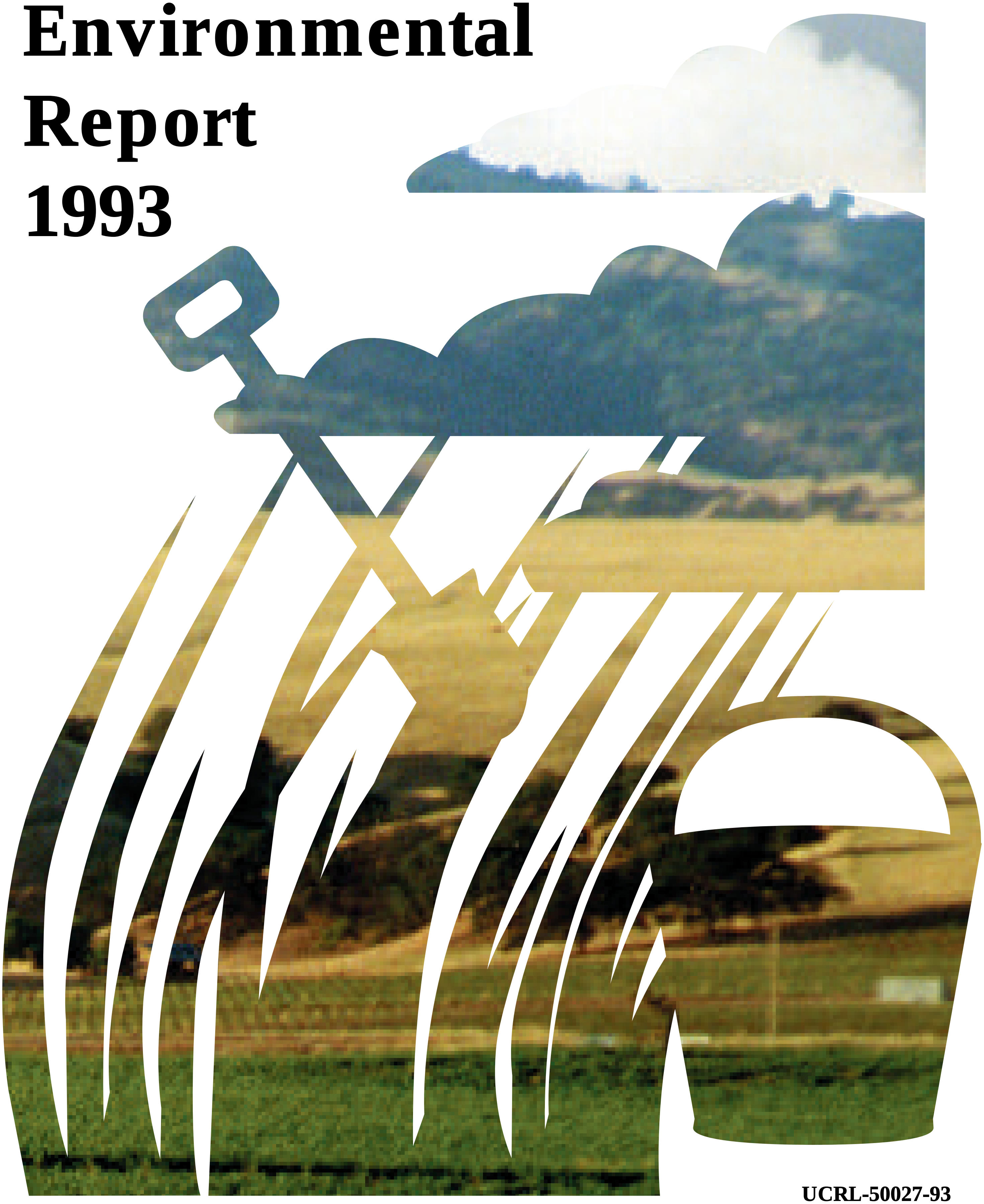
Environmental Report 1993



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Environmental Report 1993

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Preface

This report is prepared for the U.S. Department of Energy (DOE) by the Environmental Protection Department (EPD) at the Lawrence Livermore National Laboratory (LLNL). This publication presents the results of LLNL's environmental monitoring and compliance effort and provides an assessment of the impact of LLNL operations on the environment.

As in the 1992 report, data are presented in *Système International* (SI) units. This is consistent with the federal law stated in the Metric Conversion Action of 1975 (15 United States Code 205a et seq.); Presidential Executive Order 12770, Metric Usage in Federal Government programs (July 25, 1991); and DOE's policy on the use of the metric system (DOE Order 5900.2), which states in part that "All Departmental Elements should take steps, as directed by Executive Order 12770, to use the Metric System (SI) in procurements, grants, publications, and other business-related activities." Radiological results are presented in becquerels, and summary statistics are repeated in curies (1 Bq = 2.7×10^{-11}Ci). Similarly, dose ispresented in millisieverts and summary statistics are repeated in millirem (1mSv= 100 mrem).

Results for both the Livermore site and Site 300 are presented in each chapter, and trends in monitoring data are shown graphically.

This document is the responsibility of the Environmental Monitoring and Analysis Division of the EPD. Within this division, personnel from the Environmental Monitoring Section (EMS) sampled the environment, interpreted the results, performed the impact analysis of radiological emissions from LLNL, and compiled the information presented here.

Monitoring data were obtained through the combined efforts of the EMS, the Nuclear Chemistry Division, the Radiological Analytical Sciences laboratory, and the Hazards Control Department of LLNL. Special recognition is deserved for the dedication and professionalism of these environmental monitoring technicians—Paris E. Althouse, Gary A. Bear, David L. Graves, Renee Needens,* Terrance W. Poole, Donald G. Ramsey, Judith N. Rose, Rebecca J. Ward, and Rhonda L. Welsh—and to these data management personnel—Nina Hankla,* Jennifer Clark,* Colleen R. Frost, Kimberly A. Stanford, and Connie Wells.* Thanks also to Judith L. Kelly* for initial preparation of Appendix A.

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Executive Summary

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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 capability with a special focus on national security. Over the years, the Laboratory's mission has been broadened to encompass such areas as strategic defense, energy, the environment, biomedicine, the economy, and education. The Laboratory carries out this mission in compliance with local, state, and federal environmental regulatory requirements and takes measures to ensure that its operations do not adversely affect the environment or public health. It does so with the support of the Environmental Protection Department, which is responsible for environmental monitoring, environmental restoration, hazardous waste management, and ensuring environmental compliance.

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.

During 1993, the Environmental Protection Department conducted sampling of air, sewage effluent, ground water, surface water, soil, vegetation and foodstuffs, and took measurements of environmental radiation. It performed more than 190,000 analyses of environmental samples. The analytical results are summarized in the chapters that follow, along with evaluations of the impact of radioactive and nonradioactive materials, a discussion of the effects of LLNL operations on the environment, and a summary of the activities undertaken to comply with local, state, and federal environmental laws.

Environmental Monitoring Results

LLNL's sampling networks undergo constant evaluation; changes to them are made, as necessary, to ensure adequate 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 most significant radiological pollutant continues to be tritium, the radioactive isotope of hydrogen. The emissions of tritium at the Livermore site in 1993 were comparable to those in 1992, and were significantly lower than emissions prior to 1992. In 1993, air emissions of tritium from the Tritium Facility, the primary source of tritium emissions, were 8.77×10^{12}Bq (237 Ci); in 1992 these emissions were 6.55×10^{12}Bq (177 Ci). In 1991 and previous years tritium emissions from this facility were above 37×10^{12} Bq (1000Ci). The Tritium Facility has ceased operations except for inventory reduction and cleanup activities. These activities were more extensive in 1993 than in 1992, leading to a small increase in emissions. In spite of this small increase in Tritium Facility emissions, lower tritium values were measured in surface water, rain water, and runoff. Small decreases have also been seen in measured values for tritium in air and vegetation.

Particulate matter in air is monitored for beryllium and for radionuclides, including plutonium and uranium isotopes. Most of the radioactivity detected is from naturally occurring radionuclides and global fallout from historical nuclear weapons testing. Plutonium from fallout and past programmatic activity is found at low levels around the perimeter of the Livermore site. Plutonium from fallout only is detected at even lower levels at Site300.The highest average plutonium value was measured at a location on the Livermore site near Building531. The average concentration there was 2.7×10^{-13} bequerels per milliliter (Bq / mL) of air (7.4×10^{-18} µCi / mL), a small fraction of the regulatory exposure guideline of 7.4×10^{-10}Bq / mL of air (2×10^{-14} µCi / mL).

To determine whether operations at Site 300 are affecting the measured amounts of uranium, which occurs naturally, environmental analysts measure the relative amounts of two isotopes of uranium: uranium-238 and uranium-235. Natural uranium is primarily uranium-238, with 0.7% uranium-235. Most LLNL uranium operations use uranium-238, a slightly radioactive isotope. The observed ratio of the two isotopes, therefore, can reveal whether LLNL operations have added uranium-238 to the environment at Site 300. The ratios of airborne particulate uranium in April and October 1993 deviate from the natural ratio, indicating the presence of airborne uranium-238 from Site 300 operations. The measured concentrations of uranium-238, however, are only a small fraction (24 / 100,000) of the regulatory exposure guideline of 0.03 µg / m^3.

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 would be automatically activated. The diversion system will capture 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 1993, there were no releases that exceeded any discharge limits for release of materials to the sanitary sewer system. The results of the effluent monitoring program demonstrate the success of LLNL's discharge control programs.

As first discussed in the 1991 annual report, monitoring results for sewage show concentrations of plutonium and cesium slightly higher than the values seen historically. These results are related to sewer cleaning with new, more effective equipment. However, the cleaning activity around the site was less extensive during 1993. This has been reflected in the slightly lower plutonium and cesium concentrations in LLNL effluent during 1993. The plutonium levels observed in LWRP sludge (2.1 mBq/dry g, or 0.057 pCi/dry g) are more than two hundred times below the proposed EPA guideline for the unrestricted use of soil. These levels are most probably due to residues left in the sanitary sewer from previous programmatic activities.

Water sampling and analysis are a large part of the LLNL surveillance monitoring effort. The waters monitored include lakes, streams, rainfall, tap water, storm water runoff, drinking water supply wells, and ground water monitoring wells. The samples are analyzed for gross alpha and gross beta radiation, tritium, and nonradioactive pollutants, including solvents, metals, and pesticides. For the Livermore-site storm water samples, gross alpha and gross beta were generally below drinking water standards; the exceptions were at locations ALPE and GRNE. These locations are upstream and off the Livermore site. The source of the gross alpha and gross beta is unknown, and there were no analytical results from air sampling that would tie the storm water results to airborne emissions from LLNL. Tritium values for surface and drinking water samples were less than 1% of the drinking water standard of 740Bq/L (20,000pCi/L).

