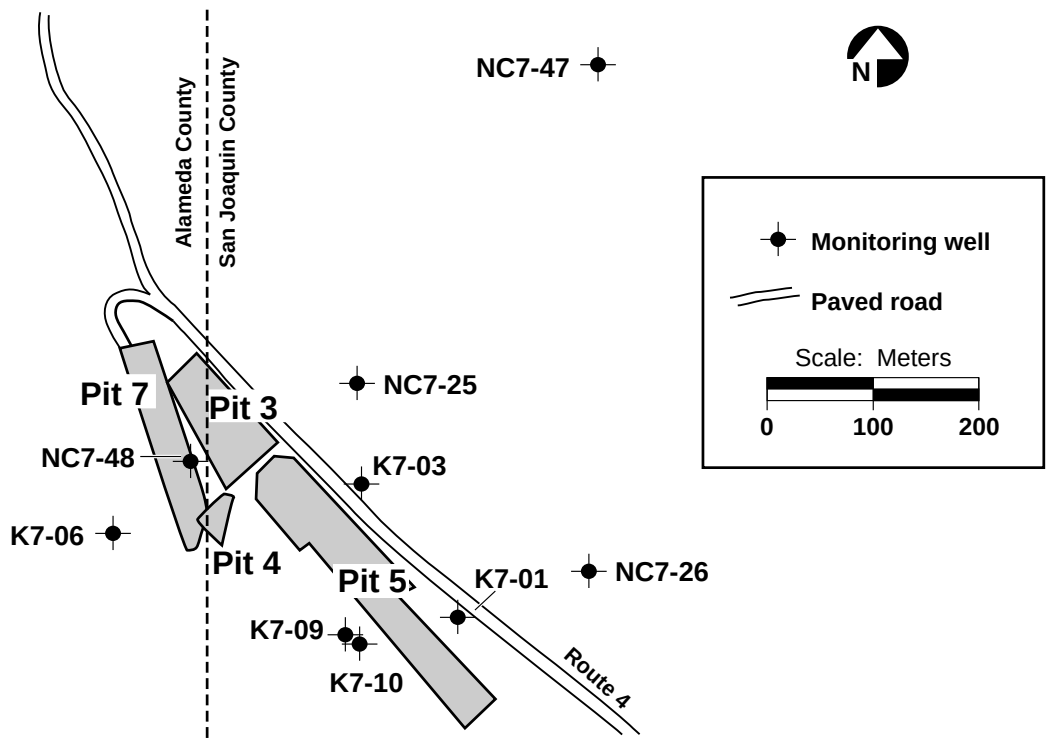

Figure 8-3. Pit 7 Complex compliance wells.

High Explosives Process Area

Figure 8-4 shows the portion of the HE Process Area that includes the two process-water impoundments, their five compliance monitoring wells, and Buildings 815 and 817. Compliance monitoring of the two impoundments is specified in permit WDR Order No. 85-188, issued by the Central Valley RWQCB (1985). Beneath both process water impoundments are systems of perforated pipes whose purpose is leak detection. Seven lysimeters installed at greater depth provide an additional leak detection system. Four of the five compliance monitoring wells are completed in the underlying Neroly upper blue sandstone, a water-bearing formation. The fifth well, W-817-03A, is completed at shallow depth in a nonmarine formation, consisting of unconsolidated sediments and sedimentary rocks, that locally overlies the Neroly Formation. The overlying formation contains a perched water-bearing zone that is very restricted laterally and vertically. The direction of water flow in both formations is approximately southeasterly. Well W-817-01 is hydrologically upgradient with respect to the impoundments, and wells W-817-02, -03, -03A, and -04 are hydrologically downgradient.

Ground water samples were collected quarterly during 1995 from the five compliance monitoring wells in the B-817 HE Process Area. Samples from the four deeper wells completed in the Neroly upper blue sandstone formation were analyzed for metals, general parameters, HE compounds, organic compounds, and tritium. Leachate collection systems were checked weekly for the presence of water, and lysimeters were operated quarterly to extract any water present.

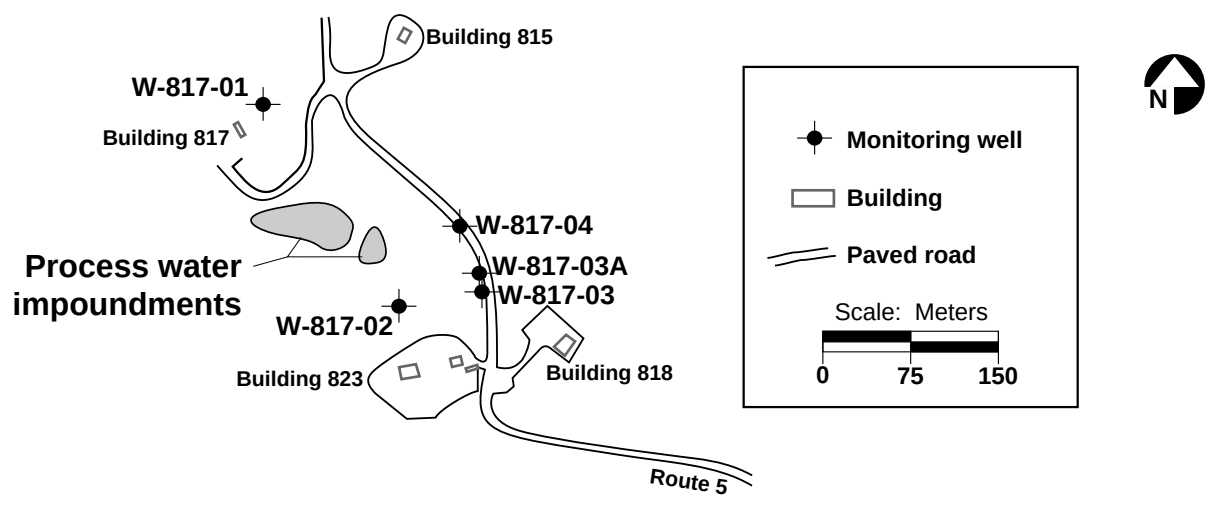

Figure 8-4. HE Process Area compliance wells.

Surveillance Ground Water Monitoring at Site 300

Methods of sampling and analysis are the same for compliance and surveillance monitoring wells, but the COCs and the frequency of sampling may differ. Special consideration is given to monitoring those elements and organic compounds known to be toxic in trace amounts. Analytical methods are selected that have reporting limits at, or lower than the toxic concentrations. Typically, drinking water maximum contaminant levels (MCLs) are referred to when selecting COCs, and EPA-approved analytical methods are used to measure them.

Thirty-four ground water wells and one spring are monitored at Site 300 as part of the ground water surveillance program (**Figure 8-1**). Twenty-two wells are on site and 12 are off site. A surveillance spring, designated 812CRK, is located on site in the Elk Ravine drainage area. Three of the 12 off-site surveillance wells are located north of Site 300, where the Altamont Hills slope down to the San Joaquin Valley. One well, designated VIE2, is located in the Altamont Hills approximately 6 km west of Site 300 in the upper reaches of the Livermore Valley watershed. The remaining eight off-site surveillance wells are located adjacent to Site 300 on the south in the Corral Hollow Creek drainage area. Twelve of the 22 on-site surveillance wells monitor three inactive landfills (closed pits). Six wells monitor Pit 6 (**Figure 8-5**). Four wells monitor Pit 9 (**Figure 8-6**). Three multiple completion wells monitor Pit 2 (**Figure 8-2**). Nine surveillance wells and one spring, designated 812CRK, are located along the system of fault-marked ravines and arroyos that comprise the Elk Ravine drainage area (**Figure 8-1**). Well 20 is a production well that provides potable water to Site 300 (**Figure 8-1**). Well 18 is the backup production well (**Figure 8-1**). The wells are described briefly below. A more complete description of the stratigraphy and the hydrogeologic conditions can be found in the Final SWRI report (Webster-Scholten 1994).

Pit 6

The closed Pit 6 landfill is positioned along the southern boundary of Site 300 at an elevation of 210 m above sea level (**Figure 8-1**). It lies in Quaternary terrace deposits above and north of the Corral Hollow Creek flood plain. The Tertiary Neroly Formation sedimentary rocks underlie the terrace deposits. Surface runoff from the pit area is southward to Corral Hollow Creek. Ground water flow beneath the pit is also southward, following the south-dipping sedimentary rocks of the Neroly Formation. However, the direction of the subsurface flow changes from south to southeast beneath the southern margin of the landfill where the Carnegie Fault has brought vertically dipping strata on the south into contact with gently dipping strata on the north. A deposit of terrace gravel fills a southeasterly trending trough within the vertically dipping strata immediately south of the landfill and acts as a channel for the ground water after it passes beneath Pit 6.

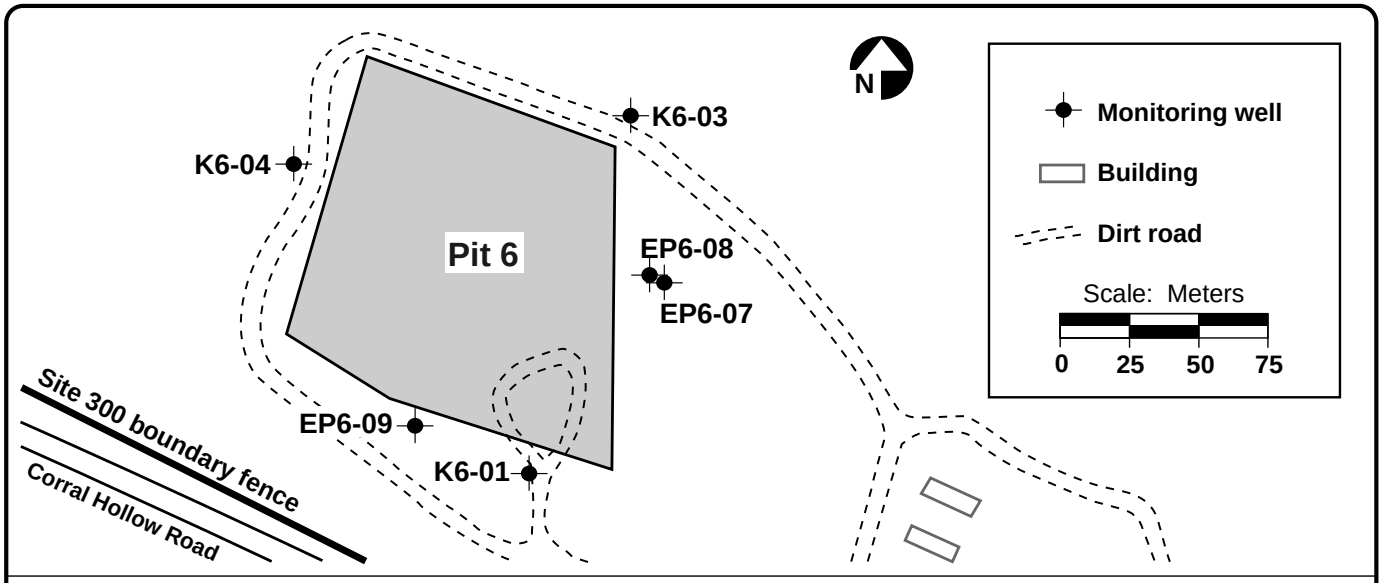

Figure 8-5. Pit 6 surveillance wells.

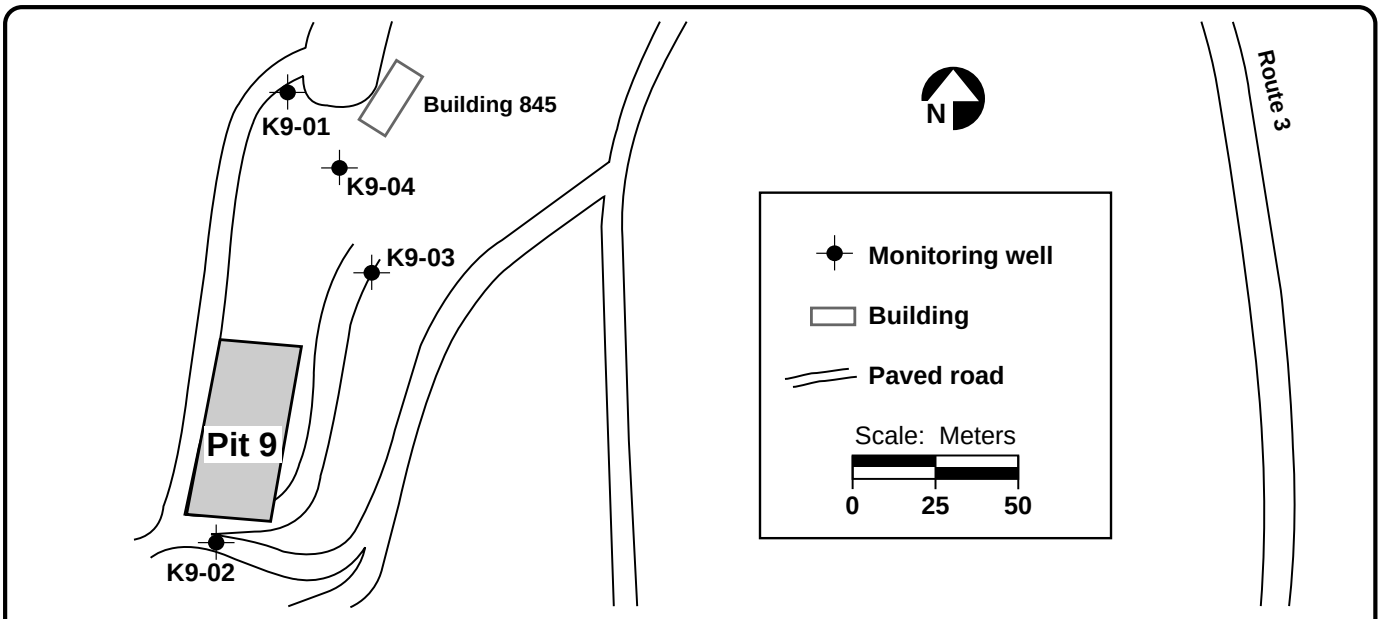

Figure 8-6. Pit 9 surveillance wells.

Six wells comprise the surveillance monitoring network at closed landfill Pit 6 (**Figure 8-5**). Well K6-03 is hydrologically upgradient from Pit 6 and is completed and screened in the gently southward dipping Tertiary Neroly sedimentary rocks. Wells K6-04, EP6-07, and EP6-08 are hydrologically cross-gradient from Pit 6 and are also completed and screened in the south-dipping Neroly sedimentary rocks. The completion interval of Well K6-04 extends upwards into the Quaternary terrace deposits. Wells EP6-09 and K6-01 are hydrologically downgradient from Pit 6 and are completed and screened in the vertically dipping Tertiary sedimentary rocks.

Ground water samples from the Pit 6 surveillance wells were analyzed for metals; toxic organic compounds, HE compounds, radioactivity (gross alpha and gross beta); and tritium (^3H).

Pit 2

The inactive Pit 2 landfill lies in the upper portion of Elk Ravine at 320 m above sea level (**Figure 8-2**). Surface runoff from the pit area is southerly into Elk Ravine. Subsurface water flow beneath the pit is east-northeasterly following the dip of the underlying Neroly and Cierbo sedimentary rocks. Multiple completion Well K1-01 (**Figure 8-2**) is completed at three separate depth intervals in the claystone and sandstone mid-Miocene Cierbo Formation. It contains three Barcad sampling devices. Each Barcad samples a discrete water-bearing zone within the Cierbo Formation. The deepest of the three zones is sampled by Barcad K1-01A, the intermediate zone by Barcad K1-01B, and the upper zone by Barcad K1-01C, which serves as one of two upgradient water monitoring points for Pit 1. Surveillance monitoring Wells K2-01 and K2-02 are hydrologically cross-gradient from Pit 2. These are also multiple completion wells and are fitted with Barcad sampling devices. Barcads K2-01A, K2-02A, and K2-02B are completed in the Cierbo Formation. Barcad K2-01B is completed in the lower blue sandstone of the Tertiary Neroly Formation that overlies the Cierbo Formation.

Samples from the Barcad-fitted multiple completion wells were taken quarterly during 1995 and were analyzed for metals; radioactivity (gross alpha and gross beta); and tritium (^3H).

Pit 9

Inactive landfill Pit 9 is centrally located within Site 300 at an elevation of 340 m above sea level. Surface runoff from Pit 9 flows northeastward into Elk Ravine. Subsurface ground water flow is also east-northeasterly in the lower blue sandstone of the Neroly Formation. **Figure 8-6** shows the locations of the surveillance monitoring wells with respect to Pit 9. Monitoring Well K9-02 is hydrologically upgradient from Pit 9. Wells K9-01, K9-03, and K9-04 are

downgradient. Well K9-02 is completed and screened in the Neroly lower blue sandstone at its contact with the underlying Cierbo Formation. Wells K9-01, K9-03, and K9-04 are completed and screened in the Cierbo Formation, just below its contact with the Neroly Formation.

Pit 9 surveillance monitoring Wells K9-01, K9-02, and K9-03 were sampled and analyzed once during 1995 for metals; radioactivity (gross alpha and gross beta); the radioisotopes tritium (^{3}H), radium (^{226}Ra), uranium (^{234}U, ^{235}U, and ^{238}U; HE compounds; and toxic organic compounds.

Elk Ravine Drainage Area

The Elk Ravine drainage area includes most of northern Site 300, the area between the drainage divides shown on **Figure 8-1**. This semiarid area collects rare surface runoff into arroyos from inactive landfill Pits 1, 2, 3, 4, 5, 7, and 9. The Pit 7 Complex comprises Pits 3, 4, 5, and 7. Surface runoff from the Pit 7 Complex area flows mainly southeastward to Doall Road, where it is deflected northeastward into Doall Ravine by a landslide deposit. At the northeastern end of Doall Ravine, the runoff combines with channeled runoff from the ATA Building 865 area. From this confluence point, the arroyo trends southeasterly within Elk Ravine. Near Well NC2-07, channeled runoff turns easterly away from the trend of the Elk Ravine fault and flows off site for approximately 2 km to its confluence with Corral Hollow Creek. Except for Doall Ravine, the arroyos traverse and follow faults, especially the extensive Elk Ravine Fault that may provide conduits to the underlying water-bearing Neroly strata. For this reason, ground waters from wells that lie within this drainage network are monitored. The monitored wells are (from highest to lowest elevation) K7-07, NC7-61, NC7-69, K2-04D, K2-04S, K2-01C, NC2-12D, NC2-11D, and NC2-07. The 812CRK sampling location is a natural spring that is designated Spring 6 in the Final SWRI report (Webster-Scholten, 1994). This spring is located in the main Elk Ravine arroyo on the Elk Ravine Fault. Individual wells are discussed below.

Well K7-07 is a shallow well, completed and screened in the upper Neroly lower blue sandstone and the overlying Quaternary alluvium. The well was dry during the first quarter of 1995. Wells NC7-61 and NC7-69 are completed and screened in and sample separate water-bearing zones beneath the upper reach of Doall Ravine, downstream from Well K7-07. Well NC7-61 is completed and screened in the shallower Neroly Formation lower blue sandstone, and Well NC7-69 is completed and screened in the deeper Cierbo Formation. Wells K2-04D and K2-04S and Barcad K2-01C are located near the join between Elk Ravine and Doall Ravine. They are all completed and screened in the upper Neroly Formation lower blue sandstone. Wells NC2-12D and NC2-11D are located in Elk Ravine below its join with Doall Ravine. Well NC2-11D is completed at the boundary between the Cierbo and the overlying Neroly formations.

NC2-07 is the furthest downstream surveillance well in the Elk Ravine drainage area. It is completed in the Neroly Formation lower blue sandstone.

Ground water samples from the Elk Ravine surveillance wells and the spring, 812CRK, were analyzed quarterly for metals; radioactivity (gross alpha and gross beta); tritium (^3H); HE compounds; and toxic organic compounds.

Wells 18 and 20

Well 20 supplied potable water at Site 300 during 1995, while Well 18 was maintained as a standby water supply well. The wells are located in the south-eastern part of Site 300 (**Figure 8-1**). Both are deep, high-production wells that are completed in the Tertiary Neroly Formation lower blue sandstone. The Well 18 completion zone extends upwards into an aquitard above the lower blue sandstone. The wells can produce up to 1500 L/min of water. Additional geologic and hydrogeologic information regarding these wells is contained in the Final SWRI report (Webster-Scholten 1994).

Ground water samples from the two on-site water supply wells were analyzed quarterly for metals (except Well 18); toxic organic compounds; radioactivity (gross alpha and gross beta); and tritium (^3H). Well 18 samples were analyzed once during 1995 for HE compounds.

Off-Site Supply Wells

Ground water samples from 12 off-site water-supply wells were analyzed during 1995 as part of the surveillance monitoring program. Eleven wells are adjacent to Site 300. The most distant well, VIE2, is located 6 km west of the site. Three wells—MUL1, MUL2, and VIE1— are adjacent to the site on the north, and eight wells, CARNRW1, CARNRW2, CDF1, CON1, CON2, GALLO1, STN, and W-35A-04, are adjacent to the site on the south (**Figure 8-1**). Wells CARNRW2, GALLO1, STN, and VIE2 supply water for human consumption.

Ground water samples from six wells were analyzed quarterly during 1995. Of these, CARNRW1 and CON2 were analyzed for toxic organic compounds, while CARNRW2, CDF1, CON1, and GALLO1 were analyzed for metals; HE compounds; toxic organic compounds; radioactivity (gross alpha and gross beta); and tritium (^3H). The remaining six wells—MUL1, MUL2, STN, VIE1, VIE2, and W-35A-04—were analyzed once during 1995 for metals; HE compounds; toxic organic compounds; radioactivity (gross alpha and gross beta); and tritium (^3H).

Results

This section presents the results of ground water measurements at Site 300 in the Pit 1 area, Pit 7 Complex area, HE Process Area, Pit 6 area, Pit 2 area, Pit 9 area, Elk Ravine drainage area, on-site water-supply wells, and off-site water-supply wells.

Pit 1 and Pit 7 Complex Areas

A major compliance monitoring effort was completed during 1995 that improved the statistical methods used to detect chemical releases from landfills Pit 1 and Pit 7. As a result of the work, LLNL petitioned the Central Valley RWQCB to revise the monitoring and reporting requirements of WDR 93-100 (Galles 1995; Hoppes 1995). New statistical concentration limits for COCs in ground water were proposed in order to reduce the number of false positive detections, together with their special reporting requirements. Special reporting is required when a COC exceeds its statistical concentration limit (see Chapter 14, Compliance Self-Monitoring, for COC limits and discussion). LLNL has reported statistically significant evidence for the release of several metallic and radioactive COCs from Pit 1 and Pit 7 since the WDR 93-100 and the RCRA post-closure monitoring plans were implemented in 1993. LLNL reviewed the ground water data for all COCs in 1995 and found additional statistical evidence for releases of arsenic, cadmium, copper, nickel, zinc, and radium-226 from Pit 7, and barium from Pit 1.

Table 8-1 lists the COCs that have shown statistically significant evidence of release, the associated landfill (Pit 1 or Pit 7), the date the statistical evidence was reported by letter to the RWQCB, and the status of their CERCLA investigation. LLNL established a CERCLA evaluation monitoring and assessment program that covers the Building 850/Pit 7 Complex Operable Unit and Pit 1 to determine if the COCs had been released to ground water as suggested from statistical analysis. LLNL completed the assessments of uranium isotopes (Pits 1 and 7), tritium (Pit 7), barium (Pit 7), vanadium (Pit 7), and lead (Pit 7) during 1995. The results of these studies were presented to the CERCLA Remedial Program Managers (RPMs) in February 1996 (Taffet et al. 1996).

The CERCLA uranium characterization was completed in 1995. It included ground water sampling and analysis for uranium isotopes, additional sampling and uranium analysis of soil and rock, fate and transport modeling, and a risk assessment (Taffet et al. 1996). Uranium activities in excess of the 0.74 Bq/L (20 pCi/L) MCL had been measured sporadically in the past in ground water samples from wells NC7-25 and NC7-48. Evidence of a manufactured form of uranium, called “depleted uranium,” or "D-38," from which most of the ^{235}U isotope had been removed, was first reported to the RWQCB in 1993 for a ground water sample from well NC7-48 (Christofferson et al. 1993). Subsequently, mass spectroscopy detected D-38 (99.8% ^{238}U) in ground water samples from other monitoring wells in the vicinity of the Pit 7 Complex and in the vicinity of the Building 850 firing table. The CERCLA study identified Pit 5, Pit 7, and the Building 850 firing table as the likely sources of the depleted uranium in the ground water (Taffet et al. 1996). The D-38 release is confined to two relatively small volumes of ground water, one spreading from the Pit 7 Complex and the other spreading from the Building 850 firing table. (Mass spectroscopic analyses showed no D-38 in ground water samples from the Pit 1 area.)

Table 8-1. Pit 1 and Pit 7 Constituents of concern showing “statistical evidence of release."

Constituent of concern	Pit	Reported to RWQCB	Status of CERCLA investigation
Metals			
Arsenic	1	6/3/94	In progress
Arsenic	7	10/17/95	In progress
Barium	1	10/17/95	In progress
Barium	7	11/9/93	Completed
Cadmium	7	10/17/95	In progress
Copper	7	10/17/95	In progress
Lead	7	2/17/94	Completed
Nickel	7	10/17/95	In progress
Vanadium	7	6/3/94	Completed
Zinc	7	10/17/95	In progress
Radioisotopes			
Radium-226	7	10/17/95	In progress
Tritium	7	11/9/93	Completed
Uranium	1	2/17/94	Completed
Uranium	7	9/10/93	Completed

Tritium activities during 1995 continued above the 740 Bq/L drinking water MCL in ground water samples from downgradient monitoring Wells K7-01, K7-03, and NC7-25. The highest tritium measured in 1995 was 10,175 Bq/L in a second-quarter sample from monitoring Well NC7-25. This activity is 14 times the MCL. However, none of the wells in this area supplies water for purposes other than monitoring.

The CERCLA tritium characterization, which extended from January 1993 to June 1995, included the collection of 1288 ground water samples and their analysis for tritium activity by scintillation counting. Three overlapping plumes of tritium-bearing ground water were found in the Pit 7 Complex Area and their sources were identified to be Pit 3 and Pit 5 in the Pit 7 Complex Area and Building 850 (Taffet et al. 1996). As a result of the CERCLA investigation, the tritium activity measured since 1989 in water samples from the Pit 1 down-gradient monitoring well K1–02B is now clearly associated with the plume

from Building 850. No evidence was found for a tritium release from either Pit 7 or Pit 1.

The CERCLA characterization of barium, vanadium, and lead, included the collection of 1288 ground water samples and their analysis for the concentrations of these metals. The CERCLA investigation concluded that barium and lead may have been released from the Pit 7 Complex landfills, but the occurrence of vanadium in the ground water is most likely natural (Taffet et al. 1996). All three of these metals show concentrations well within the ranges encountered in natural waters in the Coast Range and Great Valley Physiographic provinces, and none exceeded California MCLs for drinking water. Although statistical evidence for the release of lead from Pit 7 was reported (**Table 8-1**), retesting did not confirm a continuous presence. Lead detections occurred infrequently and inconsistently in ground water samples taken from the monitoring wells at Site 300. Lead (primarily from leaded gasoline combustion) has been deposited everywhere and extraordinary measures must be taken to prevent its introduction into water samples at the time of sampling and at the analytical laboratory. The infrequent and inconsistent detections of lead in Site 300 ground water samples most likely comes from this source. To overcome these troublesome lead detections, a validation procedure involving additional sampling and analysis has been implemented.

Of the wide range of analyses that are called for annually in the RCRA post-closure monitoring plan, only phenol, Freon 113, and di-n-butylphthalate were detected in several Pit 1 ground water samples, while quarterly monitoring of the Pit 7 Complex Area detected trichloroethene and 1,1-dichloroethene in samples from several monitoring wells. None of these compounds is associated with a release from either landfill and, except for phenol and di-n-butylphthalate, their sources have been identified (Webster-Scholten 1994; Taffet et al. 1996). The compound 1,1,2-trichloro-1,2,2-trifluoroethane, known as Freon-113, was detected far below the California State Action Level of 1200 µg/L in ground water samples from Wells K1-05, K1-08, and K1-09. However, Pit 1 has no record of Freon disposal. The Pit 1 wells that yield ground water samples containing this Freon compound are also downgradient from the ATA Building 865 area (**Figure 8-3**) where a Freon spill to ground is known to have occurred. The detections of low concentrations of phenol and di-n-butylphthalate near their detection limits are believed to result from unclean sample bottles, or analytical methodology, or both (Christofferson and MacQueen 1996b). To overcome troublesome phenol detections in Site 300 ground water samples, we have discontinued the use of EPA Method 420.1 for total recoverable phenols and will rely on EPA Method 625 that measures individual phenol concentrations.

HE Process Area

Two Class II surface impoundments are located at Site 300 in the HE Process Area. During 1995, they received process water that evaporated to the atmosphere. The adjacent impoundments were constructed at slightly different elevations and are connected by an overflow pipe. Normally, process water flows into the upper impoundment. When the process water reaches a fixed height, it flows into the lower impoundment. Leak detection systems, consisting of perforated pipes, are installed in a layer of permeable sand that is sandwiched and confined between an inner liner made of high density polyethylene (HDPE) and an outer liner made of impermeable clay. The pipes were installed on top of the clay liner. The clay liners were graded to provide optimum capture and transport of process water should a leak occur in the inner HDPE liners.

As required by WDR 85-188, the pipe outfalls were checked weekly during 1995 for the presence of leachate. In June, during a routine visual inspection, water was detected dripping into the lower impoundment from a leachate collection pipe installed beneath the upper impoundment. Analysis of the water confirmed that it was process water. It contained 55 ppb of HMX, an HE compound. The process water flow continued through 1995 at a variable rate of 2 to 30 L/day, averaging 15 L/day. Upon detection of the flow, LLNL took immediate action and diverted process water inflow to the lower impoundment. An electrical survey method was used to locate three leak points in the HDPE liner. The upper impoundment was emptied and the HDPE liner was repaired in December. The impoundment was then returned to normal operation.

No water was recovered during 1995 from lysimeters installed in the vadose zone directly beneath the outer clay liners of the impoundments. The absence of any water in the lysimeters indicates that the leaked process water remained confined to the space between the inner HDPE liner and the outer impermeable clay liner of the upper impoundment. The water flow from the leachate collection system is expected to continue until the process water stored in the confined sand layer is exhausted. LLNL makes weekly measurements of the flow rate to detect increases that would signify renewed leaking of the upper impoundment 's HDPE liner.

Ground water monitoring results confirm the lysimeter results. Monitoring data do not indicate that any of the process water was released to the ground water in the vicinity of the impoundments. The leaked process water was characterized by the presence of HMX and the absence of RDX, another HE compound, whereas the downgradient monitoring well samples contained RDX, but not HMX. The upgradient monitoring well samples showed both HMX and RDX. These results appear confusing, but the situation is explained fully in the Final SWRI report (Webster-Scholten 1994). The HE compounds presently found in the ground water were introduced by process water infiltration before 1985 when the two

surface impoundments with impermeable liners were placed in operation. Prior to 1985, unlined impoundments were used to dispose of process water.

During 1995, several COCs in ground water samples from the impoundment monitoring wells exceeded California drinking water MCLs. These were arsenic, selenium, nitrate, and trichloroethene (TCE). The maximum values measured during 1995 were: 65 ppb for arsenic (MCL = 50 ppb); 89 ppb for selenium (MCL = 50 ppb); 110 ppm for nitrate (MCL = 45 ppm); and 56 ppb for TCE (MCL = 5 ppb). Drinking water MCLs are used only for reference. The wells in this area are used only for monitoring purposes. Arsenic and selenium in the ground water are believed to result from dissolution of arsenopyrite and mafic minerals found naturally in the volcaniclastic Neroly upper sandstone (Webster-Scholten 1994, Raber and Carpenter 1983). The elevated nitrates in the ground water samples are likely due to natural sources and, possibly, to anthropogenic sources. The TCE source has been identified to be hydrologically upgradient from the process-water impoundments in the vicinity of Building B-815 (Webster-Scholten 1994; **Figure 8-4**).

Pit 6

COC data for the six Pit 6 monitoring wells are presented in Volume 2, Tables 8-3 through 8-8. Metals analyses of Pit 6 monitoring well samples showed mostly non-detections and none was above its MCL. Arsenic, barium, manganese, and selenium were detected at concentrations consistent with natural concentrations in the area ground water (Webster-Scholten 1994).

Of the organic compounds analyzed for, only the solvent TCE was detected above its 5 ppb MCL at 28 ppb in one monitoring well, EP6-09 (Volume 2, Table 8-8). Well EP6-09 lies within a shallow plume of TCE-bearing water that extends 100 m to the east of Pit 6. Computer modeling of TCE movement eastward in the ground water conservatively predicts that a maximum TCE concentration of 1 ppb will be reached in 60 years in the CARNRW2 water supply well (**Figure 8-1**). The extent of TCE in the Pit 6 area and its eastward movement are fully described in the Final SWRI report (Webster-Scholten 1994).

The radioactivity and radioisotope measurements of ground water samples from the Pit 6 area wells were low and were indistinguishable from natural background activities. No activity measurement was above EPA drinking water MCLs. Although glove boxes are known to have been buried in the landfill, no evidence for the release of radioisotopes to ground water has been uncovered.

Pit 2

COC data for the seven Pit 2 monitoring well Barcads are presented in Volume 2, Tables 8-9 through 8-15. Of the metals, arsenic, barium, cadmium, chromium and selenium were measured at least once above detection limits. Two arsenic measurements in ground water samples from Barcad K2-02A exceeded the 0.050 mg/L MCL for arsenic in drinking water. The metal concentrations are all within the range of natural background concentrations found in the ground water at Site 300 (Webster-Scholten 1994). Analysis indicated that none of the metals measured were released from the closed landfill.

The radioactivity and radioisotope measurements show only low background activities for gross alpha, gross beta, and tritium. However, although tritium activities in samples from Barcad K2-01B are barely detectable, they are elevated relative to the activities measured in samples taken from the other six Barcads in this area. This relatively elevated activity defines the boundary of a plume of tritium-bearing water flowing into the Pit 2 area from an identified source 1 km to the west near Building 850 in the West Firing Area (Webster-Scholten 1994; Taffet et al. 1996). The incursion of this tritium-bearing water into the Pit 2 area is also recorded in Barcad K1-02B ground water samples. That Barcad is a downgradient monitoring point for RCRA-closed landfill Pit 1 (**Figure 8-2**). The plume appears to be confined to the lower blue sandstone within the Neroly Formation in the vicinity of Pit 2 and Pit 1.

Pit 9

COC data for the four Pit 9 monitoring wells are presented in Volume 2, Table 8-16. All of the toxic organic compounds measured were below reporting limits. All metals, general minerals, and radioisotope measurements were indistinguishable from normal background concentrations. Tritium activity of 5.1 Bq/L in the farthest downgradient monitoring well K9-01 sample was relatively elevated. It may represent the elevated background activity that marked the period of atmospheric testing of nuclear weapons. A source of tritium in the area of Building 845 is also suggested (**Figure 8-6**). A maximum tritium activity there of 11,470 Bq/L was measured in subsurface soil and rock moisture (Webster-Scholten 1994). There is no indication that Pit 9 has released any chemicals or radioisotopes to the ground water.

Elk Ravine Drainage Area

Surveillance ground water monitoring in the Elk Ravine drainage area included analyses of samples from the wells listed below. Detailed analyses on ground water samples from the Elk Ravine drainage area surveillance monitoring wells during 1995 are given in Volume 2, Tables 8-17 through 8-26.

Well K7-07

Well K7-07 was dry during the first quarter of 1995. Analyses conducted on ground water samples for the remaining three quarters show a few detections of metals, but they are far below MCLs. No HE compounds or toxic organic compounds were detected. Fourth quarter gross alpha was 0.94 Bq/L, above the 0.56 Bq/L MCL for drinking water. This relatively elevated alpha measurement may be related to a small plume of uranium-bearing water located immediately to the north and northwest of well K7-07 in the direction of the Pit 7 Complex (Taffet et al. 1996).

Wells NC7-61 and NC7-69

Analyses detected a few metals far below MCLs. No HE compounds or toxic organic compounds were detected in either well above reporting limits.

Of the radioactivity and radioisotope measurements, Well NC7-61 samples showed elevated tritium. The mean of the four quarterly tritium measurements is 6975 Bq/L. The mean activity is about 9 times the 740 Bq/L drinking water MCL for tritium. The mean is down 7.7% from the 1994 mean of 7560 Bq/L. The decay of tritium (which has a half-life of 12.3 years) accounts for 5.5% of this decrease. The remaining 2.2% decrease is most likely due to the diffusion of tritiated water (HTO) molecules as the tritium-bearing water moves downgradient. The HTO in the Neroly lower blue sandstone at the location of Well NC7-61 comes from three sources; Pit 3, Pit 5, and the firing table at Building 850 (Webster-Scholten 1994; Taffet et al. 1996). As in previous years, HTO in the underlying Cierbo Formation was very low, less than 0.1 Bq/L, as measured in Well NC7-69 ground water samples. The marked difference in tritium activity between ground water samples from these two wells shows that the tritium-bearing water plume remains confined to the Neroly lower blue sandstone in this area.

Wells K2-04D, K2-04S, and K2-01C

Analyses detected a few metals far below MCLs. No HE compounds or toxic organic compounds were detected in these wells above reporting limits.

One gross alpha measurement of 0.85 Bq/L in a ground water sample obtained May 16 from Barcad K2-01C exceeded the 0.56 Bq/L drinking water MCL. Uranium isotope measurements were made by alpha and mass spectroscopy on duplicate ground water samples obtained from this well on March 28. The alpha spectroscopy result for total uranium activity was 0.94 Bq/L. The mass spectroscopy result was 0.69 Bq/L for total uranium activity. Although the alpha

activity in ground water samples from this well can thus be attributed to dissolved uranium, alpha and mass spectroscopy gave different results with regard to the mix of uranium isotopes present. Alpha spectroscopy indicated natural uranium, based on an activity ratio of ^{234}U to ^{238}U of 1.22. Mass spectroscopy suggested that a small amount of D-38 (3%) could be mixed with 97% natural uranium, based on a mass ratio of ^{235}U to ^{238}U of 0.00685.

Elevated tritium activity relative to background was measured in all three wells. The average tritium activity in Well K2-04D was 540 Bq/L; in Well K2-04S, 1227 Bq/L; and Well K2-01C, 227 Bq/L. These wells are located within a plume of tritium-bearing ground water in the Neroly lower blue sandstone that extends beneath Doall Ravine to Elk Ravine and Pit 1. The source of the plume is the firing table at Building 850 in the West Firing Area (Webster-Scholten 1994; Taffet et al. 1996).

Wells NC2-11D and NC2-12D

Arsenic, selenium, and vanadium were detected in samples taken from these two wells. These elements occur naturally in the sediments and sedimentary rocks at Site 300. Both gross alpha and gross beta activity measurements were below drinking water MCLs. Tritium was elevated relative to background in the samples from these wells. These wells are located near the leading edge of the plume of tritium-bearing ground water that is moving slowly northeast in the Neroly Formation beneath Elk Ravine (Webster-Scholten 1994; Taffet et al. 1996).

812CRK

Arsenic, barium, selenium, and vanadium were detected below MCLs in samples from this spring in the Elk Ravine arroyo. No HE compounds were detected above reporting limit. One sample produced the first ever detections of PCE and TCE for this spring. However, additional sampling and analysis did not confirm the presence of these two solvents. Measurements for gross alpha, gross beta, and tritium were all low and were indistinguishable from background activities at Site 300. The spring lies beyond the influence of the tritium plume that has affected the ground water in Elk Ravine upgradient of the spring.

Well NC2-07

No organic constituents of concern were detected in the samples taken in 1995. Gross alpha and gross beta measurements were low and cannot be distinguished from background activities in the Neroly Formation. Tritium measurements

were also very low. This well is downgradient from the slowly moving plume of tritium-bearing ground water, discussed above.

Water-Supply Wells 18 and 20

COC data for the two on-site potable water supply wells are presented in Volume 2, Tables 8-27 and 8-28. No metals of concern were detected in Well 20 during 1995, except zinc at 53 ppb in the first quarter water sample. As in past years, the organic solvent TCE was detected in Well 18 near the reporting limit. TCE concentrations of 0.2 ppb, 0.4 ppb, and 0.5 ppb were measured during 1995. The highest concentration, 0.5 ppb, is 10% of the 5 ppb MCL for TCE in drinking water. (First quarter 1996 measurements have been received, and TCE in the Well 18 ground water sample was below the reporting limit of 0.2 ppb using EPA Method 502.2.) The source of the TCE in Well 18 has not been determined. The radioactivity and tritium activity in water samples from both wells were very low and indistinguishable from natural background activities.

Off-Site Supply Wells

COC data for the 12 water supply wells are presented in Volume 2, Tables 8-29 to 8-35. Some metallic and organic COCs were detected in these wells, but they were far below drinking water MCLs. Well CON1 water samples exceeded the secondary (aesthetic) drinking water MCL of 50 µg/L for manganese.

As in the past, low concentrations of trihalomethanes (THMs) were detected in water samples from the CARNRW2 well. The THMs were far below drinking water MCLs for these compounds. The THMs resulted from chlorination of the well water.

TCE was reported near the reporting limit of 0.2 µg/L in the ground water samples taken from the GALLO1 surveillance well during 1995. Four similarly low detections were measured in ground water samples from this well during 1994. The GALLO1 well is hydrologically upgradient from identified areas of TCE contamination at Site 300 . A study of the GALLO1 well is included in the Final SWRI Report (Webster-Scholten 1994). It was determined that the low concentration of TCE in the well is most likely due to a localized surface spill on the property, possibly from solvents used on a pump truck or another vehicle used to service the private well.

All radioactivity and tritium activities in ground water samples from the off-site surveillance wells were low and indistinguishable from natural background activities in the Site 300 area.

Environmental Impacts

Site 300

Compliance and surveillance monitoring at Site 300 and adjacent properties in the Altamont Hills leave little doubt that the impacts of LLNL activities are minimal on ground water beyond the site boundaries.

During 1995, tritium activities in three Pit 7 downgradient monitoring wells continued to exceed the U.S. and California drinking water MCL of 740 Bq/L. Fate and transport modeling of the tritium-bearing ground water plumes at Site 300 indicates that the tritium will rapidly disappear by radioactive decay to an activity below the MCL before it reaches a site boundary (Webster-Scholten 1994). None of the tritium-bearing ground water is used for agriculture or for consumption by animals and people; therefore, it presents no health risk.

Minor and localized on-site releases of depleted uranium to ground water have occurred in the past from the closed landfills Pit 5 and Pit 7 and from the Building 850 firing table in the West Firing Area (Taffet et al. 1996). Maximum estimated ground water uranium activities that could reach potential exposure points (hypothetical ground water supply wells) are 0.08 Bq/L at the northern boundary of Site 300 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 activities are 10% or less of 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 ground water supply wells on the Site 300 boundary (Taffet et al. 1996).

Ground water data from Pit 1 indicate that the RCRA-closed landfill did not release any potential contaminants to the ground water during 1995.

9. Livermore Ground Water Protection Management Program

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Introduction

LLNL's Ground Water Protection Management Program (GWPMP) is a multifaceted effort to eliminate or minimize adverse impacts of LLNL operations on ground water. U.S. Department of Energy (DOE) Order 5400.1 and the soon-to-be promulgated 10 CFR 834 require all DOE facilities to prepare a GWPMP that describes the site's ground water regime, describes programs to monitor the ground water and monitor and control potential sources of ground water contamination, and describes areas of known contamination and remediation activities. Much of the ground water monitoring and remediation at the Livermore site is carried out under Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) restoration efforts. That monitoring and remediation is fully described in documents issued by the Livermore Site Ground Water Project (see Appendix A) and is summarized in Chapters 2 and 14 of this document. This chapter describes the site's ground water regime, programs to monitor the ground water and to monitor potential sources of ground water contamination, and programs to control potential sources of contamination.

Ground Water Regime

The ground water regime at the Livermore site is described in the following sections.

Livermore Site

Physiographic Setting

The Livermore Valley, which is the most prominent valley within the Diablo Range, is an east-west trending structural and topographic trough 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 with an average thickness of about 100 m. The valley is approximately 25 km long and averages 11 km in width. The valley floor is 220 m at its highest elevation along the eastern margin and gradually dips to 92 m at the southwest corner. The major streams dissecting the Livermore Valley are Arroyo del Valle and Arroyo Mocho, which drain the southern highlands and flow naturally only during the rainy season. Arroyo Mocho now flows the entire year because of water supplied by Zone 7.

Livermore Valley Ground Water Basin

The Livermore Valley Ground Water Basin lies within the Diablo Range, which reaches a maximum elevation of 1160 m above sea level in the tributary watershed. Including the uplands and valley floor, the ground water basin encompasses 17,000 hectares. The prominent streams, all of which are ephemeral, include Arroyo del Valle, Arroyo Las Positas, Arroyo Seco, Arroyo Mocho, Alamo Creek, South San Ramon Creek, and Tassajara Creek. Arroyo del Valle and Arroyo Mocho drain the largest areas and are the largest streams. These streams all flow toward the valley floor and then westward until they converge at Arroyo de la Laguna, which flows southward out of the valley into the Sunol Valley Ground Water Basin.

The Livermore Valley ground water system can be described as a sequence of semiconfined aquifers. Ground water moves downslope from the perimeter (the valley uplands) toward the longitudinal axis of the valley. It then flows in a generally westward direction toward the southwest portion of the basin. From this point, the ground water flows south into the Sunol Valley Ground Water Basin. However, since 1945, heavy draft from the area has eliminated any subsurface outflow from the Livermore Valley Ground Water Basin.

The Livermore Formation, with an average thickness of about 1000 m and an area of approximately 250 km^3, has an available storage capacity significantly greater than that of the overlying alluvium, which averages only about one-tenth the thickness. However, the alluvium is considerably more permeable and is, therefore, the principal water-producing formation for most of the valley (San Francisco RWQCB 1982). The largest quantities of ground water are produced in the central and western portions of the Livermore Valley, where the valley fill is thickest.

The quality of ground water in the Livermore Valley Ground Water Basin is generally a reflection of the surface water that recharges the aquifers. The chemical character ranges from an excellent quality sodium, magnesium, or calcium bicarbonate to a poor quality sodium chloride water. In the eastern part of the valley, the poor quality sodium chloride ground water is indicative of the recharge waters from Altamont Creek, which drains the marine sediments to the east of the valley. High concentrations of naturally occurring dissolved minerals, especially boron, in the eastern part of the valley render the ground water unsuitable for irrigation purposes. Infiltration of wastewater or fertilizers applied to crop lands causes locally elevated levels of nitrates (San Francisco Bay RWQCB 1982). Areas with rapid infiltration rates are limited to the larger stream courses of Arroyo del Valle, Arroyo Mocho, and, to a lesser extent, Arroyo Las Positas.