Tritium values for rain water samples were also generally lower than the drinking water standard, with one notable exception. A sample collected at location B331 during a rainy period from February 8–20, 1993, measured 5439 Bq/L (147,000 pCi/L). This is over seven times the drinking water standard. This sampling location adjoins LLNL's Tritium Facility, where various inventory reduction and cleanup activities were taking place. Tritium values for the nearest air sampling location were also elevated at this time. Modeling was used to determine that a release of about 6.3×10^{10} Bq (1.7 Ci) over eight weeks, from out-of-service equipment in the waste accumulation area east of the Tritium Facility, accounts for the observed levels of tritium in air and rain at the B331 sampling location. The calculated dose to a hypothetical member of the public having the greatest possible exposure from this event is about 0.02 µSv (0.002mrem).

LLNL's Ground Water Protection Management Program is a multifaceted effort to eliminate or minimize adverse impacts of Laboratory operations on ground water, determine the extent and understand the impact of past activities, remediate adversely affected areas, and monitor current operations. The LLNL Ground Water Protection Plan is summarized in this report. Ground water monitoring at the Livermore site investigates contamination at the site according to the Federal Facility Agreement for the Comprehensive Emergency Response, Compensation, and Liability Act (CERCLA). LLNL conducts ground water monitoring at Site 300 under two programs, one to meet regulatory commitments established for site-specific CERCLA investigations, and a second consisting of routine compliance monitoring around landfill and wastewater surface impoundment units.

Results for ground water monitoring were similar to historical results. Tritium results for Livermore Valley wells remain below the drinking water standard. Tritium results for ground water monitoring wells located near the Pit7 Complex (a former landfill disposal complex) at Site 300 continue to exceed the drinking water standard. Transport modeling of tritium, which has a half-life of 12.3 years, indicates that the tritium will be below the drinking water standard by the time the water reaches the Site 300 boundary. Some ground water near the Pit 7 Complex also is contaminated with barium, depleted uranium, and organic solvents from past releases from the landfills. LLNL will continue to determine the nature and extent of contamination by continued sampling and data analysis. Fate and transport analysis and risk assessment will be conducted. If these assessments indicate that significant (as defined by CERCLA) hazards or risks are posed by these substances, corrective actions will be taken. Neither humans nor domestic animals drink or use the water.

Vegetation and foodstuffs are monitored for their tritium content; milk is further analyzed to determine the amounts of cesium-137 (a fallout radionuclide) and potassium-40 (a naturally occurring radionuclide). The milk samples taken are of goat milk. As in past years, the levels of radiation in milk were minimal and could not be distinguished from background radiation levels. The tritium concentrations in vegetation samples taken near the Livermore site were greater than those taken from more distant locations. The tritium concentrations in nearby vegetation samples were three-fourths those reported in 1992, while the concentrations in samples taken at greater distances were essentially unchanged from 1991 and 1992. As in the past, the tritium concentrations in Livermore Valley wines analyzed in 1993 are slightly above those for wines tested from Europe and other locations in California; however, even the highest detected value, 8.25Bq/L (223pCi/L), is just over 1% of the amount California allows in drinking water. This amount is nearly the same as the highest value for 1992, 8.84Bq/L (239pCi/L).

In 1993, soil samples from the Livermore site and Site 300, and arroyo sediment samples from storm water drainage channels at the Livermore site, were analyzed for radionuclides and beryllium. All measured values for 1993 were consistent with historical data and generally showed background values.

LLNL also maintains an extensive network of direct radiation monitors, using thermoluminescent dosimeters (TLDs) for gamma radiation and neutron monitors developed at LLNL for neutron radiation. TLD measurements at the Livermore-site perimeter averaged 0.65 mSv (65 mrem) and at the Site 300 perimeter averaged 0.76 mSv (76 mrem). Neutron measurements at the Livermore-site perimeter averaged 0.058 mSv (5.8 mrem). All of these measurements are equivalent to natural background radiation levels.

Radiological Impact Assessment

DOE environmental radiation protection standards are provided in DOE Order 5400.5, *Radiation Protection of the Public and the Environment*. The primary DOE radiation standards for protection of the public are 1mSv/y (100mrem/y) effective dose equivalent for prolonged exposure, and 5mSv/y (500mrem/y) effective dose equivalent for occasional exposure. DOE and LLNL also comply with EPA's standard for radiation protection, which applies to air emissions. It limits the whole-body effective dose equivalent to 0.1 mSv/y (10mrem/y). Both limits are based on the maximum exposure that any individual member of the public could receive. Compliance with the limits is determined by computer modeling, which includes conservative assumptions and results in calculated exposures larger than exposures actually received by members of the public.

Routine LLNL operations during 1993 released a total of 9.0×10^{12} Bq (243Ci) of tritium to the atmosphere from the Tritium Facility and other operations; of that, 4.4×10^{12}Bq (119 Ci) was in the form of tritiated water. An additional 6.9×10^{12} Bq (187 Ci) was released by Sandia National Laboratories, California, with approximately 4.9×10^{12} Bq (132 Ci) in the form of tritiated water. The amount of radioactivity released from LLNL during 1993 was slightly higher than that released during 1992, but was below the range of previous years.

There was one unplanned atmospheric radionuclide release at the Livermore site in 1993 and none from Site 300. In September 1993, an analysis of gross alpha data from a continuous sampler for particulates, which is located in a stack on Building 251, revealed radon daughters, indicating a release to the atmosphere of radon-220. The source of the release was a thorium-228 experiment occurring in a glove box connected to the atmosphere by the HEPA-filtered stack. Data and calculations evaluated the total release during the entire period to be 5.9 ×

10^{11}Bq (16 Ci), with a resultant maximum dose to a hypothetical member of the public of 3×10^{-3} μSv / y (3×10^{-4} mrem / y), well below levels of health concern.

The total dose calculated for point source emissions, for a hypothetical person having the greatest possible exposure at the Livermore site, was 0.40 μSv (0.040 mrem) effective dose equivalent. From diffuse emissions it was 0.26 μSv (0.026 mrem). This yields a total dose of 0.66 μSv (0.066 mrem) for the Livermore site in 1993, which represents less than 1% of the EPA limit of 0.1 mSv / y (10mrem / y) for airborne emissions. This value is slightly lower than the value for 1992 and much lower than those for previous years: dose values reported for 1992, 1991, and 1990 were 0.69 μSv (0.069 mrem), 2.34 μSv (0.234 mrem) and 2.40 μSv (0.240 mrem). Reduced emissions of tritium from the Tritium Facility account for much of this decline.

The dose to a person having the greatest possible exposure at Site 300 in 1993 was calculated to be 0.37 μSv (0.037 mrem) effective dose equivalent. This value includes contributions from both point sources (30%) and diffuse sources (70%). Virtually all of the point source dose resulted from Building 801 firing table emissions that used depleted uranium during open air, high-explosive tests. The dose contributed by firing table operations at Site 300 shows a steady decline from year to year, reflecting reduced use of depleted uranium in the tests: in 1993 the dose from firing tables was 0.11 μSv (0.011 mrem); in 1992, 0.21 μSv (0.21mrem); in 1991, 0.44 μSv (0.044 mrem); and in 1990, 0.57 μSv (0.057 mrem).

The principal radionuclides contributing to these doses are tritium in the tritiated water form—which accounts for about 93% of the dose at the Livermore site—and the isotopes of uranium with atomic numbers 238, 234, and 235, whichaccount for about 5% of the dose at the Livermore site and all of the Site300dose.

For LLNL operations in 1993, the collective effective dose equivalent was 0.0098 person-Sv (0.98 person-rem) from the Livermore site and 0.069 person-Sv (6.9 person-rem) from Site 300, including all pathways (ingestion, air immersion, surface exposure, and inhalation pathways). The larger value for Site 300 relative to the Livermore site is traceable to highly conservative assumptions about the explosive experiments at Site 300, which overpredict the long-range dispersal of material in these experiments. These collective effective dose equivalents from the two LLNL sites are quite small compared to that from natural sources of radiation, which was estimated to be 19,000 person-Sv (1,900,000 person-rem).

Environmental Compliance Activities

Both the Livermore site and Site 300 are Superfund sites under CERCLA and are undergoing remedial activities. The proposed technique for cleaning up ground water at the Livermore site consists of managed ground water extraction at 18 locations and surface treatment. Contaminated sediments in the unsaturated zone will be treated, as appropriate, by extracting fuel hydrocarbons or volatile organic compounds by vacuum-induced venting and treatment of the vapors. EPA and local and state agencies have approved this plan. In 1993, ground water was treated at four facilities to capture and control the off-site spread of contaminated ground water: Treatment Facility A treated more than 87million liters of ground water, removing and destroying about 11 kilograms of volatile organic compounds; Treatment Facility B treated about 40 million liters of ground water, removing and destroying about 4.1 kilograms of volatile organic compounds; Treatment Facility C, which was constructed in 1993 and began operating on October 30, 1993, treated about 440,000 liters of ground water, removing 18 grams of volatile organic compounds; and Treatment FacilityF removed about 28,400 liters of gasoline. The Superfund activities at Site 300 are at an earlier stage; LLNL completed a site-wide remedial investigation report for the site in August 1993. Treatment activities have begun in the General Services Area at Site 300. During 1993, 77 million liters of ground water in the eastern section were treated to remove approximately 1 kilogram of volatile organic compounds.

Title III of the Superfund Amendments and Reauthorization Act is known as the Emergency Planning and Community Right-to-Know Act. It requires owners or operators of facilities that have certain hazardous chemicals on site to provide information on the manufacture, use, and storage of those chemicals to organizations responsible for emergency-response planning. To comply with these requirements, LLNL in 1993 implemented ChemTrak, a new computerized chemical tracking system. An extensive chemical inventory effort was initiated in November 1993. This inventory resulted in a baseline of approximately 158,000 chemical containers ranging form 55-gallon drums to gram-quantity vials.