Surface Drainage

The natural drainage at the Livermore site was altered by construction activities several times up to 1966 (Thorpe et al. 1990) so that the current northwest flow of Arroyo Seco and the north-then-west 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. An abandoned stream channel is visible on air-photo maps of the site east of the present alignment of Arroyo Seco (Carpenter et al. 1984). A Drainage Retention Basin for storm water diversion and flood control was excavated and constructed to the north and west of Building 551 and collects surface water runoff from the site and a portion of the Arroyo Las Positas drainage. This basin was lined in 1990 to prevent infiltration in this area. The gentle 0.5°-to-1° northwest slope of the ground surface (not composed of drainage ways) suggests Holocene deposition by streams flowing northwest from the south and east. Actual ground elevations range from 170 to 200 m above mean sea level.

Hydrogeology

Sediment types at the Livermore site can be grouped into four categories, based on dominant particle size by volume: clay, silt, sand, and gravel. The hydro-stratigraphic units of concern at the site are part of the Quaternary alluvial deposits of the upper Livermore member of the Livermore Formation. These strata comprise the upper section of strata at the site and vary from approximately 60 m thick on the eastern part of the site to 120 m thick to the west. Ground water flow is primarily in sand and gravel lenses and channels, bounded by the less permeable clays and silts.

Based on borehole lithologic data, a series of buried sand and gravel-filled stream channels have been identified at the site. The sand and gravel deposits, which are highly permeable, are present in narrow bands at the site and are interpreted as braided stream deposits, similar to strata deposited by the present day Arroyo Mocho. Sand and gravel deposits do not exceed about 30% of the section anywhere at the Livermore site.

The permeable sediments of the Upper Livermore Formation at the Livermore site are vertically separated by the horizontally extensive, low-permeability silt and clay of the Lower Member of the Livermore Formation, which comprise a regional confining layer.

The depth to ground water ranges from over 40 m (130 feet) in the southeast corner of the site to 10 m (33 feet) in the northwest and 12 m (40 feet) in the

northeast corners (Thorpe et al. 1990). Ground water levels respond to climate and resource use. Decreases in ground water use from the 1960s to 1985 caused the water table to rise. Heavy rains caused rises in 1986, 1993, 1994, and, 1995, and droughts caused declines in 1987 through 1991.

Ground water recharge at the Livermore site primarily consists of controlled releases from the South Bay Aqueduct and direct rainfall. Recharge enters primarily through the arroyos and, until its lining in 1990, the Drainage Retention Basin.

Ground water flow at the Livermore site is generally westward with a southerly component. The gradient is steepest near the northeast (about 0.15 m / m) and southeast corners of the site and decreases to about 0.002 m / m west of the site. The downward vertical gradient at the Livermore site ranges from 0.25 m / m on the east side to 0.3 m / m on the west side.

The site hydrogeology is discussed in detail in the *CERCLA Remedial Investigation Report for the LLNL Livermore Site* (Thorpe et al. 1990) and other reports of the ongoing Ground Water Project (see also Chapter 2).

Subsurface Migration Off Site

The conceptual model presented in the CERCLA Remedial Investigation Report for the LLNL Livermore Site (Thorpe et al. 1990) suggests that ground water generally flows towards two destinations from the Livermore site forming a gap. Ground water from the north half flows west and northwest and eventually discharges to Arroyo Las Positas near First Street in Livermore, about 2 km northwest of the Livermore site. Ground water from the southern half flows generally westward toward the gap between the Mocho I and Mocho II subbasins, about 2 km west of the Livermore site. Ground water velocities at the Livermore site average about 15 to 20 m (49 to 66 feet) per year. In the area of the gap, the magnitude and direction of ground water flow is uncertain; investigations are underway to determine if ground water from the Livermore site (Mocho I subbasin) migrates westward into the Mocho II subbasin, where several City of Livermore water supply wells are located.

Ground Water Monitoring

Distinct ground water monitoring programs are in place at the Livermore site and in the surrounding area; their purposes constitute their primary differences. One is to determine impacts from current and ongoing activities (surveillance monitoring); another is to determine if there is contamination from past practices and to remediate it (CERCLA-related monitoring). The CERCLA-related monitoring is summarized in Chapters 2 and 14 of this document and results are presented in detail elsewhere

Surveillance Ground Water Monitoring

Surveillance Monitoring of On-Site LLNL Monitor Wells

LLNL designed a ground water surveillance monitoring network that was implemented in 1995 to determine impacts to the ground water from current and ongoing activities.

Rationale and Design Criteria

DOE Order 5400.1 states that "Groundwater that is or could be affected by DOE activities shall be monitored to determine and document the effects of operations on groundwater quality and quantity and to demonstrate compliance with DOE requirements and applicable federal, state, and local laws and regulations... A groundwater monitoring plan shall be developed as a specific element of all environmental plans... Ground water monitoring programs shall be conducted on site and in the vicinity of DOE facilities to:

(1) Obtain data for the purpose of determining baseline conditions of groundwater quality and quantity;

(2) Demonstrate compliance with and implementation of all applicable regulations and DOE Orders;

(3) Provide data to permit the early detection of groundwater pollution or contamination;

(4) Provide a reporting mechanism for detected groundwater pollution or contamination;

(5) Identify existing and potential groundwater contamination sources and to maintain surveillance of these sources;

(6) Provide data upon which decisions can be made concerning land disposal practices and the management and protection of groundwater resources.

Site-specific characteristics shall determine monitoring needs. Where appropriate, monitoring programs shall be designed and implemented in accordance with 40 CFR Part 264, Subpart F, or 40 CFR Part 265, Subpart F. Monitoring for radionuclides shall be in accordance with DOE orders in the 5400 series dealing with radiation protection of the public and the environment." Title 40 of the Code of Federal Regulations (CFR) specifies the substantive requirements of the Resource Conservation and Recovery Act (RCRA); Subpart F addresses ground water monitoring requirements for existing RCRA facilities.

Surveillance ground water monitoring results are presented in a later section of this chapter.

Ground Water Remediation

The CERCLA ground water remediation efforts are summarized in Chapters 2 and 14 of this document and are presented in detail elsewhere in CERCLA documents.

Areas of Special Concern

Several areas of special concern for ground water protection have been identified at LLNL.

The objectives of the GWPMP include monitoring the impact of current operations and eliminating or minimizing adverse impacts from ongoing operations on ground water. The basic approach is to be able to detect contaminants before they can enter the ground water. To do this, areas have been identified that are contaminated or potentially contaminated with hazardous and/or radioactive waste, focusing on four areas:

- Geologic areas with rapid communication between surface water and ground water.
- Current processes and operations that could contaminate these high-risk areas.
- Current and planned Best Management Practices (BMPs) that minimize this risk.
- Current and new monitoring to provide early warning of potential ground water contamination.

With these considerations, five areas have been identified as being at risk for ground water contamination:

- The arroyos (Arroyo Las Positas and Arroyo Seco) that cross the site.
- The storm drain system.
- Soil around underground storage tanks.
- Soil around the sanitary sewer.
- The ground water beneath the hazardous waste management (HWM) buildings, B514 and B612 that may be subject to spills.

Source Control Strategies

Soil and Sediment Surveillance Monitoring

Soil monitoring in the arroyos and storm water network was one of the items targeted in the GWPMP surveillance monitoring because "..recharge of natural runoff through the stream beds of arroyos accounts for the majority (about 42%) of resupply to the Livermore Valley ground water basin..." (Webster-Scholten 1990). Infiltrating rain water may carry with it any dissolved constituents that may be present. Programs already exist that address the sanitary sewer system, the building drains, and underground storage tanks (see Chapter 2).

LLNL has developed background levels for total metals in soils and sediments and de minimis (or designated) concentration levels for soluble metals and organics based on Jon Marshack's staff report, *The Designated Level Methodology for Waste Classification and Clean-up Level Determination* (Marshack 1991). This designated level methodology determines what soluble levels of contaminants would not adversely impact ground water beyond its beneficial uses by application of a simple attenuation factor and specific water quality objectives. The attenuation factor agreed upon with the San Francisco Bay Regional Water Quality Control Board (RWQCB) is 100 except for certain metals; the attenuation factor is 1000 for copper, lead and zinc. Any constituents with soluble concentrations above these de minimis levels may adversely impact the ground water beneath. We are in the process of negotiating the appropriate water quality objectives with the San Francisco Bay RWQCB.

In 1996, shallow vadose zones in the arroyos will be sampled at three influent locations (ALPE, ASS2, and GRNE) and the two effluent locations (ASW and WPDC) corresponding to storm water sampling locations. In addition, sediment samples will be collected from settling basins upstream of the Drainage Retention Basin. Samples are to be collected and analyzed for both total and soluble metals (using California's Waste Extraction Test) and for leachable organics (using EPA's Toxicity Characteristic Leaching Potential test); samples may also be analyzed for leachable organic compounds. Furthermore, storm drain system sampling locations will be selected based on available historical information (Gallegos 1994). For a description of methods and a discussion of 1995 arroyo sediment sampling radiological results, see Chapter 10.

LLNL has designed a surveillance monitoring program to detect possible releases from the mixed-waste storage areas, Buildings 514 and 612, in the southeastern portion of LLNL (**Figure 9-1**). Monitoring of the vadose zone is not feasible in this area because most of the area is paved. Therefore, existing ground water wells were chosen for surveillance monitoring. This program consists of four upgradient and four downgradient monitoring wells and was implemented in 1995; these wells were chosen to monitor the uppermost aquifers

within that area. The four wells upgradient of the mixed-waste storage areas include monitoring wells W-017 and W-117 screened in Hydrostratigraphic Unit number 6 (HSU-6), and monitoring wells W-107 and W-268 screened in HSU-5. The monitoring wells downgradient of Building 514 and Building 612 are W-217, W-270, W-359, and W-622; all of these wells are screened within HSU-5. Although no such requirements have been imposed upon the LLNL site, the siting of these wells would satisfy any RCRA monitoring or any California Code of Regulations Title 22 monitoring requirements.

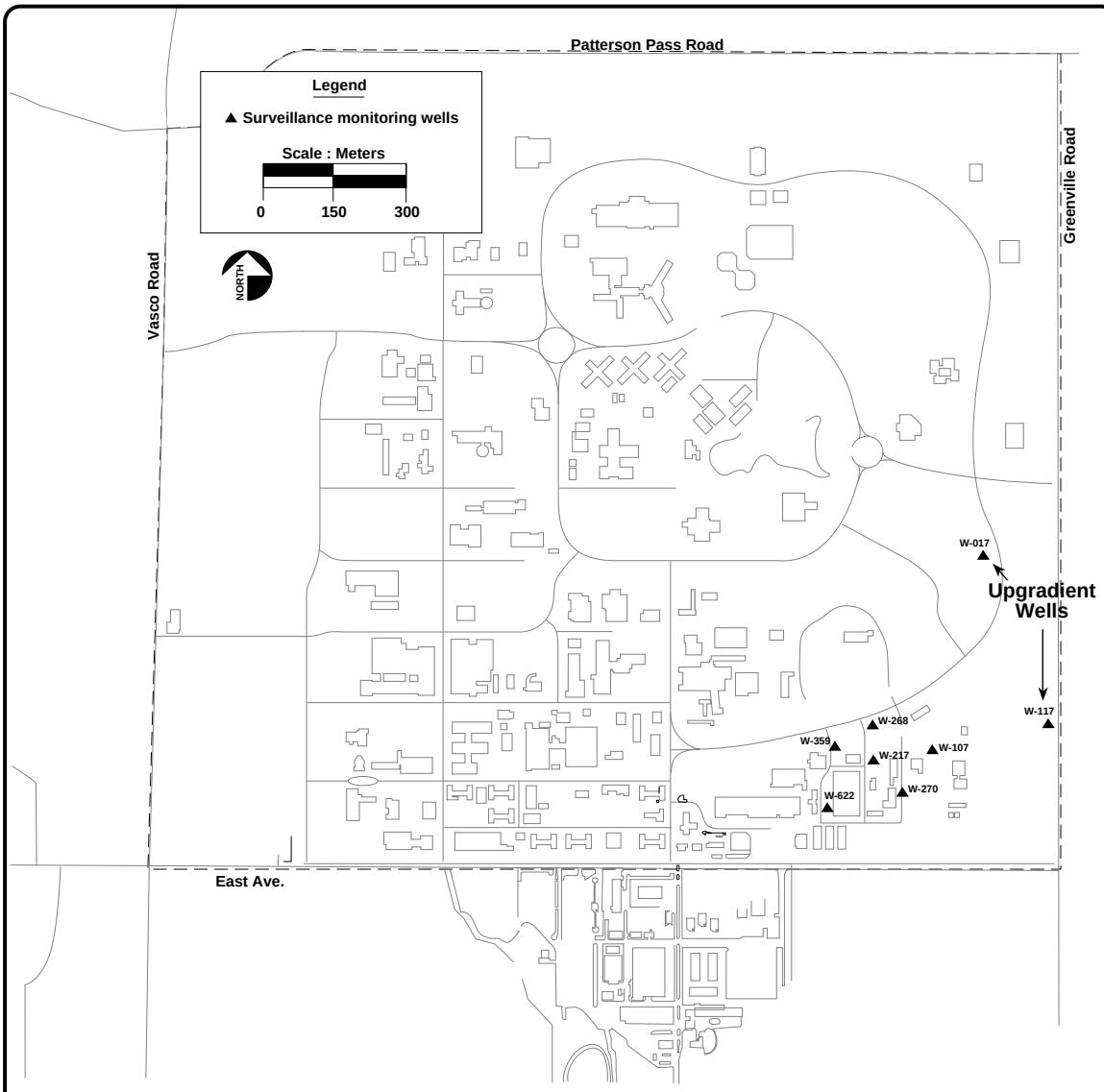

Figure 9-1. Surveillance monitoring wells in the southeastern portion of the Livermore site.

Surveillance Monitoring of On-Site LLNL Wells

Table 9-1 shows the analytes and the quarterly monitoring schedule that was chosen for these eight wells. This quarterly monitoring satisfies requirements delineated in 40 CFR Subpart F for ground water monitoring, although it is not required as a permit condition.

Table 9-1. Analyte list for surveillance monitoring wells, 1995.[a]

Analytes	EPA methods
Beryllium	210.2
Chromium (VI)	218.4
Metals by GFAA[b]	204.2, 206.2, 213.2, 239.2, 270.2, 279.2
Metals by ICP[c]	200.7
General minerals	150.1, 160.1, 200.7, 300.0, 310.2
Total cyanide	335.2
Ethylene dibromide	504
Volatile organic compounds (VOCs)	601
Semivolatiles, including PAHs[d]	625
Pesticides and herbicides	608/615
Radiological parameters	Various HASL-300 Series methods

a Surveillance monitoring wells were sampled and analyzed on a quarterly basis. This schedule was followed for 1995.

b Graphite furnace atomic absorption spectroscopy.

c Inductively coupled plasma emission spectroscopy.

d Polynuclear aromatic hydrocarbons.

Table 9-2 demonstrates the Water Quality Objectives (WQOs) that are being met by the reporting limits used for the organic analytes in this monitoring network; **Table 9-3** gives the detection limits by analyte for each of the organic analytes listed, except for ethylene dibromide. **Table 9-4** gives the WQOs for the inorganic analytes; **Table 9-5** gives the WQOs, including DOE guidelines, for radionuclides in water.

Table 9-2. Water quality objectives for organic compounds.

Analytes	EPA method	Detection limits[a] (μg/L)	CA or Federal MCLs[b] (μg/L)	One-in-a-million cancer risk[b] (μg/L)	Sampling schedule
VOCs	601	0.5	0.5+	0.015+	Quarterly
Ethylene dibromide	504	0.01	0.05	0.0004–0.055	Quarterly
Chlorinated pesticides	608	0.03–10	0.01+	0.002+	Quarterly
Chlorinated herbicides	615	0.03–10	7+	NA	Quarterly
Semivolatiles	625	10–50	0.2+	0.002+	Quarterly

[a] Detection limit of 10 μg/L for benzo(a)pyrene, the known carcinogenic polynuclear aromatic compound.

[b] + = or greater (e.g., MCLs for most VOCs are greater than 0.5 μg/L).

Surveillance Monitoring Results

This section presents the surveillance monitoring results for the eight LLNL on-site monitoring wells and for the 21 downgradient wells monitored annually for tritium, at various distances from LLNL.

Livermore Site

All surveillance monitoring analytical results are presented in Volume 2, Chapter 9 of this document. These first-year monitoring efforts are used to establish baseline conditions for future monitoring, as well as to establish if any radioactive materials in the ground water are present at levels of concern to public health or to the environment. These monitoring results are separated into the four upgradient wells and the four downgradient wells.

The volatile organic compounds (VOCs) that were detected are the same ones that are now being remediated under CERCLA, according to the *Record of Decision for Lawrence Livermore National Laboratory Site* (ROD) (Ziagos 1992) that was agreed upon for the Livermore site. Details of this cleanup effort are discussed in the CERCLA documents including the *LLNL Ground Water Project 1995 Annual Report* (Hoffman et al. 1996). Complete data tables of these detections are found in Volume 2, Chapter 9. No ethylene dibromide, chlorinated herbicides, or chlorinated pesticides were detected in this surveillance monitoring.

Table 9-3. List of ground water analyses showing EPA method, organic constituent, and typical reporting limit (a statistically determined concentration limit, above which detection is certain).

Constituent	Reporting limit (μg/L)
EPA Method 601	
1,1,1-Trichloroethane	0.5
1,1,2,2-Tetrachloroethane	0.5
1,1,2-Trichloroethane	0.5
1,1-Dichloroethane	0.5
1,1-Dichloroethene	0.5
1,2-Dichlorobenzene	0.5
1,2-Dichloroethane	0.5
1,2-Dichloroethene (total)	0.5
1,2-Dichloropropane	0.5
1,3-Dichlorobenzene	0.5
1,4-Dichlorobenzene	0.5
2-Chloroethylvinylether	0.5
Bromodichloromethane	0.5
Bromoform	0.5
Bromomethane	0.5
Carbon tetrachloride	0.5
Chlorobenzene	0.5
Chloroethane	0.5
Chloroform	0.5
Chloromethane	0.5
cis-1,3-Dichloropropene	0.5
Dibromochloromethane	0.5
Dichlorodifluoromethane	0.5
Freon-113	0.5
Methylene chloride	0.5
Tetrachloroethene	0.5
trans-1,3-Dichloropropene	0.5
Trichloroethene	0.5
Trichlorofluoromethane	0.5
Vinyl chloride	0.5
1,2-Dichlorobenzene	0.5

Constituent	Reporting limit (μg/L)
EPA Method 602	
1,3-Dichlorobenzene	0.3
1,4-Dichlorobenzene	0.3
Benzene	0.4
Chlorobenzene	0.3
Ethylbenzene	0.3
m- and p-Xylene isomers	0.4
o-Xylene	0.4
Toluene	0.3
Total xylene isomers	0.4
EPA Method 608	
Aldrin	0.05
BHC, alpha isomer	0.05
BHC, beta isomer	0.05
BHC, delta isomer	0.05
BHC, gamma isomer (Lindane)	0.05
Chlordane	0.5
Dieldrin	0.1
Endosulfan I	0.05
Endosulfan II	0.1
Endosulfan sulfate	0.1
Endrin	0.1
Endrin aldehyde	0.1
Heptachlor	0.05
Heptachlor epoxide	0.05
Methoxychlor	0.5
4,4'-DDD	0.1
4,4'-DDE	0.1
4,4'-DDT	0.1
Toxaphene	1

Table 9-3. List of ground water analyses showing EPA method, organic constituent, and typical reporting limit (a statistically determined concentration limit, above which detection is certain) (continued).

Constituent	Reporting limit (μg/L)
EPA Method 615	
2,4,5-T	0.5
2,4,5-TP (Silvex)	0.2
2,4-D	1
2,4-Dichlorophenoxy acetic acid	2
Dalapon	2
Dicamba	1
Dichloroprop	2
Dinoseb	1
MCPA	250
MCPP	250
EPA Method 625	
1,2,4-Trichlorobenzene	10
1,2-Dichlorobenzene	10
1,3-Dichlorobenzene	10
1,4-Dichlorobenzene	10
2,4,5-Trichlorophenol	10
2,4,6-Trichlorophenol	10
2,4-Dichlorophenol	10
2,4-Dimethylphenol	10
2,4-Dinitrophenol	50
2,4-Dinitrotoluene	10
2,6-Dinitrotoluene	10
2-Chloronaphthalene	10
2-Chlorophenol	10
2-Methylphenol	10
2-Methyl-4,6-dinitrophenol	50
2-Methylnaphthalene	10
2-Nitroaniline	50
2-Nitrophenol	10

Constituent	Reporting limit (μg/L)
EPA Method 625 (continued)	
3,3'-Dichlorobenzidine	20
3-Nitroaniline	50
4-Bromophenylphenylether	10
4-Chloro-3-methylphenol	20
4-Chloroaniline	20
4-Chlorophenylphenylether	10
4-Nitroaniline	50
4-Nitrophenol	50
Acenaphthene	10
Acenaphthylene	10
Anthracene	10
Benzo(a)anthracene	10
Benzo(a)pyrene	10
Benzo(b)fluoranthene	10
Benzo(g,h,i)perylene	10
Benzo(k)fluoranthene	10
Benzoic acid	50
Benzyl alcohol	20
Bis(2-chloroethoxy)methane	10
Bis(2-chloroisopropyl)ether	10
Bis(2-ethylhexyl)phthalate	10
Butylbenzylphthalate	10
Chrysene	10
Di-n-butylphthalate	10
Di-n-octylphthalate	10
Dibenzo(a,h)anthracene	10
Dibenzofuran	10
Diethylphthalate	10
Dimethylphthalate	10
Fluoranthene	10
Fluorene	10
Hexachlorobenzene	10

Table 9-3. List of ground water analyses showing EPA Method, organic constituent, and typical reporting limit (a statistically determined concentration limit, above which detection is certain) (concluded).

Constituent	Reporting limit (μg/L)
Hexachlorobutadiene	10
Hexachlorocyclopentadiene	10
Hexachloroethane	10
Indeno(1,2,3-c,d)pyrene	10
Isophorone	10
m- and p-Cresol	10
N-Nitrosodi-n-propylamine	10

Constituent	Reporting limit (μg/L)
N-Nitrosodiphenylamine	10
Naphthalene	10
Nitrobenzene	10
Pentachlorophenol	50
Phenanthrene	10
Phenol	10
Pyrene	10

Summary **Tables 9-6** and **9-7** present the summary analytical results for inorganics data for the upgradient wells and the downgradient wells, respectively. Note that the General Indicator Parameters of specific conductance and total dissolved solids are higher in the downgradient wells, especially well W-217, than in the upgradient or background wells. Likewise, particular elements and anions such as barium, chlorides, and nitrates are higher in the downgradient wells as a whole, and Well W-217 in particular, than in the background wells. In March 1995, the nitrates in Well W-217 were analyzed at 46 mg/L, which very slightly exceeds the drinking water MCL of 45 mg/L, but concentrations of nitrates in that well dropped down below the MCL for the remainder of the year. Trends of concentrations of chlorides and nitrates in ground water will be tracked in future years and attempts will be made to discover if a continuing on-site source of these anions exists.

Tables 9-8 and **9-9** present the corresponding summary analytical results for the radiological data. The only obvious trend from the summary data is that activities of tritium are somewhat higher in the downgradient wells, although still found in activities of less than 5% of the drinking water MCL (740 Bq/L, or 20,000 pCi/L) for tritium. Activities for uranium are somewhat higher in the background wells than in the downgradient wells.

This surveillance monitoring program will be reevaluated on an ongoing basis to identify areas of potential concern that may warrant further monitoring (see Chapter 11 and the *Environmental Monitoring Plan*, Tate et al. 1995, for further details).

Table 9-4. Water quality objectives for inorganic compounds.

Inorganic:	EPA method	Reporting limits (mg/L)	CA or Federal MCL[a] (mg/L)	SFRWQCB[b] basin plan WQOs[c] (mg/L)	EPA health advisory (mg/L)
Aluminum	200.7	0.2	1	5/20	NA
Antimony	204.2	0.005-0.01	0.006	0.006	0.003
Arsenic	206.2	0.002	0.05	0.05	0.00002
Barium	200.7	0.025	1	1	2
Beryllium	210.2	0.0005	0.004	0.004	0.000008
Boron	200.7	0.1	NA	0.5/2	0.6
Cadmium	213.2	0.0005	0.005	0.005	0.005
Chloride	325.3	5	250[d]	250	NA
Chromium(VI)	218.4, 218.5	0.01	0.05	0.05	0.1
Copper	200.7, 220.2	0.001-0.05	1[d]	1	NA
Cyanide	335.2	0.02	0.2	0.2	0.2
Fluoride	340.2	0.05	1.4-2.4	0.8/1.7	NA
Iron	200.7	0.1	0.3[d]	0.3	NA
Lead	239.2	0.002	0.015[e]	5/10	NA
Manganese	200.7	0.03	0.05[e]	0.05	NA
Mercury	245.1	0.0002	0.002	0.002	0.002
Molybdenum	246.1	0.05	NA	0.01/0.05	0.035
Nickel	249.2	0.005	0.1	0.1	0.1
Nitrate, as NO_3	353.2	0.5	45	45	45
Nitrite, as N	300.0	0.5	1	1	1
pH (units)	9040	0.1	6.5-8.5[d]	6.5	NA
Selenium	270.2	0.002	0.05	0.05	NA
Silver	272.2	0.01	0.1	0.05	0.1
Specific conductance (µmhos/cm)	120.1	200	900[d]	900	NA
Sulfate	375.4	1	250[d]	250	NA
Total dissolved solids (TDS)	160.1	1	500[d]	500	NA
Thallium	279.2	0.001-0.005	0.002	0.002	0.0004
Vanadium	200.7	0.025	NA	0.1/1	NA
Zinc	200.7	0.01	5[d]	5.0	2

[a] Maximum contaminant level, as listed in U.S. Environmental Protection Agency (USEPA) Region IX *Drinking Water Standards and Health Advisories Table*, dated December 1995.

[b] San Francisco Bay Regional Water Quality Control Board.

[c] Water quality objectives.

[d] USEPA Secondary MCL.

[e] USEPA action level for lead.

Table 9-5. Water quality objectives for radioactive compounds.

Radionuclide	Analytical method	Minimum detectable activity (Bq/L)	CA or Federal MCL (Bq/L)	SFRWQCB basin plan WQOs (Bq/L)	DOE's derived concentration guidelines (DCGs; in Bq/L)	EPA health advisory (Bq/L)
Gross alpha (excluding uranium and radon)	EPA 906	0.04–0.14	0.56	0.56	NA	0.0056
Gross beta	EPA 906	0.09–0.1	1.85	1.85	NA	0.4 μSv (0.04 mrem)/y
^{238}Pu	HASL-300 Series[a]	0.0001	NA	NA	1.11	NA
$^{238, 240}$Pu	HASL-300 Series	0.0001	NA	NA	1.11	NA
^{226}Ra	HASL-300 Series	0.004	0.185[b]	0.185[b]	3.7	0.0074
^{228}Th	HASL-300 Series	0.0004	NA	NA	15	NA
^{232}Th	HASL-300 Series	0.0004	NA	NA	1.85	NA
^{3}H	EMSL-LV-0539-17	1.6–1.8	740	740	74,000	NA
^{234}U	HASL-300 Series	0.0005	0.74[c]	0.74[c]	18.5	0.7 μg/L (total uranium)
^{235}U	HASL-300 Series	0.0005	0.74[c]	0.74[c]	22	0.7 μg/L (total uranium)
^{238}U	HASL-300 Series	0.0005	0.74[c]	0.74[c]	22	0.7 μg/L (total uranium)

a The HASL-300 series contains the procedures used by DOE's Environmental Measurements Laboratory.

b For both radium 226 and radium 228.

c Isotopes of uranium are undifferentiated by the USEPA guidance documents.

Surveillance Monitoring of Off-Site Livermore Valley Wells:

In order to protect downgradient users of ground water, LLNL has been monitoring tritium in wells hydraulically downgradient of LLNL since 1988. Off-site well locations are shown in **Figure 9-2**. Rain and storm water runoff in the Livermore Valley recharges local aquifers. Rain and runoff contain small amounts of tritium from natural sources, from past atmospheric nuclear weapons tests, and from atmospheric emissions from LLNL and SNL/California (see Chapter 4 on Air Monitoring for further discussion on air emissions).

Table 9-6. Analytical results (1995) for general indicators, metals, and minerals for upgradient monitor wells W-017, W-107, W-117, and W-268.

	Median	IQR[a]	Minimum	Maximum
General indicators				
pH (units)	7.40	0.5	7.20	9.70
Specific conductance (µmhos/cm)	700	165	49	990
Total dissolved solids (mg/L)	426	108	240	671
Metals and minerals (mg/L)				
Bicarbonate alkalinity (as $CaCO_3$)	165	30	10	340
Total alkalinity (as $CaCO_3$)	165	30	110	360
Barium	0.200	0.03	0.120	0.520
Boron	0.240	0.165	0.100	0.610
Calcium	48	32.2	8.2	82
Chloride	115	65	76	190
Chromium (VI)	0.012	0.004	0.010	0.032
Fluoride	0.46	0.092	0.27	0.54
Total hardness (as $CaCO_3$)	55	135	86	410
Magnesium	29	16	16	49
Nitrate (as NO_3)	11.0	5.2	0.5	16.0
Potassium	1.6	0.8	1.1	2.9
Sodium	66	8	57	76
Sulfate	26.5	21.8	6.0	54

[a] Interquartile range.

Tritium measurements of water samples collected during the summer of 1995 from 21 wells in the Livermore Valley are given in **Table 9-10**. Tritium in all well samples was very low compared to the 740 Bq/L (20,000 pCi/L) MCL established by the State of California. As in previous years, the highest tritium activity measured was from Well 11B1, located about 10 km west of LLNL. The activity in that well in 1995 was 11.4 Bq/L (309 pCi/L), a decrease of 65% from its measurement of 33.0 Bq/L (893 pCi/L) in 1988.

Table 9-7. Analytical results (1995) for general indicators, metals, and minerals for downgradient monitor wells W-217, W-270, W-359, and W-622.

	Median	IQR[a]	Minimum	Maximum
General indicator				
pH (units)	7.40	0.20	7.20	8.30
Specific conductance (μmhos/cm)	690	255	500	1100
Total dissolved solids (mg/L)	495	242	360	1100
Metals and minerals (mg/L)				
Bicarbonate alk (as $CaCO_3$)	140	32	61	190
Total alkalinity (as $CaCO_3$)	140	32	61	190
Barium	0.255	0.23	0.160	0.720
Boron	0.240	0.17	0.100	0.400
Calcium	57	13.2	48	130
Chloride	115	58	75	350
Chromium, hexavalent	0.010	0.003	0.008	0.031
Fluoride	0.29	0.068	0.22	0.38
Total hardness (as $CaCO_3$)	240	85	200	510
Magnesium	25	11	16	45
Nitrate (as NO_3)	17.0	6.8	12.0	46.0
Potassium	2.4	0..5	1.7	2.9
Sodium	56	28	35	100
Sulfate	22.5	51.8	5.2	160

[a] Interquartile range.

Table 9-8. Radiological results (1995) for upgradient monitor wells W-017, W-107, W-117, and W-268.

	MCL	Median	IQR[a]	Minimum	Maximum
General radioactivity (Bq/L)					
Gross alpha	0.56	–0.0075	0.060	–0.068	0.119
Gross beta	1.85	0.122	0.133	0.051	0.370
Radioisotopes (Bq/L)					
^{226}Ra	0.185	0.029	0.045	0.002	0.11
^{3}H	740	2.54	0.413	1.59	3.00
^{234}U	0.74	0.032	0.027	0.013	0.121
^{235}U	0.74	0.0013	0.0017	0.0002	0.0038
^{238}U	0.74	0.021	0.019	0.007	0.077

[a] Interquartile range.

Table 9-9. Radiological results (1995) for downgradient monitor wells W-217, W-270, W-359, and W-622, 1995.

	MCL	Median	IQR[a]	Minimum	Maximum
General radioactivity (Bq/L)					
Gross alpha	0.56	–0.016	0.071	–0.074	0.081
Gross beta	1.85	0.100	0.108	–0.002	0.199
Radioisotopes (Bq/L)					
^{226}Ra	0.185	0.0201	0.037	0.001	0.055
^{3}H	740	13.4	10.5	1.63	28.8
^{234}U	0.74	0.022	0.013	0.012	0.060
^{235}U	0.74	0.0008	0.0001	0.0002	0.0017
^{238}U	0.74	0.013	0.008	0.008	0.036

a Interquartile range.

The overall trend in tritium activity has been decreasing in Livermore Valley ground waters downgradient of LLNL (**Figure 9-3**). The median activities of tritium in these downgradient wells increased from 3.45 Bq/L (93.2 pCi/L) in 1988 to 4.59 Bq/L (124 pCi/L) in 1989. By summer of 1995, the median activity had dropped to 1.77 Bq/L (47.8 pCi/L).

CERCLA Remedial Actions

Livermore Site

An extensive investigation of the remediation options for the contaminated areas discussed above is summarized in the *CERCLA Feasibility Study for Lawrence Livermore National Laboratory Livermore Site* (Isherwood 1990). The *Record of Decision for Lawrence Livermore National Laboratory Livermore Site* (ROD) (Ziagos 1992) documents the remedial options selected for implementation. The selected remedies for ground water contamination involve pumping the ground water for surface treatment by a combination of ultraviolet-light hydrogen peroxide, air stripping, and granulated activated carbon. The selected remedies for contaminants in the unsaturated zone are vacuum-induced venting with surface treatment of the vapors by catalytic oxidation or activated-carbon filtration. The goal of the remedial action is to clean the ground water to the levels specified in the applicable, relevant, and appropriate requirements developed for this project and outlined in the ROD. A description of the remediation efforts during 1995 can be found in Chapters 2 and 14 of this document.

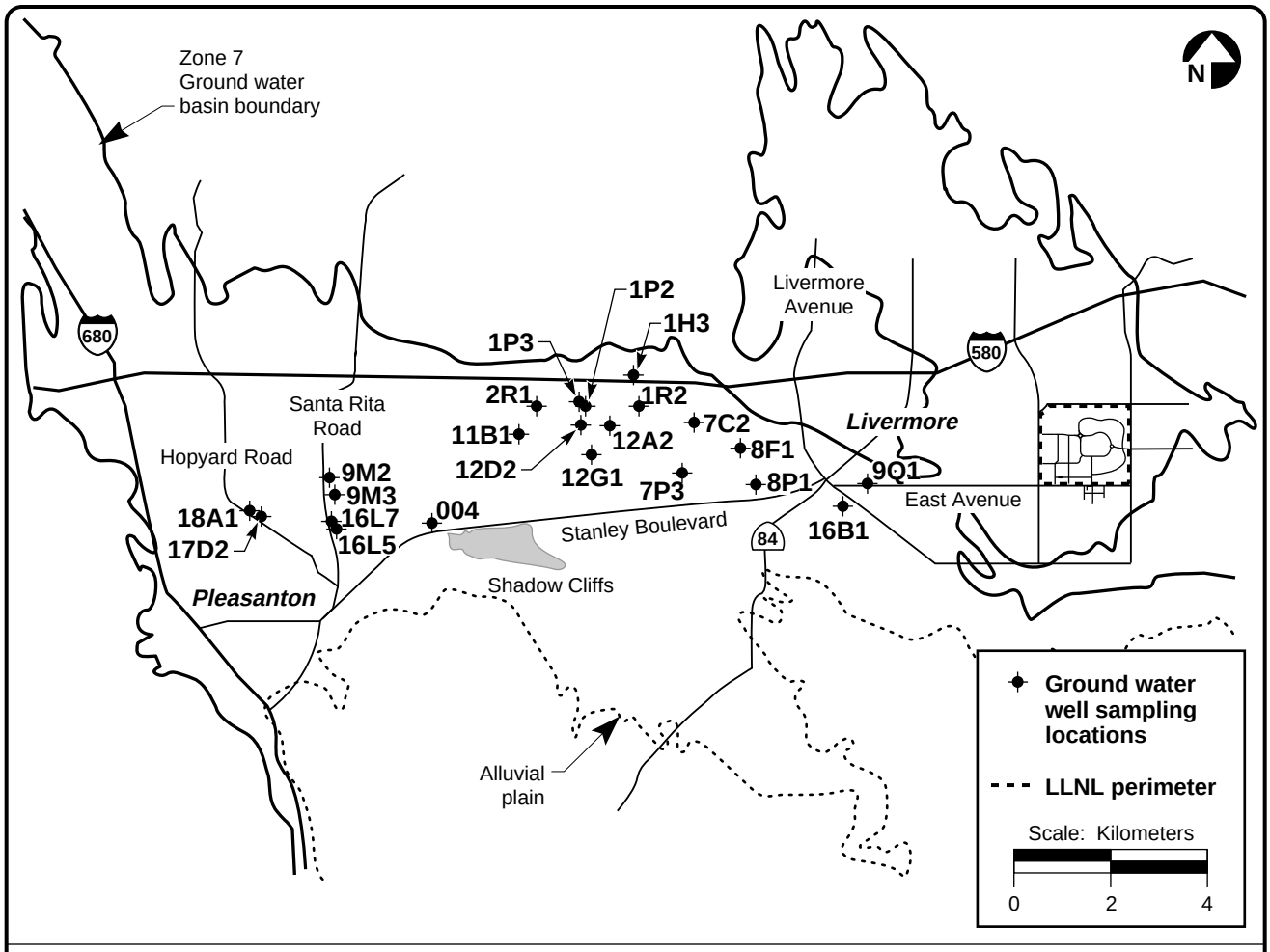

Figure 9-2. Ground water surveillance well sampling locations, Livermore Valley, 1995.

Pollution Prevention Activities

LLNL beneficially reuses excess construction soils on site if they do not pose a potential threat to beneficial uses of ground water supplies as defined by the local California RWQCB. At a CERCLA site such as LLNL, regulatory agencies usually require that the cleanup level for contaminants be background. The background level for synthetic VOCs, which are the primary contaminants at LLNL, is no contamination (zero concentration). As a result, LLNL selected an alternative method to allow reuse of soils with minimal levels of VOCs. The Designated Level Methodology (DLM), developed by Jon Marshack (Marshack 1991) of the Central Valley RWQCB has been approved for use by both the Central Valley and the San Francisco Bay RWQCB.

Table 9-10. Tritium activity in Livermore Valley wells in Bq/L, 1995.

	Bq/L
LWRP[a]	
1H3	0.54 ± 0.12
1P2	3.64 ± 0.22
1R2	1.77 ± 0.18
2R1	3.18 ± 0.23
7C2	2.84 ± 0.21
11B1	11.43 ± 0.43
12A2	2.67 ± 0.23
12D2	5.40 ± 0.30
12G1	5.22 ± 0.30
LWRP median	3.18
Livermore	
7P3	<0.1[b] ± 0.1
8F1	0.62 ± 0.72
8P1	1.27 ± 0.16
9Q1	0.69 ± 0.12
16B1	1.02 ± 0.16
Livermore median	0.86
Pleasanton	
9M2	2.70 ± 1.20
9M3	3.89 ± 1.30
004	1.39 ± 0.18
16L5	1.03 ± 0.16
16L7	0.77 ± 0.13
17D2	<1.22[b] ± 1.22
18A1	3.89 ± 1.34
Pleasanton median	1.39
Overall Statistics	
Median	2.67
Minimum	<0.1
Maximum	11.43
Interquartile range	2.74
Number of samples	19

a Livermore Water Reclamation Plant.

b Below reporting limit. Not included in statistics.

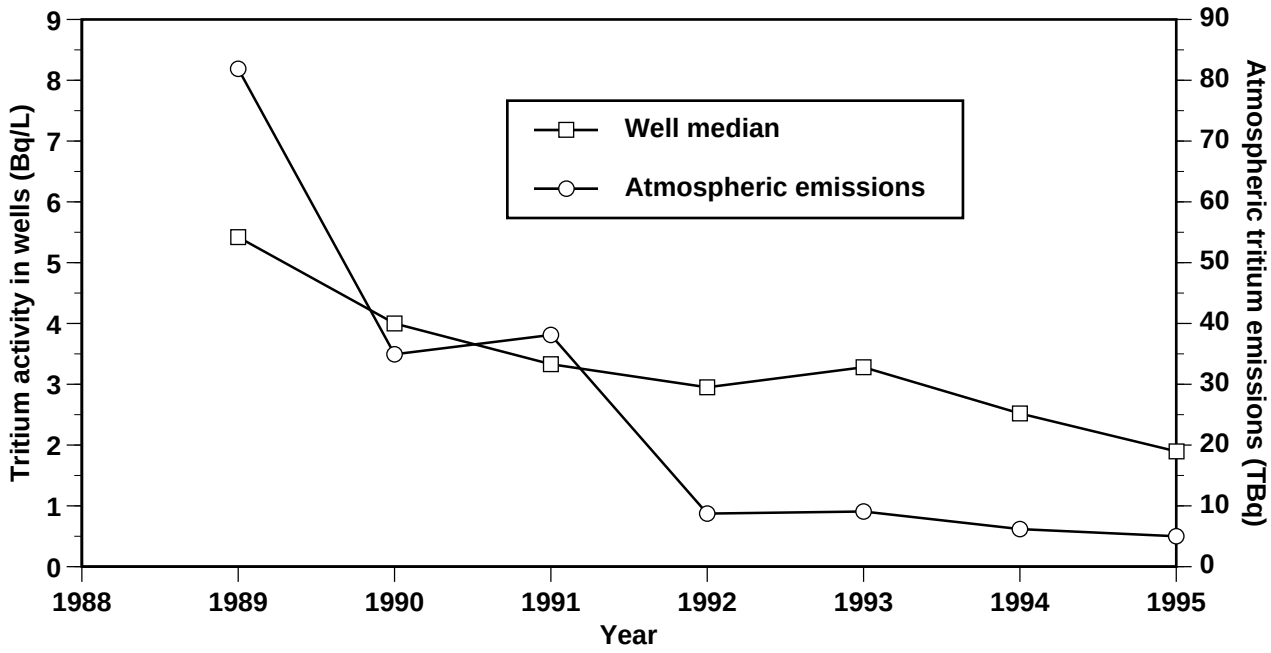

Figure 9-3. Trends of tritium in Livermore Valley wells and atmospheric emissions, 1989 to 1995.

LLNL-developed de minimis concentrations for VOC-contaminated soils based on the DLM (Isherwood 1994) were formally approved by the San Francisco Bay RWQCB for use at the Livermore site. During 1995, we also updated natural background concentrations for trace metals in soils. As an additional constraint, we also developed de minimis concentrations for soluble metals in soils using the DLM (Jackson 1995). Any soils with VOC contamination below de minimis concentrations, and with total metals below background or soluble metals less than de minimis concentrations can now be reused anywhere needed at the Livermore site. This ensures that LLNL construction activities add no unacceptable pollution to the ground water beneath the site and reduce the volume of "clean" soil shipped to landfills.

Environmental Impacts

DOE Order 5400.5 specifically establishes standards and requirements for operations of DOE and their contractors in order to protect "members of the public and the environment against undue risk from radiation." This order states that "It is the policy of DOE to provide a level of protection for persons consuming water from a public drinking water supply operated by the DOE, either directly or through a DOE contractor, that is equivalent to that provided by the public community drinking water standards, maximum contaminant levels (MCLs), of 40 CFR Part 141. These systems shall not cause persons

consuming the water to receive an effective dose equivalent greater than 0.04 mSv (4 mrem) in a year. Combined radium-226 and radium-228 activities shall not exceed 0.185 Bq/L (5 pCi/L) and gross alpha activity (including radium-226 but excluding radon and uranium) shall not exceed 0.555 Bq/L (15 pCi/L)."

Of the on-site wells, none of the inorganic data approached the primary drinking water MCLs, with the exception of nitrate. The median nitrate concentration (21.4 mg/L) for the wells downgradient of the HWM facilities was less than one-half of its MCL. Likewise, none of the radiological data approached their respective MCLs. Total uranium came the closest (27%) to its radiological MCL.

Likewise, the maximum tritium activity (11.4 Bq/L) in one of the off-site wells, Well 11B1, was about 1.5% of its MCL.

Summary

It is LLNL's policy to operate in a manner that does not adversely affect the environment. Past material-handling activities and practices have resulted in soil and ground water contamination. LLNL is working closely with local, state, and federal regulatory agencies, with input from the public, to develop and implement efficient, cost-effective ways to remediate the contamination. LLNL is also looking at its current and future operations to prevent possible negative impacts to ground water. Through ongoing plans, LLNL is working to remove sources of concern and to implement protection against accidental impacts.

10. Soil and Sediment Monitoring

Gretchen M. Gallegos
Donald H. MacQueen

Introduction

Soil is weathered material, mainly composed of disintegrated rock and organic material, that will sustain growing plants. Soil can contain pollutants originally released directly to the ground, to the air, or through liquid effluents. DOE guidance for environmental monitoring (U.S. Department of Energy 1991) 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. The guidance recommends that radionuclides specific to a particular operation or facility as well as those that occur naturally should be monitored. 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. To evaluate current conditions, LLNL samples recent sediments in storm drainage channels and the two arroyos on site. The accumulation of radioactive materials in sediment could lead to exposure of humans through ingestion of aquatic species, through sediment resuspension into drinking water supplies, or as an external radiation source (U.S. Department of Energy 1991). Note, however, that the Livermore site and Site 300 do not have habitats for aquatic species that are consumed by people, nor do they have surface drainage that directly feeds drinking water supplies. In addition, surface and subsurface sediment sampling helps support the goal of the LLNL Ground Water Protection Management Program (Chapter 9).

Since 1971, surface soil sampling in the vicinity of the Livermore site and Site 300 has been part of a continuing LLNL monitoring program designed to measure any changes in environmental levels of radioactivity and to evaluate any increase in radioactivity that might have resulted from LLNL operations. These samples have been analyzed for plutonium and gamma-emitting radionuclides, such as depleted uranium, which is used in some high-explosives tests at Site 300. The inclusion of other gamma-emitting naturally occurring nuclides (^{40}K, ^{232}Th, and ^{235}U) and the long-lived fission product ^{137}Cs provides background information and baseline data on global fallout from historical above-ground nuclear weapons testing.

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. In addition, in 1991, LLNL began analyzing surface soil samples for beryllium, a potentially toxic metal used at both the Livermore site and Site 300. However, analysis for beryllium was discontinued at the Livermore site in 1995, because beryllium was not ever measured above background values.

Location maps for soil and sediment sampling conducted during 1995 are provided in **Figures 10-1** through **10-3**. The locations were selected to represent background concentrations (distant locations unlikely to be affected by LLNL operations) as well as areas where there is the potential to be affected by LLNL operations. Areas with known contaminants, such as the Livermore Water Reclamation Plant (LWRP), are also sampled. In general, Site 300 soil sampling

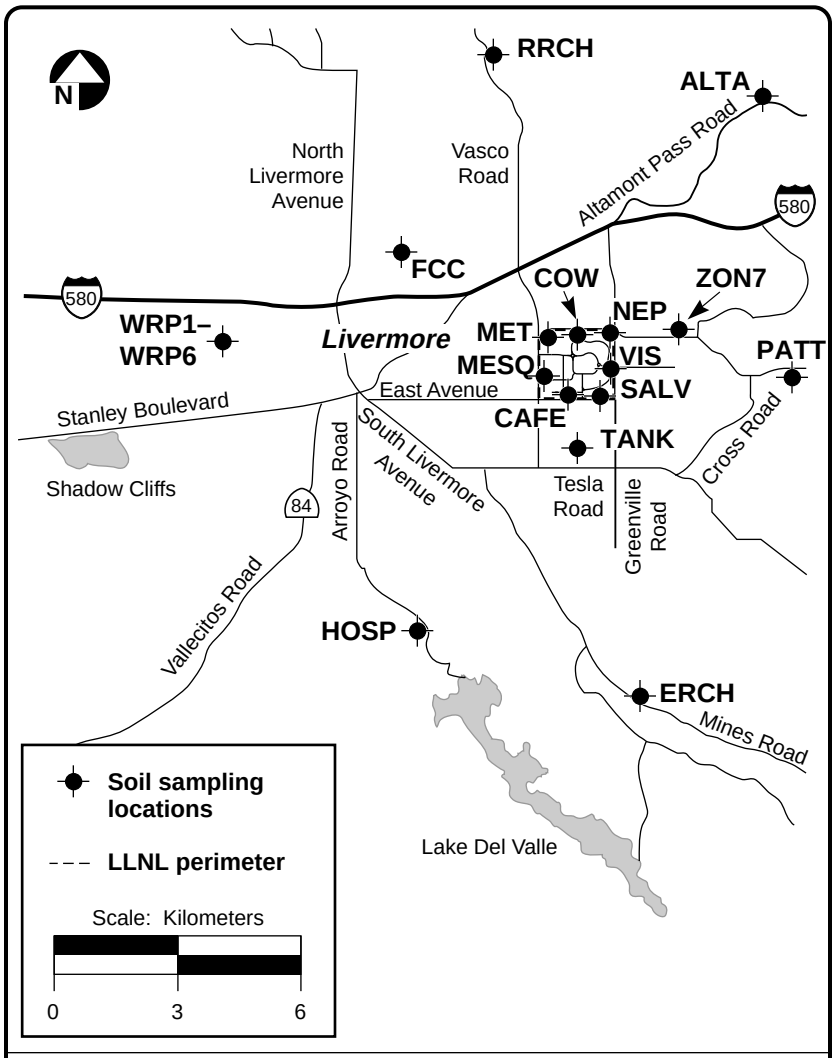

Figure 10-1. Soil sampling locations, Livermore Valley, 1995.

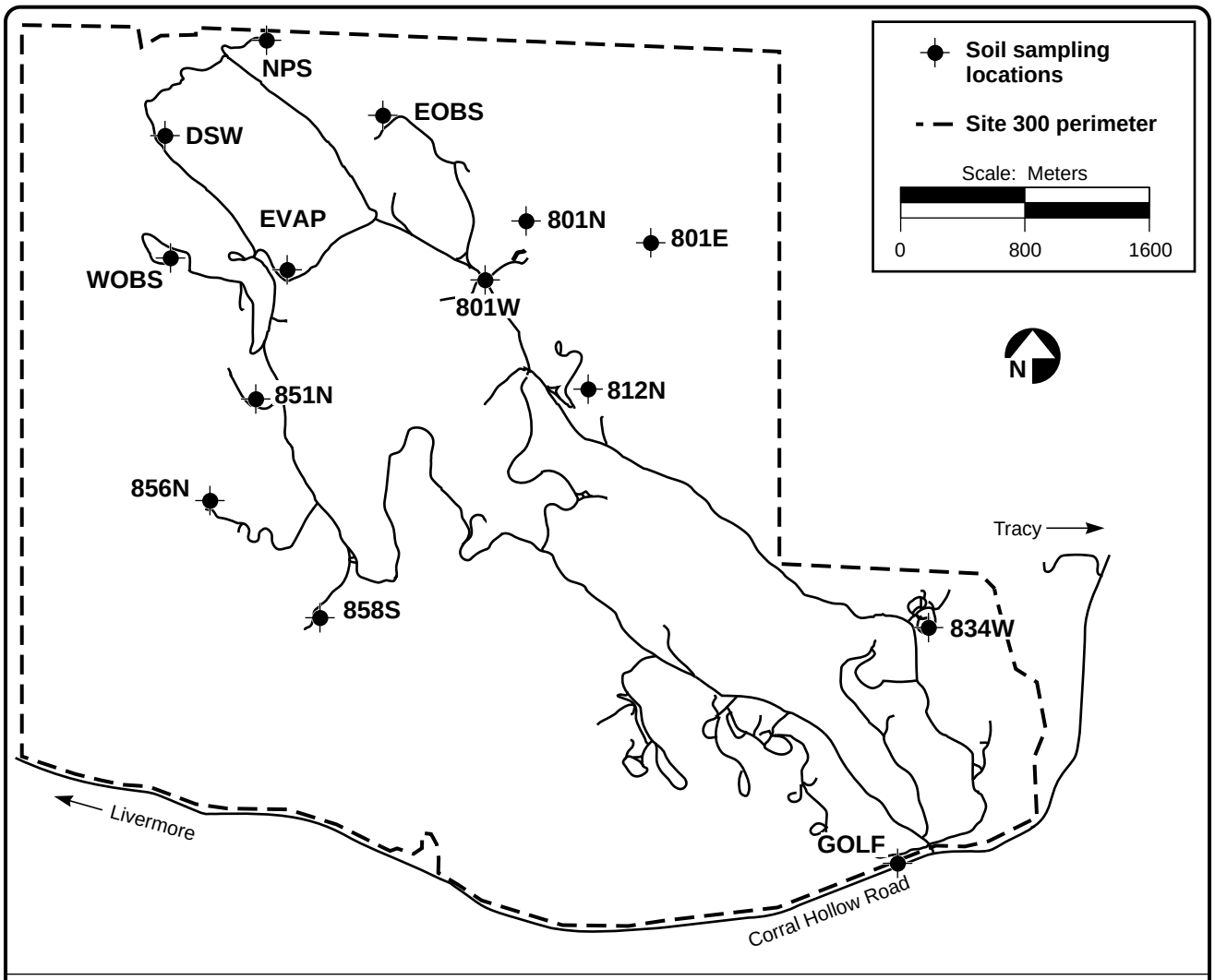

Figure 10-2. Site 300 soil sampling locations, 1995.

locations were established around firing tables and other areas of potential soil contamination. Arroyo and drainage channel sediment sampling locations were chosen to coincide with major Livermore site storm water drainages. All soil and sediment sampling locations have permanent location markers for reference.

Methods

Soil and sediment sampling is conducted according to written, standardized procedures (Tate et al. 1995, Appendix A). Soil samples are collected from undisturbed areas near the permanent sampling location marker. These areas generally are level, free of rocks, and are unsheltered by trees or buildings. All samples are collected from the top 5 cm of soil because surface deposition from

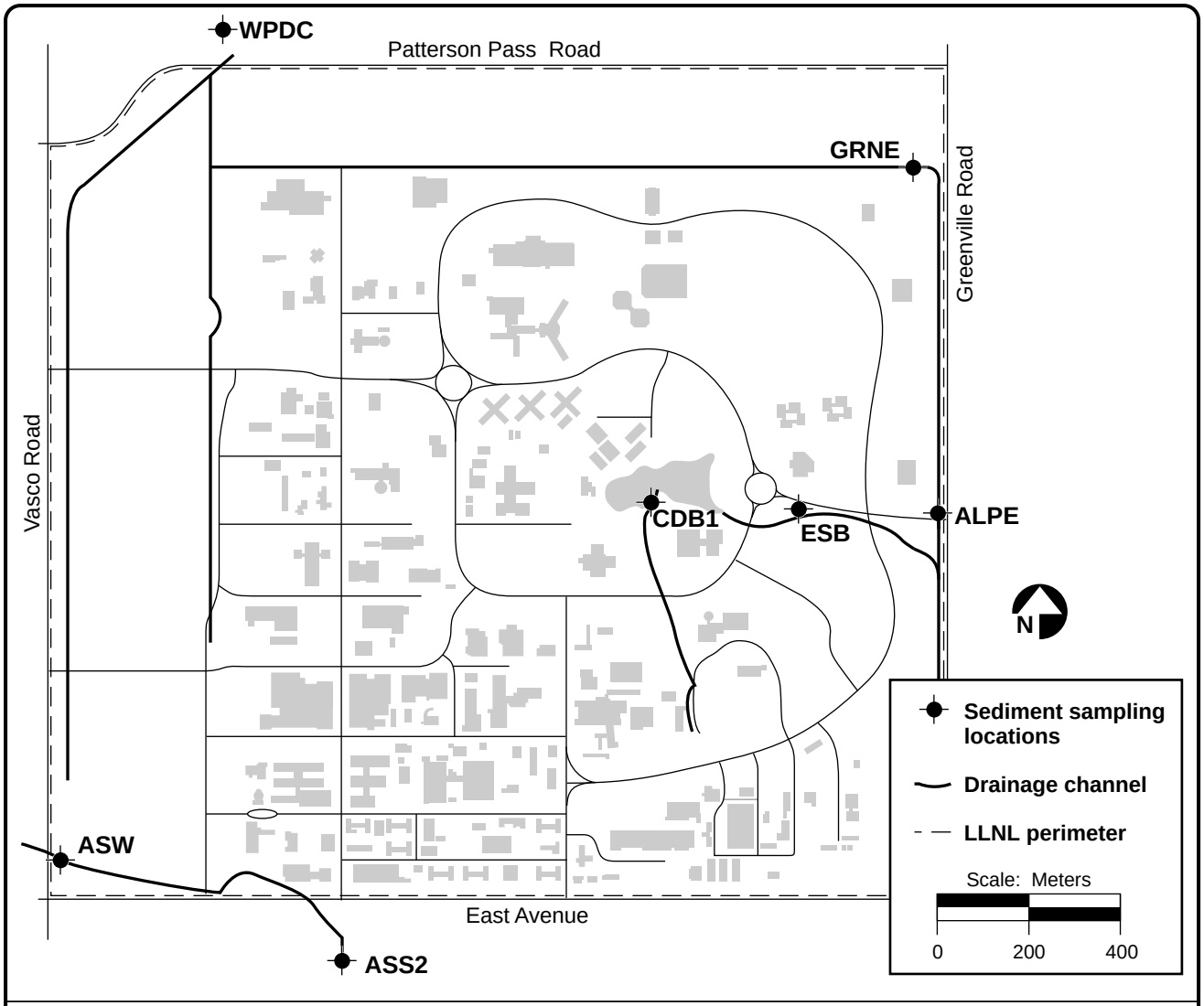

Figure 10-3. Arroyo and drainage basin sediment sampling locations, 1995.

the air is the primary pathway for potential contamination. Quality control duplicate samples are submitted with each batch of soil samples. At locations chosen for this sampling, two identical samples are collected.

Samples of recent sediment are collected annually from drainages at and around the Livermore site after the cessation of spring runoff. For 1995, samples at the Livermore site were analyzed for radionuclides and samples for Site 300 were analyzed for radionuclides and beryllium. During 1996, additional subsurface sediment sampling will support the LLNL Ground Water Protection Management Program (Chapter 9).

Soils and sediment samples are delivered to LLNL's Chemistry and Materials Science's Environmental Services (CES) laboratory for analyses. Soil samples are dried, ground, sieved, and blended. The plutonium content of a sample aliquot is determined by alpha spectroscopy (Hall and Edwards 1994). 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 1994). The 10-g subsamples for beryllium analyses are sent to a contract analytical laboratory and are analyzed by graphite-furnace atomic absorption spectroscopy. For 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. Chain-of-custody procedures are followed throughout the sampling, delivery, and analytical processes.

Livermore Valley Results

Table 10-1 presents summary data on the concentrations of $^{239+240}$Pu, ^{40}K, ^{60}Co, ^{137}Cs, ^{232}Th, ^{235}U, and ^{238}U in surface soils from the Livermore Valley sampling locations. The complete data for 1995 soils and sediment sampling is presented in Table 10-1, Volume 2, of this report. The concentrations and distributions of all observed radionuclides in soil for 1995 are within the ranges reported in previous years and generally reflect worldwide fallout and naturally occurring concentrations. The ratio of ^{235}U to ^{238}U reflects the natural ratio of 0.7%; however, there is uncertainty in the ^{235}U / ^{238}U ratio because of the difficulty in measuring small quantities of ^{238}U by gamma spectroscopy.

Plutonium has, in the past, been detected at levels above background at ZON7, the off-site soils sampling location near the LLNL 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. As in 1991 and 1994, $^{239+240}$Pu was detected at background levels—0.22×10^{-3} Bq / g (6.1×10^{-3} pCi / g)—at location ZON7. Since 1973, soil samples in this area have generally shown $^{239+240}$Pu values that are higher than background. The slightly higher values 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 any other open-air treatment of plutonium-containing waste. Nonetheless, $^{239+240}$Pu from historic operations is carried off site by resuspension of soil by wind. Similarly, elevated levels of $^{239+240}$Pu, resulting from an estimated 1.2×10^{9} Bq (32 mCi) plutonium release to the sewer in 1967 and first observed in soils near LWRP during the early 1970s, again were detected at LWRP sampling locations. As in 1990 through 1992, ^{241}Am was detected in an LWRP sample; it is most likely caused by the natural decay of the trace concentrations of ^{241}Pu that were present in the release.

Table 10-1. Summary of soils and sediment analytical data, 1995.

Analyte and location	Detection frequency	Median	IQR[a]	Maximum
$^{239+240}$Pu (10^{-3} Bq/dry g)				
Livermore Valley soils	15/15	0.09	0.19	1.1
LWRP[b] soils	6/6	3.5	6.4	25
Livermore site sediments	7/7	0.07	1.2	3.3
Site 300 soils	14/14	0.15	0.12	0.20
^{137}Cs (10^{-3} Bq/dry g)				
Livermore Valley soils	15/15	2.6	3.1	8.1
LWRP soils	6/6	1.8	4.5	7.4
Livermore site sediments	6/7	0.7	0.5	1.4
Site 300 soils	14/14	5.4	4.8	7.4
^{40}K (Bq/dry g)				
Livermore Valley soils	15/15	0.474	0.089	0.640
LWRP soils	6/6	0.386	0.065	0.459
Livermore site sediments	7/7	0.488	0.011	0.529
Site 300 soils	14/14	0.477	0.156	0.629
^{232}Th (μg/dry g)[c]				
Livermore Valley soils	15/15	6.2	1.3	10
LWRP soils	6/6	6.1	1.3	7.2
Livermore site sediments	7/7	5.4	2.7	8.2
Site 300 soils	14/14	9.4	1.3	13
^{235}U (μg/dry g)[d]				
Livermore Valley soils	14/15	0.021	0.005	0.025
LWRP soils	6/6	0.022	0.004	0.029
Livermore site sediments	5/7	0.019	—[e]	0.024
Site 300 soils[f]	13/16	<0.025	—[e]	0.34
^{238}U (μg/dry g)[g]				
Livermore Valley soils	14/15	1.8	0.3	2.8
LWRP soils	6/6	2.1	0.5	2.9
Livermore site sediments	6/7	1.6	0.4	3.0
Site 300 soils[f]	14/16	<2.7	—[e]	140.0
^{3}H (Bq/L extracted water)[h]				
Livermore site sediments	7/7	6.3	6.3	20
^{241}Am (10^{-3} Bq/dry g)[i]				
LWRP soils	1/6	<2	—[e]	8

...concluded on next page

Table 10-1. Summary of soils and sediment analytical data, 1995 (concluded).

Analyte and location	Detection frequency	Median	IQR[a]	Maximum
^{60}Co (10^{-3} Bq/dry g)[i])				
LWRP soils	2/6	<0.1	—[e]	0.5
Be (mg/kg)[j]				
Site 300 soils[f]	16/16	0.9	0.5	5.7

Note: Detection frequency means the number of samples of all samples taken having measured values above the detection limit.

a IQR = interquartile range.

b LWRP = Livermore Water Reclamation Plant.

c 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.

d 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.

e Insufficient number of detections to calculate IQR. (See Site 300 results for discussion.)

f Includes results from reanalysis of original sample and analysis of resample.

g 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.

h Tritium (^{3}H) analysis is only conducted on sediment samples.

i Cobalt-60 and Americium-241 are only detected in LWRP soil samples.

j Beryllium analysis is only conducted on soils sampled at Site 300; the analysis is a chemical, not a radiochemical analysis.

Historical plots of average $^{239+240}$Pu concentrations in soil in the Livermore Valley, at Site 300, and at LWRP are shown in **Figure 10-4**. Livermore Valley and Site 300 concentrations have remained relatively constant over the past 10 years and generally are indicative of worldwide fallout (locations on site and ZON7 show activities greater than background). Greater variability in $^{239+240}$Pu is seen at LWRP. However, six samples are evaluated to determine the median at LWRP. Moreover, the $^{239+240}$Pu is likely to be present in discrete particles, so the random presence or absence of the particles will dominate the measured $^{239+240}$Pu in any given sample.

Low levels of ^{60}Co were detected at the LWRP. While ^{60}Co is in use at the Livermore site, it is only present in gram quantities in three facilities (Buildings 151, 194, and 514) or in sealed sources. Low levels of ^{60}Co, on the order of 0.0037 Bq/g (0.1 pCi/g), have also been detected intermittently in sewage sludge samples. If the Livermore site were the source of ^{60}Co, this activity of ^{60}Co in the sludge would translate into about 1.5×10^{-6} Bq/mL (40×10^{-6} pCi/mL0 in the effluent leaving the site, which is below the detection limits of current analytical methods. This level is also well below the DOE effluent limit of 0.925 Bq/mL (25 pCi/mL). The reader should note that LLNL is

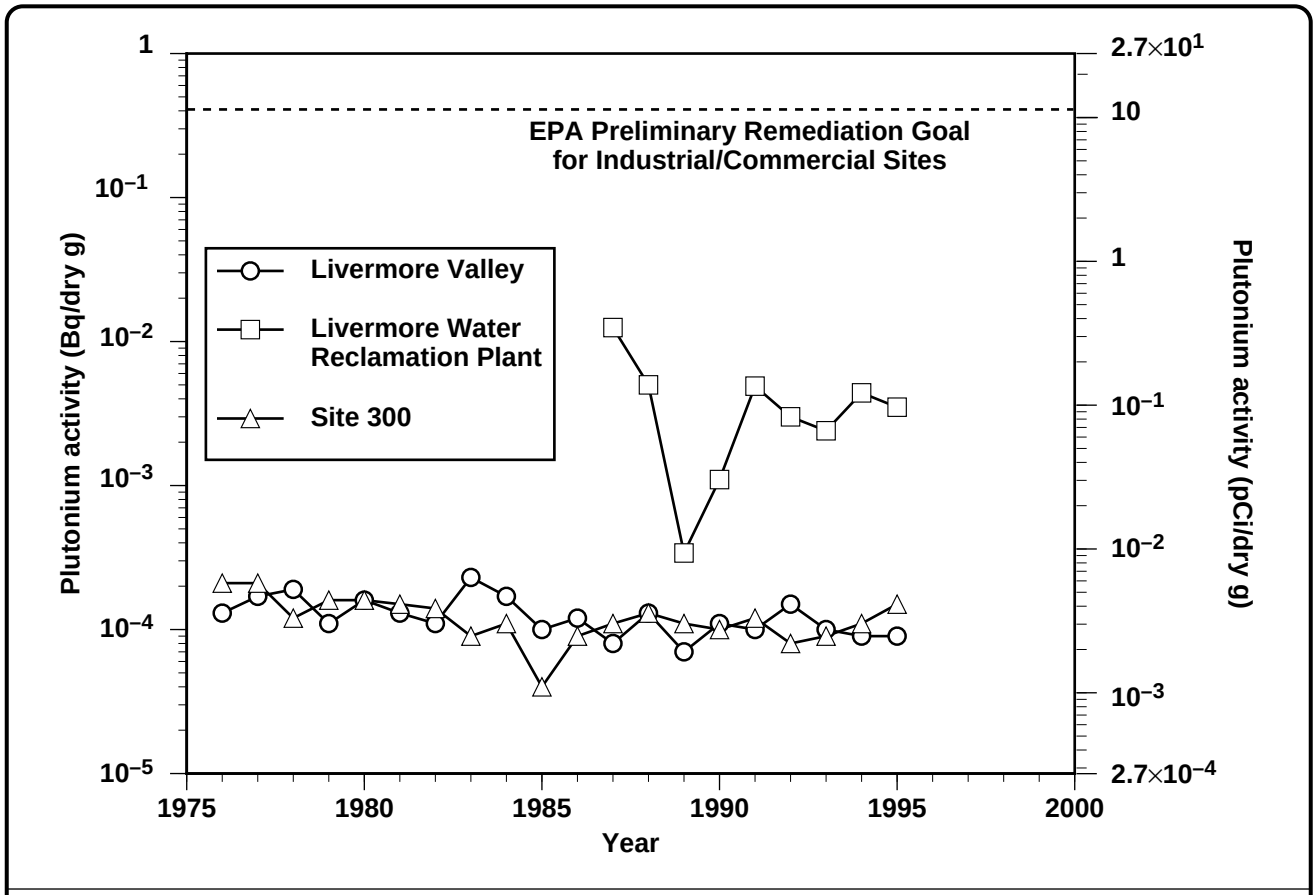

Figure 10-4. Median $^{239+240}$Pu activities in surface soils, 1976 to 1995.

not the only contributor to the waste stream that arrives at the LWRP and that ^{60}Co is used in a variety of medical, technical, and research applications. It is not possible to determine if LLNL is the source of ^{60}Co at LWRP. However, it can be concluded that LLNL controls on the release of ^{60}Co are sufficient to ensure that LLNL activities do not adversely affect LWRP applications.

Beryllium analysis for Livermore Valley soils was discontinued in 1995. The few LLNL operations that use beryllium are high efficiency particulate air (HEPA) filtered. In addition, sampling data to date have shown no evidence of beryllium contamination in the Livermore Valley (Tate et al. 1995). Should beryllium usage change, LLNL's environmental monitoring staff would reevaluate the need for beryllium monitoring in soils.

Table 10-1 presents summary data on radionuclides detected in the sediment samples; a complete presentation of 1995 sediment data is found in Table 10-1, Volume 2, of this report. The levels of $^{239+240}$Pu were generally at background concentrations, reflective of worldwide fallout. The slightly higher values at

ALPE and ESB 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 1994: ^{137}Cs, a fission product, was found at worldwide background concentrations; and ^{40}K, ^{232}Th, ^{235}U, and ^{238}U—naturally occurring radionuclides—were detected at background concentrations. Tritium concentrations were below those reported from 1988 through 1992, but above those for 1993 and 1994. Median tritium values are shown in **Figure 10-5** and show a general decline since measurement began. In 1993, the sediment sampling procedure was revised so that samples for gamma analysis were collected at the surface (5 cm deep). However, the depth for taking samples for tritium analysis was retained at 15 cm. Moreover, sampling was not later in the year than usual, so there would not have been additional evaporative losses due to sampling delays. Tritium in sediments will continue to be evaluated.

Site 300 Results

Table 10-1 presents summary data on the concentrations of $^{239+240}$Pu, ^{40}K, ^{137}Cs, ^{232}Th, ^{235}U, and ^{238}U in soil from the Site 300 sampling locations; a complete presentation of 1995 soils data for Site 300 is found in Table 10-1, Volume 2, of this report. The concentrations and distributions of all observed radionuclides in

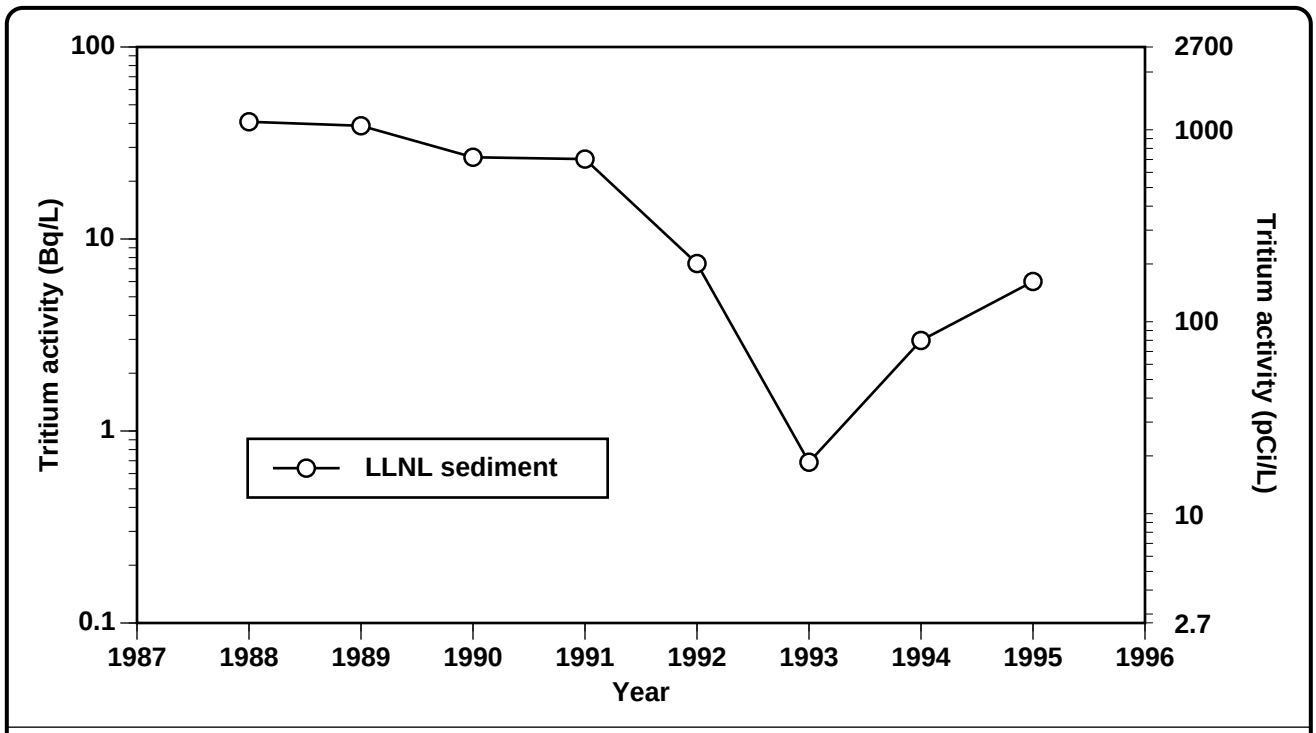

Figure 10-5. Median tritium concentrations in sediments (Bq/L of recovered water), 1988 to 1995.

Site 300 soil for 1995 lie within the ranges reported in all years since monitoring began, and, with the exceptions discussed below, reflect naturally occurring concentrations. The ratio of ^{235}U to ^{238}U generally reflects the natural ratio of 0.7%.Historical trends of ^{238}U concentrations from both the Livermore Valley and Site 300 are shown in **Figure 10-6**. Median values have remained relatively constant for both places. The highest values at Site 300 are caused by the use of depleted uranium in high-explosive tests.

During 1995, one sample from a region near a firing table (834W) had substantially higher than background concentrations of ^{238}U and beryllium. The $^{235}U/^{238}U$ ratios, at 0.2%, confirm the presence of depleted uranium; the ratio in naturally occurring material is 0.7%. To investigate the elevated ^{238}U and beryllium result at 834W, LLNL personnel reanalyzed the original soil sample and resampled and analyzed the original sampling location. The high value of 136 µg/g of ^{238}U in the original sample was confirmed by reanalysis. However,

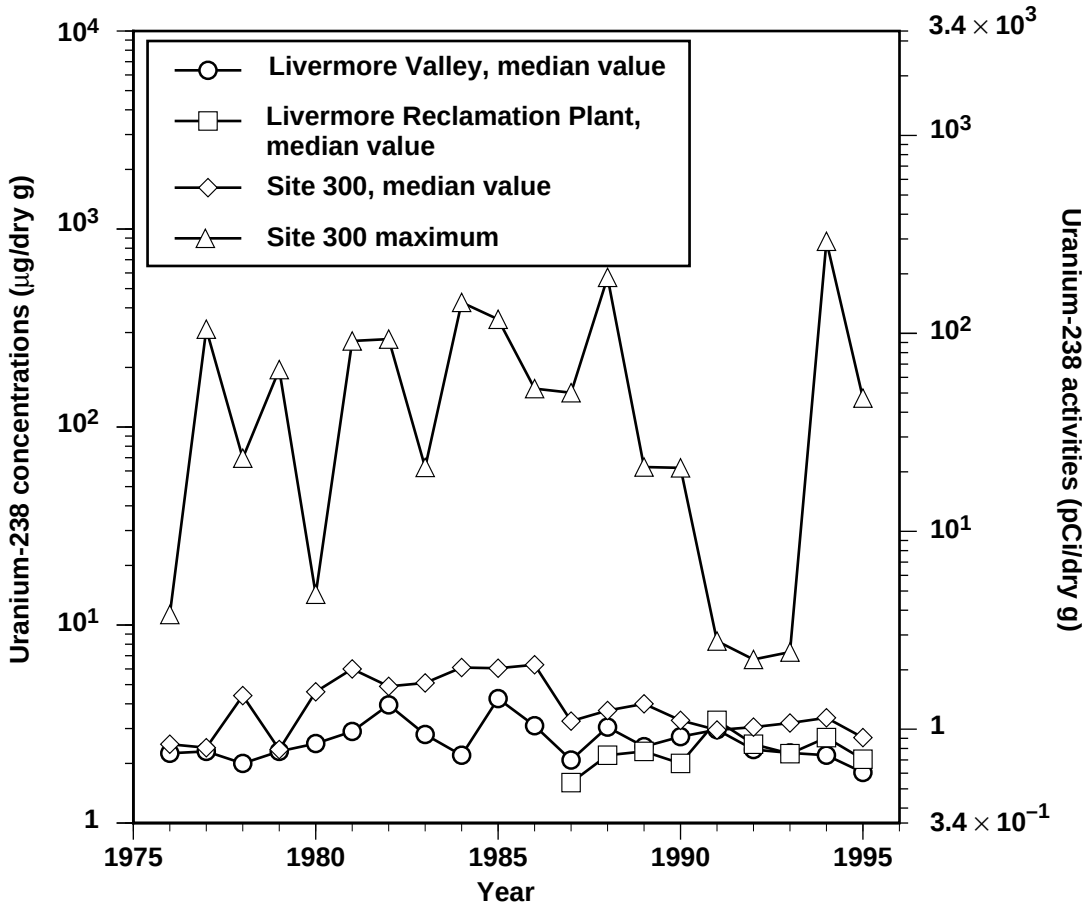

Figure 10-6. Uranium-238 concentrations in surface soils, 1976 to 1995.

the result of the resample of the location yielded <2.1 μg/g of ^{238}U, well below the original sample value; this disparity in sampling results was to be expected considering the heterogeneous nature of the contamination. In contrast, the finding of beryllium above background was not confirmed by reanalysis. An additional sampling location, 801N, yielded results having a $^{235}U/^{238}U$ ratio of 0.2%. This sampling location is near an active test area, so it is expected that results might show the presence of depleted uranium.

Environmental Impact

This section discusses the environmental impacts at the Livermore site and Site 300 inferred from soil and sediment monitoring.

Livermore Site

Routine soil and sediment sample analyses indicate that the impact of LLNL operations on these media in 1995 has not changed from previous years and remains insignificant. Most analytes of interest or concern were detected at background concentrations, in trace amounts, or could not be measured above detection limits.

The highest value of 25×10^{-3} Bq/g (0.68 pCi/g) for $^{239+240}Pu$ measured at LWRP during 1995 represents 6.8% of the EPA preliminary remediation goal for commercial or industrial sites of 0.37 Bq/g (10 pCi/g) (EPA 1991). Statistical analysis shows that all LWRP $^{239+240}Pu$ soils data are lognormally distributed, and at LWRP there is no general increase or decrease in $^{239+240}Pu$ values with time. Moreover, all measured concentrations, regardless of location and year, have been a small fraction of the proposed EPA remediation goal, which is shown in **Figure 10-4** for comparison. Sampling of soils for radiological materials will continue on an annual basis.

Site 300

With the exception of elevated concentrations of ^{238}U at locations 834W and 801N, and beryllium at location 834W, the concentrations of radionuclides and beryllium observed in soil samples collected at Site 300 are representative of background or naturally occurring levels. In 1988, contaminated gravel from the firing table at Building 812 was removed to on-site landfills, and measured values for samples from this location have generally not exhibited elevated levels of ^{238}U and beryllium. The elevated results for ^{238}U and beryllium indicate that areas outside the firing table may be contaminated by firing table debris. The investigation planned as part of the Site 300 CERCLA restoration efforts will clarify the nature and extent of the contamination in this area.

Special Studies

In 1995, LLNL conducted an on-site soil cleanup action in response to the results from a special study of soil: Plutonium in the Soil in the Southeast Quadrant of Livermore Site. LLNL also completed its study of plutonium in soil at Big Trees Park, Livermore, CA.

Plutonium in Soil, Southeast Quadrant of Livermore Site

From 1962 to 1976, solar evaporation trays were located in the southeast quadrant of LLNL. The trays were approximately 6 m × 6 m × 3 m deep, constructed of concrete coated with polyamide epoxy paint and lined with polyvinylchloride or polyethylene liners. Plutonium-containing liquid waste was put in these trays to reduce by evaporation the total volume of disposable waste (Buerer 1983).

In 1991, in response to a Tiger Team comment, 195 surface soil samples from the southeast quadrant of LLNL were collected and analyzed for plutonium. The highest level detected was 0.11 Bq/g (3 pCi/g). In 1993, EPA decided to resample the areas with levels above those expected from global fallout for further confirmation of LLNL's sampling results and to sample locations to the west of the 1991 sampling locations to assure that the boundary of the area of interest had been appropriately set. Only one location, designated LL01-064, was identified in the EPA's 1993 sampling as containing more than the EPA industrial preliminary remediation goal (PRG) of 0.37 Bq/g (10 pCi/g); the location contained up to 11.5 pCi/g of $^{239/240}$Pu.

The soil containing plutonium at the location LL-01-064 near the northwest corner of T5475 was excavated on October 14, 1995, by LLNL personnel after appropriate safety reviews. Approximately 0.45 m^3 (1.5 m^2 area × 0.3 m deep) of soil was removed. Nine samples and one duplicate were collected after the soil was excavated to verify the removal of the soil over the PRG. All nine sample locations contained concentrations well below the industrial preliminary remediation goal.

The excavated area was backfilled with clean fill and seeded with new grass. The excavated soil was placed in four 55-gallon drums and collected for disposal in accordance with the appropriate regulations. This action complies with current EPA direction for the cleanup of soils.

Plutonium in Soil, Big Trees Park, Livermore

During the 1993 EPA investigation of plutonium in soils in the southeast quadrant of the 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 EPA, LLNL, and the California Department of Health Services (DHS) in 1995.

As reported in MacQueen (1995), samples from 13 of 16 locations sampled at the park 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 for plutonium for residential areas 0.09 Bq/L (2.5 pCi/g) (EPA 1991). Background values were found in all sandboxes, school grounds, picnic areas, and under the large eucalyptus trees for which the park was named. Samples from two locations adjacent to the ballfield had plutonium concentrations slightly above background levels, but still 2/100 to 1/100 of the EPA's risk-based preliminary remediation goal for plutonium for residential areas.

Four samples taken in the area near the original EPA sample area had plutonium concentrations that were above the EPA's initial sample's concentration, but even the highest concentration detection was two-fifths of the EPA's risk-based preliminary remediation goal for plutonium for residential areas. These data confirm the initial EPA result for this small area of soil found under trees along the fence separating the Arroyo Seco from the park. The EPA and California Department of Health Services (DHS) analytical results agree with those from LLNL. Both agencies concur that there is no regulatory concern from any of the sample results, that there is no significant lifetime cancer risk resulting from the low concentrations of ^{239}Pu in the soil samples, and that there is no unacceptable risk to human health or the environment. For more detailed information, see the report *Livermore Big Trees Park, January 1995 Soil Survey Results* (MacQueen 1995).

11. Vegetation and Foodstuff Monitoring

Gretchen M. Gallegos
Joel H. White

Introduction

Because pollutants originally released to the soil, air, or water can be transported to vegetation, the sampling and analysis of native vegetation can provide information about the presence and movement of radionuclides in the environment. Vegetation can contribute a radiation dose to humans directly through ingestion or indirectly through human ingestion of products from animals that have consumed it. DOE guidance 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).

Since 1972, vegetation and foodstuff sampling in the vicinity of LLNL and Site 300 has been part of a continuing LLNL monitoring program designed to measure any changes in environmental levels of radioactivity, to evaluate any increase in radioactivity that might have resulted from LLNL operations, and to calculate potential human doses resulting from direct and indirect ingestion of these products. During 1995, LLNL collected and analyzed samples of native vegetation and wine. Potential human doses from these foodstuffs are calculated using the monitoring data and dose models presented in Appendix B.

Tritium is the nuclide of major interest in the LLNL vegetation and foodstuff monitoring program because LLNL has historically released tritium to the air both accidentally and in the course of routine operations. Tritium is likely to move into the environment as tritiated water and can be assimilated easily into vegetation and foodstuff. It can contribute to human radiation dose burdens if it is inhaled or ingested directly or indirectly. Although other radionuclides are used at LLNL, our assessments show that only tritium could be present in vegetation in detectable concentrations.

Methods

Our methods for monitoring vegetation and wine are presented in the following sections.

Vegetation

LLNL collects vegetation samples, usually annual grasses, quarterly from fixed locations in the Livermore Valley, San Joaquin Valley, San Ramon Valley, and Site 300, and then analyzes them for tritium. Sampling locations DAN and MOD were eliminated in 1995; lower release levels of tritium reduced the need for

numerous background sampling locations. Location maps are provided in **Figures 11-1** and **11-2**. These locations have been selected so samples would represent vegetation from: (1) locations near LLNL that could be affected by LLNL operations, (2) background locations where vegetation was similar to that growing near LLNL but was unlikely to be affected by LLNL operations, and (3) areas of known or suspected LLNL-induced contamination.

All vegetation sampling is conducted according to written and approved standardized procedures (Tate et al. 1995). Approximately 10% of the sites are sampled in duplicate to comply with quality assurance protocols (Garcia and Failor 1993).

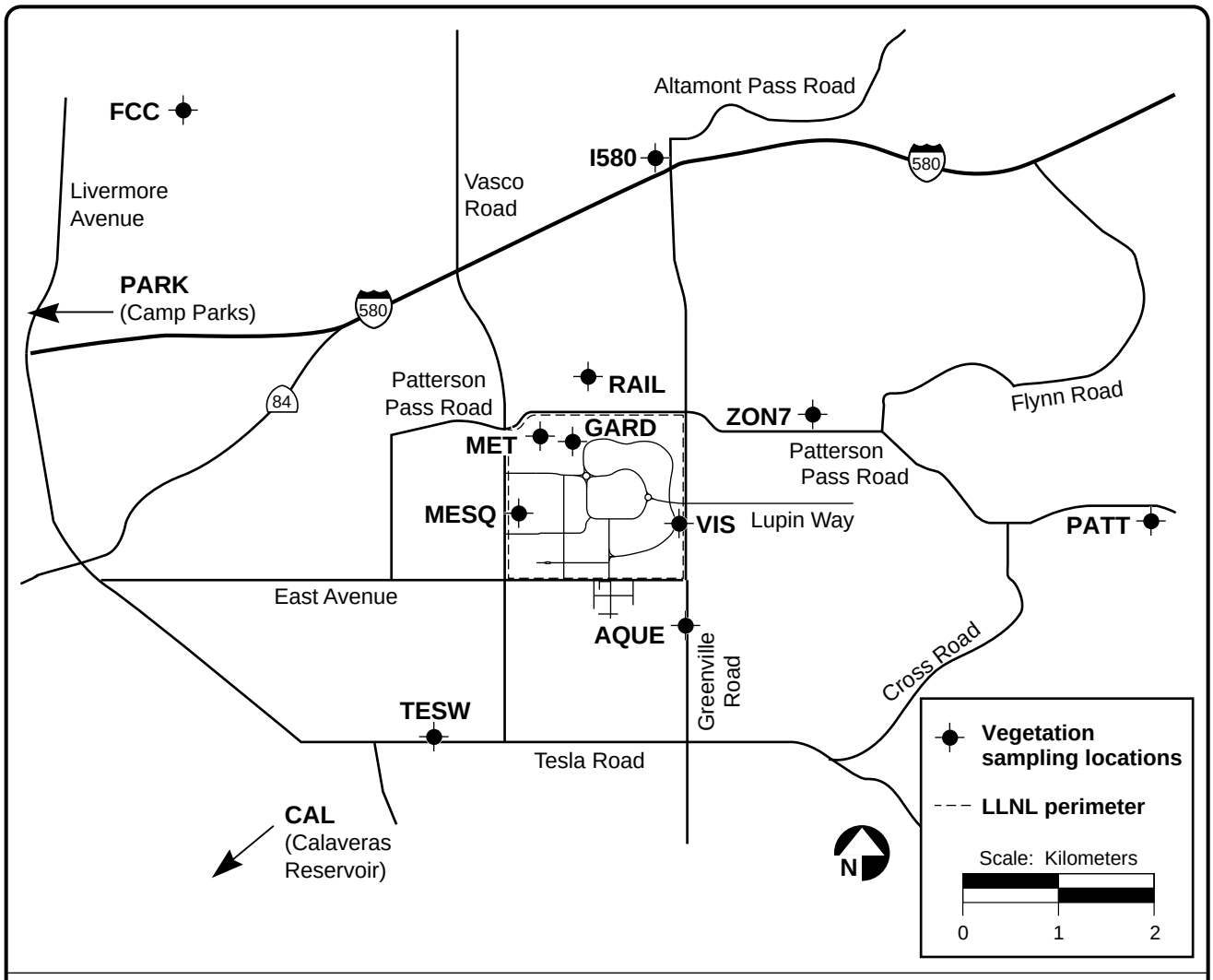

Figure 11-1. Livermore Valley vegetation sampling locations, 1995.

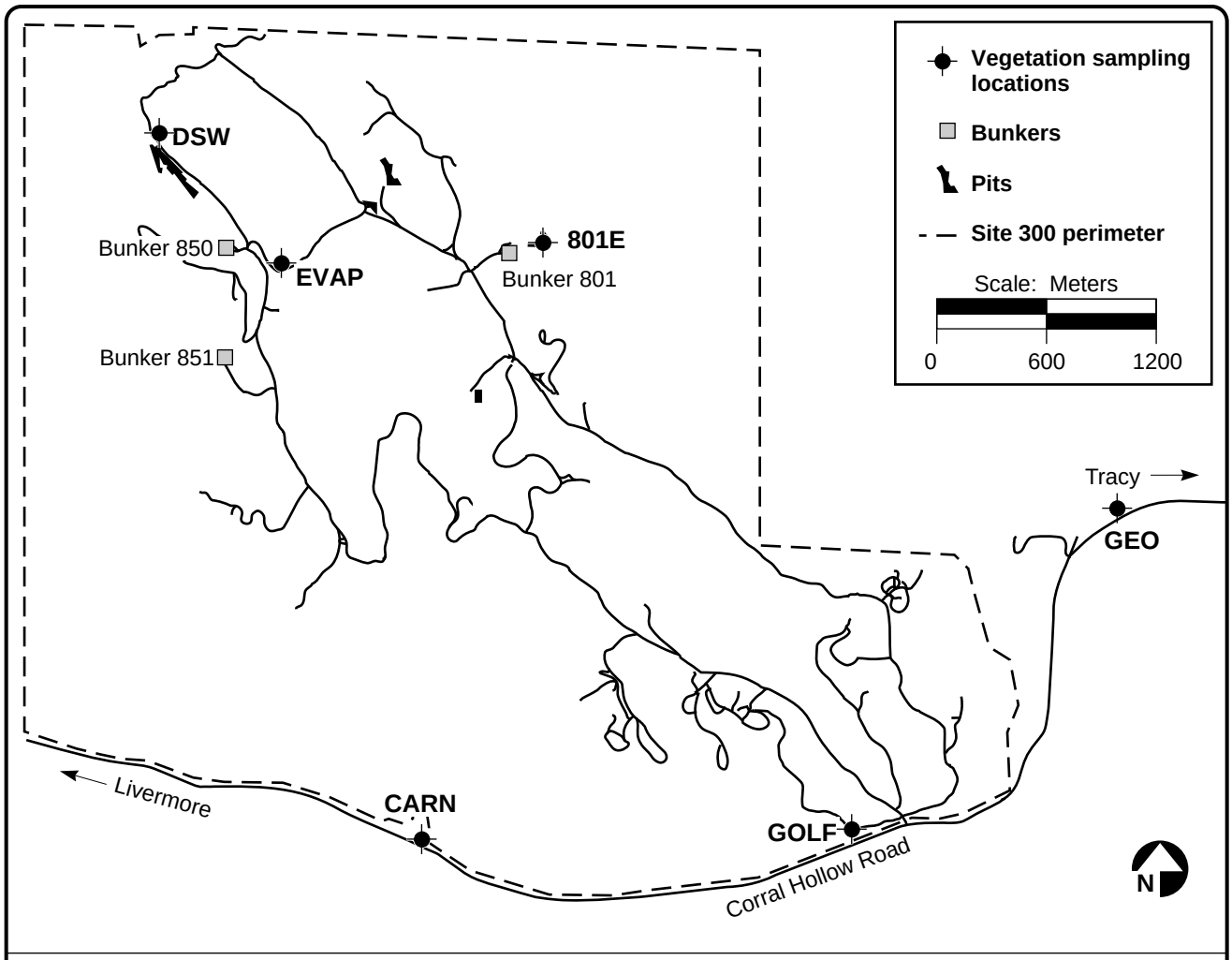

Figure 11-2. Site 300 vegetation sampling locations, 1995.

Wine

Wine is the most important agricultural product in the Livermore Valley, representing an approximately $30-million annual industry. Although the tritium concentrations in all wines are low, the data since monitoring began (in 1977) indicate that Livermore Valley wines contain statistically more tritium than do their California counterparts.

Three types of wine samples were collected and analyzed for tritium concentrations: wine produced from grapes grown in the Livermore Valley, wines produced from grapes grown in California outside the Livermore Valley, and wines produced from grapes grown in Europe (France, Germany, and Italy). The latter two groups were divided into 8 and 13 wine-producing regions, respectively, and were used as comparative samples.

The wine samples were purchased from local retailers in a variety of vintages and reflect the body of wines locally available to the general public during 1995. The resulting analytical data can be used to estimate the potential tritium dose received by consumers during the year of purchase. The 1995 sampling data cannot, however, be used to indicate how LLNL's operations affected wines produced in 1995. Some time—in some cases, several years—will have elapsed between the harvest of the grapes and the release of the vintage. However, wine sample data are decay-corrected to original tritium concentrations (given the number of months that have elapsed between wine production and LLNL analysis) to determine trends and to help determine the impact of LLNL operations during a particular vintage year.