LLNL continues to perform all activities necessary to comply with clean air and clean water requirements. In 1993, the Bay Area Air Quality Management District issued 200 permits for the Livermore site. The San Joaquin Valley Unified Air Pollution Control District issued 44 permits for Site 300 covering the operation of equipment that gives off emissions to the air. LLNL has permits for discharge of treated ground water, for discharges of industrial and sanitary sewage, and for discharge of storm water. Site 300 has four additional permits for inactive landfills; cooling tower discharges; operation of the sewer lagoon, septic tanks, and leach fields; and discharge of treated ground water. LLNL complies with all requirements for self-monitoring and inspections associated with these permits.

As of March 31, 1993, all 56 of the Livermore site and Site 300 facilities having the potential to release radionuclides to the atmosphere had been evaluated to show compliance with the National Emissions Standards for Hazardous Air Pollutants (NESHAPs). Annual doses resulting from total actual emissions (after controls) were found to be well below the NESHAPs standard of 100 µSv/y (10mrem/y). Estimates of effective dose equivalent for all evaluated facilities, assuming normal operations but no pollution control devices, have been calculated. Three facilities at the Livermore site have been identified as having potential unmitigated effective dose equivalent estimates greater than 1 µSv/y (0.1 mrem/y), and these facilities have appropriate continuous radionuclide sampling systems in place, as required by NESHAPs. Several other Livermore-site facilities also have existing sampling systems; however, potential unmitigated effective dose equivalent estimates were less than 1 µSv/y (0.1mrem/y), and they do not require continuous monitoring under NESHAPs regulations. No other facilities, including all those at Site 300, were found to require continuous monitoring systems. During 1993, LLNL demonstrated its compliance with the requirements of NESHAPs pursuant to a Federal Facility Compliance Agreement signed by DOE and EPA. In April 1994, EPA concurred that all requirements of the Agreement had been met and that LLNL was now in compliance with NESHAPs regulations.

LLNL has one endangered species, *Amsinckia grandiflora* (large-flowered fiddleneck), which is found at Site 300. On April 19, 1993, LLNL personnel counted 301 mature plants in the natural population of *Amsinckia*, down from 546plants observed in 1992. The decline in population may have been related tothe extremely wet, cool weather pattern. LLNL personnel also counted 135 plants in two experimental populations. Work on all populations will continue through 1994.

Conclusion

Like many other organizations and individuals who are concerned about the environment, LLNL is committed to protecting the environment and ensuring that operations are conducted in accordance with applicable laws and regulations that have been enacted to protect the environment. The current techniques used at LLNL for environmental monitoring are very sensitive, allowing detection at extremely low levels of constituents. The monitoring results for 1993 generally show that these low concentrations are only a very small fraction of regulatory standards. The analytical results and evaluations generally show a decrease in contaminant levels, reflecting the responsiveness of the Laboratory in controlling pollutants. In summary, the results of the 1993 environmental monitoring and modeling programs demonstrate that the environmental impacts of LLNL are minimal and pose no threat to the public or the environment.

1. Site Overview

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Introduction

Climate and geography play primary roles in how the environment is affected by human actions. Dispersal of particles in the 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, and geological and geographical characteristics are used to calculate the effects that operations at LLNL might have on the surrounding environment. Some history and a description of these data help us understand the relationship of the Laboratory to its climatic and geographic setting.

Location

LLNL consists of two main facilities—the main laboratory site located in Livermore, California (Livermore site), and the Experimental Test Facility (Site300) located near Tracy, California (**Figure 1-1**). Each site is unique, requiring a different approach for environmental monitoring and protection.

Over forty years ago, LLNL was founded on the site of a former U.S. Navy maintenance base. At that time the location was relatively isolated, being approximately 1.6kilometers from the Livermore city limits. Over the years, Livermore evolved from a small town of fewer than 7000 people to its present population of nearly 55,000. The economy diversified from primarily agricultural to include light industry and business parks. Within the last few years, low-density, single-family residential development has begun to fill the formerly vacant fields, bringing the city limits of Livermore to LLNL's western boundary.

LLNL's Livermore site occupies an area of 3.28 square kilometers, including the land that serves as a buffer zone around the site. Immediately to the south is Sandia National Laboratories, California (SNL/CA), operated by Martin-Marietta under DOE contract. SNL/CA 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/CA are separate facilities, each with its own management and each reporting to a different DOE operations office.

To the south of LLNL there are agricultural areas devoted to grazing, orchards, and vineyards; some low-density residential areas; and a business park

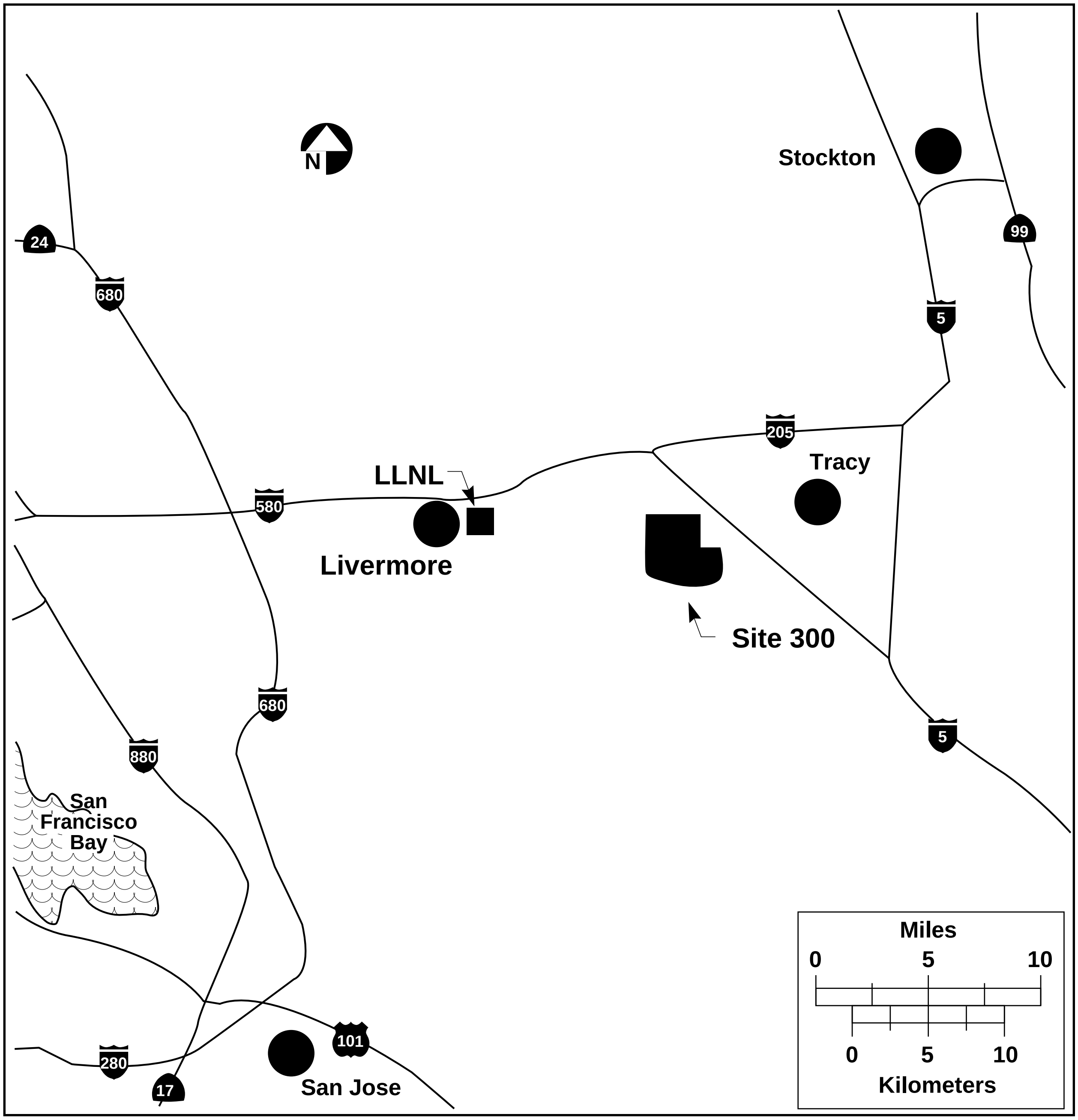

Figure 1-1. Locations of LLNL Livermore site and Site 300.

to the southwest. Farther south, property is primarily open space or rural 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 of the intercoastal range that defines the eastern margin of the Livermore Valley. A business park is located to the north, and a

199.6-hectare parcel of open space to the northeast has been rezoned to allow development of a center for heavy industry.

Site 300, LLNL's Experimental Test Site, is located 24kilometers east of the Livermore site in the Altamont Hills of the Diablo Range; it occupies an area of 30.3 square kilometers. 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 1kilometer 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 25,000), located 10 kilometers to the northeast.

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 are focused 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 personnel. At the Livermore site, food service, banking, and limited shopping services are available on site for the convenience of the employees of LLNL and SNL/CA. At Site300, services are limited but include a cafeteria in the General Services Area.

Climate

Mild, rainy winters and warm, dry summers characterize the climate of the Livermore Valley. The mean annual temperature for 1993 was 15°C. Temperatures range from –5°C during pre-dawn winter mornings to 40°C during summer afternoons. Meteorological data, wind speed, wind direction, rainfall, and temperature are continuously gathered at both the Livermore site and Site300.

Both rainfall and wind exhibit a strong seasonal pattern. Annual wind data for the Livermore site are given in **Figure 1-2** and in **Table 1-1**. These data show that the prevailing winds are from the west and southwest, accounting for 45% of the wind pattern. These wind patterns are controlled by the thermal draw of the warm central valley that results in wind blowing from the cool ocean toward the warm valley, increasing in intensity as the valley heats up. The wind does blow from the northeast, primarily during the winter storm season. Most of the precipitation occurs between October and April, with very little rainfall during the warmer months. The highest and lowest annual rainfalls on record are 782millimeters and 138 millimeters. In 1993, the Livermore site received 402millimeters of rain.