The wine samples were submitted for analysis unopened to avoid airborne tritium contamination. Wines were analyzed for tritium using ^{3}He mass spectrometry in the LLNL Isotope Sciences Noble Gas Mass Spectrometry Laboratory (Surano et al. 1991). This highly sensitive method has a detection limit of less than 0.5 Bq/L (13 pCi/L), and is used to determine the small differences in the tritium content of the samples. Conventional scintillation detection systems typically have detection limits between 5 and 10 Bq/L (150–300 pCi/L); therefore, the differences in the samples would not have been detected had conventional detection methods been used.

Approximately 10% of the total complement of wines was sampled in duplicate, 30% of all the samples were analyzed multiple times, and traceable standards were evaluated to comply with quality assurance protocols.

Results

The results of vegetation and foodstuff monitoring for the Livermore site and Site 300 are presented below.

Livermore

Vegetation

Table 11-1 shows summary tritium data for vegetation collected in the Livermore site vegetation monitoring program in 1995 (the individual sampling values are presented in Volume 2 of this document). In general, the 1995 tritium levels in vegetation were slightly less than levels measured in 1994.

The vegetation locations were put into three groups for statistical evaluation:

- Near—locations at or within 1 km of the Livermore site perimeter. Near locations include AQUE, RAIL, GARD, MESQ, MET, and VIS.

Table 11-1. Tritium in vegetation (in Bq/L), 1995.

Location[a]	Detection frequency	Median	Interquartile range	Maximum	Dose (μSv/y)[b]	
					Median	Maximum
Livermore site near locations	21/24	6.0	8.3	78	0.029	0.38
Livermore site intermediate locations	9/16	3.4	—[c]	12	0.016	0.059
Livermore site background locations	4/12	<2.0	—[c]	3.0	<0.010	0.015
Location DSW at Site 300[d]	3/4	22	160	530	0.11	2.5
Location EVAP at Site 300[d]	3/4	12	18	64	0.059	0.31
All other locations at LLNL Site 300	4/16	<2.1	—[c]	2.9	<0.010	0.014

Note: Detection frequency means the number of samples of all samples taken having measured values above the detection limit.

a See **Figures 11-1** and **11-2** for sampling locations.

b Dose calculated based on conservative assumptions that an adult's diet is exclusively vegetables with this tritium concentration and that meat and milk is derived from livestock fed on grasses with the same concentration of tritium. See Appendix B, Methods of Dose Calculations.

c Insufficient number of detections to calculate IQR.

d Sampling location in known area of contamination.

- Intermediate—locations in the Livermore Valley further from the site (1 to 5 km from the Livermore site perimeter) but close enough and often downwind so that they are still potentially under the influence of tritium releases at the site. The intermediate locations were I580, TESW, ZON7, and PATT.
- Background—locations unlikely to be affected by LLNL operations. One background location (CAL) is more than 25 km away. The other two (FCC and PARK) are in the Livermore Valley but are greater than 5 km from the Livermore site and are generally upwind so they are unlikely to be affected by LLNL operations.

The changes in tritium levels between 1994 and 1995 for the vegetation from within each of the Near, Intermediate, and Far groups were statistically insignificant.

Because the data for tritium in vegetation were lognormally distributed, the means of the logarithms were compared, using the Tukey-Kramer honestly significant difference (HSD) test. This evaluation showed a significant difference among all three groups, that is, the Near values are significantly different from Intermediate, which in turn are significantly different from the Far values. **Figure 11-3** shows the historic averages for the three groups. The highest tritium results for individual vegetation sampling locations were found at AQUE and VIS. These locations are downwind of SNL/California, and the Livermore site and historically have exhibited higher values than other locations.

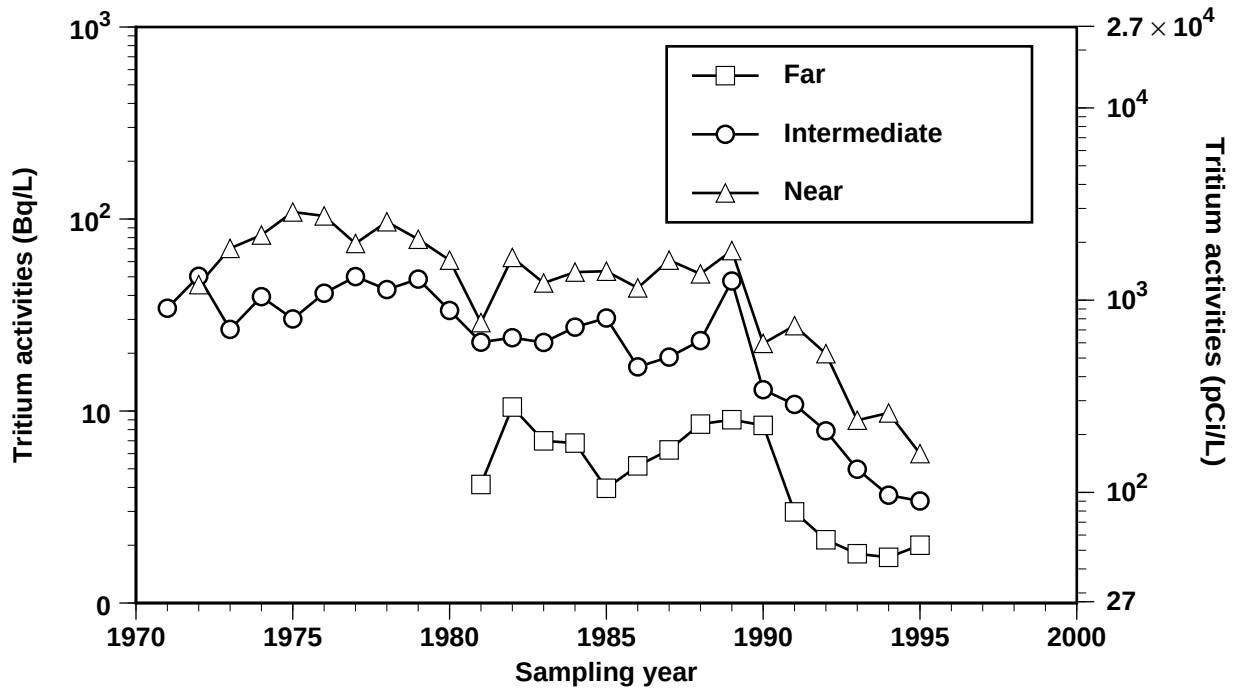

Figure 11-3. Median tritium activities in Livermore Valley vegetation samples, 1971 to 1995.

Wine

The results from the 1995 wine tritium analyses are shown in **Table 11-2**. Tritium concentrations were within the range of those reported in previous years, and they remained low in wines from all areas.

The data for the 1995 sampling year were analyzed using analysis of variance (ANOVA). The statistical analyses showed that the mean tritium concentration of the Livermore wines sampled was statistically greater than that of both the California (other than Livermore) wines and European wines sampled. The statistical analyses also indicated that there was no significant difference between the mean tritium values of the European and California wines sampled. Multiple comparison tests indicated that the mean levels of the 1995 sampling year data from all areas were not statistically different from those reported for the 1993 and 1994 sampling years. **Figure 11-4**, which shows the results of the wine analyses by sampling year since monitoring began, also shows that 1995 tritium concentrations are among the lowest for all Livermore wines since monitoring began.

During the review of historical data, it was discovered that the data for 1977 and 1979 sampling years were averages across multiple sampling years. These data have been corrected in **Figure 11-4**, and are the reason for differences observed when comparing this figure to those published in previous reports.

Table 11-2. Tritium (Bq/L) in retail wine, 1995.[a]

Region	Detection frequency	Median	Interquartile range	Mean	Maximum	Dose[b] μSv/y (mrem/y)
Livermore Valley	12/12	2.60	2.14	3.20	6.02	0.0028 (0.00028)
California	6/6	0.45	0.22	0.62	1.21	0.0005 (0.00005)
Europe	4/4	1.87	0.58	1.92	2.76	0.0017 (0.00017)

a Wines from a variety of vintages were purchased and analyzed during 1995. The concentrations shown are not decay-corrected to vintage year.

b This dose is calculated from conservative assumption of drinking 52 L wine/year and using the mean concentration of sampled wines.

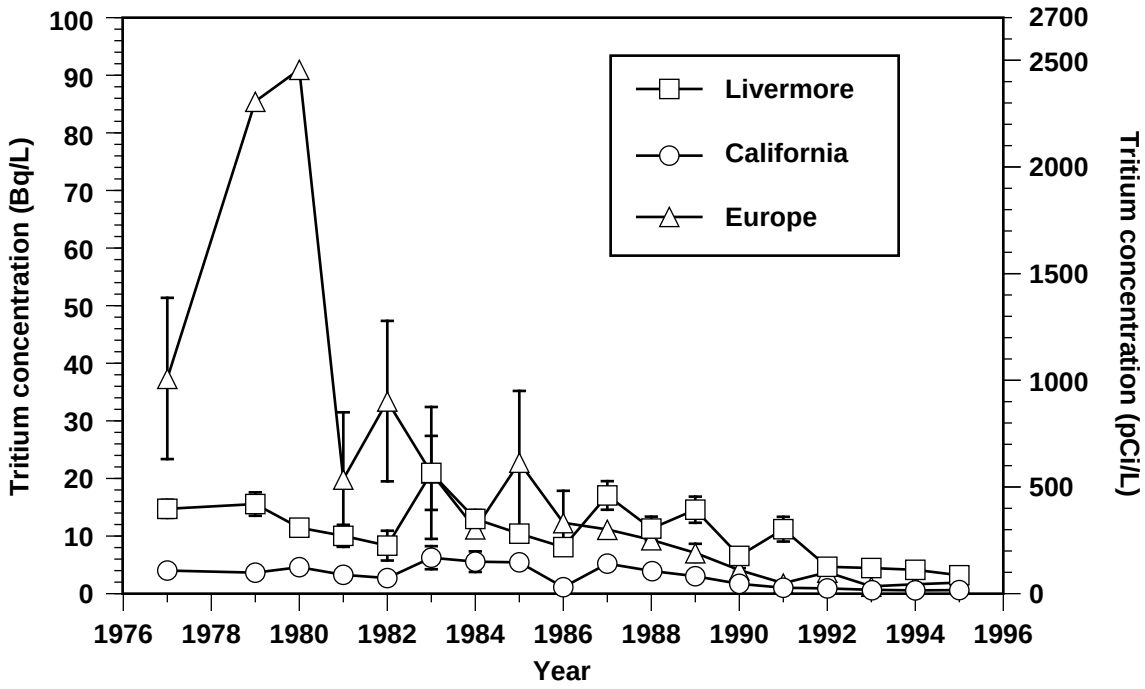

Figure 11-4. Mean tritium in retail wines, 1977 to 1995, plotted by sampling year (error bars are ±1 standard error).

Regression analyses and ANOVA of the wine data when decay-corrected (see **Figure 11-5**) and grouped by vintage year (1994 is last sampled vintage) showed tritium concentrations have statistically decreased for all regions since 1984. Livermore wines, examined by vintage year, have had statistically greater tritium concentrations since 1986 than both European and California wines. However, since 1989 when tritium operations at LLNL were scaled down and the total amount of tritium released was reduced, the concentration of tritium in the Livermore Valley wines has followed a downward trend when decay-corrected and grouped by vintage year.

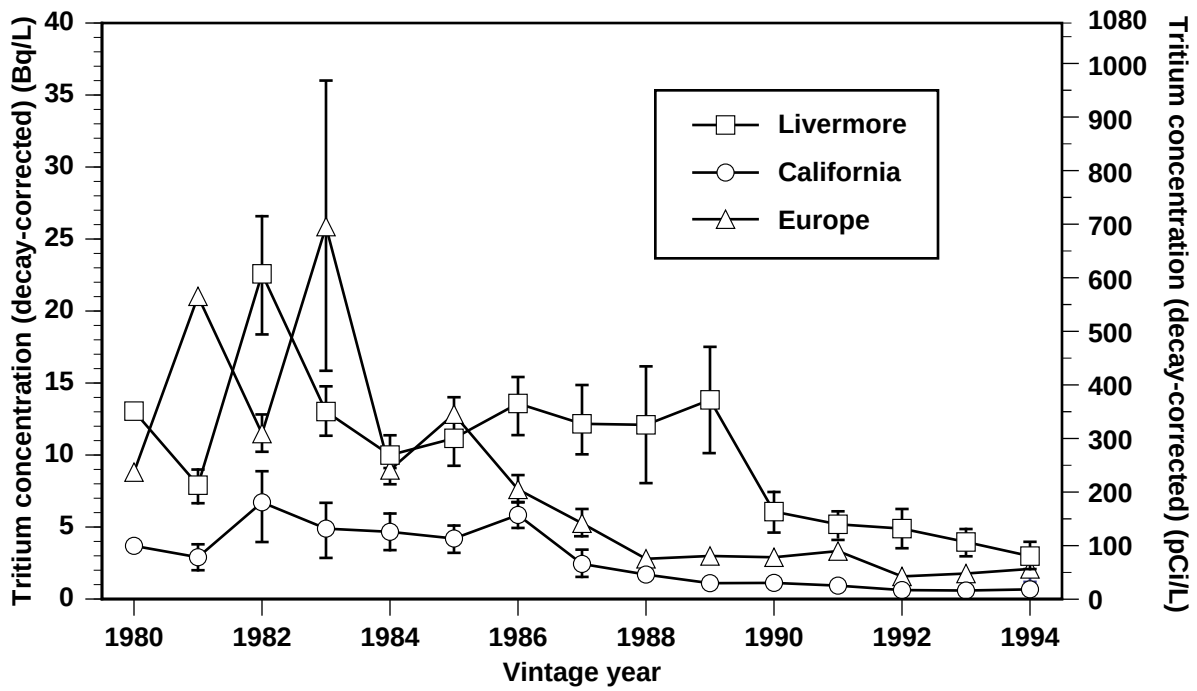

Figure 11-5. Mean tritium in retail wines, vintages 1980 to 1994, values are decay-corrected and plotted by vintage year (error bars are ±1 standard error).

Site 300

Vegetation

Table 11-1 shows summary tritium data for vegetation collected at Site 300 during 1995. Historic values for tritium at Site 300 sampling locations are shown in **Figure 11-6**. Of the six sampling locations at Site 300, four yield results at or near the detection limits. Two locations, EVAP and DSW, yield results above background.

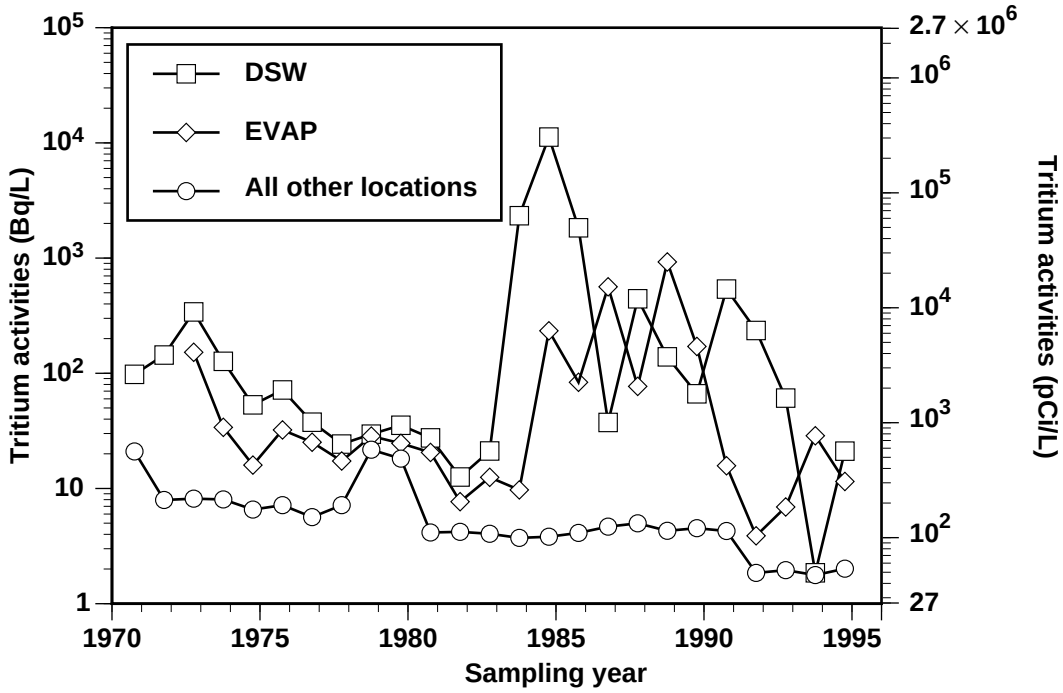

Figure 11-6. Median tritium activities in vegetation at Site 300 sampling locations, 1971 to 1995.

As was the case for 1992 to 1994, vegetation samples from location DSW contained the highest maximum tritium values detected (see **Table 11-1**). Tritium has been observed in the vegetation of the DSW sampling location since 1971; it is in an area presently being investigated under CERCLA for tritium contamination of ground water. This sampling location is adjacent to a landfill that contains debris contaminated with tritium from past experiments. The landfill area is under continued investigation for tritium in soil and ground water, as described in reports published as part of LLNL's Environmental Restoration Program (Lamarre 1989a, 1989b, and 1989c; Taffet et al. 1989a and 1989b; Taffet et al. 1991; Carlsen 1991a and 1991b; and Webster-Scholten 1994). In the past, purge water from samples of ground water monitoring wells was released to the ground at this location. This practice has been discontinued, and LLNL will continue to monitor vegetation in this area to determine whether the change in purge water deposition affects tritium activities in vegetation samples. The location EVAP is near a spring where ground water flows near the surface and evaporates. Some of the ground water near this location arises near the Building 850 firing table where tritium is released to soil (Surano et al. 1995). Consequently, higher-than-background levels of tritium are measured in vegetation in this area. Evaluation of the 1995 data using the Tukey-Kramer HSD test on the logarithms of the data yielded a significant difference between the set of locations comprising GEO, CARN, GOLF, and 801E, and locations DSW and

EVAP. This is to be expected because DSW and EVAP are areas of known tritium contamination.

Environmental Impact

The environmental impacts of LLNL operations on vegetation and foodstuff monitoring are 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 1995. 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 NRC Regulatory Guide 1.109 (U.S. Nuclear Regulatory Commission 1977). Appendix B provides a detailed discussion of dose calculation methods. The dose from tritium in vegetation is based on the conservative assumptions that an adult's diet consists exclusively of vegetables with the measured tritium concentration, and meat and milk derived from livestock fed on grasses with the same concentration. These assumptions are conservative because neither will most vegetables consumed directly by an adult contain tritium at the levels reported (the tritium levels will actually be much lower), nor will the livestock actually consume vegetation with the reported levels of tritium. Based on these conservative assumptions, the maximum potential dose (from ingestion of affected vegetation) for 1995 for the Livermore site is 0.38 µSv (0.038 mrem).

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 (6.0 Bq/L or 160 pCi/L) represents only 0.8% 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, which are detailed in Appendix B.

The annual dose that corresponds to the highest detected 1995 Livermore Valley tritium value in wine (6.0 Bq/L (160 pCi/L)) is 0.075 µSv (0.0075 mrem), based on the extremely conservative assumption that wine is consumed in the same quantities as water (730 L/year or 2 L/day). Using a more realistic wine consumption factor (52 L/year or 1 L/week of wine from a single area) and the mean tritium values detected in wines from the three sampling areas, the annual dose from Livermore wine would be 0.0028 µSv (0.00028 mrem), from European wine would be 0.0017 µSv (0.00017 mrem), and from California wine would be 0.0005 µSv (0.00005 mrem). Compared with an annual background dose of approximately 3000 µSv (300 mrem), which includes radon, and a 100-µSv (10-mrem) dose from a typical chest x-ray (Shleien and Terpilak 1984), the potential dose from consuming wine from any area is minute. Therefore,

although Livermore wines contained statistically more tritium than wines produced in other areas of California, the effects of the tritium are negligible.

Site 300

In general, LLNL impacts on vegetation at Site 300 for 1995 were insignificant. Tritium levels found in the Site 300 vegetation were comparable to those observed in previous years. With the exception of vegetation from previously identified sites of contamination, the levels were low, near the limits of detection. The areas where tritium is known to be present in the subsurface soil are well delineated and localized.

The calculated maximum potential annual dose from vegetation at sampling location DSW, based on the maximum value of 530 Bq/L (14000 pCi/L), is 2.5 µSv (0.25 mrem). This dose, which would never actually be received by anyone, is about 40 times less than a chest x-ray (Shleien and Terpilak 1984). This calculation uses the same conservative pathway modeling assumptions, as described above. In actuality, this dose never would be received because vegetation at Site 300 is not consumed by people or by grazing livestock. In comparison, the calculated potential annual dose from vegetation at all other locations at Site 300 had a median value of <0.010 µSv (<0.0010 mrem; the value is a “less than” value because all measured tritium levels were less than the detection limit). Tritium levels in vegetation at Site 300 will continue to be monitored.

12. Environmental Radiation Monitoring

Barbara C. Fields
Joel H. White

Introduction

A variety of radioisotopes are used at LLNL for biomedical, general, and nuclear weapons research. These include transuranics, tritium, and mixed fission products. In accordance with federal regulations, DOE Orders 5400.1 and 5400.5, and Title 17, California Code of Regulations, Section 30250, LLNL monitors direct gamma radiation to establish background radiation levels in its vicinity and to determine the environmental radiological impact of its operations. Gamma radiation results from natural background sources of terrestrial or cosmic origin and from man-made sources, such as fallout from past nuclear weapons testing and any contribution from LLNL operations.

Because environmental radiological monitoring is used as one measure of the potential direct radiation dose the public receives as the result of LLNL operations, LLNL has developed an extensive radiological monitoring network for its Livermore site perimeter, the Livermore Valley, and the Site 300 perimeter. Direct gamma radiation has been measured at the Livermore site since 1973, and a direct environmental radiation monitoring program was implemented at Site 300 in 1988. Direct gamma radiation is measured using thermoluminescent dosimeters (TLDs), which provide a measure of the total amount of gamma radiation at a particular location. Environmental neutron monitoring, which was also started in 1973, was discontinued at the end of 1994. Currently, environmental exposure to neutrons is not a concern at LLNL. However, should it become necessary for LLNL to start up operations that produce neutrons at significant levels, we are prepared to reinitiate environmental neutron monitoring. As a result of the gamma network assessment, we found that there was a significant amount of spatial correlation throughout the monitoring network. This allowed us to reduce the number of monitoring locations in 1995 while maintaining the integrity of the sampling network, See Chapter 11, *Environmental Monitoring Plan* (Tate et al. 1995).

Monitoring Locations

External doses from direct gamma radiation are monitored at 14 Livermore site perimeter locations (as shown in **Figure 12-1**), and 23 Livermore Valley locations (**Figure 12-2**). These off-site locations are used for background comparison with perimeter locations. Similarly, there are 10 perimeter monitoring locations at Site 300 (**Figure 12-3**) and two locations in the nearby City of Tracy. Six additional locations were added in 1993 in areas near Site 300 (**Figure 12-3**) as a special study. Sampling at locations 84 and 95 was discontinued after the first quarter. In 1995, LLNL discontinued sampling at some locations in the direct radiation network as a result of an assessment of the gamma radiation network.

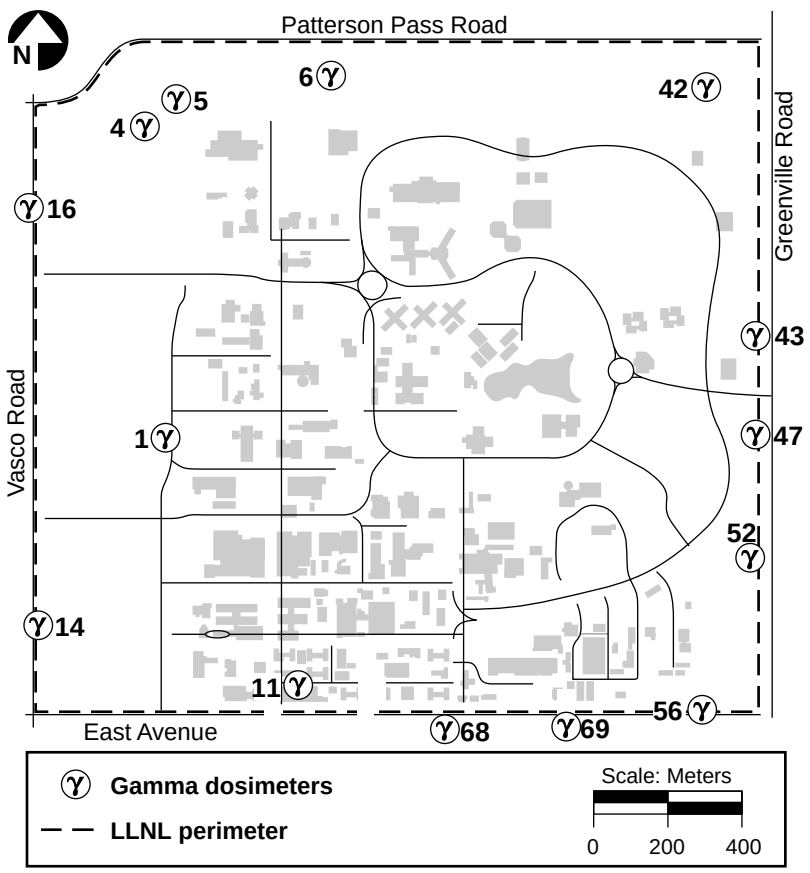

Figure 12-1. Gamma dosimeter locations, Livermore site, 1995.

Sitewide Network Assessment

In an effort to answer questions concerning apparent upward trends from the direct radiation monitoring network, we reassessed our data. We found that variations in read and anneal dates affected our overall results. As a result of this assessment, all of the quarterly data points were normalized to standard 90-day quarters, as is the practice of the Nuclear Regulatory Commission (NRC) (Struckmeyer 1994). By using the same standard-quarter reporting method, data from other DOE and NRC facilities and data from intercomparison studies can be more easily compared. As shown in **Figure 12-4**, when our data are adjusted to standard quarters, the variability in exposures that was previously reported is reduced. The adjusted doses seen at the Livermore site perimeter and the Livermore Valley are comparable and lack significant trend from 1988 to 1995. However, while Site 300 doses are similarly without trend, they continue to measure slightly higher direct gamma doses than the Livermore site and the Livermore Valley, which is expected given the differences in geology between these sites.

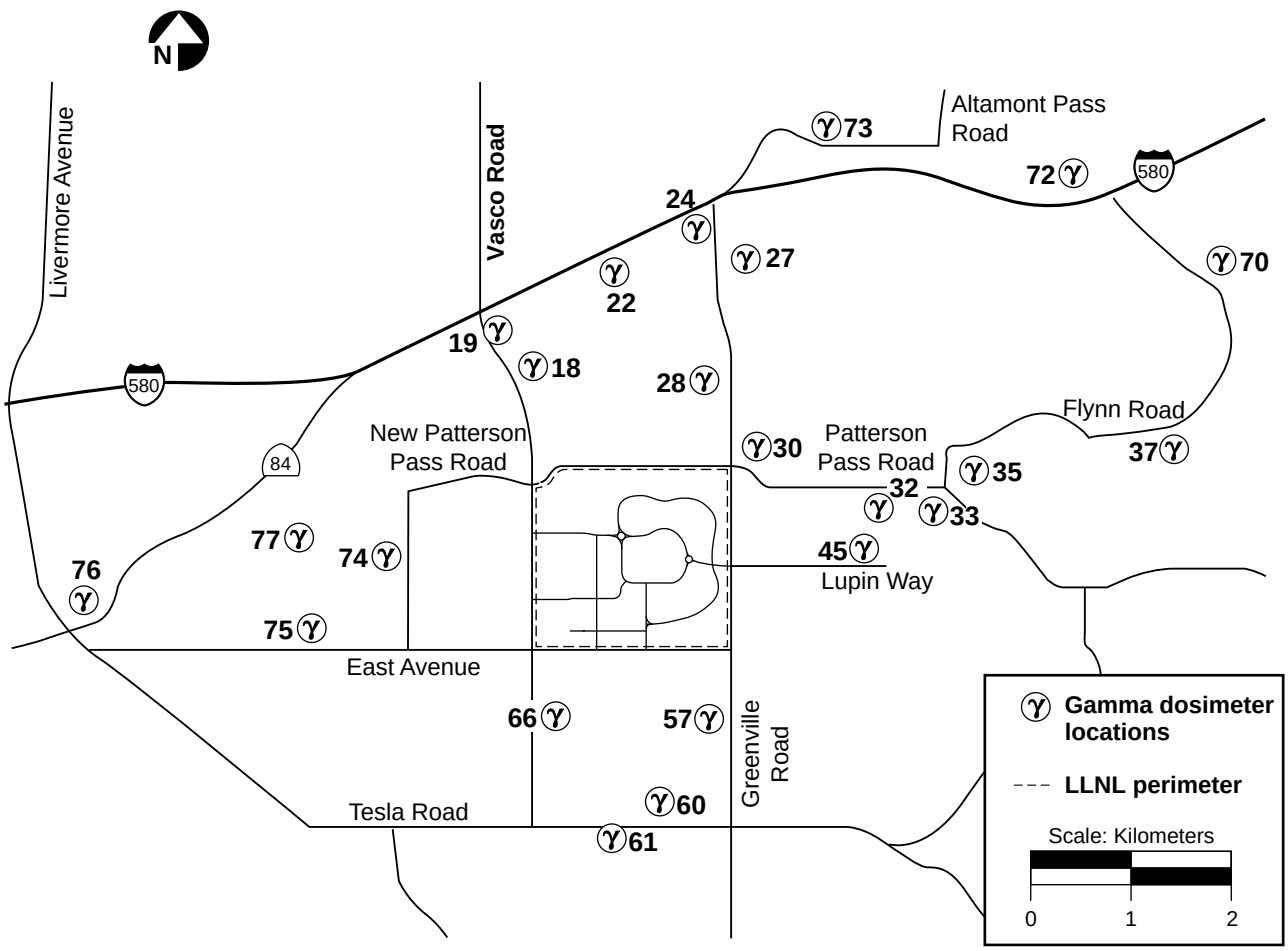

Figure 12-2. Gamma dosimeter locations, Livermore Valley, 1995.

In reviewing the trends of the standard quarter data as shown in **Figure 12-4**, it appears that seasonal variation can occur during the rainy season, most likely because of a decrease in radon emanation from the moist soil. As shown in the figure, the variation was absent during the severe drought years in Northern California (1990 – 1992) but is apparent once again when rainfall returned to normal (1994 – 1995) and above-normal levels (1993).

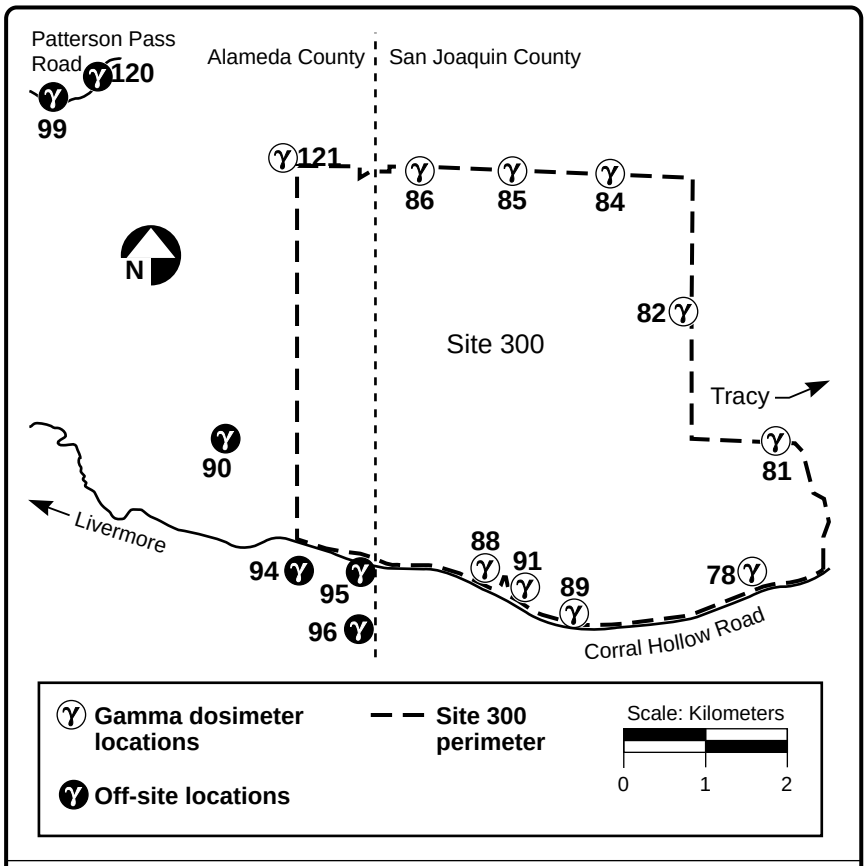

Figure 12-3. Gamma dosimeter locations, Site 300 and vicinity, 1995.

Results of Gamma Monitoring in 1994

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 1995 dose equivalent from external direct radiation exposure at the Livermore site perimeter, 0.56 mSv (56 mrem), is about the same as background external dose measured in the Livermore Valley, 0.55 mSv (55 mrem). **Table 12-2** lists the yearly doses due to direct gamma radiation at the LLNL site perimeter. The data, normalized to 90-day standard quarters, show no significant variation from year to year. **Figure 12-5** presents the frequency distribution for external radiation dose measured at 23 Livermore Valley locations. See Chapter 12, Volume 2, of this report for a discussion of methods and more comprehensive presentation of the data.

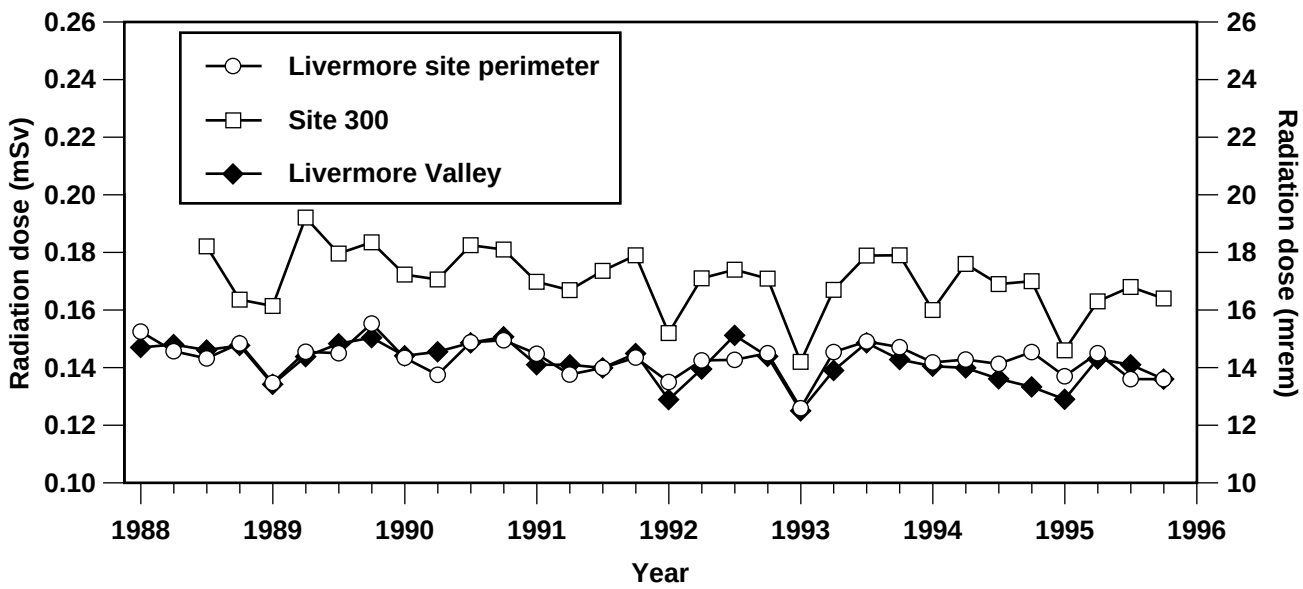

Figure 12-4. Gamma measurements at the Livermore site perimeter, Livermore Valley, and Site 300, 1988 to 1995.

Table 12-1. Summary statistics for all sites in mSv[(a)].

Quarter	Location									
	Livermore site		Livermore Valley		Site 300		Tracy		Off Site	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
First	0.137	0.015	0.129	0.010	0.146	0.012	0.130	0.012	0.158	0.016
Second	0.145	0.011	0.143	0.014	0.162	0.015	0.134	0.006	0.176	0.032
Third	0.142	0.011	0.141	0.016	0.169	0.015	0.137	0.017	0.182	0.025
Fourth	0.136	0.008	0.136	0.011	0.164	0.014	0.135	0.014	0.170	0.027
Total	0.561		0.548		0.639		0.535		0.677	

[a] 1 mSv = 100 mrem.

Table 12-2. Annual dose by year at the Livermore site perimeter due to 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

a Data normalized to standard 90-day quarters (360-day years).

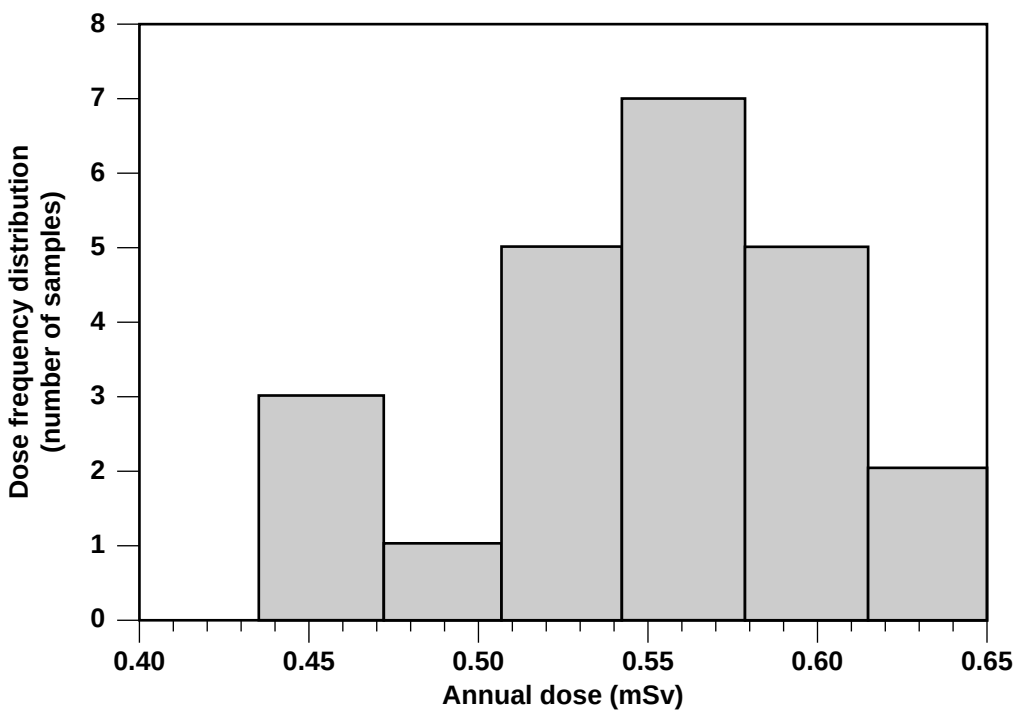

Figure 12-5. Annual direct gamma radiation dose, Livermore Valley, 1995.

Site 300

As seen in **Table 12-1**, the measured Site 300 perimeter average dose in 1995 was 0.64 mSv (64 mrem), the measured dose at the off-site locations near Site 300 was 0.68 mSv (68 mrem), and the measured doses in and near Tracy were 0.54 mSv (54 mrem). All doses are within the predicted range for background radiation, and no LLNL operational impacts are discernible.

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 Tracy locations are located on a geological substrate different from that at Site 300. The region around Site 300 has elevated levels of naturally occurring uranium, which is present in 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 0.68 mSv (68 mrem) and is greater than the Site 300 perimeter dose of 0.64 mSv (64 mrem). The Tracy area, with a dose of 0.54 mSv (54 mrem), is at a lower elevation, with geological constituents composed of alluvium deposits of clays, sands, and silts overlying the bedrock. The difference in doses can be directly attributed to the difference in geologic substrates.

Environmental Impact

Based on past measurements (Lindeken et al. 1973), environmental terrestrial (geologic) radiation doses in the Livermore Valley vary from 0.25 to 0.60 mSv/y (25 to 60 mrem/y). Cosmic radiation, as calculated for the local elevation and geomagnetic latitude according to the data of Lowder and Beck (1966), is about 0.35 mSv/y (35 mrem/y). This combination results in a typical total direct radiation dose level of 0.60 to 0.70 mSv/y (60 to 70 mrem/y); however, local geological and meteorological factors will impact these dose levels. Direct radiation doses measured at the Livermore site perimeter in 1995 are near these predicted values and are statistically equivalent to the Livermore Valley doses, which are considered natural background levels. This indicates that any dose from LLNL operations is not large enough to be seen within the wide range of natural variation in background levels in different locations.

13. Radiological Dose Assessment

Robert J. Harrach
Gretchen M. Gallegos

Introduction

Radiological doses to the public result from both natural and man-made radiation. The total dose to different populations can be determined by measurements and calculations. This chapter describes LLNL's radiological dose assessments, made to determine the impact of LLNL operations, and contains a discussion of the analyses we performed to demonstrate LLNL's compliance with the radiological National Emission Standards for Hazardous Air Pollutants (NESHAPs).

Because this report is distributed outside the scientific community, we have included a brief preliminary discussion to enable the nontechnical reader to understand more easily the radiological dose assessment information we report. For more information, see *Radiation: Doses, Effects, Risks* (U.N. Environment Programme 1985).

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 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 there is less air overhead to act as a shield, and 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 owing to 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, the production of energy, and the production of nuclear weapons. 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 nuclear reactor accident at Chernobyl in 1986 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. Nuclear decay divides into three main categories: 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, 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, which is a stable isotope.

Radioactivity can be hazardous because radiation (alpha particles, beta particles, or gamma rays) 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 naturally occurring radioactivity.

Three main factors determine the radiation-induced damage that might be caused to living tissue: the number of radioactive nuclei that are present, the rate at which they give off energy, and the effectiveness of energy transfer to the host medium, i.e., how the radiation interacts with the tissue. Alpha radiation can be halted by a piece of paper and can scarcely penetrate the dead outer layers of skin. Radioisotopes that give off alpha radiation are generally not health hazards unless they get inside the body through an open wound or are ingested or inhaled. In those cases, alpha radiation can be especially damaging because its disruptive energy can be deposited within a small distance, resulting in significant energy deposition in a few cells. Beta radiation from nuclear decay typically penetrates a centimeter or two of living tissue. It therefore deposits energy over many cells, decreasing the damage to any single cell. Gamma radiation is extremely penetrating and can pass through most materials, only being significantly attenuated 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 becquerel is one decay per second, or alternatively in curies, Ci, where 1 curie 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. This 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. 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); 1 Sv equals 100 rem. Also commonly used are the millirem (mrem) and the 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 others, so the different parts of the body are given weightings. For example, a given 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,” also expressed in rem or sievert.

The effective dose equivalent (EDE) describes doses to individuals. When individual effective dose equivalents received by a group of people are summed, the result is called the "collective effective dose equivalent" 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 effective dose equivalent and the collective effective dose equivalent.

Doses from Natural and Man-Made Radioactivity

The average radiation dose from natural sources in the United States, according to the National Council on Radiation Protection and Measurement (NCRP 1987b), 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 we ingest through food and drink, resulting in approximately 0.4 m Sv / 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 our inhalation dose is dominated by radon's short-lived decay products. **Figure 13-1** shows the distribution of annual radiation doses from natural and other common sources.

Radon dose varies significantly with geographic location. Levels several times higher than the average occur in some regions of the U.S., while at LLNL and its environs doses as low as half the average are typical. Radon gas seeps out of the earth worldwide. Radon in water and natural gas provide additional but less important sources of radon in homes. Consumption of water high in radon is not the main exposure source; a greater exposure is believed to arise from inhalation of radon in water vapor when showering. The United States Environmental Protection Agency (EPA) has instituted a major program to educate the public regarding the effects of naturally occurring radon (U.S. Environmental Protection Agency and U.S. Department of Health and Human Services 1986).

Medical treatment is the largest common source of public exposure to man-made radiation, and most of it is from medical x-rays. These contribute 0.39 mSv (39 mrem) to the average whole-body dose in the United States, but individual doses vary enormously. For example, a typical dental x-ray series results in a skin dose (not whole body) of approximately 2.5 mSv (250 mrem). Nuclear

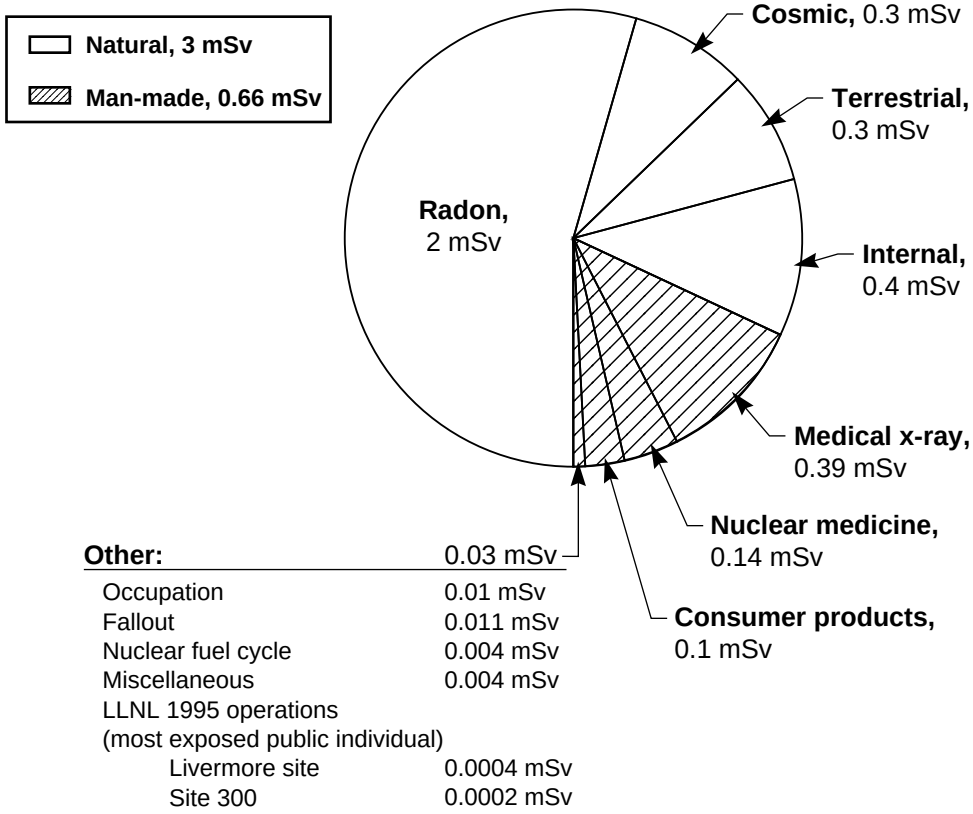

Figure 13-1. Typical annual radiation doses from natural and man-made sources (National Council on Radiation Protection and Measurements 1987b).

medicine contributes 0.14 mSv (14 mrem) to the average dose, and consumer products add 0.1 mSv (10 mrem). For a typical member of the public, radiation from medical procedures and consumer products result in a dose of approximately 0.63 mSv / y (63 mrem / y). The average dose from other man-made sources, including fallout from nuclear testing, is less than 0.03 mSv (3 mrem). As will be described in the following sections, the contributions from LLNL operations to the dose of even the most affected resident would not be discernible on the scale shown in **Figure 13-1**; these contributions are listed under "Other" in the figure, anticipating our conclusions presented near the end of this chapter.