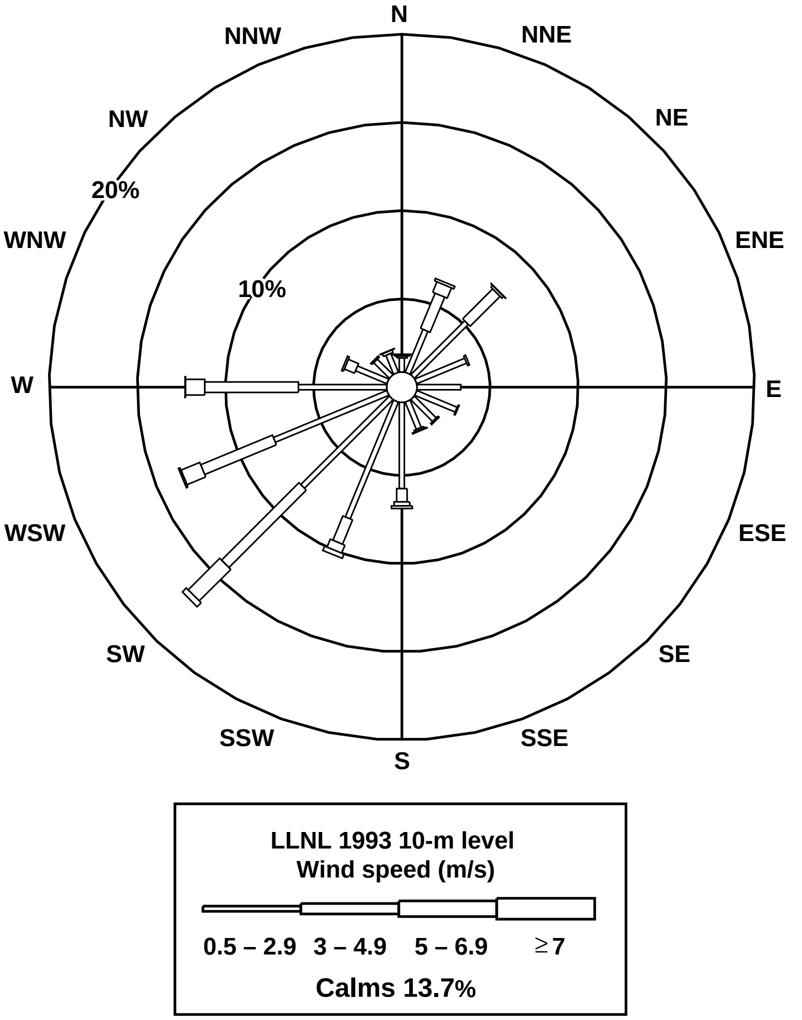

Figure 1-2. Wind rose showing the average annual wind speed, frequency of occurrence, and direction at the Livermore Site, 1993.

The climate at Site 300, while generally similar to the Livermore site, is 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 **Figure1-3** and **Table 1-1**. 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 1993 was 315 millimeters.

Geology

Topography

Livermore Site. 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 within 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, with an average thickness of about 100meters. The valley is approximately 25 kilometers long and averages 11 kilometers in width. The valley floor is at its highest elevation of 220 meters along the eastern margin and gradually dips to 92 meters 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 only during the rainy season.

Site 300. 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, in which 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 150meters at the southeast corner of the site to approximately 538 meters in the northwestern portion.

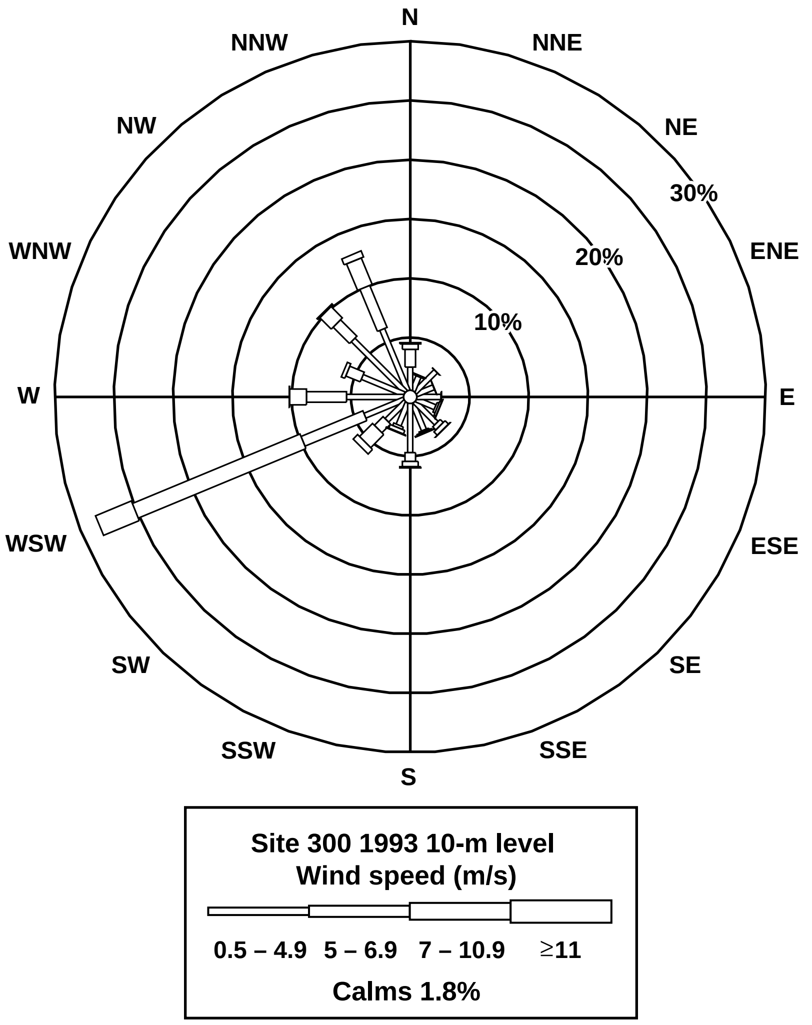

Figure 1-3. Wind rose showing the average annual wind speed, frequency of occurrence, and direction at Site 300, 1993.

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 forground water management in the Livermore Valley basin (California RWQCB1982).

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 generally assumed to be primarily horizontal, although a significant vertical component probably exists in fringe areas and also under localized sources of recharge and in the vicinity of heavily used extraction (production) wells.

Beneath the Livermore site, the depth to the water table varies from about 8to 40meters. **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 the northern and western portions of the site is generally westward. 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 meters per day (Isherwood et al. 1991). This, in combination with the observed water table gradients, yields an average ground water velocity estimate of 20 meters per year (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.

Site 300. Site300 is generally underlain by gently dipping sedimentary bedrock dissected by steep ravines. 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

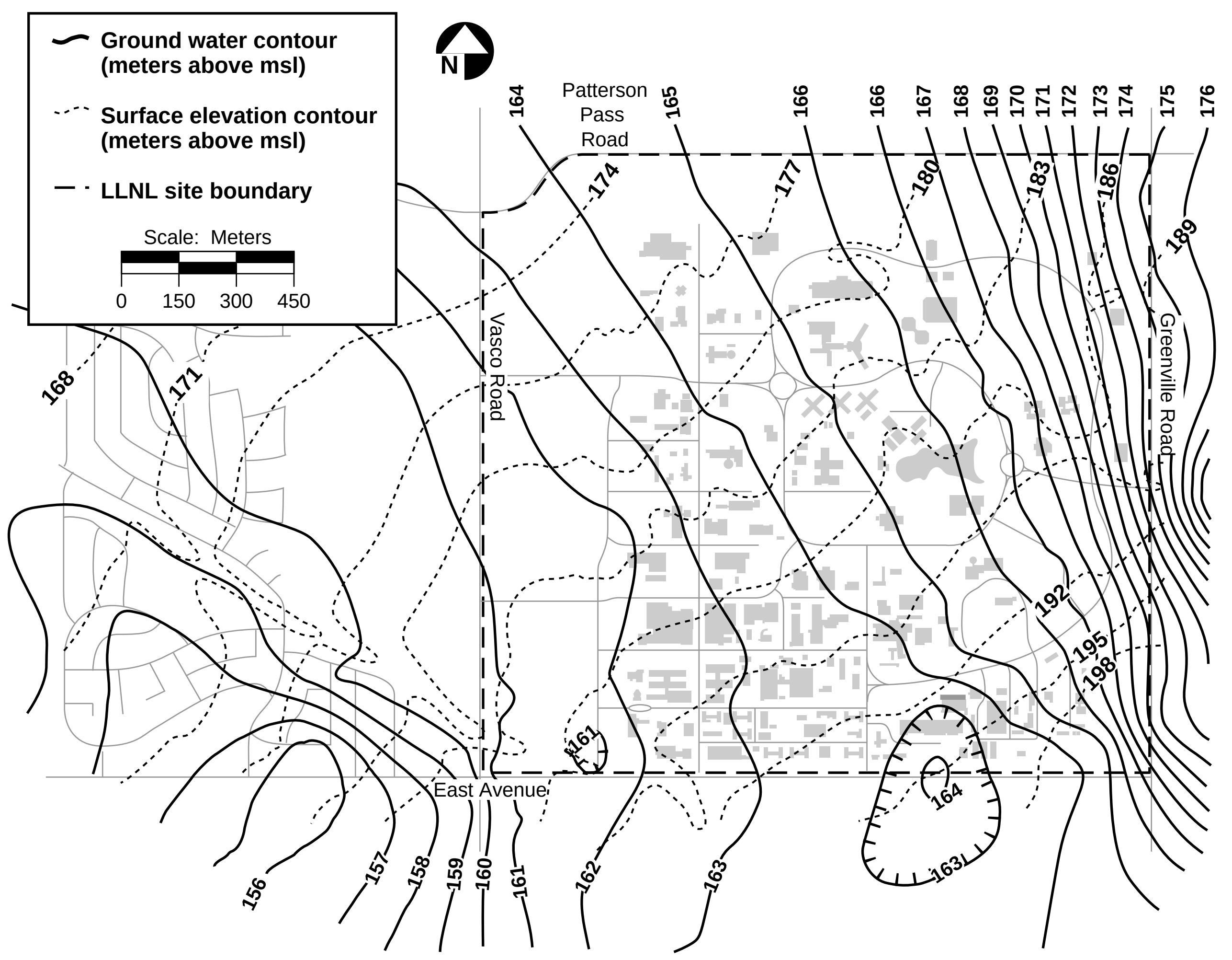

Figure 1-4. Approximate ground water and surface elevation contours, Livermore site and vicinity.

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 Site300, 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 processwater.

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 Chapter 8.

Conclusion

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 within this document—air, soil, ground water, and vegetation—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.

LLNL's environmental policy is to meet, and generally exceed, the requirements of the applicable laws, regulations, and DOE Orders that are in place to protect the environment. This report does not document every activity in this effort; rather, it summarizes our regulatory compliance activities and provides substantial data to allow the reader to understand the effects of current and past practices of the Laboratory, the previous operators of this site, and, in some cases, of other industrial activities in our area.

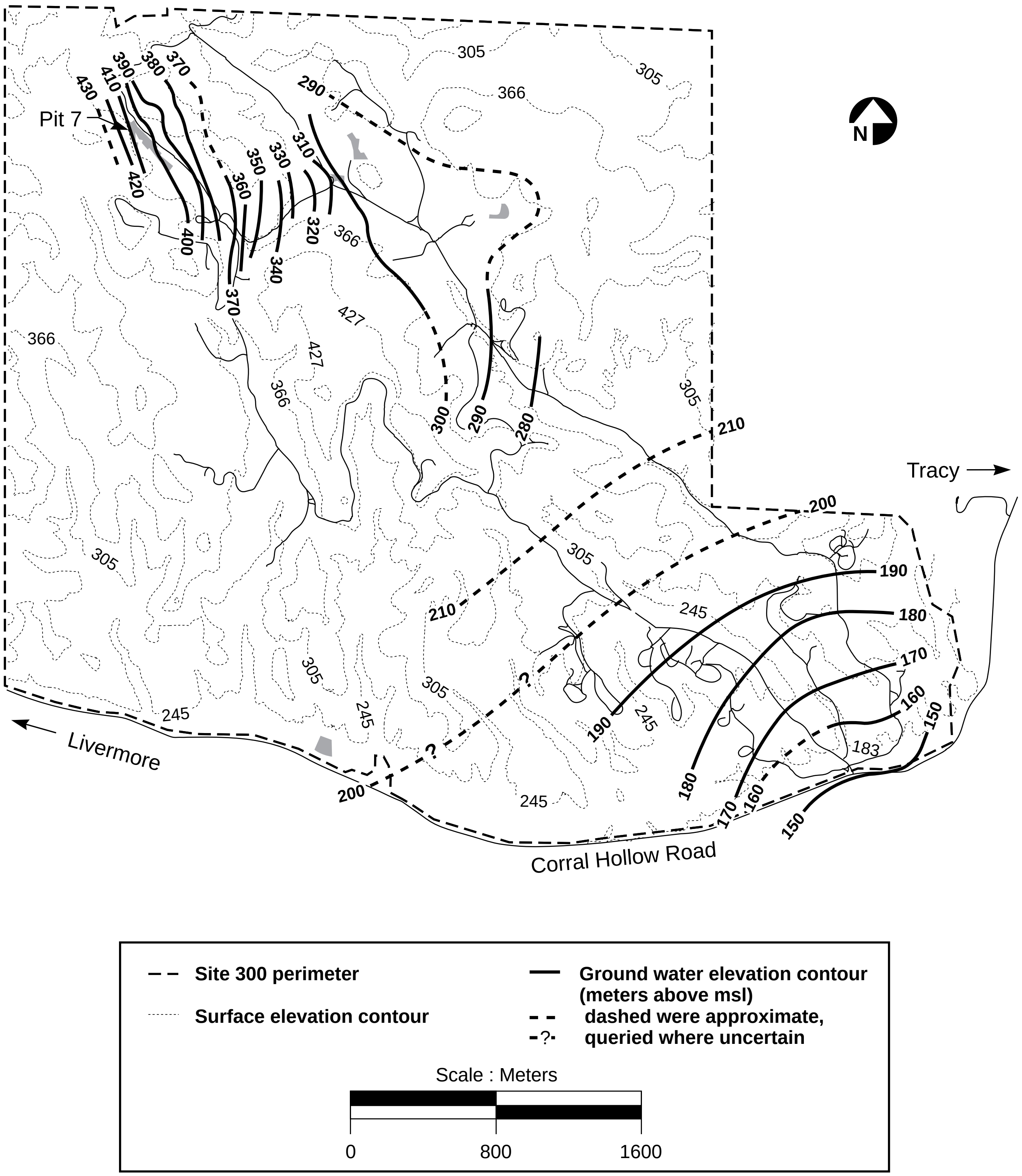

Figure 1-5. Approximate ground water elevations in principal continuous water-bearing zone aquifer at Site 300, 1993.

Table 1-1. Wind rose for LLNL during 1993 at the 10-meter level. Values are frequency of occurrence (in percent).

	Livermore site					
	Wind speed (m/s)					
Direction	**0.0-0.4[a]**	**0.5-2.9**	**3.0-4.9**	**5.0-6.9**	**≥7.0**	**Total**
NNE	0.9	2.6	2.2	0.6	0.2	6.5
NE	0.9	4.3	2.4	0.1	0.0	7.2
ENE	0.9	3.1	0.1	0.0	0.0	4.1
E	0.9	2.5	0.0	0.0	0.0	3.4
ESE	0.9	2.5	0.0	0.0	0.0	3.4
SE	0.9	1.8	0.0	0.0	0.0	2.7
SSE	0.9	1.7	0.1	0.0	0.0	2.7
S	0.9	4.9	0.8	0.2	0.2	7.0
SSW	0.9	7.2	1.5	0.5	0.3	10.4
SW	0.9	7.1	6.2	2.5	0.3	17.0
WSW	0.9	7.0	4.4	1.1	0.1	13.5
W	0.9	5.0	5.3	1.1	0.0	12.3
WNW	0.9	1.9	0.6	0.1	0.0	3.5
NW	0.9	1.3	0.0	0.0	0.0	2.2
NNW	0.9	1.1	0.2	0.0	0.0	2.2
N	0.9	0.8	0.1	0.0	0.0	1.8
Total	**14.4**	**54.8**	**23.9**	**6.2**	**1.1**	**100.4**

	Site 300					
	Wind speed (m/s)					
Direction	**0.0-0.4[a]**	**0.5-4.9**	**5.0-6.9**	**7.0-10.9**	**≥11.0**	**Total**
NNE	0.1	1.3	0.1	0.0	0.0	1.5
NE	0.1	2.5	0.0	0.0	0.0	2.6
ENE	0.1	1.6	0.0	0.0	0.0	1.7
E	0.1	2.0	0.0	0.0	0.0	2.1
ESE	0.1	1.7	0.2	0.2	0.0	2.2
SE	0.1	2.6	0.4	0.4	0.0	3.5
SSE	0.1	2.5	0.1	0.1	0.0	2.8
S	0.1	4.1	0.8	0.4	0.1	5.5
SSW	0.1	2.0	0.2	0.3	0.0	2.6
SW	0.1	2.2	1.0	1.6	0.5	5.4
WSW	0.1	3.6	5.6	15.3	3.3	27.9
W	0.1	4.8	3.4	1.4	0.0	9.7
WNW	0.1	3.8	1.3	0.3	0.0	5.5
NW	0.1	6.3	2.0	1.4	0.1	9.9
NNW	0.1	5.6	3.8	2.4	0.6	12.5
N	0.1	2.0	1.5	0.4	0.1	4.1
Total	**1.6**	**48.6**	**20.4**	**24.2**	**4.7**	**100.0**

[a] Wind speeds under 0.5 m/s do not provide sufficient force to allow the instruments to register the direction of the wind; therefore, we assume an even distribution of wind speeds at this magnitude.

2. Compliance Summary

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Introduction

In 1993, LLNL conducted numerous environmental activities to comply with regulatory and internal requirements. These activities, performed at both the Livermore site and Site 300, encompassed ground water quality, hazardous waste management, wastewater, air quality, and general environmental issues. Documents providing detailed information on these activities are available for review at the LLNL Visitors Center and the City of Livermore Public Library. A summary of the environmental permits issued to or held by LLNL during 1993 is presented at the end of this chapter (**Table 2-1**). In addition, a list of 1993 Environmental Protection Department publications is presented in Appendix A. This chapter includes background information to place the 1993 activities in context.

CERCLA/SARA—Title I

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as the "Superfund" Act, is a federal law that gives the U.S. Environmental Protection Agency (EPA) the authority to identify and clean up sites when hazardous chemicals and substances have been released to the environment. The Superfund Amendments and Reauthorization Act (SARA) amended various provisions of CERCLA and established a process for federal facility participation in CERCLA.

The Livermore site was placed on the National Priorities List for Superfund cleanup in July 1987 because some of the ground water at the site contains volatile organic compounds (VOCs), primarily trichloroethene and tetrachloroethene. As a result, LLNL structured a Ground Water Project to restore the site, in conformance with specific EPA CERCLA guidance and a negotiated Federal Facility Agreement (U.S. Department of Energy 1988). The multiyear environmental restoration effort encompasses numerous activities to be performed to investigate, evaluate, and eventually remediate potentially hazardous compounds that may have affected soil, sediment, and ground water quality. The Ground Water Project also encompasses air and surface water as these environmental media relate to the investigation and remediation efforts. Because the impact of past releases to the air and surface water have been relatively minor, most of the emphasis is placed on investigating the soil, sediment, and ground water. The Ground Water Project as it relates to compliance matters is covered in the following pages; ground water protection information is discussed in Chapter 8.

Livermore-Site Ground Water Project

Background. The Ground Water Project complies with provisions specified in a Federal Facility Agreement entered into between the 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.

Required Documentation. On January 6, 1993, the *Remedial Action Implementation Plan* (Ziagos et al. 1993) was issued to comply with the requirements of the Federal Facility Agreement for the Livermore site. This implementation plan deals with the remedies selected in the CERCLA Record of Decision (U.S. Department of Energy and University of California 1992a,b) to clean up ground water and soil. It involves the preparation of six remedial design reports, including remedial action work plans and startup dates for ground water treatment facilities. The EPA, DTSC, and San Francisco Bay RWQCB have all approved this *Remedial Action Implementation Plan.*

The final versions of the first two remedial design reports were issued during 1993. *Remedial Design Report No. 1 for Treatment Facilities A and B* was issued on April 12, 1993 (Boegel et al. 1993). *Remedial Design Report No. 2 for Treatment Facilities C and F* was issued on September 10, 1993 (Dresen et al. 1994). In addition, the draft version of *Remedial Design Report No. 3 for Treatment Facilities D and E* (Ziagos et al. 1994a) was distributed to the regulatory agencies and the community for review on September 30, 1993.

An Explanation of Significant Difference (Dresen et al. 1993) was signed by DOE and EPA on June 15, 1993. This document describes a change, from the catalytic oxidation technology (described in the CERCLA Record of Decision) to granular activated carbon, for treatment of fuel hydrocarbon and VOC vapors at Treatment Facility F.