Radiation Control Measures and Standards

Radioisotopes used at LLNL include uranium, transuranics, biomedical tracers, tritium, and mixed-fission products. This section describes control measures taken to minimize both worker and off-site exposures and presents the federal standards defining allowable radiation exposures to the public from operations at DOE facilities.

LLNL's Radiation Control Program

Protection of employees and the public from the uncontrolled release of radioactive materials into the environment is a primary consideration for LLNL. This effort consists of several stages. First, when an operation or facility is designed, 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. Facility Safety Analysis Reports and Facility Safety Procedures are written to document the need for these measures and to specify the requirements for maintenance, training, emergency response, and other administrative control measures.

Another stage of the radiation control program comes into play when a facility is occupied for use. Prior to the conduct of an operation in the facility, an Operational Safety Procedure (OSP) is written that specifies the actions to be taken in conducting a research or development project. This procedure is reviewed by environmental analysts, industrial hygienists, and health physicists. These reviews assess the safety of the operation, its compliance with current occupational health and environmental standards, and the adequacy of proposed engineering and administrative controls. The OSP also specifies training requirements for personnel performing the procedure. This part of the control program enables LLNL personnel who work with radiation and radioactivity to recognize and prevent the execution of unsafe operations.

The next stage of the radiation control program involves direct monitoring of the workplace environment. This includes sampling of the air and surfaces in facilities where radioactive materials are handled, and includes personal dosimetry and bioassay programs used to monitor potential worker exposure to direct radiation and radioactive isotopes. This monitoring program helps to determine the effectiveness of a facility's radiation control program as well as providing information on worker exposures.

Finally, the surveillance and effluent monitoring of radiation in air, water, soils, vegetation, and sewage, as discussed in Chapters 2 and 4 through 12 of this report, are an important indicator of the success of LLNL's radionuclide discharge control program in limiting exposures of the public. 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 vital that our assessments provide the best information possible regarding the radiological impact of LLNL operations.

Radiation Protection Standards

DOE environmental radiation protection standards are provided in DOE Order 5400.5, *Radiation Protection of the Public and the Environment* and federal regulation 10 CFR 835, *Occupational Radiation Protection*, which incorporate standards for controlling exposures to the public from operations at DOE facilities. These standards are based on recommendations by the International Commission on Radiological Protection (ICRP 1977, 1980) and the National Council on Radiation Protection and Measurements (NCRP 1987a). The primary DOE radiation standards for protection of the public are 1 mSv/y (100 mrem/y) effective dose equivalent for prolonged exposure, and 5 mSv/y (500 mrem/y) effective dose equivalent for occasional exposure. These limits are based on the dose to the maximally exposed individual in an uncontrolled area, and include all pathways of exposure. The limits apply to the sum of the effective dose equivalent from external radiation and the committed (50-y) effective dose equivalent from radioactive materials that may remain in the body for many years after being ingested or inhaled.

DOE and LLNL also comply with the EPA's standard for radiation protection, promulgated under Section 112 of the Clean Air Act, as amended. This EPA radiation dose standard, which applies to air emissions, is defined in Subpart H of NESHAPs under 40 CFR 61. It limits to 0.1 mSv/y (10 mrem/y) the whole-body effective dose equivalent to members of the public from DOE activities. Before December 15, 1989, the standard was 0.25 mSv/y (25 mrem/y) dose equivalent for whole-body exposures from the air pathway, and 0.75 mSv/y (75 mrem/y) dose equivalent for exposure of any organ from the air pathway.

Because the EPA standard is small and the doses caused by radionuclides released from LLNL are smaller still compared to doses from exposures to natural radioactivity, it would be difficult to prove compliance with the standard by measurements alone. EPA therefore developed computer codes that implement its approved dosimetry model and mandated that these codes be used to calculate potential doses to the public for compliance demonstrations. Calculations reported here used EPA's CAP88-PC code. As described in the following section, it is similar to previous regulatory codes but is improved and expanded. The models used in these codes to evaluate doses and risks contain conservative assumptions that are expected to result in calculated doses larger than ones actually received by members of the public.

Calculations of Radiological Dose

This section presents LLNL's methods for estimating radiological dose. It describes the CAP88-PC air dispersion and dose model, identifies principal doses and maximally exposed individuals, specifies source terms in the model runs, and presents a calculated results summary.

Description of the CAP88-PC Air Dispersion and Dose Model

EPA-mandated computer models were used to carry out our radiological dose assessments, as noted above. Early in 1992, when the CAP88-PC code became available, we began using it exclusively for our standard calculations to take advantage of the significant improvements made in the model. The CAP88-PC code was developed under an Interagency Agreement between DOE and EPA. It provides the capability to compute dose and risk to both exposed individuals and collective populations resulting from radionuclide emissions to air. The differences between CAP88-PC and earlier similar codes such as AIRDOS-PC are discussed in Appendix E of the *User's Guide for CAP88-PC, Version 1.0* (Parks 1992).

CAP88-PC uses a modified Gaussian plume equation to calculate the average dispersion of radionuclides released from up to six sources. Plume rise can be driven by momentum or buoyancy or set to a predetermined level. Flat terrain is assumed; variation in radionuclide concentrations caused by complex terrain cannot be modeled by CAP88-PC. Assessments are done for a circular grid with a radius of 80 km or less around a facility, allowing up to 20 user-selected radial distances. Concentrations and doses are sector-averaged for each area element in the sixteen 22.5° compass sectors; each area element is bounded above and below by arcs with radii from the set of user-selected distances and on its sides by radial line segments separating the sectors. The population in each area element can be set by a user-created population data input file. The mathematical models and explicit equations used in CAP88-PC are described in Chapter 8 of Parks (1992).

CAP88-PC accepts site-specific meteorological, as well as population, data files. Input data for the LLNL modeling are collected from on-site meteorological towers at both the Livermore site and Site 300. Wind speed and direction are sampled every few seconds, temperature every minute, and all are averaged into quarter-hour increments, time-tagged, and computer-recorded for conversion into a CAP88-PC wind file. Numbers specifying the annual average precipitation, temperature, and average height of the atmospheric inversion layer are also put into the model. The code automatically computes results for each of seven Pasquill-Gifford atmospheric stability categories.

CAP88-PC computes radionuclide concentrations in air, rates of deposition on ground surfaces, concentrations in food, and intake rates to people from ingestion of food produced in the assessment area. Calculated doses then include the four principal exposure pathways: internal exposures from inhalation of air and ingestion of foodstuffs and drinking water, and external exposures through irradiation from contaminated ground and immersion in contaminated air. Dose and risk are tabulated as a function of radionuclide, pathway, spatial location, and body organ. Up to 36 radionuclides can be included in a single run, chosen from a total library of 265 radionuclides. The frequency distribution of risk is tabulated, showing the number of people at various levels of risk on a logarithmic scale from 1 in 10 to 1 in 10 million. Dose and risk estimates from

CAP88-PC are applicable only to low-level chronic exposures because the health effects and dosimetric data it uses are based on low-level chronic intakes. The code is not intended for modeling either short-term or high-level radionuclide intakes. The doses are expressed as whole-body effective dose equivalents (EDEs) in units of mrem / y (1 mrem = 10 µSv = 0.01 mSv).

Because CAP88-PC does not contain all the radionuclides present at LLNL, surrogate radionuclides were used in some cases to estimate EDEs. In selecting the surrogates, we used the most restrictive lung class (whether clearance from the lungs takes place in days, weeks, or years). When possible, we used a surrogate radionuclide with similar lung class chemistry and similar values for "annual limits of intake via inhalation and derived air concentration," as specified in the EPA guidance, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion* (Eckerman et al. 1988). CAP88-PC contains a library of considerably more radionuclides than earlier regulatory codes, such as AIRDOS-PC. By rerunning calculations with CAP88-PC previously modeled with AIRDOS-PC, we have found that the use of surrogates in the calculations typically results in conservative estimates of EDEs.

Maximally Exposed Individuals and Populations

We report separate determinations of doses for the Livermore site and Site 300. Three potential doses are emphasized: (1) The dose to the sitewide maximally exposed individual member of the public (denoted as SW-MEI and defined below), which combines the effects of all emission points; (2) the maximum dose to any member of the public, in any direction (generally occurring at the site boundary and commonly referred to as the maximum "fence line" dose) due to each emission point on the site; and (3) the collective dose to the populations residing within 80 km of the Livermore site and Site 300 (treated separately), adding the products of individual doses received and the number of people receiving them. Dose to the SW-MEI (the first type above) is used to evaluate LLNL's compliance with the EPA standard limiting the total radionuclide emissions to air from DOE facilities to 100 µSv / y (10 mrem / y) (NESHAPs, 40 CFR Part 61.92, Subpart H). In this evaluation, credit is taken for any emission abatement devices, such as filters that are in place. The second type or fence line dose is calculated without taking credit for any existing emission abatement devices; it is used to evaluate the need for continuous monitoring of individual emission points under the EPA's 1-µSv / y (0.1-mrem / y) standard on potential unabated emissions (40 CFR Part 61.93).

The SW-MEI is defined as the hypothetical member of the public (individual receptor at a residence, place of business, school, church, or similar public facility) who could receive the greatest LLNL-induced EDE from all sources at a single site. At the Livermore site, the SW-MEI is located at the UNCLE Credit

Union, about 10 m outside the controlled eastern perimeter of the site. This location lies 0.95 km from LLNL's principal source of radionuclide emissions to air, the Tritium Facility (Building 331), in an east-northeast direction. At Site 300, the SW-MEI is located in an experimental area termed "Bunker 2" operated by Physics International. Bunker 2 lies about 300 m outside the east-central boundary of Site 300. This bunker is 2.4 km east-southeast of the principal source of radionuclide emissions to air at Site 300, the firing table at Building 801.

It is possible for the location of the SW-MEI to change from year to year, e.g., with changing wind patterns, changing population distributions near site boundaries, or changing emission levels of sources. An illustration of the effect of different wind patterns on dose is given in the *LLNL NESHAPs 1993 Annual Report* (Harrach et al. 1994). Four prime candidates for the SW-MEI were evaluated for the Livermore site in confirming the UNCLE Credit Union location for 1995, as described in the *LLNL NESHAPs 1995 Annual Report* (Gallegos et al. 1996).

Specification of Source Terms in the Model Runs; Point and Diffuse Sources

Emission sources of radionuclides (stacks on buildings, drums in waste storage areas, etc.) are evaluated in two ways. For unmonitored and noncontinuously monitored sources, the releases are estimated from radionuclide inventory data using EPA methods; for continuously monitored facilities, actual emission measurements are used. In this section, we discuss the determination of source terms for these monitored and inventoried facilities, as well as for areas (generally exterior to buildings) at the Livermore site and Site 300 where diffuse emissions occur. Source terms at Site 300 locations where high explosives experiments are carried out are also discussed. New dose-assessment modeling runs, using these source terms and 1995 on-site meteorological data (wind, precipitation, and temperature), were conducted this past year for each key facility and for each new emission point.

Because surface and ground waters impacted by LLNL operations and its sewer effluents are not consumed, they do not represent an ingestion or inhalation pathway for radiation exposure. Therefore, our assessment of radiological dose to the public is based solely on material that enters the environment via air releases.

Table 13-1 lists all LLNL sources having the potential to release radionuclides to air (with some exceptions noted below). The table gives the number of potential radionuclide discharge points associated with each building, lists the largest dose to a public individual due to any one of the emission points at each building, and identifies the types of operations occurring in each building. Facilities in which no operations using radionuclides took place in 1995 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 to air: stacks (on buildings containing radioactive materials management areas) and diffuse area sources.[a,b]

Bldg	Facility	Potential emission points	Maximum EDE[c] (μSv/y)	Operations
131	Engineering	4	1.8×10^{-4}	Handling, storing, machining, characterizing, assembling, sorting, and transferring materials; repackaging of waste
151	Isotope Sciences	20	4.5×10^{-7}	Chemical separation, crushing and dissolving, aliquot preparation and storage, gas analysis, radiochemical separations, preparation of radioactive counting standards
166	Pyrochemistry Demonstration Facility	1	0.0[d]	Conversion of uranium to halides and oxides
175	Laser Isotope Separation	6	0.0[d]	Cleaning and refurbishing of uranium parts
177	Laser Isotope Separation	4	6.5×10^{-5}	Sample preparation, cleaning and refurbishing of parts, processing uranium oxide powders
194	Physics & Space Technology	3	2.5×10^{-4}	Accelerator
212	Physics & Space Technology	2	8.0×10^{-11}	Environmental, safety, and health surveillance for shutdown of accelerator
222	Chemistry & Materials Science	21	1.7×10^{-3}	Radioanalytical analyses and tracer use
224	Chemistry & Materials Science	4	4.8×10^{-4}	Waste samples analysis
226	Chemistry & Materials Science	2	5.8×10^{-9}	Radioactive and mixed waste chemical analyses
227	Chemistry & Materials Science	5	2.4×10^{-6}	Uranium bonding and testing
231	Mechanical Engineering	16	1.3×10^{-2}	Materials research and testing, plastics shop work, electron-beam welding
	Mechanical Engineering Vault	1	0.0[d]	Storage, handling, and shipping of radionuclides
235	Chemistry & Materials Science	10	2.7×10^{-7}	Welding, actinide and uranium catalyst research
241	Chemistry & Materials Science	7	3.5×10^{-9}	Materials development, measurement, and testing
251	Heavy Elements			Heavy-element research
	Hardened area	4	0.0[d]	
	Unhardened areas	37	1.5×10^{-4}	
253	Hazards Control	12	5.5×10^{-9}	Radiochemical analyses
254	Hazards Control	5	5.6×10^{-11}	Radiochemical analyses of bioassays
255	Hazards Control	2	1.0×10^{-4}	Instrument calibration
281	Chemistry & Materials Science	9	5.0×10^{-9}	Preparation and storage of radiochemical stock solutions
292	Physics & Space Technology	3	7.3×10^{-5}	Tritium contamination from prior operations
298	Laser Fusion	2	1.3×10^{-4}	Handling and assembly of tritium-filled targets, sputtering uranium
321	Materials Fabrication	5	4.2×10^{-6}	Machining

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Table 13-1. Sources of radiation dose from LLNL releases to air: stacks (on buildings containing radioactive materials management areas) and diffuse area sources[a,b] (continued).

Bldg	Facility	Potential emission points	Maximum EDE[c] (μSv/y)	Operations
322	Mechanical Engineering	1	8×10^{-8}	Cleaning and plating of depleted uranium
327	Mechanical Engineering	1	1.3×10^{-8}	Nondestructive ultrasonic material evaluation
331	Tritium	2	1.7×10^{-1}[d]	Decontamination and decommissioning operations
332	Plutonium	6	0.0[d]	Machining and metallurgy
361	Biological Research	24	1.1×10^{-5}	Radiolabeling; biological dosimetry; DNA sequencing, hybridization, and repair; human genome; enzyme assay; radioactive probes
362	Biological Research	1	2.2×10^{-7}	Dose preparation for animal experiments
363	Biological Research	1	1.9×10^{-5}	Dispensing samples
364	Biological Research	2	6.3×10^{-5}	DNA labeling; isolation and purification
365	Biological Research	1	6.4×10^{-12}	Housing research animals
366	Biological Research	2	2.5×10^{-8}	DNA sequencing; metabolization
378	Environmental Research	2	1.5×10^{-9}	Environmental analysis
381	Laser Fusion	1	2.7×10^{-13}	Tritium handling for laser target research
391	NOVA Laser	1	2.8×10^{-4}	Vaporization of targets
412 W	Health and Ecological Assessment Division	1	2.3×10^{-12}	Sample preparation for measurement of Ni-59 and Ni-63
419	Hazardous Waste Management	2	9.8×10^{-4}[d]	Decontamination and decommissioning
490	Laser Isotope Separation	4	0.0[d]	U.S. Enrichment Corporation operations
491	Laser Isotope Separation	1	0.0[d]	U.S. Enrichment Corporation operations
513	Hazardous Waste Management	3	3.8×10^{-7}	Drum repacking and sludge stabilization
514	See diffuse sources below			
801	Site 300 Firing Table at 801	—[e]	1.2×10^{-1}	Detonation of explosives
851	Site 300 Firing Table at 851	—[e]	8.2×10^{-2}	Detonation of explosives
	Livermore site diffuse sources[f]	6	See next six entries below	Storage areas and contaminated ground
292	Physics & Space Technology	1	1.3×10^{-6}	Tank leakage area
331	Tritium	1	5.9×10^{-2}	Outdoor waste accumulation area
419	Hazardous Waste Management	1	4.6×10^{-4}	Pipe removal as part of tank project
514	Hazardous Waste Management	1	7.2×10^{-3}	Waste treatment and storage

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Table 13-1. Sources of radiation dose from LLNL releases to air: stacks (on buildings containing radioactive materials management areas) and diffuse area sources[a,b] (concluded).

Bldg	Facility	Potential emission points	Maximum EDE[c] (μSv/y)	Operations
	Livermore site diffuse sources[f] (continued)			
612	Hazardous Waste Management	1	1.4×10^{-1}	Waste storage
—	Southeast quadrant of Livermore site	1	9.4×10^{-3}	Contaminated ground
	Site 300 diffuse sources[f]	6	See next six entries below	Contaminated ground and water
—	Pit 7 Complex	1	3.5×10^{-4}	Contaminated ground and purge water
802	Site 300	1	6.2×10^{-7}	Contaminated ground
850	Site 300	1	6.2×10^{-5}	Contaminated ground
851	Site 300	1	2.1×10^{-7}	Contaminated ground
—	Well 8 Spring	1	1.4×10^{-6}	Contaminated spring water
—	Full Site 300 area	1	2.6×10^{-2}	Contaminated ground

a *LLNL NESHAPs 1995 Annual Report* (Gallegos et al. 1996).

b RMMAs in which no operations using radionuclides took place in 1995 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 effective dose equivalent to the sitewide maximally exposed individual member of the public (SW-MEI) from a single discharge point, among all discharge points modeled for the indicated facility or building. The SW-MEI is defined in the section on Maximally Exposed Individuals and Populations.

d The effluents from the facility are monitored. Zeroes refer to monitored values below the limit of sensitivity, as discussed in the Monitored Facilities section.

e Open air dispersal in 1995.

f Diffuse sources are described briefly in the section on specifications of source terms, and more fully in the *LLNL 1995 NESHAPs Annual Report* cited in footnote a.

Monitored Facilities

The continuously monitored facilities at LLNL are Buildings 166, 175, 231 Vault, 251, 331, 332, 419, 490, and 491. In 1995 a new sampling system was installed at Building 166, the Pyrochemistry Demonstration Facility, as described in the *LLNL NESHAPs 1995 Annual Report* (Gallegos et al. 1996). Most of the monitored facilities show emission levels below the minimum detection limit (MDL), primarily because of the use of multiple-stage, high-efficiency particulate air (HEPA) filters in all significant release pathways. The efficiency of a single-stage HEPA filter is 99.97%. Double-stage filter systems are in place on some discharge points. Triple-stage HEPA filters are used on glove box ventilation

systems in the Building 332 Plutonium Facility and in a portion of Building 251. In 1995, samples from three emissions points at two of the monitored facilities, Buildings 251 (unhardened section) and 419, yielded results for gross alpha radioactivity greater than the MDL on a majority of the samples collected throughout the year. For a discussion of these results see Chapter 5, Air Effluent Monitoring, in the section entitled "Results: Measured Emissions."

Dose calculations based on actual monitoring data are expected to be more accurate than those using assumptions based on inventory data, physical state release fractions, and emission-control factors. Among the nine continuously monitored facilities at the Livermore site, most do not require monitoring under the EPA 1 μSv/y (0.1 mrem/y) standard. Nonetheless, all of these facilities are continuously monitored for programmatic and other reasons. For example, continuous monitoring is maintained at Building 331 (the Tritium Facility) to provide the most direct and accurate measure of its release of tritium to the atmosphere, even though the EDEs we calculate from measured unabated emissions are below the 1 μSv/y (0.1 mrem/y) level (see **Table 13-1**). As other examples, continuous monitoring is maintained at Building 332 and the hardened portion of Building 251 in lieu of undertaking a modeling and measurement effort that would be required to demonstrate that monitoring is not needed.

Beyond the stack effluent monitoring, site-specific surveillance air monitors are placed in the vicinity of diffuse emission sources on site, such as those (described below) associated with Buildings 292, 331, 514, and 612 and in and around the southeast quadrant of the Livermore site. These special monitors measure the concentrations of radionuclides present in the air near the sources and allow a direct determination of their environmental impact.

Monitoring showed that the amount of radioactivity released from LLNL during 1995 was slightly less than in 1994 and was below the range of earlier years (see Chapter 5; especially **Table 5-3** and **Figure 5-2**).

Inventoried Sources

For unmonitored or noncontinuously monitored facilities, we relied on inventories, together with EPA-specified fractions for potential release to air of materials in different physical states (solid, liquid, powder, or gas), in accordance with 40 CFR Part 61, Subpart H, Appendix D. Use of the state-dependent potential release fraction adjusts (by multiplication) the total annual inventory to give conservative potential annual release to air. If the material was an unconfined gas, then the release fraction 1.0 was used; for liquids and powders, 1.0×10^{-3} was used; and for solids, 1.0×10^{-6} was used. In addition, credit was

taken for radionuclide emission control devices when calculating total dose for evaluation under the 10 mrem / y (100 μSv / y) EPA standard; e.g., EPA allows an emission-reduction factor of 1.0×10^{-2} for each stage of HEPA filtration. However, emissions were assumed to be unabated for evaluations under the 1 μSv / y (0.1 mrem / y) EPA standard for required continuous monitoring.

For 1995, we updated the radionuclide inventories in our Livermore site key facilities, defined as those on a ranked list that contributed to 90% of the 1994 Livermore site radiological dose to members of the public. We also inventoried all RMMAs that began operations in 1995. Inventory forms, accompanied by detailed guidance for completing them, were provided to all of these facilities, filled out by experimenters, and certified by facility managers.

Explosive Tests at Site 300

Modeling releases to the atmosphere from explosive tests at Site 300 requires special attention 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 promptly forms over the firing table, and disperses as it is carried downwind. (The uranium does not contribute to the explosive energy, which is entirely of chemical origin.) In the absence of measurements of the properties of the cloud, we assume for modeling purposes that it 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. Isotopic ratios for depleted uranium are used. The masses of the three uranium isotopes with atomic weights 238, 235, and 234 (occurring in depleted uranium in the weight-percentages 99.8, 0.2, and 5×10^{-4}, respectively) are multiplied by their respective specific activities to get the total number of curies for each isotope in the cloud.

LLNL's modeling of these Site 300 explosive tests to determine the resultant off-site doses is based on the CAP88-PC code. CAP88-PC simulates each explosive experiment or shot as a low-level, steady-state (year-long), stack-type emission occurring over flat terrain with meteorological data appropriate to annual average conditions at Site 300. An alternative modeling methodology that treats these transient explosive events as short-duration puffs, and that incorporates some of the effects of the hilly terrain at Site 300, was submitted for approval in 1992 (*LLNL NESHAPs Project Quarterly Progress Repor*t, Biermann et al. 1993), but LLNL was directed by EPA to use the CAP88-PC code for these calculations despite the recognized difficulties.

Several conservative assumptions are made in the absence of detailed data: (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 micrometer; (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 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.

Diffuse Sources

Another category of sources requiring special attention is diffuse emissions, including fugitive emissions. Diffuse, or nonpoint, sources often are difficult to quantify. Presently, methods of dose calculations associated with them are left to the discretion of each DOE facility; LLNL reviewed a second draft of proposed EPA guidance on this topic in 1994.

Four different modeling approaches were used for diffuse sources at LLNL's Livermore site in 1995. Elevated tritium levels in soil moisture near Buildings 292 and 419 required a calculation of the source term and the use of CAP88-PC. Estimated releases from tritium-contaminated equipment outside Building 331 were derived from measurements of surface contamination, process and facility knowledge, and environmental surveillance measurements. Radioactive wastes stored in the Building 612 Yard required environmental surveillance data to estimate emissions. For Building 514, which houses the Hazardous Waste Management tank farm for waste processing and storage, radiological-inventory data were used with standard CAP88-PC modeling techniques. Direct ambient air monitoring of plutonium in surface soils in the southeast quadrant of the Livermore site provided data on which to base dose calculations.

Diffuse sources at Site 300 involve tritium and uranium. Their evaluation was based on data provided in the *Final Site-Wide Remedial Investigation Report Lawrence Livermore National Laboratory Site 300* (Webster-Scholten 1994), where potential routes of tritium and uranium migration from soil to air were identified and evaluated. These radionuclides were components of the explosives assemblies tested on the Site 300 firing tables over many years. Five diffuse sources of tritium (the Pit 7 Complex, Well 8 Spring, and ground areas associated with Buildings 802, 850, and 851) were characterized.

Our method of calculating the diffuse source dose from the resuspension of depleted uranium in soil at Site 300 relies on air emissions monitoring. We have revised our method to eliminate the contribution of naturally occurring uranium to the measured values and to eliminate double-counting due to experiments that occurred during monitoring periods. Descriptions of each diffuse source at the two sites and the assumptions made regarding their emissions are given in the *LLNL NESHAPs 1995 Annual Report* (Gallegos et al. 1996).

Calculated Results Summary—Livermore Site and Site 300, 1995

Table 13-1, as discussed earlier, summarizes the sources of the radiation dose from airborne radionuclides emitted by routine LLNL operations in 1995. In particular, the number of potential discharge points at each facility is given along with the largest EDE value from any one discharge point at each facility. Corresponding information is given for Site 300 facilities and for the diffuse sources at both sites, again referring to releases during routine operations. There were no unplanned atmospheric radionuclide releases at either the Livermore site or Site 300 in 1995.

Table 13-2 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 accounted for approximately 93% of the total EDE resulting from Livermore site operations and nearly 100% of the total EDE from Site 300 operations. The dominant radionuclide(s) are indicated for each facility. Tritium accounted for about 90% of the Livermore site dose, and uranium (principally uranium-238) for most of the remaining 10%. At Site 300, practically the entire dose was due to the isotopes uranium-238, -235, and -234 that make up depleted uranium.

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. In contrast to previous years when we assumed that all food was locally produced, in 1995 we specified an agricultural option in CAP88-PC in which milk is imported while the remainder of the food is still produced locally. We found that when we used this assumption with the meteorological conditions and source emission characteristics at LLNL in 1995, ingestion remained the most important pathway in the case of tritium, and inhalation was still most important for uranium. However, the numbers changed: Ingestion contributed 82% of the dose for tritium and inhalation accounted for 97% of the dose for uranium, versus 86% and 89%, respectively, under the previous assumptions. For both uranium and tritium, external doses from air immersion and ground irradiation were negligible.

Table 13-2. Major contributors to LLNL's radiation dose via airborne emissions, 1995.

Facility or operation[a]	Dominant radionuclide(s)	EDE at SW-MEI[b]	
		μSv/y	mrem/y
Livermore site			
B331/Tritium Facility	^{3}H	0.17	0.017
B612 Yard Area[c]	^{3}H	0.14	0.014
B331 Exterior[c]	^{3}H	0.059	0.0059
B231	^{238}U, ^{234}U, ^{235}U	0.014	0.0014
Sum of other sources	Various	0.03	0.003
Total		**0.41**[d]	**0.041**[d]
Site 300			
B801/firing table	^{238}U, ^{234}U, ^{235}U	0.12	0.012
B851/firing table	^{238}U, ^{234}U, ^{235}U	0.082	0.0082
Soil resuspension[c]	^{238}U, ^{234}U, ^{235}U	0.026	0.0026
Total		**0.23**[d]	**0.023**[d]

a The facilities cited here are discussed in the text of this report and in more detail in the 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 on each facility. The sitewide maximally exposed individual member of the public (SW-MEI) is defined in the section on Maximally Exposed Individuals and Populations.

c Diffuse sources (see text).

d These Livermore site and Site 300 totals represent 0.4% and 0.2%, respectively, of the federal standard.

Maximum Dose to an Individual Member of the Public

The calculated EDE to the SW-MEI at the Livermore site in 1995 was 0.19 μSv (0.019 mrem) from point source emissions and was 0.22 μSv (0.022 mrem) from diffuse source emissions. Summing these contributions yields a total dose of 0.41 μSv (0.041mrem) for the Livermore site in 1995—46% from point sources, 54% from diffuse sources. The leading contributors to dose were 41% of the total from the two 30-m stacks at the LLNL Tritium Facility (Building 331), 34% from the Building 612 Yard diffuse source, and 14% from the Building 331 Waste Accumulation Area. No other source contributed more than 3% to the dose.

The total dose to the SW-MEI at Site 300 during 1995 was calculated to be 0.23 μSv (0.023 mrem). Explosive tests at the Building 801 and Building 851 firing tables accounted for all of the point source dose of 0.20 μSv (0.020 mrem), while a source representing resuspension of LLNL-contributed uranium in surface soils throughout the site was responsible for nearly all of the diffuse sources total of 0.03 μSv (0.003 mrem).

Table 13-3 shows the dose values from firing table experiments for 1990 through 1995, correlated with the total amounts of depleted uranium and the total quantity (TNT-equivalent) of high explosives used in the experiments. (Only experiments that included depleted uranium are considered; most have none.) The data show that variations from year to year in these doses mainly reflect differences in the amount of depleted uranium used in the tests.

Table 13-3. Annual dose to the SW-MEI from explosives experiments on firing tables at Site 300, 1990–1995, related to the total quantity of depleted uranium used in the experiments and the total quantity of high explosives (HE) driving the detonations.

Year	Dose to SW-MEI (μSv)	Dose to SW-MEI (mrem)	Total depleted U used in experiments (kg)	Total HE used in depleted U experiments (kg)
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

The trends in dose to the SW-MEI from emissions at the Livermore site and Site 300 over the last 6 years are shown in **Figure 13-2** and **Table 13-4**. The levels of public exposure indicated in this figure and table are well below the EPA standard, which limits the whole-body air-pathway EDE to members of the public from DOE activities to 100 μSv / y (10 mrem / y).

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. As noted earlier, CAP88-PC evaluates the four principal exposure pathways for releases to air: ingestion through food and water consumption, inhalation, air immersion, and irradiation by contaminated ground surface.

Population distributions centered on the two LLNL sites were compiled from 1990 census data. Our population data files, specifying the distribution of population with distance and direction, are tabulated in the *LLNL NESHAPs 1995 Annual Report* (Gallegos et al. 1996) Key population centers affected by LLNL

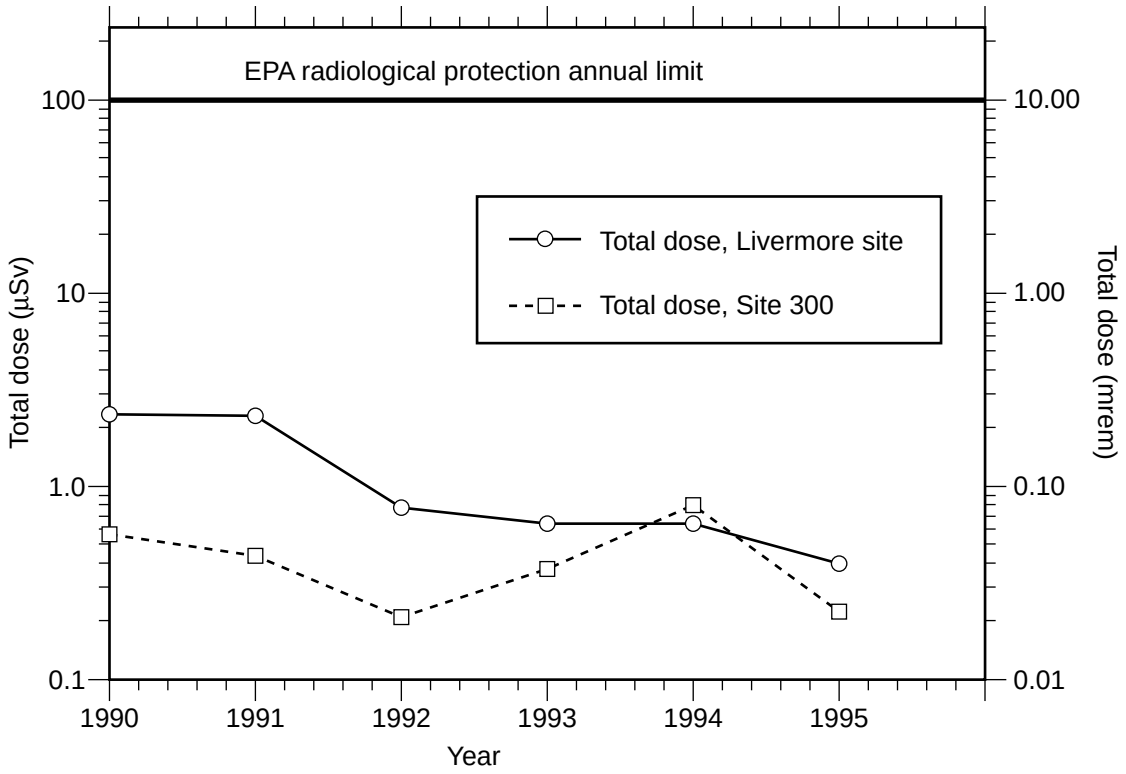

Figure 13-2. Dose to the sitewide maximally exposed individual member of the public, 1990 to 1995.

emissions are the relatively nearby communities of Livermore and Tracy, and the more distant metropolitan areas of Oakland, San Francisco, and San Jose, as well as the San Joaquin Valley communities of Modesto and Stockton. Within the 80-km outer distance specified by the EPA, there are 6.3 million residents included for the Livermore site collective dose determination, and 5.4 million for Site 300. (Because the two sites are separated by 24 km, some of the residents are common to both determinations.)

The collective EDE due to 1995 Livermore site operations was 0.0059 person-Sv (0.59 person-rem), of which 0.0038 person-Sv (0.38 person-rem), or 64%, was from point-source emissions and the remaining 36% from diffuse sources. This value is slightly less than the 1994 result of 0.0076 person-Sv (0.76 person-rem). The corresponding collective EDE from Site 300 operations in 1995 was 0.077 person-Sv (7.7 person-rem), composed of 0.72 person-Sv (7.2 person-rem), or 94%, due to point-source emissions, and 0.005 person-Sv (0.5 person-rem) from diffuse-source emissions. The total collective EDE value is less than half the 1994 value of 0.17 person-Sv (17 person-rem) but is very similar to the 1993 value of 0.069 person-Sv(6.9 person-rem). Year-to-year differences result primarily

Table 13-4. Doses (in µSv) calculated for the site-wide maximally exposed individual for the Livermore site and Site 300, 1990 to 1995.

Year	Total dose	Point source dose	Diffuse source dose
Livermore site			
1995	0.41	0.19	0.22
1994	0.65	0.42	0.23
1993	0.66	0.40	0.26
1992	0.79	0.69	0.10
1991	2.34	—[a]	—[a]
1990	2.40	—[a]	—[a]
Site 300			
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	—[b]
1991	0.44	0.44	—[b]
1990	0.57	0.57	—[b]

[a] Diffuse source doses were not reported separately from the total dose for the Livermore site for 1990 and 1991.

[b] No diffuse emissions were reported at Site 300 for years prior to 1993.

from differences in the amount of high explosives used in experiments at Site 300. In 1995, our more realistic treatment of the Site 300 diffuse-source contribution from resuspension of uranium in the soil lowered the population dose by about 0.02 person-Sv (2 person-rem).

The larger collective dose (vis-à-vis individual dose to the SW-MEI) for Site 300 relative to that for the Livermore site is traceable primarily to our highly conservative assumptions used in modeling the Site 300 explosives experiments. As described in the section above on "Explosive tests at Site 300," these assumptions concern especially the height and trajectory of the explosive-debris cloud, the fraction of radioactive material that is aerosolized, and the lung clearance class assumed for inhaled material. For example, the scaling laws used to set initial conditions for the explosive debris cloud typically give cloud heights of about 200 m and diameters of about 20 m. Calculations show that such highly elevated, large clouds are readily carried long distances to reach population centers downwind, compared to emissions from even the large stacks at LLNL's Tritium Facility, which have 30-m stack heights and stack diameters of order 1 m.

We note that the diffuse sources influence the individual dose to the SW-MEI more than they impact the population dose. The reason is the relatively less dynamic nature of the diffuse-source emissions, originating low to the ground at low initial velocity, producing peak concentrations near the site.

Summary and Conclusion

The annual radiological dose from all emissions at the Livermore site and Site 300 in 1995 was found to be well below the applicable standards for radiation protection of the public, in particular the NESHAPs standard for DOE facilities, which limits total annual emissions of radionuclides to the ambient air to 100 μSv / y (10 mrem / y). Using EPA-mandated computer models, actual LLNL meteorology, and population distributions appropriate to the two sites, the dose to the maximally exposed public individual was found to be 0.41 μSv (0.041 mrem) from Livermore site emissions and 0.23 μSv (0.023 mrem) from Site 300. The major radionuclides accounting for the doses were tritium at the Livermore site and the three isotopes in depleted uranium (^{238}U, ^{235}U, and ^{234}U) at Site 300.

The collective effective dose equivalent or population dose for LLNL 1995 operations was calculated to be 0.0059 person-Sv (0.59 person-rem) from Livermore site operations and 0.077 person-Sv (7.7 person-rem) from Site 300. 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.

Table 13-5 compares the individual and collective radiation doses from atmospheric emissions at LLNL to other sources of radioactivity to which the U.S. population is exposed. The dose to the maximally exposed member of the public resulting from Livermore site and Site 300 operations is seen to be about 8000 times smaller the doses from background radiation (see also **Figure 13-1**), and the population dose from LLNL operations is about 200,000 times smaller than those caused by natural radioactivity in the environment.

We conclude that the potential radiological doses from LLNL operations were well within regulatory standards and very small compared to doses normally received by these populations from natural background radiation sources, even though highly conservative assumptions were used in the determinations. Thus, the maximum credible doses show that LLNL's use of radionuclides had no significant impact on public health during 1995.

Table 13-5. Comparison of background and LLNL radiation doses, 1995.

Location/Source	Individual dose[a]		Population dose[b]	
	(μSv)	(mrem)	(person-Sv)	(person-rem)
Livermore site sources				
Atmospheric emissions	0.41	0.041	0.0059	0.59
Site 300 sources				
Atmospheric emissions	0.23	0.023	0.077	7.7
Other sources[c]				
Natural radioactivity[d,e]				
Cosmic radiation	300	30	1,900	190,000
Terrestrial radiation	300	30	1,900	190,000
Internal (food consumption)	400	40	2,500	250,000
Radon	2000	200	12,500	1,250,000
Medical radiation (diagnostic procedures)[e]	530	53	3,300	330,000
Weapons test fallout[e]	11	1.1	68	6,800
Nuclear fuel cycle	4	0.4	25	2,500

a For LLNL sources, this dose represents that experienced by the sitewide maximally exposed individual 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 From National Council on Radiation Protection (NCRP 1987).

d These values vary with location.

e This dose is an average over the U.S. population.

14. Compliance Self-Monitoring

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Introduction

Unlike other chapters in this annual report, which describe mostly voluntary monitoring efforts that focus on potential impacts to the local community and environment, this chapter focuses on the monitoring of specific waste streams as required by regulatory permits as well as site influent and effluent waste streams. The monitoring methods range from sampling a specific process waste stream at the point of discharge to visual inspection of operational conditions of the waste stream. The type of monitoring depends on the waste stream and the applicable regulatory requirements. Since LLNL implements process controls to prevent the release of significant quantities of pollutants and to minimize waste, the volume of the waste streams and potential impacts are usually modest compared to commercial or industrial standards.

Discharges of Treated Ground Water

LLNL operates five treatment facilities (TFA, TFB, TFC, TFD, and TFF) for Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) cleanup of ground water at the Livermore site (see **Figure 14-1**). Self-monitoring is required at the point of discharge from each treatment facility to verify performance and effectiveness. Ground water contamination at the Livermore site and Site 300 resulted from past hazardous materials handling and disposal practices and leaks and spills both prior to and during LLNL operations. LLNL addresses CERCLA compliance issues. LLNL also assesses the impact of releases on the environment and determines the restoration activities needed to reduce contamination and thereby protect human health and the environment. Restoration activities include soil removal, ground water treatment, and closure of inactive facilities in a manner designed to prevent further environmental contamination.

Additional detail on specific treatment processes is contained in both the *LLNL Ground Water Project 1995 Annual Report* (Hoffman et al. 1995) and the *LLNL Site 300 Ground Water Monitoring Program Quarterly Reports* (Christofferson 1995a, 1995b, 1995c, 1996a). The self-monitoring activities and compliance sampling results that LLNL performs specifically for compliance with environmental discharge parameters are described below.

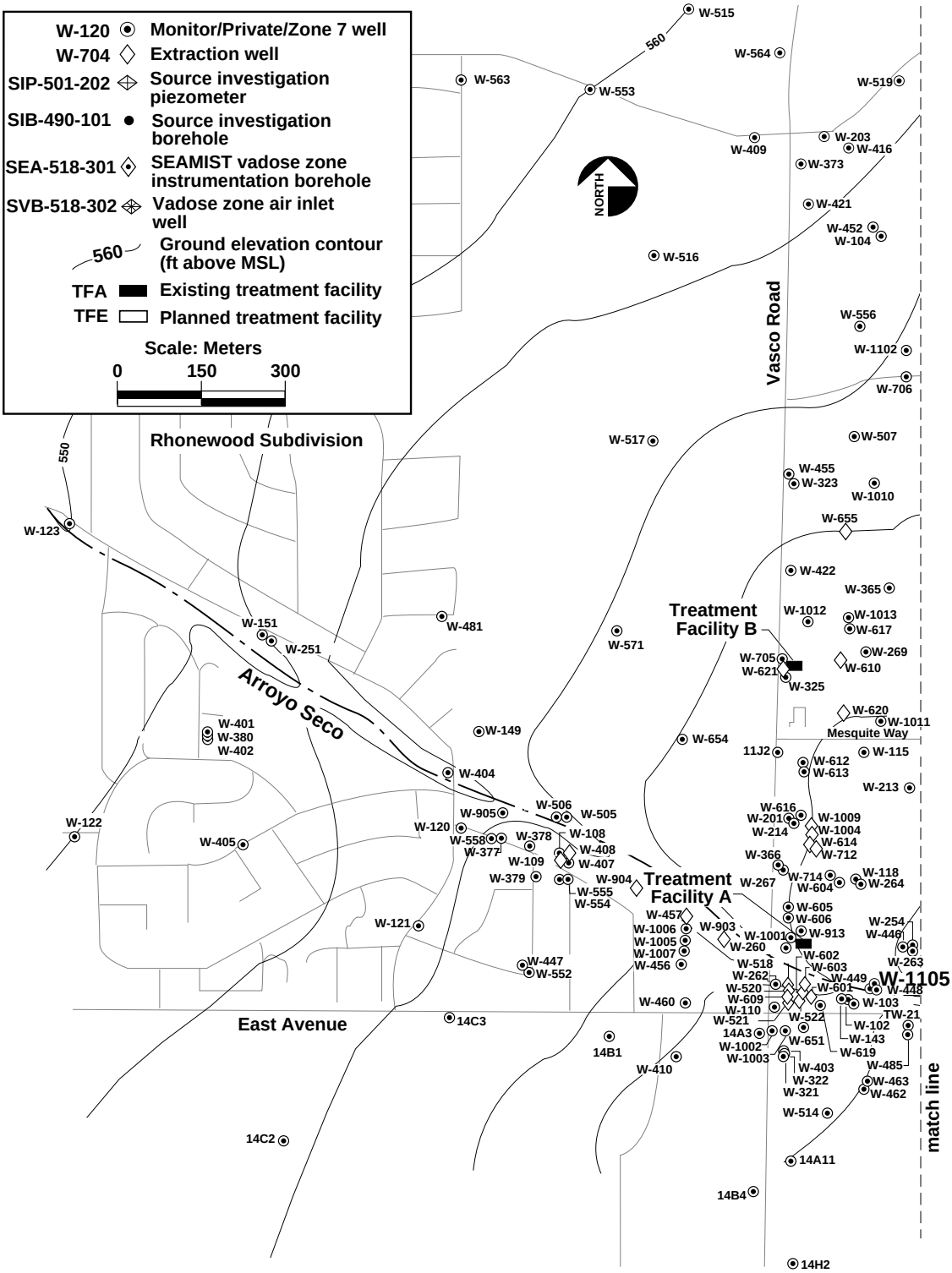

Figure 14-1. Livermore site location map for monitor wells, piezometers, extraction wells, and treatment facilities, December 1995.

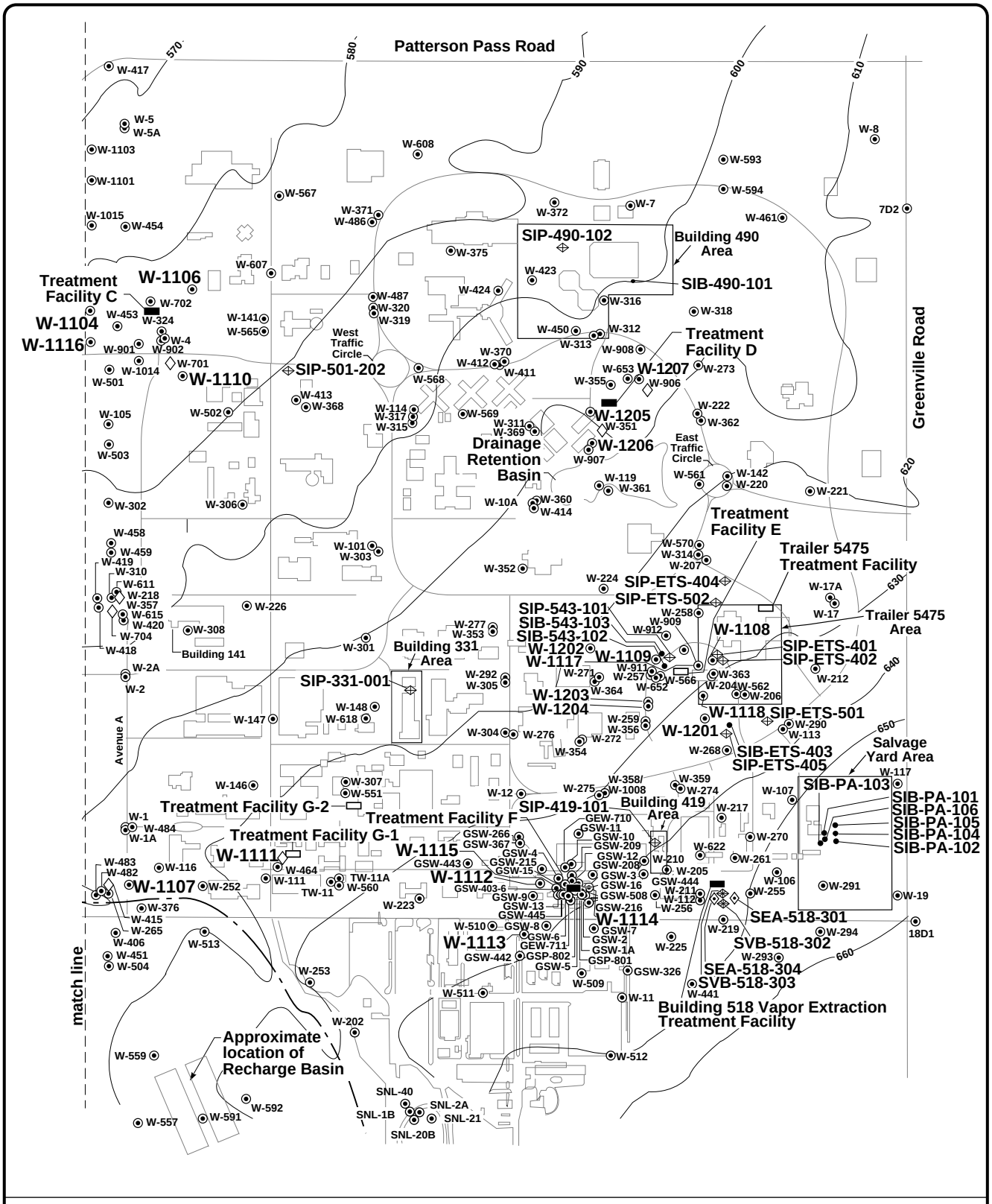

Figure 14-1. (continued).

Treatment Facility A

Treatment Facility A (TFA) is located in the southwestern part of LLNL near Vasco Road. At TFA, volatile organic compounds (VOCs) are removed from ground water using a vapor extractor with granulated activated-carbon canisters.

Western off-site plumes at TFA were hydraulically captured in 1995 (**Figures 14-2** and **14-3**). Ground water was pumped from W-415 from January through July at an average rate of 189 liters per minute (L / min). Eight wells south of TFA provided an additional average flow rate of 378 L / min via the TFA South Pipeline.

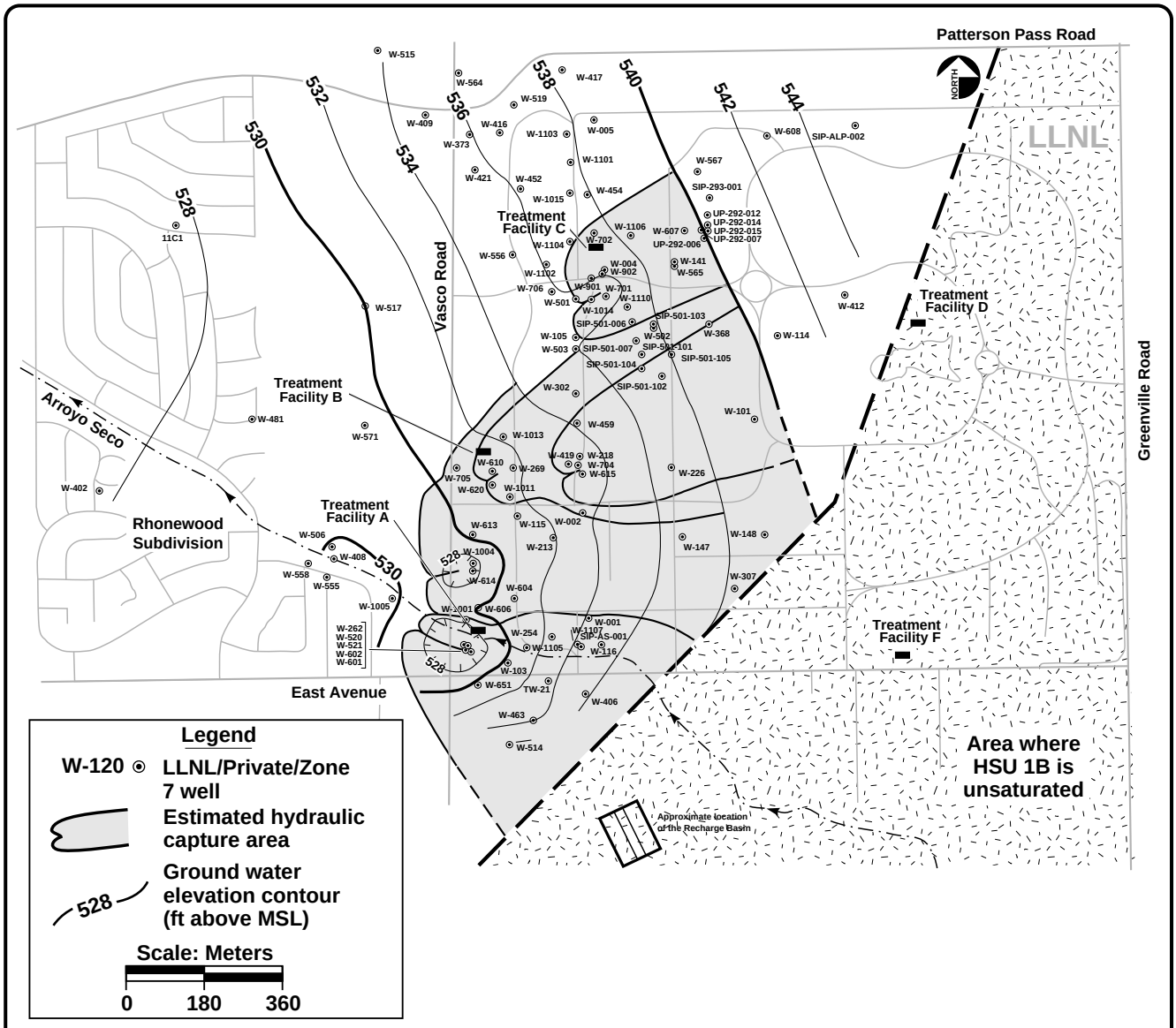

Figure 14-2. Ground water elevation contour map based on 107 wells completed within HSU 1B and estimated HSU 1B hydraulic capture areas, LLNL and vicinity, November 1995.

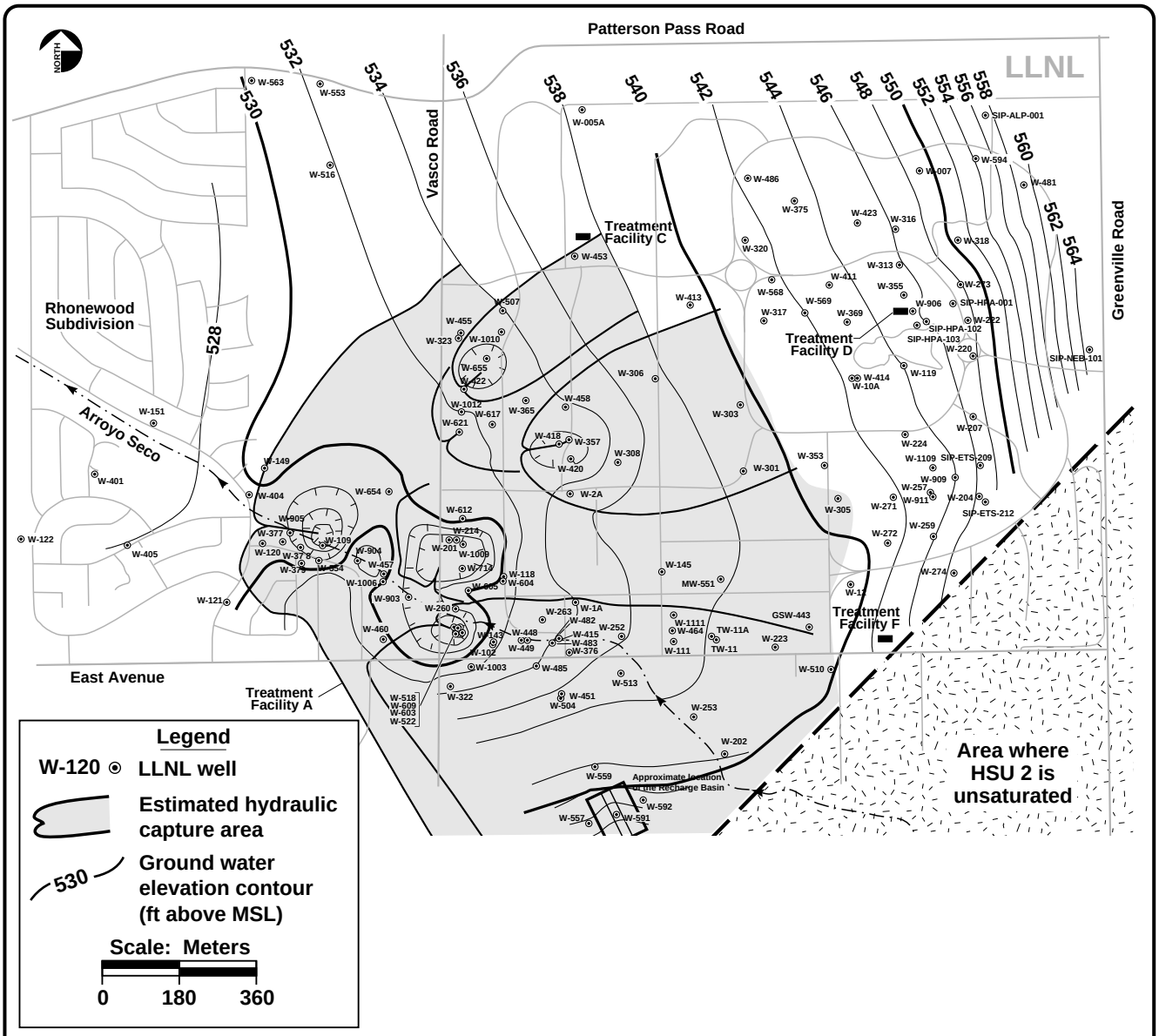

Figure 14-3. Ground water elevation contour map based on 127 wells completed within HSU 2 and estimated HSU 2 hydraulic capture areas, LLNL and vicinity, November 1995.

The TFA North Pipeline was completed in July, and pumping began from extraction wells W-614, W-712, W-1004, and W-1009 (**Figure 14-1**) at an average combined flow rate of 189 L/min. Arroyo Pipeline extraction wells W-109 and W-408 were pumped at an average flow of about 170 L/min in 1995. Three new Arroyo Pipeline extraction wells (W-457, W-903, and W-904), located west of Vasco Road, were activated in October 1995 and were fully operational in April 1996. With completion of the four TFA pipelines, the TFA well field has the ability to extract about 1136 L/min, which would exceed the TFA design capacity of 757 L/min.

In December 1995, TFA was shut down for facility modifications designed to increase the maximum flow rate. Under a new air permit issued by the Bay Area Air Quality Management District (BAAQMD), TFA can treat up to 3785 L/min. The regional water quality control boards and remedial project managers agreed to the treatment of up to 1325 L/min.

During 1995, more than 273 million liters (ML) of ground water containing VOCs was processed at TFA. All treated ground water was discharged to the Recharge Basin, located about 610 m southeast of TFA. Based on monthly influent concentrations and flow data, about 12 kg of VOCs was removed during 1995. Between system startup in 1989 and 1995, TFA has processed nearly 643 ML of ground water and removed about 58 kg of VOCs from the subsurface.

Waste Discharge Requirement (WDR) No. 88-075 requires a sampling program for this facility (**Table 14-1**). Self-monitoring analytical results of TFA effluent samples indicate that the VOC discharge limit of 5 parts per billion (ppb) was exceeded on August 2, 1995, August 16, 1995, and November 29, 1995, with results of 5.1, 5.3, and 5.5 ppb, respectively.

Treatment Facility B

Treatment Facility B (TFB) is located along Vasco Road just north of Mesquite Way (**Figure 14-1**). Similar to TFA, TFB processes ground water contaminated with chromium and VOCs using a combination of UV/H_2O_2 treatment and air-stripping technologies. During 1995, construction of the TFB North Pipeline was completed, and the pipeline was activated on September 5, 1995. This pipeline connects wells W-610, W-620, W-621, and W-655 to TFB. These wells add an additional 95 L/min, increasing the total flow to TFB to about 189 L/min. The facility discharges the treated water into a north-flowing drainage ditch along Vasco Road. Maintenance of the drainage ditch was completed in August before the flow was increased in September.

During 1995, about 40 ML of ground water was extracted from wells W-357, W-704, W-610, W-620, W-621, and W-655 and treated at TFB. The total mass of VOCs removed was about 3.4 kg. Between system startup in 1991 and 1995, TFB processed 127 ML of ground water and removed about 12.4 kg of VOCs from the subsurface.

National Pollutant Discharge Elimination System (NPDES) Permit No. CA0029289 and WDR No. 91-091 governs the operation of TFB and imposes sampling requirements (**Table 14-2**). Self-monitoring analytical results of TFB effluent samples indicate that the VOC discharge limit of 5 ppb was not exceeded. Metals concentrations were all in compliance with discharge limits, except for hexavalent chromium (Cr [VI]), which reached a high of 78 ppb.

Table 14-1. Treated ground water discharge limits identified in WDR Order No. 88-075 for TFA.

Constituent	Discharge limit[a]
Metals (μg/L)	
Antimony	1460
Arsenic	500
Beryllium	0.68
Boron	7000
Cadmium	100
Chromium (III)	1700×10^3
Chromium (VI)	500
Copper	2000
Iron	3000
Lead	500
Manganese	500
Mercury	20
Nickel	134
Selenium	100
Silver	500
Thallium	130
Zinc	20,000
Volatile organic compounds (μg/L)	
Total volatile organic compounds	5
Acid extractable organic compounds (μg/L)	
2,4-Dimethylphenol	400
Phenol	5
2,4,6-Trichlorophenol	5
Base/neutral extractable organic compounds (μg/L)	
1,4-Dichlorobenzene	5
Naphthalene	620
Phenanthrene	5
Pyrene	5

[a] These limits are instantaneous maximum values.

Table 14-2. Treated ground water and Drainage Retention Basin discharge limits identified in WDR Order No. 91-091 for outfalls at locations CDBX, TFB, TFC, and TFD.

Constituent	Discharge limit
Metals (μg/L)	
Antimony	1460
Arsenic	20
Beryllium	0.7
Boron	7000
Cadmium	5
Chromium (total)	50
Chromium (VI)	11
Copper	20
Iron	3000
Lead	5.6
Manganese	500
Mercury	1
Nickel	7.1
Selenium	100
Silver	2.3
Thallium	130
Zinc	58
Organics (μg/L)	
Volatile organic compounds (total)	5
Benzene	0.7
Tetrachloroethene	4
Vinyl chloride	2
1,2-Dibromoethane	0.02
Total petroleum hydrocarbons	50
Polynuclear aromatic hydrocarbons	15
Base/neutral and acid extractable compounds and pesticides	5
Physical	
pH	6.5–8.5
Toxicity	
Aquatic survival bioassay (96 hours)	90% survival median, 90 percentile value of not less than 70% survival

Tests have shown that hexavalent chromium can be reduced to trivalent chromium by adding 20 to 25 ppm of hydrogen peroxide, lowering the pH of ground water to about 7, and then increasing the residence time prior to air stripping. The pH of ground water is lowered by adding carbon dioxide after it comes out of the UV reactor. Necessary changes have been made in the facility to enable the continuous addition of carbon dioxide and provide a reaction tank in the flow path of the ground water between the UV reactor and the air stripper. The low concentration of hydrogen peroxide in the effluent meets fish toxicity requirements.

Treatment Facility C

Treatment Facility C (TFC) is located in the northwest quadrant of LLNL and employs air-stripping and ion-exchange technologies to process ground water contaminated with VOCs and chromium. The ion-exchange resin was regenerated seven times and replaced once in 1995. A polyphosphate additive is now being used to control calcium carbonate scale in the TFC piping. No major repairs or upgrades were performed on the system during 1995.

In 1995, the design of the TFC North Pipeline was completed. This pipeline will convey water from monitoring/extraction Wells W-1015, W-1102, W-1103, W-1104, and W-1116 to TFC (**Figure 14-1**). Construction of the pipeline is expected to be completed by mid-1996.

During 1995, TFC processed about 22 ML of ground water extracted from Well W-701 at an average flow rate of about 57 L/min. The total VOC mass removed during 1995 was about 2.7 kg. Between system startup in October 1993 and 1995, TFC processed about 32 ML of ground water and removed about 3.8 kg of VOCs.

LLNL conducted samplings at TFC in compliance with WDR No. 91-091 requirements. The self-monitoring analytical results of TFC effluent samples indicate that the VOC discharge limit of 5 ppb was not exceeded during 1995. All regulated metals parameters were below discharge limits designated in the WDR No. 91-091 requirements.

Treatment Facility D

Treatment Facility D (TFD) is located in the northeast quadrant of LLNL and uses air-stripping and ion-exchange technologies to process contaminated ground water (**Figure 14-1**).

TFD processed water from extraction wells W-351 and W-906 (**Figure 14-1**) during most of 1995. Because nickel concentrations exceeded the 7.1 ppb NPDES discharge limit, we were constrained from using extraction well W-907.

In January 1995, TFD discharged about 665,000 L of treated ground water into the Drainage Retention Basin. On January 30, treated water was temporarily diverted past the Drainage Retention Basin into an underground pipe that discharges into the Arroyo Las Positas. In February 1995, injection of polyphosphate at 10 ppm or less to control calcium carbonate scale began. To avoid loading additional phosphates into the Drainage Retention Basin, TFD water was permanently diverted to the underground pipe on May 18, 1995. However, the capability to discharge to the basin still exists.

During 1995, TFD processed about 8 ML of ground water containing VOCs. The combined flow rate from wells W-351 and W-906 averaged about 32 L/min. The total VOC mass removed during 1995 was about 5.8 kg. Between system startup in September 1994 and 1995, about 8 ML of ground water has been treated, removing about 6.1 kg of VOCs.

LLNL conducted samplings at TFD in accordance with WDR No. 91-091 requirements. The self-monitoring analytical results of TFD effluent samples indicated that metals and VOC, were within compliance discharge limits during 1995.

Treatment Facility F

Treatment Facility F (TFF) is located in the southeastern portion of LLNL (**Figure 14-1**). Prior to remediation, significant fuel hydrocarbon contamination existed in the vadose zone and in the ground water and saturated sediments in hydrostratigraphic units 3A and 3B. Only low levels of VOCs were found within the hydrocarbon plume. An extensive VOC plume exists in the TFF area in HSUs-4 and -5 extending from B-518 southwest onto SNL/California property.

A series of remedial actions were implemented at TFF beginning in 1988 for the remediation of the hydrocarbon contamination in the vadose zone and HSU-3 ground water. In 1993, TFF was used as a research site in support of the DOE-sponsored Dynamic Stripping Research Project, which removed approximately 28,388 L of gasoline from the TFF soil and HSU-3 ground water.

In 1995, chemical analyses of vadose sediment samples from pilot boreholes of two new TFF wells clearly indicated the absence of residual fuel hydrocarbons (FHCs) in the vadose zone. Based on these results and the exponential decline of recovered hydrocarbons in extracted vapors, treatment of the vadose zone at TFF was discontinued with the consent of the regulatory agencies in August 1995.

During 1995, ground water was extracted and treated at TFF for 5 months, during business hours only. Ground water extraction ceased at TFF on April 18, 1995, for a 6-month biodegradation study, and restarted on October 17. The treatment facility was again shut down on December 8 because of storm damage. With regulatory concurrence, extraction and treatment of the residual

dissolved FHCs in the HSU-3 ground water has been discontinued in favor of a passive bioremediation approach. We submitted a draft Containment Zone (CZ) report for the hydrocarbon-contaminated ground water zone in the TFF area to the regulatory agencies in early 1996.

TFF treated and discharged to sanitary sewer approximately 5.3 ML of ground water in 1995 from extraction wells GEW-808 and GEW-816, which contained a volume-weighted average FHC concentration of about 1323 ppb. This is equivalent to about 11 L of liquid gasoline. In addition, TFF extracted about 40,000 cubic meters (m^3)of vapor from extraction wells GEW-808, GEW-816, and GSW-16, containing a volume-weighted FHC concentration of about 20 parts per million by volume (ppmv), about 2.8 L of liquid gasoline. The total liquid-equivalent of gasoline removed from the TFF subsurface during 1995 was about 14 L.

The sampling requirements for TFF discharges are: quarterly sampling for benzene, ethyl benzene, toluene, and xylene (BETX; EPA Method 624) and annual sampling for total toxic organic compounds (EPA Methods 624 and 625), metals, and inorganic compounds. **Table 14-3** shows the BETX sampling results; no result was above the detection limit. Annual sample results for total toxic organics, sampled on November 15, 1995, showed no detections for all reportable organic compounds (detection limit is 0.01 mg/L). Annual metals sample results for National Pollutant Discharge Elimination System (NPDES) metals (EPA Method 200) are shown in **Table 14-3**. No results were found above discharge limits. Annual total cyanide sample results (EPA Method 335.2) for the year, sampled on November 15, 1995, showed no detections at the reporting limit of 0.020 mg/L. The LWRP permit limit for cyanide is 0.040 mg/L.

Sitewide Treatability Testing

LLNL's ground water discharge permit allows ground water from hydraulic tests and VOC treatability studies to be discharged to the City of Livermore sanitary sewer. Permit No. 1510G (1995–1996) allows discharges of ground water to the sanitary sewer in compliance with **Table 14-3** effluent limitations taken from the Livermore municipal code. During 1995, discharges were associated with treatability testing performed at TFD. Ground water was sampled and released to the sanitary sewer, all in compliance with metals, total toxic organic, and self-monitoring permit provisions.

Total ground water discharged to the sanitary sewer during this annual period was 129,000 L.

Table 14-3. Treatment Facility F self-monitoring sampling results.

Constituent	Sample date (1995)	Concentration (μg/L)	Effluent limitations[a] (μg/L)
BETX (total)	February 9	<10	250 (LWRP permit)
	No discharge	---	
	No discharge	---	
	October 25	<10	
Metals[a]	November 15		
Arsenic		<2	60
Cadmium		<0.5	140
Copper		<10	1000
Chromium (total)		<10	620
Lead		<2.0	200
Mercury		1.5	10
Nickel		<5.0	610
Silver		<0.5	200
Zinc		<200	3000
Cyanide	November 15	<20	40
Toxic organics (total)	November 15	<10	1000

a From Section 13.32.100 of the Livermore Municipal Code.

Site 300 Central and Eastern General Services Area Treatment Facilities

Since 1993, a ground water treatment system has been in operation at Site 300 as a CERCLA Removal Action. This system is located at the Experimental Test Facility in the central General Services Area (GSA) in the vicinity of Building 875. Following dewatering of bedrock through ground water extraction, soil vapor extraction and treatment was initiated in July 1994 . During 1995, 830,620 L of ground water was extracted and treated, and a total of 19.3 kg of VOCs was removed from ground water and soil vapor by the central GSA system. Monthly self-monitoring sample requirements are listed in **Table 14-4**.

Since June 1991, a ground water extraction and treatment system has been operating in the eastern GSA as a CERCLA Removal Action. During 1995, 73.4 ML of ground water containing 724 g of VOCs was extracted and treated by the eastern GSA system. Monthly self-monitoring requirements for GSA water treatment system effluent samples are listed in **Table 14-4**.

Table 14-4. General Services Area ground water treatment system effluent limitations.

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	≥5.0 mg/L	≥5.0 mg/L
pH	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 conditions more than 3°C	No alteration of ambient conditions more than 3°C
Place of discharge	Surface water drainage course in eastern GSA canyon	Corral Hollow Creek
Flow rate (30-day average daily dry weather maximum discharge limit)	328,320 L	273,600 L
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—method detection limit of 0.5 µg/L EPA Method 602—method detection limit of 0.3 µg/L	EPA Method 601—method detection limit of 0.5 µg/L

The central GSA is operating under Substantive Requirements for wastewater discharge issued by the Central Valley Regional Water Quality Control Board (RWQCB). The central GSA treatment facility discharges to bedrock in the eastern GSA canyon, where the water percolates to the surface. The eastern GSA operates under NPDES permit No. CA0082651, WDR 91-052 issued by the Central Valley RWQCB for discharges into Corral Hollow Creek. Both the central and eastern GSA treatment systems operated in compliance with regulatory requirements during 1995.

Site 300
Building 834
Treatment Facility

The ground water and soil vapor extraction treatment facility at Building 834 was significantly modified during 1995. Modifications were performed in accordance with Site 300 CERCLA Removal Action requirements. This facility was designed to treat VOCs extracted from soil and ground water by air sparging and soil venting, with carbon absorption to remove VOCs from offgas streams. Additional modifications to the facility were identified as a result of a spring 1994 Proof-of-System test (POS1), and a second test in the winter of 1995 (POS2). Influent ground water concentrations ranged from 60 to 100 parts per million (ppm) total VOCs during both tests. Despite a substantial increase in the aggressiveness of sparging and recirculation, trichloroethene (TCE) permeated into polymeric components during the initial phase of water treatment in POS1.

During the sparging process, TCE slowly diffused from the polymeric material back into the water as the concentration gradient shifted, greatly slowing the removal of VOCs at concentration, near the discharge limits.

All polymeric components were eliminated from the influent side of the treatment facility. Numerous components were salvaged from LLNL Salvage and dismantled equipment from Building 834. The facility also incorporates additional liquid-phase carbon filtration following the two sparging stages to ensure complete removal of the tetrabutyl orthosilicate (TBOS) present in substantial amounts (<100 ppm) in the influent ground water. Once ground water is treated to the permit standards, it is discharged by air-misting towers located east of the treatment facility.

The modified facility was tested in February 1995 and successfully demonstrated removal of VOCs and TBOS. Additional equipment was installed in fiscal year 1995 to support automated operation, continuous gas-phase monitoring, and remote inspection of facility status. The treatment facility was constructed with modularity in mind so that experimental treatment apparatus could be readily incorporated for direct comparison with the baseline sparging and carbon filtration approach.

During 1995, while modifications were being made, no ground water was treated or discharged from this facility. Continuous, full-scale ground water treatment was begun on October, 30 1995. Final operating substantive requirements granted by the Central Valley RWQCB are expected to be issued in 1996. **Table 14-5** lists the CERCLA substantive requirements for this removal action.

Table 14-5. Site 300 Building 834 ground water treatment effluent limitations.

Parameter	Building 834 Treatment Facility
VOCs[a]	
Maximum daily (per compound)	5.0 µg/L
Monthly median	0.5 µg/L
pH	Between 6.5 and 8.5
Location discharge	Treated effluent will be discharged by air misting east of Building 834.
Total petroleum hydrocarbons	
Daily maximum contaminant level	100 µg/L
Monthly median	50 µg/L
Flow rate (30-day average daily dry weather maximum discharge limit)	7580 L
Mineralization	Mineralization must be controlled to no more than a reasonable increment
Methods and detection limits	
VOCs	Method EPA 601/602[b]
TBOS	Modified EPA Method 8015, discharge limit = 100 µg/L[c]

a The sum of VOC concentrations in a single sample shall not exceed 5.0 µg/L.

b Confirmatory VOC identifications were sometimes required during treatment facility characterization, and EPA 624 analyses were requested in addition to the EPA 601/602 analyses.

c Detection limits for TBOS are currently ~100 µg/L by a modified EPA 8015 procedure.

Storm Water Runoff

Storm water contacts a large number of potential pollution sources and has the potential to disperse contaminants across broad areas. For this reason, comprehensive sampling and analysis of storm water discharges is not a practical means of isolating and controlling pollutant releases. To evaluate the overall impact of Livermore site and Site 300 operations on storm water quality, samples are taken of the integrated storm water flows where they leave the site. These samples, described in Chapter 7, provide information used to evaluate the effectiveness of LLNL's pollution control program. The monitoring requirements in NPDES permits, under which storm water is discharged, require that LLNL conduct effluent sampling, wet and dry season observations, and annual facility inspections to assure that the necessary management measures are implemented and are adequate. The goals of the industrial activity storm water monitoring program are to:

- Demonstrate compliance with permit requirements.

- Aid in implementing the Storm Water Pollution Prevention Plan (SWPPP) (Eccher 1994).
- Measure the effectiveness of the Best Management Practices (BMPs) in removing pollutants in storm water discharges.
- Ensure that storm water discharges are in compliance with the discharge prohibitions, effluent limitations, and receiving water limitations as specified in the permits.
- Ensure that practices at the facility to control pollutants are evaluated and revised to meet changing conditions.

The storm water compliance monitoring program includes:

(1) Annual facility inspections conducted by each Directorate.

(2) Sampling and analysis of storm water from two qualifying storm events for pH, total suspended solids (TSS), total organic carbon (TOC), specific conductance, toxic substances, and other pollutants that are likely to be in storm water discharges in significant quantities.

(3) Visual observations at storm water discharge points and areas with high potential for storm water pollution during the dry and wet seasons.

(4) Annual reporting to the appropriate regional water quality control boards.

(5) Analysis of samples collected at several influent locations to provide background information. These influent samples are only collected at the Livermore site.

Under the WDR Order No. 95-174 for the Livermore site and WDR Order No. 94-131 for Site 300, visual inspections of the storm drainage system are required monthly during the wet season, when significant storm events occur, and twice during the dry season to identify any dry weather flows. During the wet weather observations, LLNL noted floatables, evidence of debris (mostly leaves and twigs with some litter) washing from the site, and cloudy water from the heavy sediment load carried in the storm water at both the Livermore site and Site 300. Dry weather observations at the Livermore site noted that water flowed in Arroyo Las Positas all year. In previous years, Arroyo Las Positas only flowed during rain events. This water was traced to two sources: natural flow of water from off site that entered LLNL property at the ALPO influent location and permitted discharges from ground water treatment facilities. Dry weather inspections at Site 300 showed no indication of nonstorm water flows discharging from the site.

Each LLNL directorate inspected its facilities to verify that the BMPs identified in the LLNL's Storm Water Pollution Prevention Plans were in place, properly implemented, and adequate. LLNL implements BMPs at construction sites and at facilities that use significant materials (as defined by the storm water regulations) to prevent storm water from being contaminated. The results of the inspections indicated LLNL facilities were in compliance with the requirements of the SWPPPs and the provisions of the NPDES permits. LLNL submits an annual storm water monitoring report to the San Francisco Bay RWQCB and the Central Valley RWQCB reporting the results of sampling, observations, and inspections.

LLNL also meets the storm water compliance monitoring requirements that are authorized under the California General Construction Activity Storm Water Permit for construction projects disturbing 2 hectares of land or more. Monitoring for these construction projects included visual observation of sites before and after storms to assess the effectiveness of implemented BMPs. Using the monitoring results, LLNL determined whether or not it was necessary to modify these practices to accomplish better storm water runoff protection. Two Livermore construction sites were inspected during 1995, Building 132 and the MWMF/DWTF project area. LLNL made only minor changes to the BMPs implemented at MWMF/DWTF project area. Minor changes were also made to smaller projects located in environmentally sensitive areas. These changes included modifying the placement of straw bales and adding silt fences where needed to minimize sediment in runoff. As required by the California General Construction Activity Storm Water Permit, the construction manager annually certifies compliance with the Storm Water Pollution Prevention Plan and the requirements of this general permit.

Livermore Site Drainage Retention Basin

The Drainage Retention Basin (DRB) (**Figure 14-4**) can hold approximately 53 ML (43 acre-feet) of water. The DRB was lined in March 1992 after remedial action studies indicated that infiltration of storm water from the basin was a cause of increased dispersal of ground water contaminants. When the basin lining was completed, LLNL adopted the *Drainage Retention Basin Management Plan* (The Limnion Corporation 1991).

The focus of the management plan was to implement a long-term biological monitoring and maintenance program and to address water quality problems by bioremediation and by reducing the nutrient load. The management plan identified two water sources to fill and maintain the level of the DRB. The primary source was water generated from ground water treatment units and discharged to the basin through the existing storm water collection system or piped directly to the DRB. The secondary water source was storm water runoff. During 1995, storm water runoff was the only DRB water source.

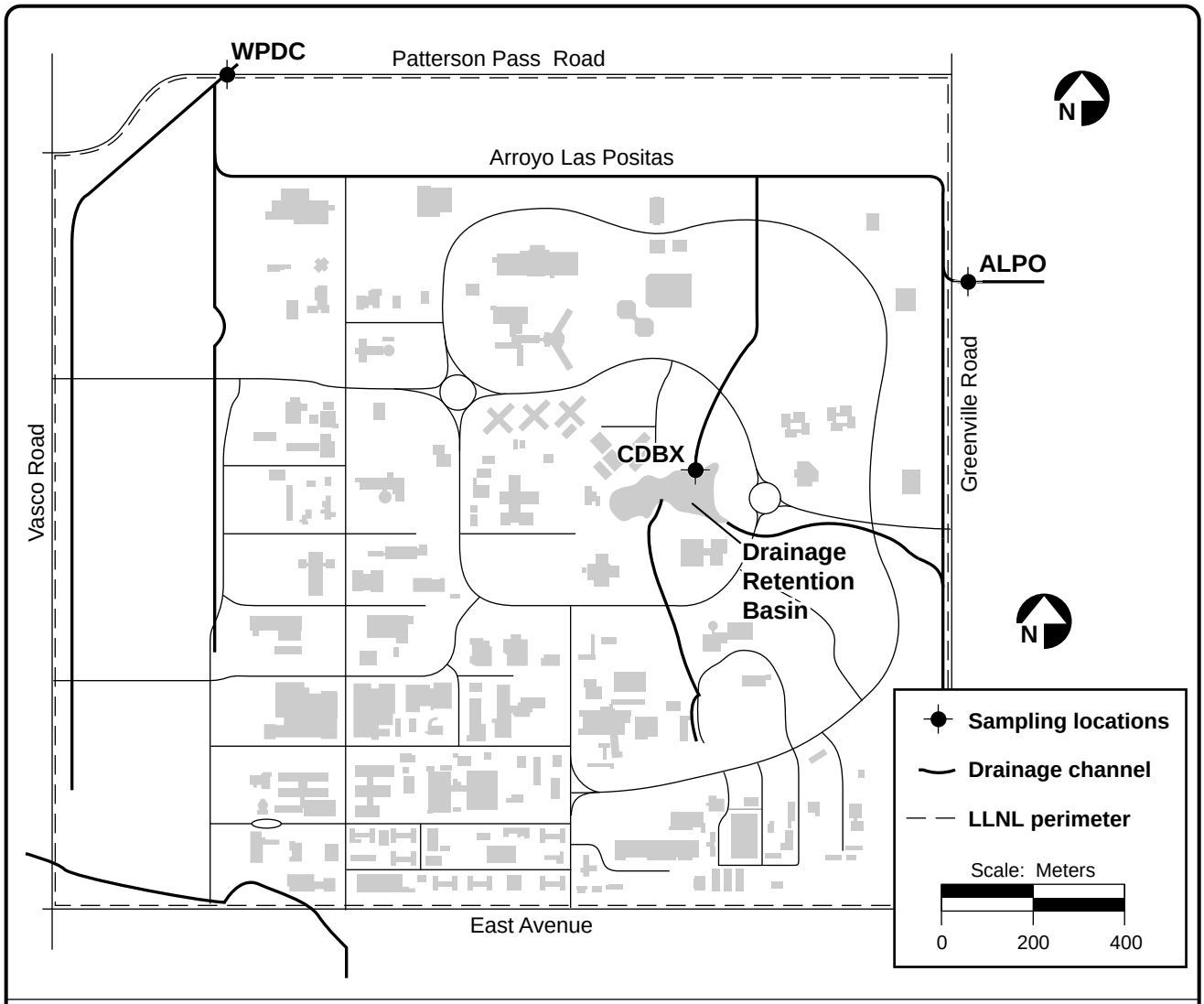

Figure 14-4. Sampling locations to monitor compliance with waste discharge permit.

The San Francisco Bay RWQCB regulates discharges from the basin under WDR Order No. 91-091, NPDES Permit No. CA0029289, and the Livermore site CERCLA Record of Decision. WDR Order No. 91-091 and the CERCLA Record of Decision establish discharge limits for all remedial activities at the Livermore site. In 1992, LLNL developed a sampling program for the DRB, which was approved by the San Francisco Bay RWQCB. The sampling program consists of sampling discharges from the DRB (location CDBX) and the site storm water outfall (location WPDC; **Figure 14-4**) during the first release from the DRB and a minimum of one additional storm (chosen in conjunction with storm water runoff monitoring). Samples are taken at the DRB outfall (CDBX) to determine compliance with WDR Order No. 91-091. Additional sampling at the site storm

water outfall monitoring location at Arroyo Las Positas (WPDC) is done to identify the change in water quality as the DRB discharges travel through the LLNL storm water drainage system and leave the site. Effluent limits established in WDR 91-091 for discharges from the DRB are found in **Table 14-2**.

By agreement with the San Francisco Bay RWQCB, LLNL reports quarterly on the routine weekly, monthly, quarterly, semiannual, and annual monitoring of the basin as specified in the *Drainage Retention Basin Management Plan* (The Limnion Corporation 1991) to meet water quality management objectives. Sampling to determine whether water quality maintenance objectives are met is conducted at several points within the DRB. Water at eight locations (**Figure 14-5**) is sampled for dissolved oxygen and temperature. Sampling during the 1992–1993 wet season was also conducted at all these monitoring locations for all other monitoring parameters. However, because there was evidence of limited variability between sampling locations for all parameters except dissolved oxygen and temperature, all sampling locations except CDBE located at the middle depth of the DRB were eliminated starting March 31, 1993. The routine maintenance parameters are identified in **Table 14-6**.

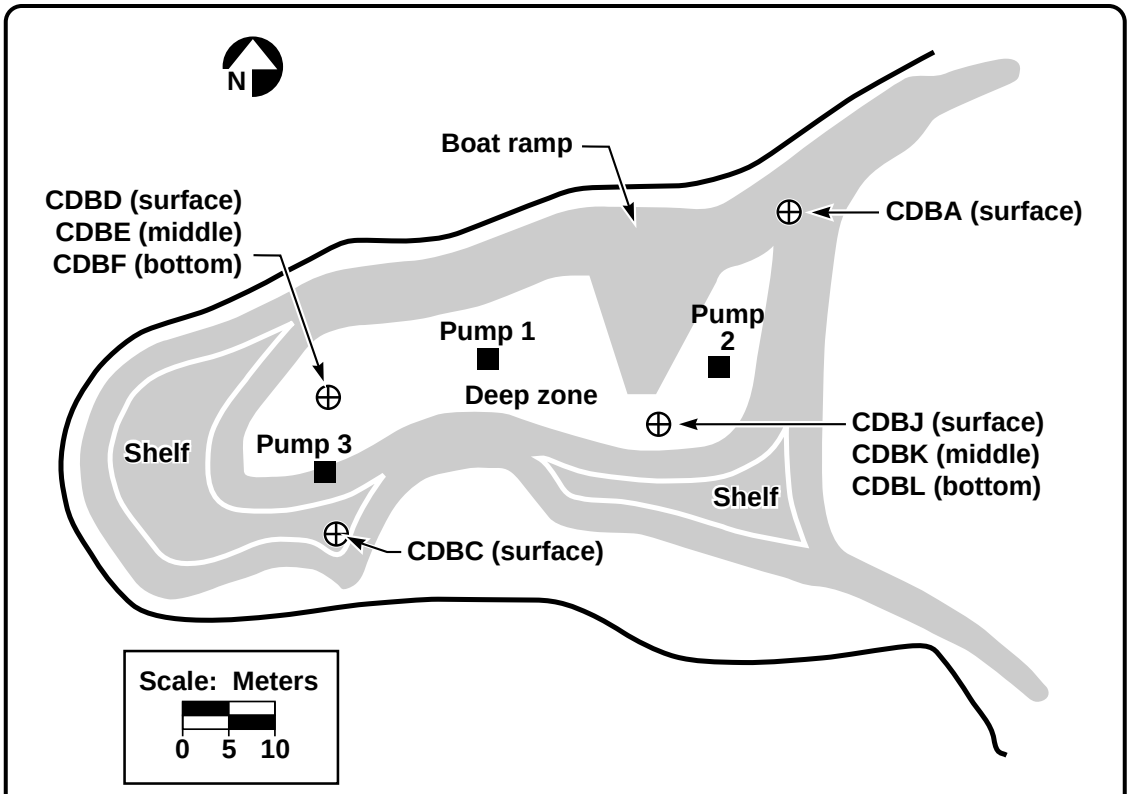

Figure 14-5. Sampling locations within Drainage Retention Basin to determine maintenance of water quality management objectives.

During 1995, summaries of results of routine water quality monitoring for management parameters and discharge monitoring were reported to regulatory agencies in the quarterly progress reports and annual ground water project report(Hoffman et al. 1996).

During 1995, only one release from the DRB was sampled. This was the first release sampled in the 1995–1996 rainy season. The second sample required by the DRB monitoring plan was collected in 1996 concurrent with a storm water sampling event. During 1995, releases from the DRB exceeded NPDES discharge limits for iron, lead, and zinc (**Table 14-7**) established in WDR 91-091. These same three metals plus copper were found above the discharge limits in samples of storm water runoff collected at WPDC at the time of the DRB release. Samples collected at the WPDC represent a combination of storm water running onto the Livermore site, storm water running off the site, NPDES permitted treated ground water and process discharges, and the DRB release.

Metals concentrations in the sample collected at location WPDC were higher than samples collected from the DRB discharge showing the presence of these metals at the measured concentrations is consistent with typical storm water runoff from the site. Lead showed up for the first time in the November 15, 1994, release from the DRB. Lead was not detected in the subsequent December 1994 discharge sample but was again seen in the December 1995 sample (the first release of the 1995–1996 rainy season). Zinc and iron appeared for the first time in the December 1995 sample. Previously, in samples of discharges from the DRB collected at CDBX from 1992 through 1994, neither zinc nor iron were present above discharge limits. However, these and other metals have been detected with increasing frequency above the discharge limits within the DRB as demonstrated by the results of maintenance monitoring sampling occurring at CDBE.

During 1995, temperature, turbidity, alkalinity, nitrate, nitrite, ammonia nitrogen, phosphorous, iron, lead, nickel, and zinc were measured at levels exceeding management action levels (MALs) at sampling location CDBE (**Table 14-8**).

Dissolved oxygen concentrations rarely were maintained at or above the management action level of at least 80% saturation of oxygen in the water (**Figure 14-6**). However, concentrations did not drop below the critical management action level of 5 mg/L. Dissolved oxygen levels were controlled manually with aeration pumps. The two solar powered aeration pumps operate during daylight hours and the traditional pump can be operated 24 hours a day. The aeration pumps are started whenever oxygen levels at any level of the DRB drop close to or below the critical management action level of 5 mg/L. Typically, these pumps are used continuously through the spring, summer, and fall months. During the winter, the pumps are started as needed.

Table 14-6. Routine water quality management levels for the Drainage Retention Basin.

Parameter	Location	Frequency	Management action levels
Physical			
Dissolved oxygen (mg/L)	CDBA, CDBC, CDBD, CDBE, CDBF, CDFJ, CDBK, CDBL	Weekly	<80% saturation
Temperature (°C)	CDBA, CDBC, CDBD, CDBE, CDBF, CDFJ, CDBK, CDBL	Weekly	<15 and >26
Total alkalinity (as $CaCO_3$) (mg/L)	CDBE	Monthly	<50
Chlorophyll a (mg/L)	CDBE	Monthly	>10
pH	CDBA, CDBC, CDBD, CDBE, CDBF, CDFJ, CDBK, CDBL	Weekly	<6.0 and >9.0
Total suspended solids (mg/L)	CDBE	Monthly	none
Total dissolved solids (mg/L)	CDBE	Monthly	>350
Turbidity (m)	CDBE	Monthly	<0.914
Chemical oxygen demand (mg/L)	CDBE	Quarterly	>20
Oil and grease (mg/L)	CDBE	Quarterly	>15
Conductivity (μmhos/cm)	CDBE	Monthly	>900
Nutrients			
Nitrate (mg/L)	CDBE	Monthly	>0.2
Nitrite (mg/L)	CDBE	Monthly	>0.2
Ammonia nitrogen (mg/L)	CDBE	Monthly	>0.1
Phosphate (as phosphorous) (mg/L)	CDBE	Monthly	>0.02
Microbiological			
Total coliform (MPN[(a)]/0.1L)	CDBE	Quarterly	>5000
Fecal coliform (MPN[(a)]/0.1L)	CDBE	Quarterly	>400
Metals (μg/L)			
Antimony	CDBE	Semiannually	>1460
Arsenic	CDBE	Semiannually	>20
Beryllium	CDBE	Semiannually	>0.7
Boron	CDBE	Semiannually	>7000
Cadmium	CDBE	Semiannually	>5
Chromium, total	CDBE	Semiannually	>50

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Table 14-6. Routine water quality management levels for the Drainage Retention Basin (concluded).

Parameter	Location	Frequency	Management action levels
Metals (μg/L) (continued)			
Chromium (VI)	CDBE	Semiannually	>11
Copper	CDBE	Semiannually	>20
Iron	CDBE	Semiannually	>3000
Lead	CDBE	Semiannually	>5.6
Manganese	CDBE	Semiannually	>500
Mercury	CDBE	Semiannually	>1
Nickel	CDBE	Semiannually	>7.1
Selenium	CDBE	Semiannually	>100
Silver	CDBE	Semiannually	>2.3
Thallium	CDBE	Semiannually	>130
Zinc	CDBE	Semiannually	>58
Organics (μg/L)			
Total volatile organic compounds	CDBE	Semiannually	>5
Benzene	CDBE	Semiannually	>0.7
Tetrachloroethene	CDBE	Semiannually	>4
Vinyl chloride	CDBE	Semiannually	>2
Ethylene dibromide	CDBE	Semiannually	>0.02
Total petroleum hydrocarbons	CDBE	Semiannually	>50
Polynuclear aromatic hydrocarbons	CDBE	Semiannually	>15
Base/neutral acid extractable compounds and pesticide	CDBE	Semiannually	>5
Radiological (pCi/L)			
Gross alpha	CDBE	Semiannually	>15
Gross beta	CDBE	Semiannually	>50
Tritium	CDBE	Semiannually	>20,000
Toxicity (% survival/96-hour)			
Aquatic bioassay	CDBE	Annually	90% survival median, 90 percentile value of not less than 70% survival

[a] Most probable number.

Table 14-7. Drainage Retention Basin monitoring event in which the concentration of metals exceeded discharge limits at CDBX shown with associated metal concentration at WPDC. A single sample was taken on December 12, 1995.