Treatment Facilities. Treatment Facility A (TFA) has been operating since September 1989; TFA treated more than 87 million liters of ground water during 1993**,** removing and destroying approximately 11 kilograms (6.9 liters) of VOCs. About 280 million liters have been treated since TFA began operating. Treatment

Facility B (TFB) has operated intermittently since October 1990; TFB treated about 40million liters of ground water in 1993, removing and destroying approximately 4.1kilograms (2.6 liters) of VOCs. More than 55 million liters have been treated since TFB began operating.

Treatment Facility C (TFC) was constructed in 1993 and began operating on October 30, 1993. A total of 18 grams of VOCs was removed from approximately 439,500 liters of ground water treated at TFC during 1993.

Treatment Facility F (TFF) supports the DOE-sponsored Dynamic Underground Stripping research project as well as unsaturated zone and ground water remediation. Dynamic Underground Stripping consists of heating the subsurface with electricity and injected steam to accelerate fuel hydrocarbon mobilization for removal by ground water extraction and vacuum-induced venting. Previous remedial activities from 1988 through 1992 at TFF resulted in a total removal of about 7600 liters of gasoline. An additional 28,400 liters of gasoline were removed during 1993. Therefore, through 1993 a total of about 36,000 liters of gasoline has been removed.

In addition, Treatment Facility D is under construction and will begin operation in Fall 1994. Treatment Facilities E and G are in the planning stages. See **Figure 2-1** for locations of existing and planned treatment facilities.

Community Relations. A major 1993 CERCLA activity was the revision of the Community Relations Plan, originally developed in 1989. The revised plan was based on an extensive survey designed to elicit information on a range of topics: general community knowledge and concerns regarding the Livermore Site Cleanup Project, preferences for future communication techniques, and suggestions for upgrading the representation on the Community Work Group. Fifty-eight interviews were conducted, representing a broad cross section of the community. Based on this survey, a new community relations direction was set for the cleanup project. Most notably, the Community Work Group was expanded to include a greater cross section of the local community. Six people were added, based on nominations or recommendations from historically unrepresented or under-represented groups: the Livermore Chamber of Commerce, the Livermore Unified School District, the Livermore Valley Winegrowers Association, and local realtors / developers associations.

Other community relations activities in 1993 included periodic meetings with Tri-Valley Citizens Against a Radioactive Environment and its Technical Advisors (including a site tour in December), distribution of the *Environmental Community Letter* (which includes information regarding environmentally related activities occurring at the Livermore site), maintenance of the information repositories and administrative records, support for off-site private well sampling activities, and staffing a telephone information line for public and news media inquiries. In December, a ribbon-cutting event marking the startup of

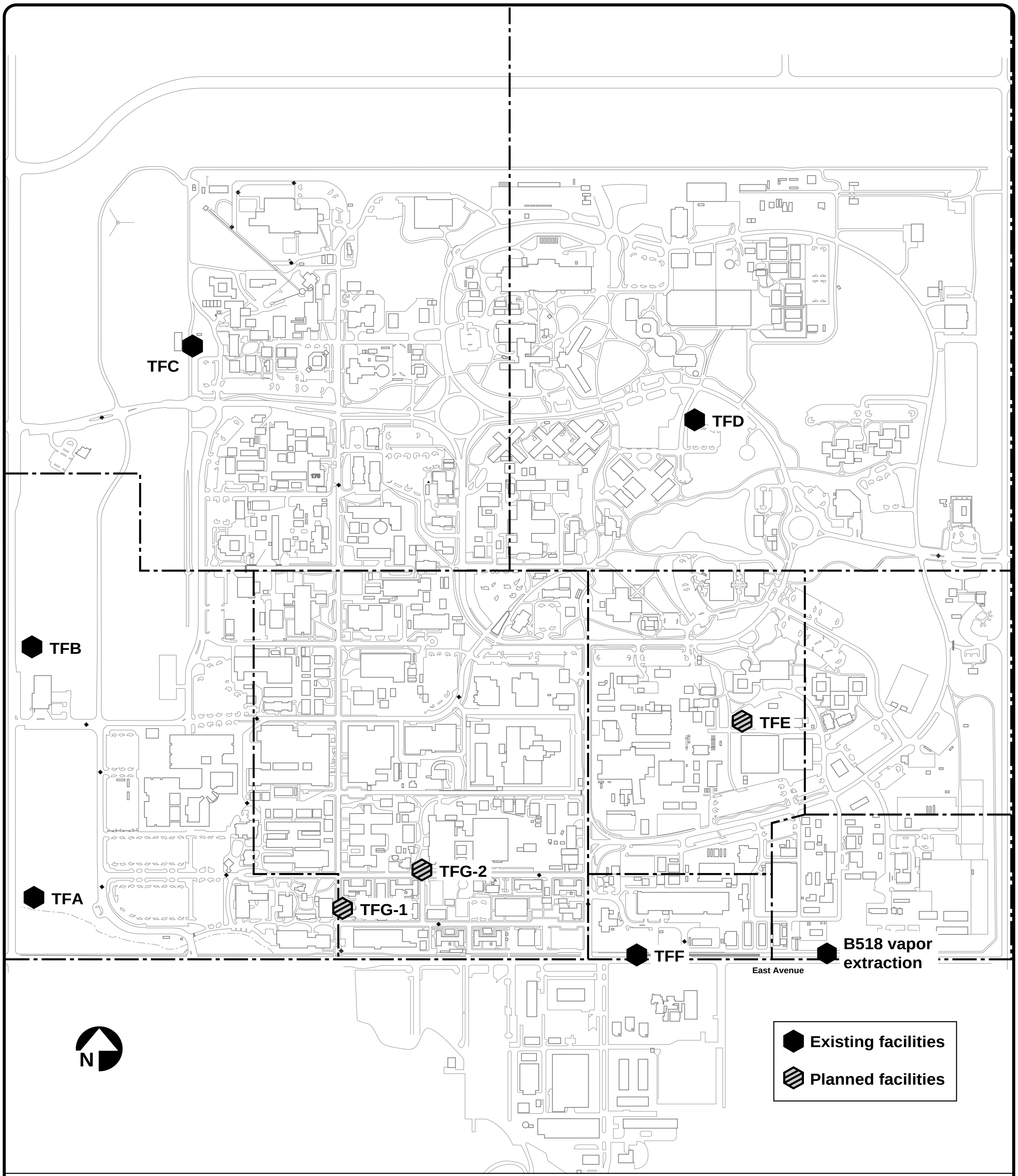

Figure 2-1. Location of existing and planned treatment facilities.

Treatment Facility C was attended by Community Work Group representatives and public officials as well as DOE and LLNL officials and staff.

Treatability Testing. In June 1993, LLNL conducted a treatability test in the Building 518 Area (see **Figure 2-1** for location). The results of this test indicated that soil vapor extraction can effectively remove trichloroethene (TCE) vapor and that granulated activated carbon can successfully treat the extracted vapor. Four wells were installed in 1993 to support future vapor extraction and to complete characterization of thearea. In addition, treatability testing was started during September and October in the Trailer 5475 Area to investigate the proposal of using granulated activated carbon and air-stripping technologies to treat the groundwater.

Site 300 Environmental Restoration Project

At Site 300, ongoing remedial investigations, feasibility studies, and remedial actions are being performed as a part of the Environmental Restoration Project. 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 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 a Federal Facility Agreement that describes the ground water and soil investigations to be conducted and specifies reporting duedates.

The study areas and constituents of concern at Site 300 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 cyclotetra-methyltetramine and 1,3,5-trinitro-1,3,5-triazine in soil, rock and ground water); (4) East and West Firing Areas (EFA / WFA)—tritium, VOCs (primarily TCE), and depleted uranium, in soil, rock, and ground water; (5) Pit 6 Area—VOCs, primarily TCE, in soil, rock, and ground water; and (6)Building833 Area—TCE in soil and rock (**Figure2-2**). These study areas roughly correspond to programmatic areas at Site 300.

Prior to the placing of Site 300 on the National Priorities List, a number of draft Remedial Investigation and Feasibility Study reports were completed for the study areas. The draft Remedial Investigation reports include 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 include proposals for remedial action alternatives with cost estimates under several conditions, from

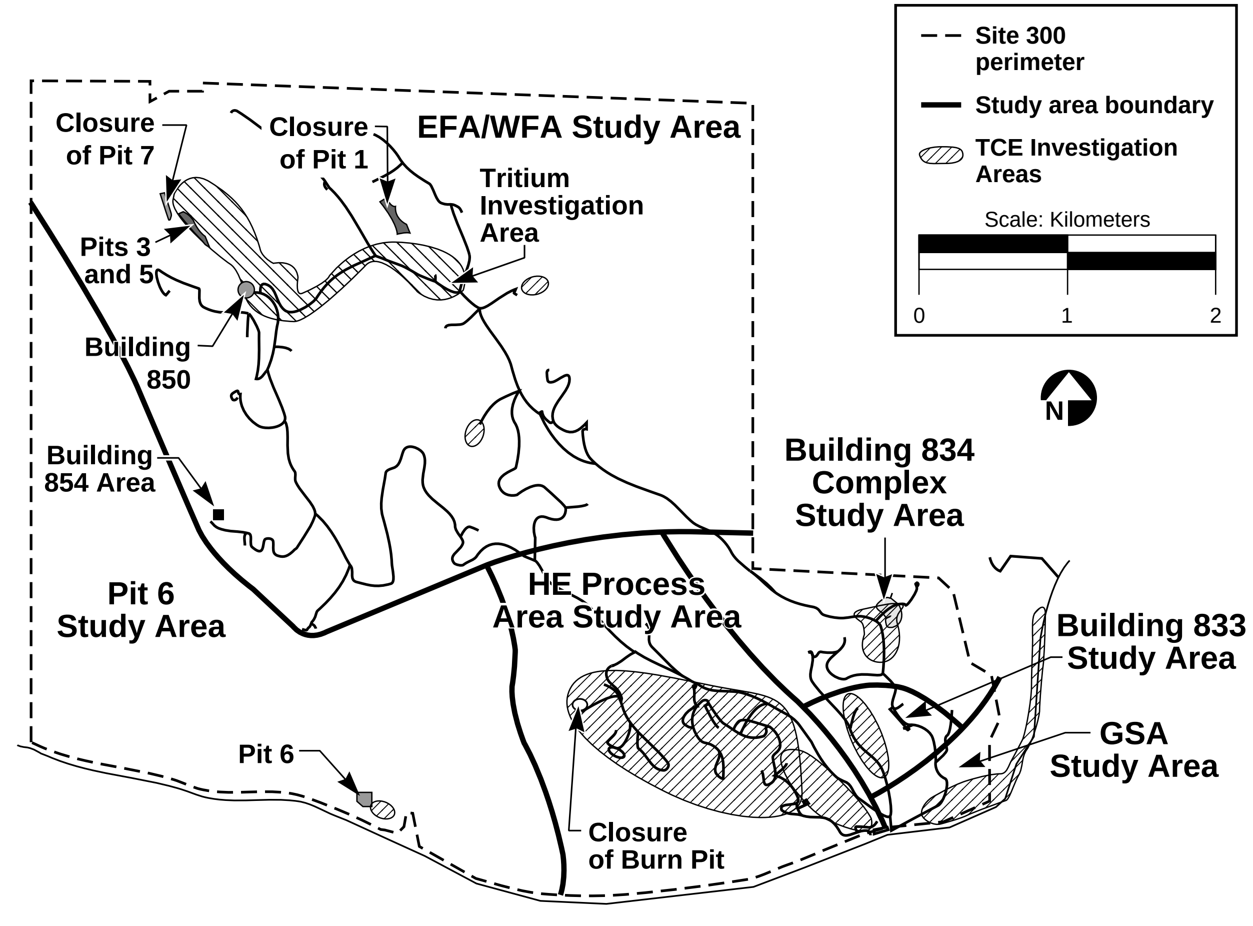

Figure 2-2. Environmental restoration study areas and activities at Site 300.