Parameter	Location, result (μg/L)		Discharge limit (μg/L)
	CDBX	WPDC	
Iron	4700	17,000	3000
Copper	11	24	20
Lead	8	11	2
Zinc	70	200	58

Table 14-8. Drainage Retention Basin monitoring events exceeding Management Action Levels, 1995.

Parameter	Action level	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)	<15.6 >26.7	10.0	12.1	13.5	—[a]	—[a]	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]	12.2
Turbidity (secchi disk)[c] (m)	<0.914	0.24	0.20	0.17	0.21	0.22	0.23	0.31	0.29	0.28	0.33	0.51	0.41
Alkalinity (as $CaCo_3$) (mg/L)	<50	37	42	28	36	41	46	—[b]	45	43	—[b]	—[b]	45
Nitrate (as NO_3) (mg/L)	≥0.2	<0.5	0.74	1.8	1.9	1.9	<0.5	1.5	<0.5	<0.5	<0.5	<0.5	3.4
Nitrite as N (mg/L)	≥0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ammonia nitrogen (mg/L)	>0.1	—[b]	—[b]	—[b]	—[b]	0.12	0.12	0.32	0.21	0.3	—[b]	—[b]	0.12
Phosphate (as P) (mg/L)	≥0.02	0.076	0.096	0.12	0.22	0.23	0.22	0.17	0.21	0.18	0.18	0.10	0.17
Iron (μg/L)	>3000	—[a]	—[a]	—[a]	6800	—[a]	—[a]	4600	4400	4100	—[b]	—[b]	3200
Lead (μg/L)	>2	—[a]	—[a]	—[a]	4.8	—[a]	—[a]	6	4.4	3.5	—[b]	—[b]	<5
Nickel (μg/L)	>7.1	—[a]	—[a]	—[a]	17	—[a]	—[a]	—[b]	13	11	12	—[b]	17
Silver (μg/L)	>2.3	—[a]	—[a]	—[a]	—[b]	—[a]	—[a]	—[b]	—[b]	—[b]	—[b]	—[b]	<5
Zinc (μg/L)	>58	—[a]	—[a]	—[a]	—[b]	—[a]	—[a]	410	—[b]	—[b]	—[b]	—[b]	

a Not measured.

b Data are below the management action level.

c Monthly average .

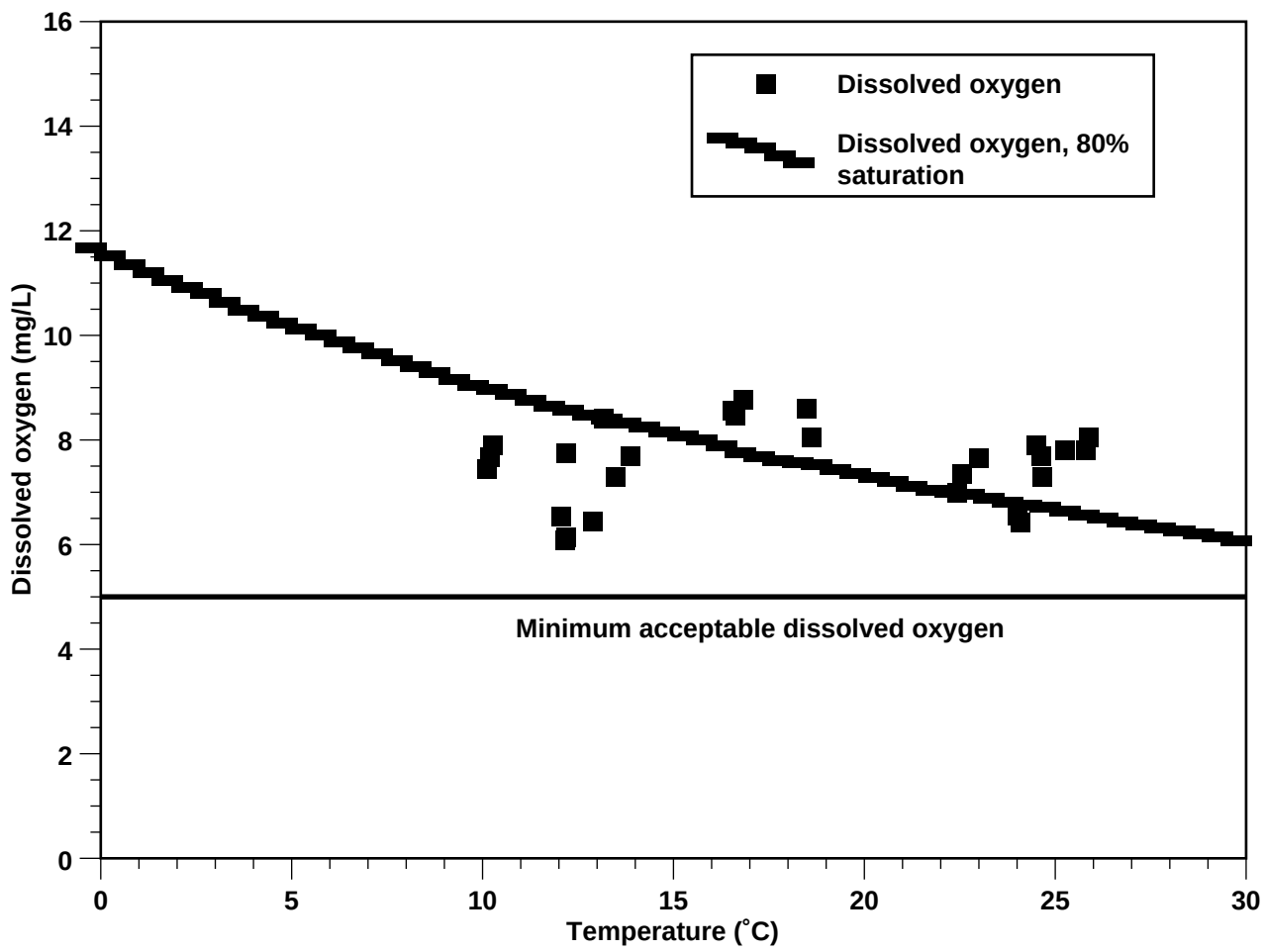

Figure 14-6. Dissolved oxygen vs temperature in the Drainage Retention Basin from January through December, 1995.

Pump operation probably is responsible for the relatively uniform distribution of dissolved oxygen at the surface, middle, and bottom elevations seen throughout the 3 years of DRB operation. The oxygen distribution for 1995 is shown in **Figure 14-7**. Adequate dissolved-oxygen levels prevent nutrient release back into the DRB water column by decaying organic matter in the bottom sediments. Temperature, the other important parameter in determining how much oxygen is dissolved in water, showed characteristic seasonal trends (**Figure 14-8**). Dissolved oxygen and temperature monitoring were not conducted in April and May because of equipment failure and repairs. The uniform distribution of temperature in the top, middle, and bottom elevations also reflects the uniform mixing achieved by the operation of the pumps. Without mixing, the water temperature would be expected to show seasonal stratification in addition to the changes in temperature.

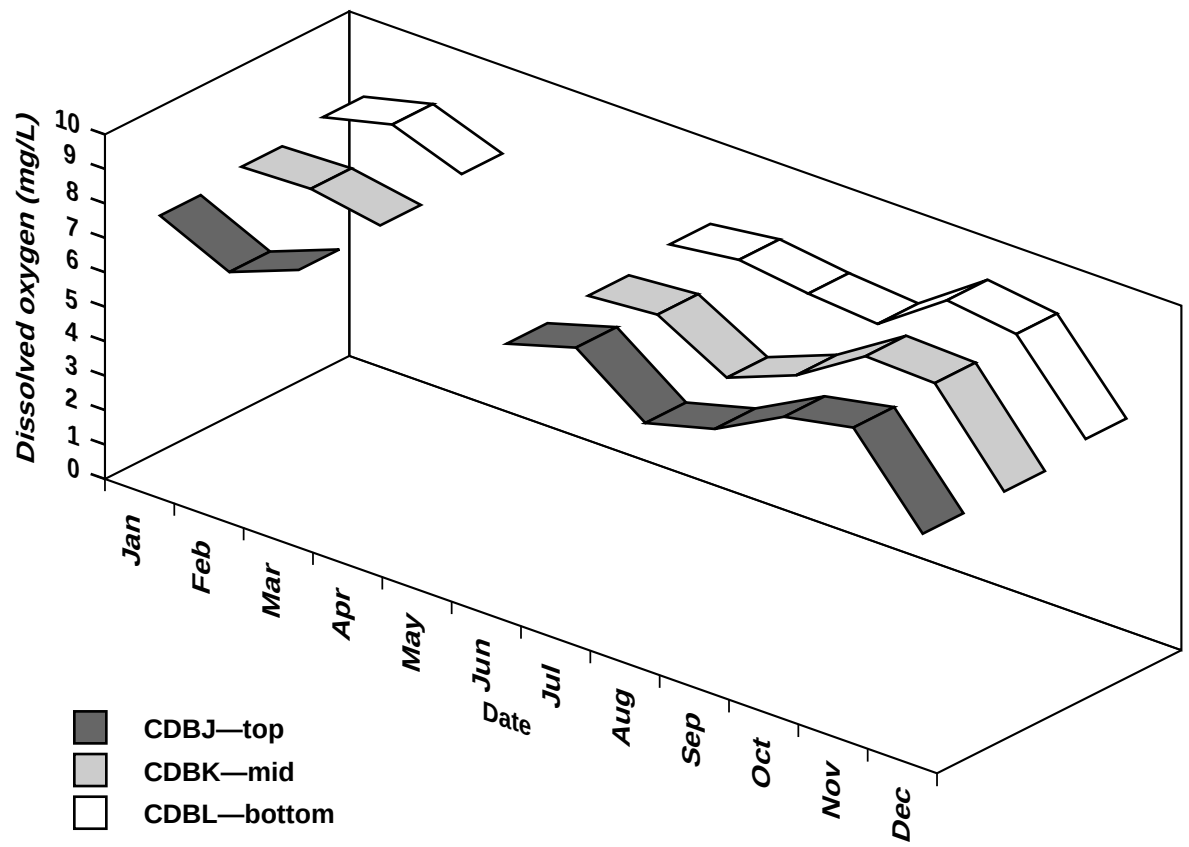

Figure 14-7. Dissolved oxygen vs time at three monitoring points within the Drainage Retention Basin, 1995.

Turbidity rose above acceptable management levels during the 1993–1994 wet season, and throughout 1994 and 1995. Wet season turbidity probably results from sediments that pass through the sediment traps discharging into the DRB. Turbidity seen during the warmer summer months of 1994 was most likely the result of algae growth. This was confirmed by high chlorophyll a values and visual observations during the 1994 summer months. However, during 1995, though turbidity continued to be high, chlorophyll-a values were just above detection indicating very little algae growth. Visual observations made during sampling events confirmed that there was little or no algae growth. In January 1995, total alkalinity dropped below the MAL for the first time since June 1993 and continued below the MAL in every month except October and November.

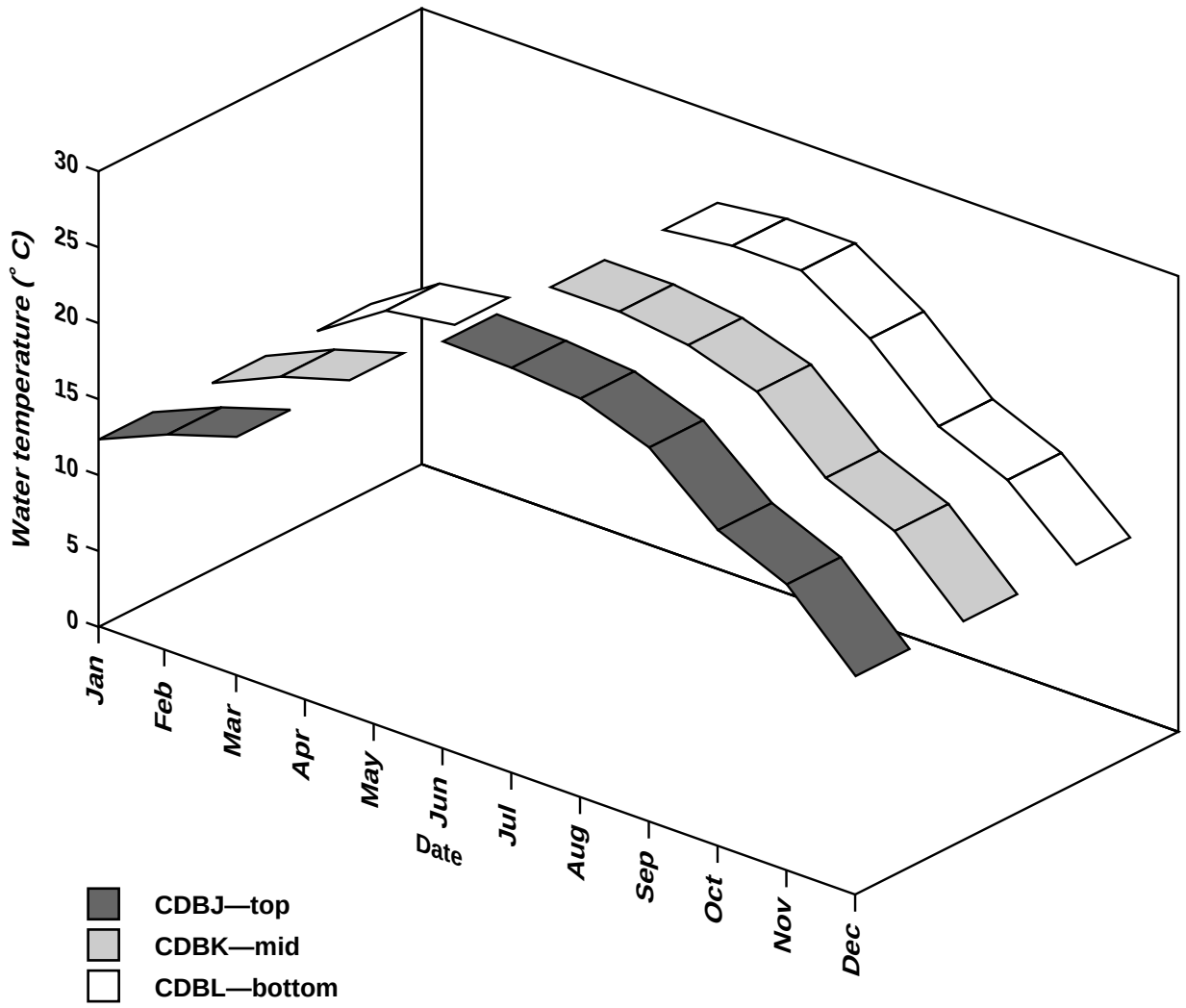

Figure 14-8. Temperature vs time at three monitoring points within the Drainage Retention Basin, 1995.

The Drainage Retention Basin Management Plan did not anticipate alkalinity drops below 50 mg/L but recommends that if this does occur that the alkalinity be adjusted to 75 mg/L using either hydrated lime or sodium sesquicarbonate. Low alkalinity could contribute to the high turbidity observed in the DRB by affecting the ability of solids to settle out of solution. In 1996, LLNL will attempt to treat the DRB to maintain alkalinity above the MAL.

During September 1995, LLNL conducted chronic toxicity tests on algae and fish to determine if the lack of algae growth was due to something other than the high turbidity, which would reduce light penetration in the water and limit the photic zone where plant growth could occur. The results of the test using algae,

Selanastrum capricornutum, indicated that algae growth was inhibited at 12.5% concentration of DRB water. The test using fathead minnow, *Pimephales promelas* showed no chronic toxicity in 100% DRB water. This indicates that the observed absence of algae in the DRB is caused by an agent other than turbidity.

LLNL is continuing to study the cause of the low algae growth within the DRB as well as investigating a means to remove the turbidity and establish a viable plant community within the DRB.

Levels for nitrates, nitrites, total ammonia, and phosphorous exceeded the MALs for most of 1995. Concentrations of these nutrients continued to increase over 1992 through 1994 levels. The nutrients are introduced from storm water discharges, fecal matter from migrating water fowl, and mosquito fish and decaying organic matter. Attempts in 1993 and 1994 to reduce nutrient loading by introducing plants both within the Nutri-Pods (suspended nylon sacks that house the plants) and planted on the shallow shelves were not successful. This is most likely the result of the chronic turbidity problem and some operational difficulties encountered with the Nutri-Pods. Until a healthy plant community is established in the DRB, high nutrient loadings are expected to continue.

Semiannual and annual samplings were conducted during April and September 1995. Quarterly sampling was conducted in January, April, July, and November. In July, LLNL began monitoring for metals on a monthly basis to track three metals (iron, nickel, and lead), which were detected above the MALs in previous semiannual monitoring. Since starting monthly monitoring, iron and zinc have also been detected above MALs. Silver, though not detected above the analytical reporting limit, still had a reporting limit above the MAL in December as a result of a change in analytical laboratories. The source of these elevated metals is unknown. However, storm water runoff data discussed in Chapter 7 indicate that the concentrations of these metals found in water collected within in the DRB are consistent with concentrations found in storm water running on to and off of the Livermore site.

Data for maintenance monitoring at sampling location CDBE , CDBX, and CDBA through L are presented in Tables 14-1, 14-2, and 14-3 in Volume 2. Data from location WPDC are summarized in Chapter 7.

Site 300 Cooling Tower Discharges

LLNL samples cooling-tower wastewater discharges as required by the Self-Monitoring Program of WDR 94-131, NPDES permit CA0081396 and reports the results of the compliance sampling to the Central Valley Regional Water Quality Control Board (CVRWQCB) quarterly.

The cooling towers, used to cool buildings and equipment at Site 300, discharge noncontact cooling water to man-made and natural drainage courses (**Figure 14-9**). These drainage courses flow into Corral Hollow Creek, a tributary of the San Joaquin River. Because the San Joaquin River is a "water of the United States" all discharges to it and its tributaries require NPDES permits.

WDR 94-131 establishes effluent limits for three parameters: (1) daily flow must not exceed the maximum design flow; (2) total dissolved solids (TDS) must not exceed a monthly average of 2000 mg/L or a maximum daily limitation of 2400 mg/L; and (3) pH must not exceed a maximum of 10. Along with effluent monitoring, when Corral Hollow Creek is flowing, the permit requires LLNL to collect pH samples upstream and downstream of the cooling tower discharge points into the creek and to conduct visual observations of the creek. Cooling tower discharges must not raise the pH of Corral Hollow Creek above 8.5 or alter the ambient pH by more than 0.5.

Three cooling towers located at Building 801, 836A, and 865 regularly discharge to surface water drainage courses under the requirements of WDR 94-131. Fourteen other cooling towers routinely discharge to percolation pits under a waiver of waste discharge requirements from the CVRWQCB. WDR 94-131 establishes effluent limits for these 14 towers in the event that discharge to surface water drainage courses is necessary, such as during maintenance of the percolation pits; however, no surface water discharges occurred from these towers during 1995.

In July 1995, the cooling tower at Building 865 was taken off line as a result of a planned facility mothballing. To preserve the tower for future use, components of the wooden tower are kept wet with the use of a sprinkler system to prevent the loss of structural integrity. LLNL informed the CVRWQCB of the change in the tower status and continues to monitor the sprinkler water discharge according to the requirements of WDR 94-131.

Monitoring results demonstrate that all cooling tower discharges were in compliance with all permitted limits. Monitoring results are detailed in the quarterly reports to the CVRWQCB and are summarized in **Table 14-9**. All pH samples collected at the of cooling tower discharges were below the permitted maximum of 10. The cooling towers routinely discharge less than half the permitted maximum. TDS concentrations are consistently below both the daily maximum and monthly average limits. During the 1995 reporting period, flow only occurred in Corral Hollow Creek in the first quarter. The pH measurements of 8.3 upstream, and 8.3 and 8.44 downstream were below 8.5. The difference of 0.14 between the

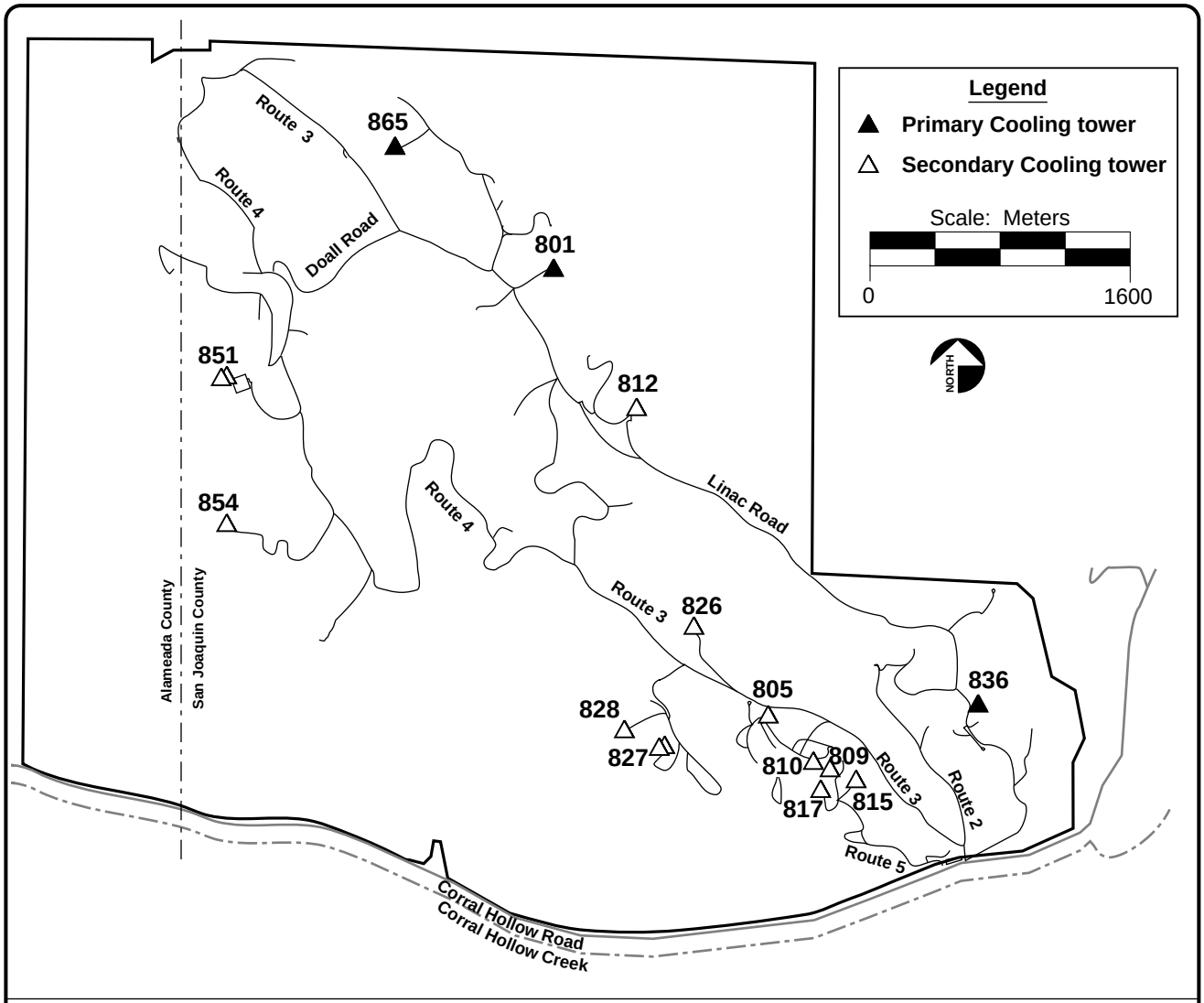

Figure 14-9. Site 300 cooling tower locations, 1995.

two locations indicates the cooling towers did not adversely affect the creek's ambient pH. No visible oil, grease, scum, foam, or floating or suspended materials were observed in the creek.

Industrial Pretreatment and Categorical Discharges

Self-monitoring pretreatment programs are required at both the Livermore site and Site 300 by the Livermore Water Reclamation Plant (LWRP) under the authority of San Francisco Bay Regional Water Quality Control Board. The sampling and monitoring of nondomestic, industrial sources covered by pretreatment standards defined in 40 CFR 403 is required in the 1995–1996

Table 14-9. Summary data from measurements of Site 300 primary cooling-towers, 1995.

Test	Tower No.	Minimum	Maximum	Median	Interquartile range	Number of samples
Total dissolved solids (mg/L)[a]	801	1200	1400	1300	50	23
	836A	800	1300	1200	50	23
	865	1000	1300	1150	75	15
Flow (L/day)	801[b]	0	13,936	6355	5300	28
	836A[c]	0	7684	1083	1628	28
	865[d]	0	48,467	17,048	27,805	23
pH[e]	801	8.43	8.96	8.71	0.21	23
	836A	8.46	9.03	8.76	0.21	23
	865	8.27	8.74	8.50	0.10	15

a Maximum permitted total dissolved solids = 2400 mg/L.

b Maximum permitted design flow, 16,276 L/day.

c Maximum permitted design flow, 8138 L/day.

d Maximum permitted design flow, 90,840 L/day.

e Maximum permitted pH = 10.

Wastewater Discharge Permit (No. 1250) issued for the discharge of wastewater from LLNL into the City of Livermore sewer system. 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. Categorical standards are published by the EPA as separate regulations and contain numerical limits for the discharge of pollutants from specified processes (or industrial categories). The LWRP has identified specific LLNL wastewater generating processes that fall under the definition of two Categorical Standards: electrical and electronic components and metal finishing.

LLNL petitioned the EPA for an exemption from the Categorical Standards. To date, no decision has been rendered. This year, LLNL maintained compliance with the applicable categorical standard discharge limits that apply to the significant industrial processes that discharge to the sanitary sewer. This compliance was achieved through the review of retention-tank data prior to discharge and the application of the appropriate categorical discharge limits to the discharge. The analytical data and discharge records are available for review by any regulatory agency. However, pending a decision on our request, we suspended the formal monitoring and reporting requirements stated in the Standards. Quarterly and semiannual sampling of minor discharges were suspended, and semiannual wastewater reports were not submitted to the LWRP. Similarly LWRP suspended its inspection schedule of the regulated processes at LLNL. This is being done with the understanding and concurrence of both the LWRP and the Pretreatment Coordinator, EPA Region 9. LLNL wastewater

representatives are working closely with LWRP and the EPA personnel to reach a decision in this matter. When a decision is reached on the future level of compliance LLNL must follow regarding the categorical standards, LLNL will continue to maintain strict adherence to the applicable requirements.

Tables 14-10 and **14-11** show LLNL's internal discharge limits for wastewaters discharged to the sanitary sewer. Those processes that discharge to the sanitary sewer are subject to the pretreatment self-monitoring program specified in the Wastewater Discharge Permit issued by the LWRP. In 1995, no exceptions to the pollutant limitations of the discharge permit were observed.

Site 300 Ground Water Compliance Monitoring

Ground water compliance monitoring programs are carried out at Site 300 in response to LLNL Site 300 Resource Conservation and Recovery Act (RCRA) Closure and Post-Closure Plans for Landfill Pits 1 and 7 and WDR Order Nos. 93-100 and 85-188. Compliance monitoring and reporting allow LLNL to

Table 14-10. LLNL's internal discharge limits for nonradioactive parameters in wastewaters from noncategorical and categorical processes, mg/L.

Parameter	Noncategorical[b]	Discharge limits[a]	
		Metal finishing	Electronic components
Metals			
Beryllium	0.74		
Cadmium	0.9	0.26	
Chromium	4.9	1.0	
Copper	10	2.07	
Cyanide[c]	5	0.65	
Lead	4.9	0.43	
Mercury	0.05		
Nickel	5	2.38	
Silver	1	0.24	
Zinc	15	1.48	
Organics			
Total toxic organics	4.57	2.13	1.37
Physical			
pH	5–10	5–10	5–10

a These standards are specified by the EPA. By regulation, the EPA or City of Livermore limit is used, whichever is lower. Noncategorical limits apply where no standard is specified.

b These standards have been established to meet the City of Livermore's requirements at the Building 196 outfall.

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

Table 14-11. LLNL's internal discharge limits for radioisotopes in wastewaters. There is no gross gamma limit; isotope-specific limits apply.

Parameter	Individual discharges		Total daily limit for site	
Gross alpha	11.1 Bq/L	(0.3 µCi/1000 L)	185 kBq	(5.0 µCi)
Gross beta	111 Bq/L	(3.0 µCi/1000 L)	1.85 MBq	(50.0 µCi)
Tritium	185 kBq/L	(5.0 mCi/1000 L)	3.7 GBq	(100.0 mCi)

evaluate operations of closed RCRA Landfill Pits 1 and 7 and the High Explosive(HE) Process Area Class II surface impoundments and assure that they are consistent with regulatory requirements. WDR Order No. 85-188 establishes the basis for compliance monitoring for HE Process Area Class II surface impoundments. WDR Order No. 93-100 and the post-closure monitoring plan developed within the RCRA Closure and Post-Closure Plans established the basis for the compliance monitoring network around Pits 1 and 7. Data presentation and evaluation for these compliance networks are presented in Chapter 7, Site 300 Ground Water Monitoring. These monitoring programs include quarterly monitoring of the ground water wells in each monitoring network and quarterly and annual self-monitoring reporting.

Monitoring Reporting Program (MRP) No. 93-100 for the Pits 1 and 7 network includes sampling and analysis of ground water monitoring wells for parameters listed in **Table 14-12** and establishes concentration limits at the point of compliance. In letters submitted to the Central Valley RWQCB on October 17 and December 21, 1995, LLNL requested modifications to MRP No. 93-100 proposing to change the concentration limits for most parameters as well as the statistical test method to determine statisticallyt significant evidence of a release.

The Central Valley RWQCB verbally accepted the proposal and LLNL implemented the new concentration limits and statistical test methods to evaluate fourth quarter 1995 data. The new concentration limits and statistical test levels are listed in **Tables 14-13** and **14-14**.

The post-closure monitoring plan requires sampling and analysis of ground water from wells for following the parameters:

- Pit 1—Arsenic, cadmium, chloride, chromium, iron, phenols, manganese, mercury, nickel, nitrate, selenium, silver, sodium, sulfate, conductivity, pH, TOC, TOX, barium, beryllium, lead, VOCs using EPA Method 601/624, semivolatile organic compounds using EPA Method 625, gross alpha, gross beta, tritium, HMX, RDX, and TNT.

Table 14-12 Monitoring parameters and concentration limits for landfill Pits 1 and 7 under MRP Order No. 93-100 used to evaluate first through third quarter monitoring data.

Constituents	Concentration limits Pit 1	Concentration limits Pit 7
Parameters		
Depth to ground water (m)	TBD	TBD
Total dissolved solids (mg/L)	TBD	TBD
Specific conductance (μmho/cm)	TBD	TBD
Temperature (°C)	TBD	TBD
pH	TBD	TBD
Metals (μg/L)		
Arsenic	20	TBD[a]
Barium	50	90
Beryllium	0.5	0.5
Cadmium	0.5	TBD
Cobalt	TBD	TBD
Copper	70	TBD
Lead	9	2
Nickel	100	TBD
Vanadium	90	50
Zinc	60	TBD
Radionuclides (Bq/L)		
Radium 226	0.037	TBD
Tritium	18.5	3.17
Uranium-233,234	0.074	0.078
Uranium-235	0.0074	0.0037
Uranium-238	0.037	0.059
Thorium 228	TBD	TBD
Thorium 232	TBD	TBD
Explosives (μg/L)		
HMX	26	TBD
RDX	30	TBD

[a] TBD = Concentration limits are to be determined.

Table 14-13. Monitoring parameters and concentration limits for landfill Pit 1 amendments to MRP Order No. 93-100 used to evaluate fourth quarter monitoring data.

Constituent of concern	Well	Concentration limit[a]	Statistical limit
Metals (μg/L)			
Arsenic	K1-02B	11	16
	K1-03	12	18
	K1-04	10	14
	K1-05	14	27
	K1-08	14	18
	K1-09	13	18
Barium	K1-02B	<25	25
	K1-03	<25	25
	K1-04	<25	25
	K1-05	28	34
	K1-08	34	45
	K1-09	32	38
Beryllium	All	<0.5	0.5
Cadmium	All	<0.5	0.5
Cobalt	All	<50	50
Copper	All	<70	70
Lead	All	<6	6
Nickel	All	<100	100
Vanadium	All	58	103
Zinc	All	17	91
Radionuclides (Bq/L)			
Radium 226	All	0.005	0.046
Tritium	K1-03	3.78	11.4
	K1-04	0.859	6.15
	K1-05	1.24	6.89
	K1-08	1.36	5.22
	K1-09	1.43	5.52
Uranium (Total)	All	0.084	0.13
Thorium 228	All	0.006	0.039
Thorium 232	All	0.001	0.02
Energetic Materials (μg/L)			
HMX	All	<20	20
RDX	All	<30	30

a Background concentration (mean of LLNL historical data).

Table 14-14. Monitoring parameters and concentration limits for landfill Pit 7 amendments to MRP Order No. 93-100 used to evaluate fourth quarter monitoring data.

Constituent of concern	Well	Concentration limit[a]	Statistical limit
Metals (μg/L)			
Arsenic	K7-01	9.7	14
	K7-03	3.3	6.4
	K7-09	<2	2
	K7-10	3.8	8.6
	NC7-25	6.1	8.9
	NC7-26	4.1	13
	NC7-47	14	21
	NC7-48	8.4	14
Barium	K7-01	180	210
	K7-03	66	79
	K7-09	<50	50
	K7-10	41	92
	NC7-25	58	70
	NC7-26	<50	50
	NC7-47	42	62
	NC7-48	150	290
Beryllium	All	<0.5	0.5
Cadmium	K7-01	<0.5	0.5
	K7-03	<0.5	0.5
	K7-09	<0.5	0.5
	K7-10	<1.6	1.6
	NC7-25	<0.6	0.6
	NC7-26	<0.5	0.5
	NC7-47	<1.5	1.5
	NC7-48	<1.5	1.5
Cobalt	All	<25	25
Copper	K7-01	12	47
	K7-03	71	140
	K7-09	<10	10
	K7-10	<10	10
	NC7-25	<10	10
	NC7-26	<10	10
	NC7-47	<10	10
	NC7-48	<10	10

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Table 14-14. Monitoring parameters and concentration limits for landfill Pit 7 amendments to MRP Order No. 93-100 used to evaluate fourth quarter monitoring data (continued).

Constituent of concern	Well	Concentration limit[a]	Statistical limit
Lead	K7-01	1.4	6
	K7-03	1.3	6.1
	K7-09	<5.9	5.9
	K7-10	<2	2
	NC7-25	<2	2
	NC7-26	1.1	5.1
	NC7-47	1.5	7.6
	NC7-48	<2	2
Nickel	K7-01	2.9	12
	K7-03	10	21
	K7-09	<5	5
	K7-10	7.4	37
	NC7-25	5.7	23
	NC7-26	<5	5
	NC7-47	2.5	14
	NC7-48	22	65
Vanadium	K7-01	<50	50
	K7-03	<50	50
	K7-09	<50	50
	K7-10	<50	50
	NC7-25	<50	50
	NC7-26	<50	50
	NC7-47	49	77
	NC7-48	46	140
Zinc	K7-01	<54	54
	K7-03	34	70
	K7-09	<20	20
	K7-10	<20	20
	NC7-25	<36	36
	NC7-26	<20	20
	NC7-47	<27	27
	NC7-48	20	71

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Table 14-14. Monitoring parameters and concentration limits for landfill Pit 7 amendments to MRP Order No. 93-100 used to evaluate fourth quarter monitoring data (concluded).

Constituent of concern	Well	Concentration limit[a]	Statistical limit
Radionuclides (Bq/L)			
^{226}Ra	K7-01	1.18	2.61
	K7-03	0.52	1.20
	K7-09	0.23	0.59
	K7-10	0.40	0.88
	NC7-25	0.70	1.31
	NC7-26	0.41	0.93
	NC7-47	0.14	0.79
	NC7-48	9.11	29.7
Tritium	K7-09	64.8	373
	K7-10	64.8	373
	NC7-47	64.8	373
	NC7-48	64.8	373
Uranium (Total)	K7-01	12.8	16.0
	K7-03	3.65	6.16
	K7-09	0.59	1.13
	K7-10	1.10	2.17
	NC7-25	21.6	33.0
	NC7-26	0.40	0.87
	NC7-47	2.28	3.30
	NC7-48	27.2	60.0
^{228}Th	All	0.0	0.86
^{232}Th	All	0.13	1.36
Energetic materials (μg/L)			
HMX	All	<20	20
RDX	All	<30	30

a Background concentration (mean of LLNL historical data).

- Pit 7—Antimony, VOCs using 601/624, gross alpha, gross beta, and tritium.

MRP No. 85-188 does not establish concentration limits at the point of compliance but requires quarterly sampling for the following parameters and constituents: total organic halogens (TOX), total organic carbon (TOC), pH, electrical conductivity, nitrate, nitrite, high explosive compounds (HMX and RDX), nickel, selenium, silver, thallium, vanadium, zinc, molybdenum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, and mercury. The monitoring program also requires weekly inspection of the surface impoundments leachate collection systems for fluid accumulation and quarterly checking of lysimeters or the leachate collection systems. If water is found in the lysimeters or the leachate collection systems, the water must be analyzed for pH, electrical conductivity, HMX, and RDX.

In June 1995, during a routine inspection, water was detected dripping from one of the three perforated pipes that comprise the leachate collection system for the upper of the two surface impoundments. The flow, which goes directly into the lower surface impoundment, averaged about 15 L/day. As required by MRP 85-188, samples were collected on June 16, 19, 22, and 30. The results of these samples were reported to the Central Valley RWQCB in the *LLNL Experimental Test Site 300 Compliance Monitoring Program for RCRA Closed Landfills Pits 1 and 7 and Process Water Surface Impoundments Second Quarter Report April – June 1995* (Christofferson 1995b). As indicated in this and other subsequent reports, LLNL took immediate actions upon discovery of the leak including diverting the majority of flows from the upper surface impoundment to the lower surface impoundment and reducing water volume contained in the upper surface impoundment.

In October, LLNL located three leak points using an electrical surveying method. The upper impoundment was drained and its inner high density polyethylene liner (HDPE) was repaired on December 19, 1995. The leachate collection system pipe continues to drip at the same average flow rate even through repairs to the inner liner were completed. As stated in the *LLNL Experimental Test Site 300 Compliance Monitoring Program for RCRA Closed Landfills Pits 1 and 7 and Process Water Surface Impoundments Fourth Quarter Report October – December 1995* (Christofferson 1995a), the leachate collection system could not immediately reflect the cessation of HDPE liner leakage, because previously leaked water is stored in the sand layer surrounding the pipes. Until exhausted, this previously leaked water will continue to flow from the leachate collection system.

Environmental Impact

Wastewater, treated water, storm water, and Site 300 water were monitored as part of our compliance self-monitoring activities. Monitoring results from the compliance networks indicate that LLNL operations had no adverse impacts on human health or the environment in 1995.

No exceptions to the discharge limits of the LWRP Wastewater Discharge Permit were observed.

Treated ground water from all treatment facilities was within compliance limits set up by the remedial project managers, a group comprising project managers from EPA, DTSC, and the San Francisco Bay Area RWQCB, for VOCs and metals during 1995. Although Cr(VI) exceeded limits in water discharged from TFB and the VOC limit of 5 ppb was slightly exceeded three times at TFA, the impact of these discharges was deemed to be not significant by the remedial project managers.

Storm water was monitored at two locations during 1995. Captured storm water from the Drainage Retention Basin (DRB) was found to contain iron, lead, and zinc, at levels above the water quality objectives stated in the management plan. Monitoring at the LLNL storm water outfall also found these three metals plus copper at levels above the objectives. While above the objectives of the management plan, storm water was within compliance.

No environmental impacts on Site 300 ground water were detected in 1995. Even though water was found dripping from one of the perforated pipes that make up the leachate collection system, immediate action ensured that no process water was released to the environment. All cooling towers at Site 300 were also found to be in compliance with permitted limits.

15. Quality Assurance

Lucinda M. Garcia
Donald H. MacQueen

Introduction

Quality assurance (QA) is a system of activities and processes put in place to assure that monitoring and measurement data meet user requirements and needs. Quality Control (QC) consists of procedures used to verify that prescribed standards of performance in the monitoring and measurement process are attained. QA requirements for environmental monitoring of DOE facilities are mandated by DOE Orders and guidance. DOE Order 5400.1 identifies QA requirements for radiological effluent and surveillance monitoring and specifies that a QA program consistent with DOE Order 5700.6 be established. The latter Order sets forth policy, requirements, and responsibilities for the establishment and maintenance of plans and actions that assure quality achievement in DOE programs. 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 that contains a QA section discussing the applicable elements of the American National Standards Institute / American Society of Mechanical Engineers (ANSI / ASME) NQA-1, *Quality Assurance Program Requirements for Nuclear Facilities* (ASME 1989).

LLNL conducted QA activities in 1995 at the Livermore site and Site 300 in accordance with a plan based on DOE Order 5700.6C (Garcia and Failor 1993). DOE Order 5700.6C 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, maximizing the effectiveness and efficiency in resource use.

LLNL environmental sampling is conducted according to procedures published in an appendix to the LLNL *Environmental Monitoring Plan* (Tate et al. 1995). Environmental monitoring samples are analyzed by LLNL or commercial laboratories using 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. When analyses are performed by independent contractors, LLNL requires that their laboratories be certified by the State of California for the analyses performed for LLNL. In addition, LLNL requires all analytical laboratories to maintain adequate QA programs and documentation of methods.

15. Quality Assurance

Quality Assurance Activities

The LLNL environmental monitoring program was audited successfully by the Department of Energy in 1995.

During 1995, 132 Nonconformance Reports (NCRs) related to environmental monitoring were written by the environmental monitoring staff. The major sources of NCRs were air particulate sampling equipment failures and analytical laboratory problems. Air particulate sampling equipment problems are ongoing and cannot be eliminated without a major resource expenditure for upgraded equipment. Analytical laboratory issues are addressed as they arise. It is anticipated that the detailed Statement of Work developed for the contracts starting in 1996 will result in improved data quality from off-site analytical laboratories.

Discrepancies and inconsistent results for radiological samples analyzed by off-site contract laboratories during 1995 led to an extensive performance evaluation study of these laboratories. Because results of this evaluation were inconclusive, a joint EPD / CES Performance Evaluation Committee will continue to study this issue.

Analytical Laboratories

In April of 1995, reorganization within LLNL and EPD affected the Radiation Analytical Sciences (RAS) analytical laboratory. This laboratory, which had been a part of the Environmental Protection Department (EPD), was transferred to the Chemistry and Materials Science Directorate and combined with a nonradiological laboratory that had also been a part of EPD to form Chemistry and Materials Science Environmental Services (CES). This laboratory continues to perform radiological analyses of extremely low-level environmental samples.

The off-site contract analytical laboratory that had been analyzing nonradiological Quality Control (QC) duplicates was also reorganized during 1995. This reorganization made it impossible for that laboratory to continue analyzing LLNL samples. In June of 1995, a replacement laboratory was audited and qualified for use as a QC lab until existing analytical contracts expired in January of 1996.

Three of the remaining four off-site contract analytical laboratories were audited by EPD and CES QA and technical personnel during 1995 under the terms of the existing contract. Audit reports were prepared detailing the results of these audits. The fourth laboratory was audited in late 1994.

In April of 1995, LLNL began preparations to rebid its contracts for external analytical services. These contracts were originally intended to include all EPD off-site environmental analyses, including environmental and hazardous waste samples. Late in the rebid process, the scope of the contracts was expanded to

include samples from Lawrence Berkeley National Laboratory (LBNL). A detailed Statement of Work was developed, requests for proposals were sent out, and candidate laboratories were evaluated. The top three candidates for each of two bid packages (nonradiological environmental samples and full service radiological and nonradiological) were evaluated by performance evaluation samples and audits. Two primary laboratories and one QC laboratory were selected for each bid package in late 1995 for contracts scheduled to begin in early 1996.

Participation in Laboratory Intercomparison Studies

During 1995, the CES Environmental Monitoring Radiation Laboratory (CES EMRL) and the Hazards Control Department's Analytical Laboratory (HCAL) participated in both the EPA's Environmental Monitoring Systems Laboratory (EMSL) intercomparison studies program and the DOE Environmental Monitoring Laboratory (EML) intercomparison studies program. In the EMSL program, CES EMRL successfully analyzed 28 of 30 samples within established acceptance control limits, and HCAL successfully analyzed 6 of 8 samples. In the EML program, 54 of 54 sample results from the CES EMRL were within acceptance control limits as were 10 of 10 samples from the HCAL.

The HCAL also participated in four EPA Water Pollution and Water Supply studies during 1995. Of 70 samples that were analyzed, 68 fell within established acceptance control limits.

The intercomparison study results, as well as the follow-up explanation and response for data that fell outside the acceptance control limits are presented in Volume 2. Contract laboratories are also required to participate in laboratory intercomparison programs; however, permission to publish their results for comparison purposes was not granted for 1995.

The potential effects of unacceptable intercomparison study results on routine data have not been fully determined or evaluated. A joint EPD/CES performance evaluation committee has been formed to create a systematic process for evaluating laboratory performance using traceable standards. A method for evaluating the results of intercomparison studies will be developed by that committee.

Duplicate Analyses

Duplicate or collocated samples are samples collected independently, as close as possible to the same point in space and time, and intended to be identical in all respects. Collocated samples processed and analyzed by the same organization provide intralaboratory precision information for the entire measurement system including sample acquisition, homogeneity, handling, shipping, storage,

preparation, and analysis. Collocated samples processed and analyzed by different organizations provide interlaboratory precision information for the entire measurement system (USEPA 1987b). Collocated samples may also be used to identify errors—for example, mislabeled samples and data entry errors.

Tables 15-1 through **15-3** present data generated by collocated sample pairs, grouped by sample matrix and analyte. Samples from both the Livermore site and Site 300 are included. **Tables 15-1** and **15-2** contain data pairs in which both values are above the detection limit and all radiological results for which a reported value was available. The tables exclude radiological values for which only a minimum detectable activity was reported. In addition, **Table 15-2** excludes radiological results for which the reported value was negative. **Table 15-3** contains data pairs in which either or both values are below the detection limit.

If there were more than eight data pairs with both results above the detection limit, precision and regression analyses were performed; the results are presented in **Table 15-1**. Precision is measured by the percent relative standard deviation (%RSD); see the EPA *Data Quality Objectives for Remedial Response Activities: Development Process,* Section 4.6 (U.S. Environmental Protection Agency 1987).

Acceptable values for %RSD vary greatly with matrix, analyte, and analytical method; however, values above 30% are common. The results for %RSD given in **Table 15-1** 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 one and intercept equal to zero, as illustrated in **Figure 15-1**. 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 >0.8.

If there are eight or fewer data pairs with both results above the detection limit, the ratios of the individual duplicate sample pairs are averaged; the average, minimum, and maximum ratios for selected analytes are given in **Table 15-2.** The mean ratio should be between 0.7 and 1.3.