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 site-wide remedial investigation report to replace the previously submitted individual draft Remedial Investigation reports. Preparation of the *Final Site-Wide Remedial Investigation Report* (Final SWRI; Webster-Scholten 1994) began in 1991 and was submitted in its entirety to EPA, Central Valley RWQCB, and DTSC in August 1993. The Final SWRI report is organized by study areas that roughly correspond to the areas covered by the individual Remedial Investigation reports. It is a compilation of all ground water and soil investigation information for the entire site and contains an assessment of potential human health and ecological hazards or risks resulting from contamination of soil, sediment, and ground water. Feasibility Study reports will be prepared for portions of the individual study areas where the Final SWRI indicates that unacceptable potential hazard or risk exists. Current milestone dates for Draft Final Feasibility Study Reports for the pertinent study areas are General Services Area, September 15, 1995; Building 834 Complex, June 15, 1994; HE Process Area, April 15, 1996; Building 850 / Pits 3 and 5, November 1, 1995; and Pit 6, November 15, 1994.

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 General Services Area and off-site areas to locate VOC release points and to define the vertical and horizontal distribution of VOCs, primarily trichloroethene (TCE) and tetrachloroethene (PCE), in the soil, rock, and ground water. According to the Final SWRI, Draft Remedial Investigation (McIlvride et al. 1990), and Draft Feasibility Study (Ferry etal. 1990) reports, VOCs in excess of drinking water maximum contaminant levels (MCLs) have been identified in the shallow ground water beneath the General Services Area in two localities. Two small plumes occur in the central section of the study area, and one plume occurs in the eastern section, in the gravels of Corral Hollow Creek. A ground water treatment unit to remove VOCs from the eastern section was put into operation in June 1991 as a CERCLA Removal Action; it was operated throughout 1993. Total volume of water treated here through December 1992 was about 42million liters; 160 grams of VOCs were removed from the water. During 1993, an additional 77million liters of ground water in the eastern section were treated to remove approximately 1kilogram of VOCs. Prior to cleanup, this plume extended about 1200meters off site; it now extends about 300meters off site.

The two plumes of VOCs in ground water in the central section are present inalluvium and shallow bedrock, and deeper bedrock, respectively. Construction of a ground water treatment and vapor extraction unit for a CERCLA Removal Action to remove VOCs from this section was completed in 1993,and ground water extraction and treatment began. During 1993, some 433,000liters of ground water containing 190 grams of VOCs were treated. Pilot vapor extraction and treatment of VOCs began in 1993 and is ongoing.

Building 834 Complex. The Building 834 Complex is located in the central eastern portion of Site 300. An isolated, perched aquifer that contains TCE in excess of the MCL of 5 ppb has been defined and reported in the Final SWRI and Draft Remedial Investigation / Feasibility Study reports (Bryn et al. 1990). 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 extraction wells and from soil vapor extraction wells under vacuum. Pilot remediation has begun at the Building 834 Complex, where about 300 kilograms of TCE have been 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, set to begin in early 1994.

HE Process Area. During field investigations of ground water, concentrations of TCE above MCLs and low concentrations of the high-explosive compound 1,3,5-trinitro-1,3,5-triazine 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). Discharges of rinse water from buildings within the HE Process Area historically have been disposed of in unlined lagoons adjacent to the processing buildings. Use of these lagoons was terminated in 1985; the lagoons were closed and capped with impermeable clay in 1989. Sporadic, but generally low, concentrations of high-explosive 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). The full extent of the contamination has been determined and remedial alternatives are being studied.

East and West Firing Areas. Debris from explosive tests historically conducted in this study area in the northern part of Site 300 was disposed of in adjacent landfill pits; these landfill pits are designated Pit1 and Pit7 Complex (which consists of Pits3, 4, 5, and7). 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 740Bq/L (20,000pCi/L).

A tritium investigation was initiated, and two areas where tritium in ground water occurs above background activities and MCLs have been delineated: (1)the Pit 7 Complex and (2) Building 850, Doall Road, and Elk Ravine in the East and West Firing Areas. **Figure 2-3** shows the distribution of tritium in ground water as of October 1993. The Final SWRI report indicates that, at the Building850 firing table, tritium was released to the subsurface by percolation of rainfall runoff and dust control water. Tritium was released to ground water from Pits3 and 5 (in the Pit7 Complex) by heavy rains in 1982–83 and the resulting rising water table. 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 Site300 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 the Final SWRI report.

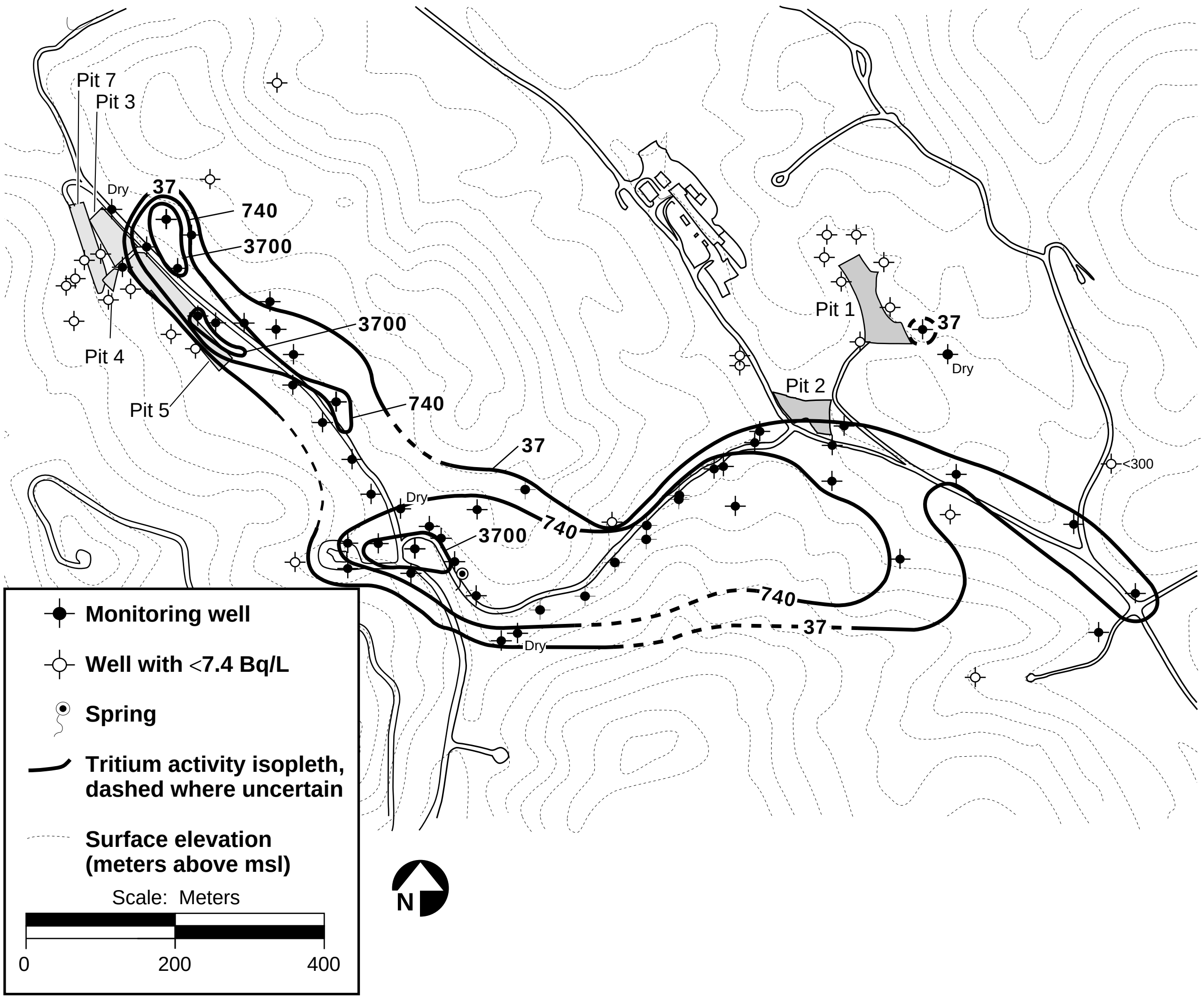

Figure 2-3. Tritium activities (Bq/L) in ground water in the Pit 7 Complex, Building 850/Doall Ravine, and EFA study areas, EFA/WFA study area.

Recent monitoring has also revealed trace amounts of TCE in ground water near the Pit 7 Complex (emanating from Pit 5) and at Building801. An occurrence of Freon-113 far below the California Action Level of 1.2ppm is present near Pit 1 and is the result of an old release near Building 865.

Total uranium activities in excess of the State MCL of 0.74Bq/L (20pCi/L) continued to be measured in samples from several ground water monitoring wells for the Pit7 Complex; several of these samples contain isotopic ratios indicative of depleted uranium. Analyses of ground water samples collected adjacent to Building850 also indicate depleted uranium signatures.