If one of the results in a pair is below the detection limit, then the other result should be less than two times the detection limit. **Table 15-3** identifies the sample media and analytes for which at least one pair failed this criterion. Analytes with fewer than four pairs total are omitted from the table.

Table 15-1. 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	Units
Air	Beryllium[d]	21	16.3	1.08	0.82	–0.45	pg/m^3
	Gross alpha[d]	93	82.8	0.328	0.12	-2.33×10^{-7}	pCi/L
	Gross beta	93	28.9	0.823	0.81	2.053×10^{-6}	pCi/L
	Tritium	33	21.3	0.946	0.95	–0.00006	pCi/L (air)
Radiation dose	Radiation dose[d]	27	2.95	0.943	0.78	112	µSv
Ground water	Arsenic	25	9.43	1.00	1.0	0.00013	mg/L
	Bicarbonate alkalinity (as $CaCO_3$)[e]	18	4.56	0.892	0.65	22.1	mg/L
	Calcium	18	1.96	0.896	0.85	2.64	mg/L
	Chloride	18	2.31	1.03	1.0	–1.86	mg/L
	Fluoride	18	3.11	0.977	0.99	0.00532	mg/L
	Gross alpha[d]	17	60.6	0.399	0.48	0.729	pCi/L
	Gross beta[d]	17	25.6	0.217	0.28	3.88	pCi/L
	Magnesium	18	3.45	0.972	0.99	0.149	mg/L
	Nitrate (as NO_3)	15	1.69	0.989	1.0	0.578	mg/L
	Potassium	18	6.61	0.959	0.99	–0.0440	mg/L
	Sodium	18	2.77	0.989	1.0	–0.561	mg/L
	Specific conductance	18	3.77	1.01	0.99	–6.99	µmhos/cm
	Sulfate	18	3.14	0.990	1.0	1.15	mg/L
	TDS[e]	18	3.37	1.25	0.018	525.	mg/L
	Total alkalinity[d] (as $CaCO_3$)	18	4.56	0.892	0.65	22.1	mg/L
	Total hardness (as $CaCO_3$)	18	2.67	0.917	0.92	8.82	mg/L
	Vanadium	9	5.24	1.12	1.0	–0.00546	mg/L
	pH	19	0.949	0.942	0.97	0.466	Units
Sewer	Gross alpha[d]	32	99.3	0.0981	0.0073	0.852	pCi/L
	Gross beta	51	19.5	1.15	1.0	–2.78	pCi/L
	Tritium	34	56.4	1.02	0.96	–53.9	pCi/L

a Number of duplicate pairs included in regression analysis.

b 75th percentile of percent relative standard deviation (%RSD), where %RSD = $\left(200/\sqrt{2}\right)\left(|x_1 - x_2| / (x_1 + x_2)\right)$ 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 due to variability.

e Outside acceptable range of slope or r^2 due to outliers.

Table 15-2. 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[a]	Mean ratio	Minimum ratio	Maximum ratio
Air	Plutonium-239[b]	8	0.69	0.10	1.6
Ground water	Chromium	4	1.0	0.97	1.1
	Thorium-230	2	1.3	0.41	2.2
	Thorium-232[b]	1	2.9	2.9	2.9
	Uranium-234, Uranium-233	7	1.1	0.72	1.4
	Uranium-235, Uranium-236[b]	5	1.9	0.57	5.5
	Uranium-238	7	1.1	0.71	1.4
Rain	Tritium	4	0.99	0.79	1.2
Runoff (from rain)	Gross alpha[b]	4	0.57	0.20	0.95
	Gross beta	4	1.1	0.86	1.3
	Tritium	2	0.73	0.73	0.73
Other water	Gross alpha[b]	4	2.0	0.33	5.5
	Gross beta[b]	4	0.68	0.42	1.1
	Tritium	3	0.91	0.86	0.95
Soil	Beryllium[b]	1	2.4	2.4	2.4
	Cesium-137	2	0.75	0.45	1.0
	Plutonium-239	2	0.81	0.47	1.1
	Plutonium-239, Plutonium-240[b]	4	2.2	0.21	6.2
Vegetation	Tritium	5	1.1	0.66	1.7
	Tritium, per gram dry weight	5	1.1	0.69	2.0

a Number of data pairs.

b Outside acceptable range of 0.7–1.3, for mean ratio.

Table 15-3. 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	Number of pairs	Percent of inconsistent pairs
Air	Tritium	4	12	33.3
Ground water	Copper	1	18	5.6
	Freon 113	1	18	5.6
	Tritium	1	13	7.7
Runoff (from rain)	Copper	1	5	20
	Nickel	1	5	20
Sewer	Methylene chloride	1	4	25
Other water	Iron	2	4	50
	Manganese	1	5	20
	Silver	1	7	14.3
	Zinc	1	5	20
Vegetation	Tritium	1	7	14.3

These analyses show generally good agreement between routine samples and quality assurance duplicates: approximately 84% of the pairs have a precision better than 30%. Data sets not meeting our precision criteria generally 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 29 data sets reported in **Table 15-1**, four did not meet the criterion for acceptability because of outliers. **Figure 15-1** illustrates a set of collocated pairs with a single outlier. The other category of results that does not meet the criterion for acceptability consists of data sets in which there is a lot of scatter. This tends to be typical of measurements at extremely low concentrations as illustrated in **Figure 15-2.**

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 impact results. Another cause of high variability is sampling and analytical methodology. Analyses of total organic carbon and total organic halides in water are particularly difficult to control. Of the 26 data sets in **Table 15-1**, seven show sufficient variability in results to make them fall outside of the acceptable range.

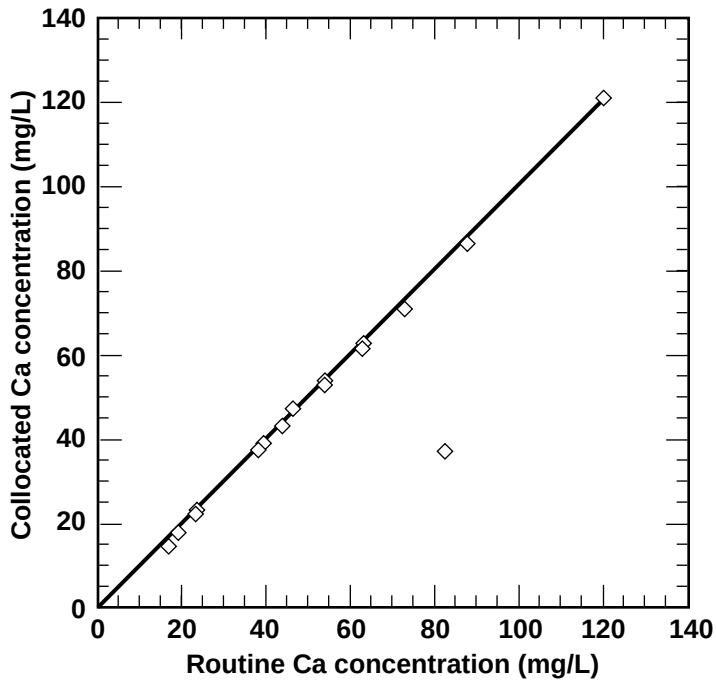

Figure 15-1. Calcium concentration in ground water from collocated samples. For each pair of samples, one result is plotted on ordinate (collocated) and the other result on the abscissa (routine). Data are shown with a line having a slope equal to one and intercept equal to zero. The measure of acceptability is determined by how well the data fall on the line.

Deviations and Changes to the Sampling Program

The sections that follow summarize changes to the environmental sampling effort made during 1995, deviations from planned environmental sampling, and omissions of data expected from regularly scheduled samples.

Changes to Environmental Monitoring Networks

Changes that were made to environmental monitoring networks in 1995 are summarized in **Table 15-4**.

The LLNL environmental monitoring program uses alpha-numeric location designator codes to define sampling locations. Volume 2 includes tables that decode these sampling location designators and provide a cross-reference between current designators and those used in previous years. Changes made in 1995 are noted on those tables.

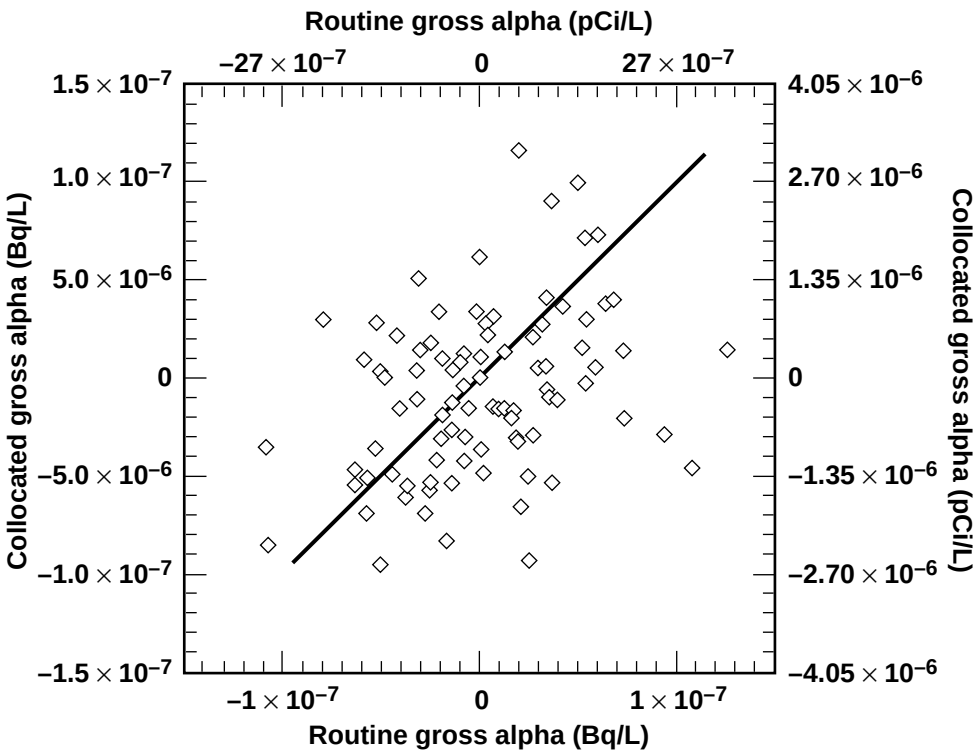

Figure 15-2. Gross alpha data from collocated samples collected on air filters. Data are shown with a line having a slope equal to one and intercept equal to zero.

One off-site air particulate monitoring station was eliminated during 1995 because of problems with electrical safety at that location. Two off-site vegetation monitoring locations were eliminated after 1994 as a result of a technical assessment of the vegetation monitoring network. The two locations that were removed, both of which are more than 25 km from LLNL, are no longer necessary because the remaining background locations are adequate for surveillance purposes.

The LLNL radiation monitoring networks changed significantly at the end of 1994. Neutron monitoring at the Livermore site was eliminated because of the absence of neutron sources requiring monitoring. The need for this monitoring will be reevaluated if new sources of neutrons are introduced. The thermoluminescent dosimeter network was also significantly reduced at the end of 1994, when a technical assessment of that network showed that environmental radiation could be adequately characterized with a smaller number of dosimeters.

Table 15-4. Changes to environmental monitoring networks in 1995.

Environmental medium	Livermore site	Site 300
Air particulate	L-ERCH dropped 10/10/95	No changes
Air tritium	No changes	Not sampled
Soil	No changes	No changes
Arroyo sediment	No changes	Not sampled
Vegetation	Dropped locations L-DAN and C-MOD after 1994	No changes
Wine	No changes	Not sampled
Rain	Reinstated locations L-BVA, L-GTES, and L-VINE in 1995	No changes
Storm water runoff	Reinstated location L-ALPO between 1Q and 4Q 1995	Added locations 3-GEOCRK and 3-CARN between 1Q and 4Q 1995
Drainage Retention Basin	No changes	Not sampled
Other surface water	No changes	Transferred location 3-GEOCRK to runoff network between 1Q and 4Q 1995
Ground water	Network added in 1995	No changes
Cooling towers	Not sampled	No changes
Sewage	No changes	Not sampled
Thermoluminescent dosimeters	Dropped 28 locations after 1994	Added 1 location
	Dropped 6 of 12 duplicates after 1994	Dropped 4 locations after 1994
	Dropped 5 of 7 transit controls after 1994	Dropped 2 additional locations after 1Q 1995
		Dropped 2 transit controls after 1994
Neutrons	Stopped monitoring after 1994	Not sampled

Three rain monitoring stations that had been eliminated in 1994 were reinstated in 1995 when a study of rain and meteorological data revealed that those locations were necessary to completely characterize precipitation of tritium from LLNL and SNL/California sources. Storm water monitoring location L-ALPO was reinstated in 1995 to measure influent to LLNL in response to elevated levels of gross alpha and beta in storm water runoff at another influent location. Two

monitoring locations at Site 300 were transferred from the surface water monitoring network to the storm water monitoring network.

Finally, surveillance monitoring of ground water at the Livermore site was added in 1995. This network is intended to provide data to establish baseline conditions of ground water quality and quantity in response to DOE Order 5400.1 and to meet the ground water monitoring requirements of 40 CFR Part 265, Subpart F.

Explanation of Missing Samples

Planned samples and actual samples collected and analyzed in 1995 are summarized in **Table 15-5.**

Table 15-5. Sampling completeness in 1995, Livermore site and Site 300.

Environmental medium	Samples planned	Samples analyzed	Completeness (%)
Air particulate	2091	2030	97.1
Air tritium	468	447	95.5
Soil	76	76	100
Arroyo sediment	24	24	100
Vegetation	76	76	100
Wine	22	22	100
Rain	110	108	98.2
Storm water runoff			
Site 300	123	82	66.7
Livermore	397	308	77.0
Drainage Retention Basin			
Field Measurements	238	416	54.8
Samples	89	88	98.9
Other surface water	120	116	96.6
Ground water			
Site 300	406	405	99.8
Livermore	1592	1592	100
Sewage	614	595	96.9
Thermoluminescent dosimeters	212	200	94.3
Cooling towers	16	16	100

Sample loss for the air particulate network were caused by a number of factors: tripped ground fault interrupt (GFI) circuits (24%), loss of location L-ERCH (18%), missed maintenance (12%), motor problems (12%), inadequate air flow (11%), access problems due to weather (11%), power off or unit unplugged (8%), samples not collected (2%), and the government shutdown (2%). Lost samples for the air tritium network were due to: flow out of range (24%), broken flasks (24%), motor problems (19%), tripped GFI circuits (19%), and power off upon arrival to collect the sample (14%). Two rain samples were lost because the sample bottles broke before reaching the laboratory. Two surface water samples were also missed because of an oversight on the part of sampling personnel.

The primary cause of lost samples for the Site 300 storm water runoff monitoring network was insufficient flow for sample collection. One set of samples was not analyzed because the sampling location is a spring and the flow at that location was determined to be spring water rather than storm water runoff at the time of sampling. One planned sampling event for storm water runoff was not accomplished at the Livermore site. Typically, the first storm of a rainy season is sampled in October or November and a second storm is sampled in December. Because of the late start of the 1995 – 1996 rainy season, the first storm that could be sampled during this season did not arrive until December, with the result that one less storm than was planned was sampled in 1995. Additional losses for the Livermore site storm water runoff network occurred because total suspended solids and Chrome VI analyses were not requested on the Chain of Custody for one storm.

The lost sample for the Drainage Retention Basin was a QC duplicate that was inadvertently omitted. Field sample losses were due to equipment malfunction (59%) and scheduling problems (41%). These samples are taken for basin management only and are not required for regulatory compliance.

The sample for Site 300 ground water monitoring was lost when a bottle containing a sample for tritium analysis broke. In the past, these bottles were cleaned and reused. The chance of this reoccurring has been minimized by replacing these sample bottles.

Sewer sampling and analysis is performed on a daily, weekly, and monthly basis. Thirteen daily samples could not be collected because of pump failures and planned equipment upgrades. All weekly samples were collected. One monthly sample was not analyzed because the analysis was not requested. Several analyses were not completed on the October monthly sample because the sample was too small after the Livermore Water Reclamation Plant (LWRP) used part of it to verify LLNL results.

Thermoluminescent dosimeters were lost when they were destroyed by vandals or eaten by cows. Because the majority of these samples are located off-site, it is difficult to protect them from people or animals. Unfortunately, these dosimeters have proven to be particularly appetizing to cows.

Statistical Methods

Statistical methods used in this report have been implemented pursuant to the *Environmental Monitoring Plan* (Tate et al. 1995). These methods reduce the large volumes of monitoring data to summary concentration estimates that are suitable for both temporal and spatial comparisons. Attention is given to estimating accuracy, bias, and precision of all data.

Data review and analyses are conducted in accordance with the *Environmental Monitoring Plan* and the Environmental Monitoring Section's Data Analysis Procedure. 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 Volume 2 data tables as the 2σ counting error. The counting errors are not used in any summary statistic calculations. By convention, any radiological result exhibiting a 2σ counting error greater than 100% is said to be below the detection criterion and is presented in the tables with a less-than symbol (<) to indicate its status. No value of error is reported for values below the detection criterion. The reported concentration is derived from the number of sample counts minus the number of background counts. A sample with a low or zero concentration may therefore be reported to have a negative value; such results are reported in the tables and used in the calculation of summary statistics and statistical comparisons. Some analytical laboratory reports provide a minimum detectable activity rather than a reported value when the radiological result is below the detection criterion.

Nonradiological Data

Nonradiological data that are reported as being below the analytical detection limit also are displayed in the tables with a less-than symbol. The actual detection 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. These uses instead 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. 1995). For data sets not containing 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. 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, 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.

Radiation Units

Data for 1995 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.

Appendix A. 1995 EPD Publications

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Appendix B. Methods of Dose Calculations

Robert J. Harrach
Kris A. Surano

Introduction

Radiological doses calculated from measured activities are a principal indicator of the potential impact of LLNL operations on surrounding populations. The doses from ingestion of water and locally produced foodstuff are based on actual measurements of radionuclide concentrations in the various media, determined by sampling, as described in Chapters 7 through 11. Data needed to evaluate potential doses from the inhalation and immersion pathways are provided by air surveillance monitoring, as described in Chapter 4.

The data on radionuclide concentrations or activities in these media are necessary inputs to the dose-rate equations described here. The examples presented below concern dose assessments for significant agricultural products of the Livermore Valley, including milk, wine, honey, and general vegetation, and in particular describe the forage-cow-milk pathway for ingestion of tritium in vegetation. The rate equations can also be used to estimate doses that would occur from ingestion of water at each of the Livermore Valley and Site 300 water sampling locations, though none of these is actually a primary source of drinking water.

Dose Calculation Methods

The dose calculation methods given here for the ingestion, inhalation, and immersion pathways are based on the 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 and dose-rate conversion factors used in these calculations were obtained from the committed dose equivalent tables for DOE dose calculations and are consistent with those specified in *ICRP 30, Limits of Intakes of Radionuclides by Workers* [International Commission on Radiological Protection (ICRP) 1980].

The calculations use conventional activity units of picocuries (pCi) and dose units of millirem (mrem). The conversion constants that apply when converting to Système International (SI) activity units of becquerels (Bq) and dose units of sieverts (Sv) are:

$$1 \text{ pCi} = (3.7 \times 10^{-2}) \text{ Bq}$$
$$1 \text{ mrem} = (1 \times 10^{-5}) \text{ Sv} = 10 \ \mu\text{Sv} = 1 \times 10^{-2} \text{ mSv}$$

The annual whole-body dose rate from ingestion of a particular food or drink is expressible as a product of three factors: the rate the food or drink is consumed (e.g., in L/y), the radionuclide concentration (e.g., in pCi/L) in the food or drink, and the dose rate conversion factor (e.g., in mrem/pCi) for the radionuclide. In

the following subsections, equations of this type are used to estimate the annual dose from tritium in water and milk (directly consumed), as well as radionuclides in meat, leafy vegetables, wine, and honey. Milk and honey are no longer sampled by LLNL because they are not impacted by LLNL's radionuclide releases, but the calculational examples have been retained here.

Generally, the concentrations are measured, while the appropriate consumption-rate factors are taken from the literature. The water and milk consumption rates are estimated to be 730 L / y and 310 L / y, respectively, in Appendix 1 of the NRC Regulatory Guide 1.109 (U.S. Nuclear Regulatory Commission 1977). The consumption rate for honey is reported to be 0.51 kg / y per person, or about 0.36 L / y, in the U.S. Department of Agriculture food consumption survey of 1977–1978 (Shlein and Terpilak 1984). In the absence of consumption data on locally produced wine, we employ the conservative (high dose) assumption that the intake rate for wine is the same as that for water. The resultant dose is expected to be several times too high for wine but well below levels of health concern.

LLNL's first use of these dose-rate formulas in our environmental annual reports is described by Lindeken et al. (1978) and by Silver et al. (1980).

Annual Dose from Potable Water

Based on the assumption that all water sampled is available as drinking water, the annual whole-body dose for tritium in mrem / y is calculated using the following equation:

$$D_{\text{whole body}}(\text{mrem / y}) = C_{\text{w}} \times U_{\text{w}} \times D_{\text{w}} \qquad \text{(B-1)}$$

where

C_{w} = concentration of tritium in water (pCi / L)

U_{w} = water consumption rate (L / y) = 730 L / y for maximally exposed individual

D_{w} = dose conversion factor (mrem / pCi)

= 6.3×10^{-8} mrem / pCi for tritium for the whole-body ingestion pathway for an adult (similarly, for ^{40}K the dose conversion factor is 1.88×10^{-5} mrem / pCi, and for ^{137}Cs, it is 2.17×10^{-7} mrem / pCi)

$D_{\text{whole body}}$ = effective dose equivalent (mrem / y) from ingestion of 730 L of potable water with tritium concentration C_{w}.

Annual Dose from Forage-Cow-Milk Pathway for Tritium in Vegetation

Based on the assumption that all feed for the cattle was pasture grass, the effective dose equivalent per mCi/mL of tritiated water (HTO) for the maximally exposed individual is calculated using the following equation:

$$D_{\text{whole body}}(\text{mrem/y}) = D_{\text{veg}} + D_{\text{meat}} + D_{\text{milk}} \quad \text{(B-2)}$$

where

D_{veg} = mrem/y dose from ingestion of vegetables

D_{meat} = mrem/y dose from ingestion of meat

D_{milk} = mrem/y dose from ingestion of milk.

Vegetation

$$D_{\text{veg(leafy)}} = U_{\text{veg}} \times C_{\text{veg}} \times D_{\text{HTO}} \quad \text{(B-2a)}$$

where

U_{veg} = intake rate (kg/y): 64 kg/y for maximally exposed individual

C_{veg} = concentration (pCi/kg): $10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}} \times (C_{\text{veg}}\ [\mu\text{Ci/mL measured}])$

D_{HTO} = dose factor (mrem/pCi): 6.3×10^{-8} mrem/pCi for ^{3}H for the adult wholebody ingestion pathway.

The tritium dose from ingestion of vegetation is then

$$D_{\text{veg}}(\text{mrem/y}) = (0.40 \times 10^4) \times (C_{\text{veg}}\ [\mu\text{Ci/mL measured}]).$$

Meat

$$D_{\text{meat}}(\text{mrem/y}) = U_{\text{meat}} \times C_{\text{meat}} \times D_{\text{HTO}} \quad \text{(B-2b)}$$

where

U_{meat} = intake rate (kg/y): 110 kg/y for maximally exposed individual

D_{HTO} = dose factor (mrem/pCi): 6.3×10^{-8} mrem/pCi for ^{3}H for the adult whole-body ingestion pathway

C_{meat} = $(F_f) \times (Q_f) \times (C_{\text{veg}}) \times (e^{[-\lambda i t s]})$

D_{HTO} = dose factor (mrem/pCi): 6.3×10^{-8} mrem/pCi for ^{3}H for the adult whole-body ingestion pathway

F_f = fraction of daily intake of nuclide per kilogram of animal/fish (pCi/kg in meat per pCi/d ingested by the animal) (d/kg): 1.2×10^{-2} d/kg

Q_f = amount of feed consumed (kg/d): 50 kg/d

C_{veg} = concentration (pCi/kg): $10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}}$

$\times (C_{veg}$ [μCi/mL measured])

λ_i = radiological decay constant (d^{-1}): 1.5×10^{-4} d^{-1}

t_s = time between slaughter to consumption (d): 20 d

$$C_{meat} = (1.2 \times 10^{-2}\ \text{d/kg}) \times (50\ \text{kg/d}) \times (C_{veg}\ [\mu\text{Ci/mL}]) \times (10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}}) \times (\exp[\{-1.5 \times 10^{-4}\} \times \{20\}])$$

$$= 0.6 \times 10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}}) \times (C_{veg}\ [\mu\text{Ci/mL measured}]).$$

The tritium dose rate from meat consumption is then

$$D_{meat}(\text{mrem/y}) = (110\ \text{kg/y}) \times (0.6 \times 10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}} \times C_{veg}\ [\mu\text{Ci/mL measured}]) \times (6.3 \times 10^{-8}\ \text{mrem/pCi})$$

$$= (0.41 \times 10^4) \times (C_{veg}\ [\mu\text{Ci/mL measured}]).$$

Milk

$$D_{milk}(\text{mrem/y}) = U_{milk} \times C_{milk} \times D_{HTO} \qquad \text{(B-2c)}$$

where

U_{milk} = intake rate (L/y): 310 L/y for maximally exposed individual

D_{HTO} = dose factor (mrem/pCi): 6.3×10^{-8} mrem/pCi for ^3H for the adult whole-body ingestion pathway

C_{milk} = $(F_m) \times (Q_f) \times (C_{veg}) \times (e^{[-\lambda i t_f]})$

F_m = fraction of daily intake of nuclide per liter of milk (pCi/L in milk per pCi/d ingested by the animal) (d/L): 1.0×10^{-2} d/L

Q_f = amount of feed consumed by the animal (kg/d): 50 kg/d

$$C_{veg} = \text{concentration (pCi/kg): } (10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}}) \times (C_{veg} \text{ [}\mu\text{Ci/mL measured]})$$

$$\lambda_i = \text{radiological decay constant (d}^{-1}\text{): } 1.5 \times 10^{-4} \text{ d}^{-1}$$

$$t_f = \text{time from milking to milk consumption (d): 2 d}$$

$$C_{milk} = (1.0 \times 10^{-2} \text{ d/L}) \times (50 \text{ kg/d}) \times (C_{veg} \text{ [}\mu\text{Ci/mL]}) \times (10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}}) \times (\exp[\{-1.5 \times 10^{-4}\} \times \{2\}])$$

$$= (0.5 \times 10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}}) \times (C_{veg} \text{ [}\mu\text{Ci/mL measured]}).$$

The tritium dose rate from directly consumed milk is then

$$D_{milk} \text{ (mrem/y)} = (310 \text{ L/y}) \times ([0.5 \times 10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}}] \times [C_{veg} \{\mu\text{Ci/mL measured}\}]) \times (6.3 \times 10^{-8} \text{ mrem/pCi})$$

$$= (0.97 \times 10^4) \times (C_{veg} \text{ [}\mu\text{Ci/mL measured]}).$$

Whole Body

$$D_{whole\ body} \text{ (mrem/y)} = ([0.40 \times 10^4] \times [C_{veg} \{\mu\text{Ci/mL measured}\}]) + ([0.41 \times 10^4] \times [C_{veg} \{\mu\text{Ci/mL measured}\}]) + ([0.97 \times 10^4] \times [C_{veg} \{\mu\text{Ci/mL measured}\}]).$$

The total annual dose rate from the forage-cow-milk pathway for tritium in vegetation is then

$$D_{whole\ body} \text{ (mrem/y)} = ([1.78 \times 10^4] \times [C_{veg} \{\mu\text{Ci/mL measured}\}]).$$

Inhalation/ Immersion Dose

Doses due to inhalation of and immersion in radionuclide-contaminated air can be estimated in an analogous way to the preceding treatment of ingestion doses. The starting point is to evaluate the radionuclide concentration in air, χ(Ci/m^3) at the location of interest. χ can be directly measured, or calculated using a Gaussian dispersion air transport model. In the latter approach, the calculated quantity is the atmospheric dispersion parameter, χ/Q, which is the product of the radionuclide concentration in air χ(Ci/m^3) at all locations of interest and the source release rate Q(Ci/s).

For inhalation dose, once χ or the product (χ/Q) × (Q) is evaluated, it is multiplied by the inhalation rate of a human to obtain the number of curies of radioactive material inhaled by the human body. Dose and dose-rate conversion

factors provided by the DOE (U.S. Department of Energy 1988), which are consistent with those specified in *ICRP 30* (International Commission on Radiological Protection 1980), are used to relate the intake of radioactive material into the body to dose commitment. These dose factors provide estimates of 50-year dose from a chronic one-year intake of radioactivity.

The inhalation dose is expressible as

$$D_{\text{whole body}}(\text{mrem/y}) = U_{\text{inhalation}} \times C_{\text{radionuclide}} \times D_{\text{radionuclide}} \qquad \text{(B-3)}$$

where

$U_{\text{inhalation}}$ = air intake rate (L/y): 8,400 m^3/y for an adult

$D_{\text{radionuclide}}$ = dose conversion factor (mrem/pCi) for the radionuclide of interest [for HTO this factor is $1.5 \times 6.4 \times 10^{-8}$ mrem/pCi = 9.6×10^{-8} mrem/pCi for the adult whole-body inhalation pathway, where the factor 1.5 accounts for absorption through the skin; for other radionuclides, see Table 2.1 in Eckerman et al. (1988)]

$C_{\text{radionuclide}}$ = $(F) \times (\chi/Q) \times (Q)$ = radionuclide concentration at the receptor (pCi/m^3)

$F = \dfrac{1 \times 10^{12}\ \text{pCi/Ci}}{3.15 \times 10^7\ \text{s/y}} = 3.17 \times 10^4\ (\text{pCi/Ci})/(\text{s/y})$

Q = radionuclide release rate (Ci/y)

χ/Q = diffusion parameter (s/m^3); calculated.

The wholebody inhalation dose rate is then

$$D_{\text{whole body}}(\text{mrem/y}) = (3.17 \times 10^4\ [\text{pCi/Ci}]/[\text{s/y}]) \times (\chi/Q)(\text{s/m}^3) \times (Q[\text{Ci/y}]) \times (8.4 \times 10^3\ \text{m}^3/\text{y}) \times D_{\text{radionuclide}}\ (\text{mrem/pCi}).$$

The immersion dose is similarly expressible as

$$D_{\text{whole body}}(\text{mrem/y}) = C_{\text{radionuclide}} \times (DRF) \qquad \text{(B-4)}$$

where

$C_{\text{radionuclide}}$ = $(F) \times (\chi/Q) \times (Q)$ = radionuclide concentration at the receptor (pCi/m^3)

$F = \dfrac{1 \times 10^{12}\ \text{pCi/Ci}}{3.15 \times 10^7\ \text{s/y}} = 3.17 \times 10^4\ (\text{pCi/Ci})/(\text{s/y})$

Q = radionuclide release rate (Ci/y)

χ / Q = diffusion parameter (s / m^3), calculated

DRF = the external dose-equivalent rate factor per unit radionuclide concentration (mrem / y) / (pCi / m^3) [for elemental ^3H this factor *DRF* is 3.9×10^{-8} (mrem / y) / (pCi / m^3); for the short-lived isotopes ^{13}N and ^{15}O it equals 5.1×10^{-3} (mrem / y) / (pCi / m^3); for other radionuclides see Table 2.3 in Eckerman et al. (1988)].

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Acronyms and Abbreviations

A	ACEHS	Alameda County Environmental Health Services.
	ACG	Ambient concentration guide.
	AIP	Agreement in principle.
	ALARA	As low as reasonably achievable.
	ANSI	American National Standards Institute.
	ASME	American Society of Mechanical Engineers.
	ATA	Advanced Test Accelerator.
	AVLIS	Atomic Vapor Laser Isotope Separation.
	AWQC	Ambient Water Quality Criteria.
B	BAAQMD	Bay Area Air Quality Management District. The local agency responsible for regulating stationary air emission sources (including the Livermore site) in the San Francisco Bay Area.
	BAT	Best available technology.
	BETX	Benzene, ethyl benzene, toluene, and xylene.
	BMP	Best Management Practice.
	Bq	Becquerel. The SI unit of activity of a radionuclide, equal to the activity of a radionuclide having one spontaneous nuclear transition per second.
C	Cal-EPA	California Environmental Protection Agency.
	CAM	Continuous air monitor.
	CAP88-PC	Computer code required by the EPA for modeling air emissions of radionuclides.
	CARE	Citizens Against a Radioactive Environment.

	CCR	California Code of Regulations. Codification of regulations promulgated by the state of California.
	CCTV	Closed-circuit television.
	CDF	California Department of Forestry.
	CDFG	California Department of Fish and Game
	CEPRC	Chemical Emergency Planning and Response Commission.
	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 (see Technical Terms).
	CES	Chemistry and Materials Science Environmental Services. An LLNL laboratory that analyzes environmental samples.
	CFC	Chlorofluorocarbon.
	CFR	Code of Federal Regulations. A codification of all regulations promulgated by federal government agencies.
	Chem Track	Computerized chemical inventory and tracking system.
	CHEW	Chemical Exchange Warehouse.
	CHP	California Highway Patrol.
	Ci	Curie (see Technical Terms).
	COC	Constituent of concern.
	CRWQCB	California Regional Water Quality Control Board.
	CSA	Container storage area.
D	DCG	Derived Concentration Guide (see Technical Terms).
	DCL	Discharge Concentration Limit (City of Livermore Ordinance 13.32).
	1,2-DCA	1,2-dichloroethane.
	DHS	California Department of Health Services

	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.
	DOT	U.S. Department of Transportation.
	DRB	Drainage Retention Basin. Man-made, lined pond used to capture stormwater runoff from SE quadrant of Livermore site for the purposes of study and/or remediation treated water.
	DTSC	California Environmental Protection Agency, Department of Toxic Substances Control.
	DUS	Donation, Utilization, and Sales (Group).
	DWTF	Decontamination and Waste Treatment Facility.
E	EA	Environmental Assessment. An environmental review document that identifies environmental impacts from any federally approved or funded project. If an EA shows significant impact, an EIS is required.
	EDE	Effective dose equivalent (see Technical Terms).
	EDO	Environmental Duty Officer.
	EE/CA	Engineering evaluation/cost analysis.
	EFA	East Firing Area (LLNL Site 300).
	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.
	ELAP	Environmental Laboratory Accreditation Program.
	EMAD	Environmental Monitoring and Analysis Division (LLNL). Defunct as of April 1995.

	EML	U.S. Department of Energy Environmental Measurements Laboratory.
	EMRL	Environmental Monitoring Radiation Laboratory.
	EMS	Environmental Monitoring Section in the Environmental Monitoring and Analysis Division of the Environmental Protection Department (at LLNL). Defunct as of April 1995.
	EMSL	Environmental Monitoring Systems Laboratory.
	EOG	Environmental Operations Group
	EPA	Environmental Protection Agency, (see Technical Terms).
	EPCRA	Emergency Planning and Community Right-to-Know Act.
	EPD	Environmental Protection Department (LLNL).
	ERD	Environmental Restoration Division of the Environmental Protection Department at LLNL.
	ERP	Environmental Restoration Program.
	ES&H	Environmental, Safety, and Health.
	ESP	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, DHS, RWQCB, and DOE).
	FFCA	Federal Facilities Compliance Agreement.
	FHC	Fuel hydrocarbon.
	Freon 113	1,1,2-trichloro-1,2,2-trifluoroethane.
G	g	Gram. The standard metric measure of weight approximately equal to 0.035 ounce.
	GSA	General Services Area (LLNL Site 300).
	GWP	Ground Water Project.

	GWPMP	Ground Water Project Management Program.
	Gy	Gray. The SI unit of measure for absorbed dose. It is the quantity of energy imparted by ionizing radiation to a unit mass of matter such as tissue. One gray corresponds to 1 joule per kilogram and equals 100 rads.
H	HCAL	Hazards Control Department Analytical Laboratory.
	HCD	Hazards Control Department.
	HDPE	High density polyethylene.
	HE	High explosives. Materials that release large amounts of chemical energy when detonated.
	HEPA	High-efficiency particulate air (filter).
	HF	Hydrogen fluoride.
	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.
	HSU	Hydrostratigraphic unit.
	HT	Tritiated hydrogen gas. Tritium is the hydrogen isotope with one proton and two neutrons in the nucleus. It emits a low-energy beta particle and has a half-life of 12.3 years.
	HTO	Tritiated water and water vapor (see HT).
	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.
	IQR	Interquartile range, (see Technical Terms).
	ISD	Interim status document.

L	LEPC	Local Emergency Planning Committee.
	LLNL	Lawrence Livermore National Laboratory.
	LOS	Limit of sensitivity (delectability).
	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	MCL	Maximum contaminant level in drinking water established by EPA or DTSC.
	MDC	Minimum detection 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.
	mR	Milliroentgen. 10^{-3} roentgen.
	mrem	Millrem. 10^{-3} rem.
	MSDS	Material Safety Data Sheet.
	mSv	Millisievert. 10^{-3} sievert.
	MWMF	Mixed Waste Management Facility.
N	NAAQS	National Ambient Air Quality Standards. Air standards established pursuant to the Clean Air Act to protect human health and the environment.
	NCR	Nonconformance Report.
	NCRP	National Council on Radiation Protection.
	NEPA	National Environmental Policy Act.

	NESHAPs	National Emission Standards 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.
	NOD	Notice of Deficiency.
	NOI	Notice of Intent.
	NOV	Notice of Violation.
	NO_X	Nitrogen oxides.
	NPDES	National Pollutant Discharge Elimination System. This federal regulation, under the Clean Water Act, requires permits for discharges into surface waterways.
	NPL	National Priorities List. EPA's list of the top-priority hazardous waste sites in the country that are subject to the Superfund program.
	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.
	NTS	Nevada Test Site (DOE). The facility in the United States where nuclear weapons are tested.
O	ORAD	Operations and Regulatory Affairs Division of the Environmental Protection Department at LLNL.
	OSHA	Occupational Safety and Health Act.
	OSP	Operational Safety Procedure.
P	PCB	Polychlorinated biphenyl.
	PCE	Tetrachloroethylene (or perchloroethylene).
	pCi	Picocurie .
	PM	Performance measure.

	%RSD	Percent relative standard deviation, a measure of precision
	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.
	PPOA	Pollution Prevention Opportunity Assessment.
	PRG	Preliminary remediation goal.
Q	QA	Quality assurance.
	QC	Quality control.
R	R	Roentgen, (see Technical Terms).
	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.
	RML	Radiological Measurements Laboratory.
	RMMA	Radioactive materials management areas.
	ROD	Record of Decision.
	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	SAL	State Action Level. See Action Level.
	SNL/California	Sandia National Laboratories, California.
	SDWA	Safe Water Drinking Act.

	SERC	State Emergency Response Commission.
	SHPO	State Historic Preservation Office.
	SI	*Système International d'Unités*. An international system of physical units. Units of measure in this system include meters (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.
	SJCPHS	San Joaquin County Public Health Services.
	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.
	STLC	Soluble Threshold Limit Concentration. A value that can be used to determine if a waste is hazardous.
	SW-MEI	Sitewide maximally exposed individual member of the public.
	SWPPP	Storm Water Pollution Prevention Plan.
	SWRCB	California State Water Resources Control Board.
T	TAGG	Tank Assessments and Guidance Group.
	TBOS	Tetrabutyl orthosilicate.
	TBq	Terabequerel. 10^{12} Bequerel.
	TCE	Trichloroethene.
	TDS	Total dissolved solids. The portion of solid material in a waste stream that is dissolved and passed through a filter.
	TF518	Treatment facility located near Building 518 in the southeast quadrant of LLNL .
	TFA	Treatment Facility A.
	TFB	Treatment Facility B.

	TFC	Treatment Facility C.
	TFD	Treatment Facility D.
	TFF	Treatment Facility F.
	TLD	Thermoluminescent dosimeter. A device used to measure external gamma radiation levels.
	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.
	TPH	Total petroleum hydrocarbons.
	TPH-D	Total petroleum hydrocarbons-diesel.
	TRI	Toxic Chemical Release Inventory.
	TRU	Transuranic waste.
	TSCA	Toxic Substances Control Act. The law governing the manufacture, processing, and use of chemical substances.
	TSS	Total suspended solids.
U	UC	University of California.
	USEPA	U.S. Environmental Protection Agency.
	USGS	U.S. Geological Survey. The federal agency responsible for maintaining maps of the United States.
	UST	Underground storage tank. A stationary device designed to contain an accumulation of hazardous materials or waste. A tank is constructed primarily of nonearthen material, but the entire surface area of the tank is totally below the surface of, and covered by, the ground.
V	VHS	Volatile halogenated solvent. A term used by LLNL for analysis of the solvents detectable by EPA Method 601.
	VOC	Volatile organic compound. Liquid or solid organic compounds that have a tendency to spontaneously pass into the vapor state.

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.
	WFA	West Firing Area (LLNL Site 300).
	WMP	Waste Minimization Project.
	WMPPA Plan	Waste Minimization and Pollution Prevention Awareness Plan.
	WPAA	Workplace accumulation area.
	WQO	Water quality objective.

Technical Terms

A	Absorbed dose	The amount of energy deposited by radiation in a given amount of material. The unit of absorbed dose is the rad.
	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. It has a 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	A constituent that is being analyzed.
	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 bed that bounds an aquifer.
	Atom	The smallest particle of an element capable of entering into a chemical reaction.
	Atomic absorption spectroscopy	Abbreviated AA. 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.
	Beta particle	A negatively charged particle emitted from the nucleus of an atom. It has a mass and charge equal to those of an electron.
	BOD	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.
	CERCLA/SARA	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. 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.
	CFC	Chlorofluorocarbon. 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 tetrachloroethylene.
	Curie	A unit of measurement of radioactivity, defined as the amount of radioactive material in which the decay rate is 2.22×10^{12} disintegrations per minute (3.7×10^{10} disintegrations per second). One Ci is approximately equal to the decay rate of one gram of pure radium.
	Collective dose equivalent	The sums of the dose equivalents of all individuals in an exposed population within a certain radius, expressed in units of person-rem (or person-sievert).
	Collective effective dose equivalent	The sums of the effective dose equivalents of all individuals in an exposed population within a certain radius, expressed in units of person-rem (or person-sievert).
	Committed dose equivalent	The predicted total dose equivalent to a tissue or organ over a 50-year period after known intake of a radionuclide into the body. It does not include contributions from external dose. Committed dose equivalent is expressed in units of sievert (or rem).
	Committed effective dose equivalent	The sum of the committed dose equivalents to various tissues, each multiplied by the appropriate weighting factor. Committed effective dose equivalent is expressed in units of sievert (or rem).
	Cosmic radiation	Radiation with very high energies, originating outside the earth's atmosphere. Cosmic radiation is one source contributing to natural background radiation.
D	Daughter nuclide	A nuclide formed by the radioactive decay of another nuclide, which is called the parent.
	Depleted uranium	Uranium having less ^{235}U than is found in natural uranium.
	DCG	Derived Concentration Guide. Concentrations of radionuclides in water and air that could be continuously consumed or inhaled (365 days / y) and not exceed the DOE primary radiation protection standard to the public (100 mrem / y effective dose equivalent).
	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 which an organ or tissue would receive during a specified period of time (e.g., 50 or 100 years) as a result of intake of one or more radionuclides from one year's release.

	Dose equivalent	The product of the absorbed dose (rad) in tissue and a quality factor. Dose equivalent is expressed in units of rem (or sievert). The dose equivalent to an organ, tissue, or whole body in a year will be that received from the direct exposure plus the committed dose equivalent received from radionuclides taken into the body during the year.
	Dosimeter	A portable detection device for measuring the total accumulated exposure to ionizing radiation.
	Dosimetry	The theory and application of the principles and techniques involved in the measurement and recording of radiation doses. Its practical aspect is concerned with the use of various types of radiation measurement instruments.
	Downgradient	In the direction of ground water flow from a designated area; analogous to downstream.
E	EDE	Effective dose equivalent. An estimate of the total risk of potential effects from radiation exposure. It is the sum of the committed effective dose equivalent from internal deposition and the effective dose equivalent from external penetrating radiation received during a calendar year. The committed effective dose equivalent is the sum of the individual organ committed dose equivalents multiplied by weighting factors that represent the proportion of the total random risk that each organ would receive from uniform irradiation of the whole body.
	Effluent	A liquid or gaseous waste discharged to the environment.
	EPA	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.
	Evapotranspiration	Process by which water is transferred from the soil to the air by plants that take the water up through their roots and give it off 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.
	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 1 half-life, 50 out of 100 atoms (on average) will have decayed; during the next half-life, 25 more will decay, 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.
	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 (carbon monoxide, 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 other 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.
	IQR	Interquartile range. 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	Mixed waste	Waste that has the properties of both hazardous and radioactive waste.
N	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.
	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).

	NPDES General Permit	National Pollutant Discharge Elimination System General Industrial Activities Storm Water Permit.
	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.
	Piezometer	Generally, a small-diameter, nonpumping well used to measure the elevation of the water table or potentiometric surface.
	Pliocene	Geological epoch of the Tertiary period, starting about 12 million years ago.
	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.
	Point source	Any confined and discrete conveyance (e.g., pipe, ditch, well, or stack).
	Pretreatment	Any process used to reduce a pollutant load before it enters the sewer system.
	Pretreatment regulations	National wastewater pretreatment regulations, adopted by EPA in compliance with the 1977 amendments to the Clean Water Act, which required that EPA establish pretreatment standards for existing and new industrial sources.

	Priority pollutants	A set of organic and inorganic chemicals identified by EPA as indicators of environmental contamination.
Q	QA	Quality assurance. A system of activities whose purpose is to provide the producer or user of a product or service the assurance that it meets defined standards of quality with a stated level of confidence.
	QC	Quality control. 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. It is used because some types of radiation, such as alpha particles, are more biologically damaging than others.
	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.
	Radioactive decay	The spontaneous transformation of one radionuclide into a different radioactive or nonradioactive nuclide, or into a different energy state of the same radionuclide.
	Radioactivity	The spontaneous emission of 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	Radiological unit of dose equivalent. This is the product of the absorbed dose (rad), quality factor (Q), distribution factor, and other necessary modifying factors. The unit rem describes the effectiveness of various radiations to produce biological effects (1 rem = 0.01 sievert).
	Risk assessment	The use of established methods to measure the risks posed by an activity such as hazardous waste treatment. Risk assessments evaluate (1) the relationship between exposure to toxic substances and the subsequent occurrence of health effects and (2) the potential for that exposure.
	Roentgen	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 groundwater samples. The plan details quality control measures that will be 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.
	SARA Title III	Superfund Amendment and Reauthorization Act.
	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)	A unit of radiation dose to a person. It describes the ability of a type of radiation to produce biological effects. A Sievert is the SI unit that corresponds to the rem; 1 Sv = 100 rem.
	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	Tritium is the hydrogen isotope with one proton and two neutrons in the nucleus. It emits a low-energy beta particle and has a half-life of 12.3 years.

	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.
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.
	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 ICRP (Publication 26).
	Wind rose	A diagram that shows the frequency and intensity of wind from different directions at a particular place.
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.

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