During December 1992, LLNL completed the construction for capping landfill Pits 1 and 7. This work was conducted under an LLNL Resource Conservation and Recovery Act closure plan previously approved by DTSC; the legal date of closure was February 12, 1993. The primary components of the closure design are a closure cover system, surface water control system, and subsurface water control system. The *Construction Quality Assurance Closure Report, Lawrence Livermore National Laboratory Site 300, Pits 1 and 7* (Golder Associates 1993) documents the construction quality assurance activities for the final closure of Pits 1 and 7. It documents the construction and permeability testing of the clay test fill pad and the sealed double-ring infiltrometer, construction and construction quality assurance verification of the closure cover cap system, construction of the subsurface interceptor drainage trench (Pit 7), and construction and construction quality assurance testing of the concrete surface water control channels. The caps and drainage systems should prevent future releases from the pits.

Pit 6 Area. *T*he Final SWRI report and Draft Remedial Investigation for the Pit 6 Area (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 plume is the Pit 6 landfill. Concentrations of VOCs in the plume have been declining since 1992. The Draft Feasibility Study (Taffet et al. 1991) discusses options for its remediation.

Building 833 Area. Low concentrations of TCE and associated VOCs have been detected in shallow soils and sediments (to a depth of 15 meters) beneath the Building 833 Area. During the remedial investigation of the Building 833 Area, concentrations of up to 1800 micrograms per liter (parts per billion) were detected in ground water in two boreholes. Results of the investigation were published in the Final SWRI and in Webster-Scholten et al. (1991).

SARA—Title III

Title III of the SARA 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 storage and use of those chemicals to organizations responsible for emergency response planning. In California, chemical inventory information is provided to the California Chemical Emergency Planning and Response Commission, the county, and the local fire department. Executive Order 12856, signed by President Clinton on August 3, 1993, directs all federal agencies not only to comply with the chemical inventory requirements of EPCRA but also to participate in the SARA 313 Toxic Release Inventory Program beginning in calendar year 1994.

LLNL recently implemented ChemTrack, a new computerized chemical tracking system, that complies with SARA Title III requirements and improves management of hazardous chemicals at LLNL. This system will also enhance LLNL's ability to obtain toxic release information necessary to complete SARA313 submittals. An extensive chemical inventory effort, including site-wide bar coding of chemicals, was initiated in November 1993 and successfully concluded in February 1994. This inventory resulted in a baseline of approximately 158,000 chemical containers ranging from 55-gallon drums to gram-quantity vials. Newly purchased chemical containers are bar coded and entered into ChemTrack as they arrive on site. Procedures for scanning bar codes from discarded containers also have been implemented.

ChemTrack has enhanced LLNL's capability to report chemical inventory data to regulatory agencies and to improve overall chemical management. In the future, ChemTrack will provide improved employee access to Material Safety Data Sheets and enable sharing of excess chemicals, thus reducing hazardous chemical purchases and waste disposal costs.

Waste Permitting

Hazardous Waste Management Activities

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 the management of hazardous wastes in California. RCRA and HWCA regulate hazardous waste treatment, storage, and disposal facilities, including permit requirements. In July 1992, California was authorized to administer the federal RCRA program; the DTSC became the primary agency administering these activities. The permit process requires DTSC to review and approve the RCRA Parts A and B permit application, which provides information on the facility and the wastes managed therein.

In January 1993, the California Legislature made extensive changes in the laws governing the treatment and storage of hazardous wastes. The changes established five levels, or "tiers," of permitting for hazardous waste treatment and storage activities, and reduced the regulatory requirements for many storage and treatment activities that required a hazardous waste permit under state authorization but did not require such a permit under federal laws.

During 1993, LLNL continued discussions with the DTSC regarding classification of LLNL's waste accumulation areas (WAAs). These negotiations resulted in a January 1994 verbal agreement to allow the WAAs to revert to 90-day "generator" storage units, provided LLNL ensures that storage in the WAAsdoes not exceed 90 days and that the aggregate volume in storage at any one time in the WAAs does not exceed 189,000 liters. The RCRA Parts A and B permit application was revised in March 1994 and submitted to DTSC. The permit application incorporated this agreement.

Hazardous Waste Reports for 1992 and 1993

The 1992 Hazardous Waste Report, required by the DTSC under 22CCR 66264.75, was submitted by the adjusted April 1, 1993, deadline. The state did not require an annual report for 1993. The 1993 federal report, required under 40 CFR 262.41, 264.75, and 265.75, was delivered to the EPA on April 28, 1994.

Both 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 represents "cradle-to-grave" tracking of each waste stream category. The Waste Received form includes descriptions and quantities of wastes that were received from theoff-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 Permit

The Livermore-site hazardous waste storage and treatment management units continue to operate under interim status provisions (ISD CA2890012584). Waste management units include container storage, tank storage, and various treatment processes (e.g., wastewater filtration, blending, and size reduction).

With RCRA program authorization being delegated to the State of California in 1992, LLNL now works solely with DTSC in obtaining a hazardous waste permit for the Livermore site. Subsequent to the submittals of the Part A permit application revision on December 18, 1992, and the Part B permit application revision on April 30, 1993, LLNL was requested by the DTSC to make additional modifications to both parts of the permit application. Accordingly, newly revised parts of the permit application were submitted to DTSC on March 1, 1994.

Extremely Hazardous Waste Permit

Permit Number 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 prior to the shipment of any such waste. This permit must be renewed annually; the application for renewal was submitted in August 1993.

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 renewal application was sent to DTSC in October 1993.

Tiered Permitting Conditional Exemption

Various programs at LLNL generate waste resin components. Unlike federal law, California law regulates waste resin components as hazardous waste, and regulates the mixing of the waste resin components to produce nonhazardous reactant material as a treatment activity. This mixing of waste resins is allowed when the provisions of the Conditional Exemption permitting tier are met for the treatment unit, and authorization to perform the activity is requested from the DTSC. LLNL established two such treatment units (Unit CE231-1 in Building 231 and UnitCE443-1 in Building 443) at the Livermore site, and requested authorization from the DTSC in March 1993. LLNL received formal, written authorization in December 1993 for the operation of the two units.

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. The registration and 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, as well as medical wastes generated at Site 300. The treatment permit was issued in August 1991 and is valid through July 1996. The registration is issued annually and is currently valid through July 1994.

Site 300 Permits

The Site300 Building 883 Hazardous Waste Container Storage Facility continues to be a permitted facility under the provisions of the PartB permit (Part B CA2890090002) issued by EPA and DTSC in November 1989, which allows the facility to store specific wastes in containers, provided that certain administrative and operational conditions are met. Due to interpretations of RCRA waste codes by DTSC, this facility is presently unusable.

DTSC reviewed the storage facility Part B permit application and issued a Notice of Deficiency in October 1992. LLNL submitted a response to the notice on February 25, 1993. In addition, LLNL submitted a RCRA Part B permit application for a Site 300 Explosive Waste Treatment Facility to DTSC on May 17, 1993. Currently, DTSC is considering the option of combining the proposed treatment facility with the proposed storage facility into a single application. A tentative schedule is being considered for the combined application.

The high-explosive open burn facility resumed operation at Site 300 in October 1993 under a mutually-agreed-to enforcement order received from DTSC in September 1993. Work has begun on the design and permitting of a new explosive waste open burn/open detonation facility to replace this unit. The new facility will allow longer than 90-day storage of explosive wastes prior to treatment.

Inspections of Hazardous Waste Management Facilities

The DTSC performed its annual inspection of the Livermore site on June 22 to 25, and on July 14, 1993. The inspection included the review of the four Hazardous Waste Management Facilities (Area 612 Facility, Area 514 Facility, Building 233, and Building 693 Facility), the Hydrogen Fluoride Scrubber in Building 231, sixteen WAAs, five satellite accumulation areas (SAAs), the hazardous waste storage tank systems at Buildings 141, 298, 322, and 611, and the registered hazardous waste transportation vehicles at the Area 612 and Building 693 facilities and at the Transportation Division 6126 yard. The five SAAs inspected were those at Buildings 253, 254, 292, 551W, and 141; the sixteen WAAs inspected were those at Buildings 151B, 169, 227, 231, 233, 235, 253, 254, 321A, 321B, 321C, 331, 490, 495, 551W, and 597.

Following its inspection of the Livermore site, DTSC issued a Report of Violation, which LLNL received on August 6, 1993. Seventeen alleged violations were noted, and LLNL took appropriate actions in response. Some of these actions included, for example, separating incompatible wastes in the Building 321C WAA and at the Building 292 SAA, reviewing waste generator training records, and conducting additional waste generator training courses.

DTSC conducted an inspection of the Site 300 hazardous waste facilities on February 16 and 17, 1993. Following this inspection, DTSC issued a Report of Violation, received at LLNL on April 7, 1993, noting three violations. LLNL took appropriate actions in response, including modification of the manifesting process to provide Land Disposal Restriction notifications on all hazardous wastes, including the California-only, non-RCRA wastes cited.

DTSC conducted a second inspection of the Site 300 hazardous waste facilities on November 15 and 16, 1993. Following this inspection, DTSC issued a Report of Violation that LLNL received on January 15, 1994. Three violations were noted, and in response, LLNL personnel corrected labeling violations, reviewed the adequacy of the safety shower/eyewash installation plan, and installed a portable eyewash at the Building805 WAA.

Waste Accumulation Areas

In January 1993, there were 52 WAAs in operation at LLNL: 51 at the Livermore site and one at the Livermore Airport. During the year, one WAA was put in service and five WAAs were removed from service, bringing the total to 48 WAAs currently in operation: 47 at the Livermore site and one at the Livermore Airport. Environmental Protection Department personnel performed 992 WAA walk-throughs at the Livermore site and 14 WAA walk-throughs at the Livermore Airport during 1993. The walk-throughs are informal checks of items such as capacity, labeling, and secondary containment; formal inspections of these items are conducted by personnel in the programs using the WAA.

There were 13 WAAs operated at Site 300 during 1993. Environmental Protection Department personnel performed 247 WAA walk-throughs at Site 300 during 1993.

Tank Systems Management

State and federal laws provide comprehensive regulation of the design, operation, monitoring, and closing of tank systems that contain hazardous products or hazardous waste. The California Underground Tank Regulations, found in 23 CCR Chapter 16, regulate underground storage tank (UST) systems used for containment of hazardous products or hazardous waste. The state underground tank regulations are administered at the Livermore site by Alameda County Environmental Health Services and at Site300 by San Joaquin County Public Health Services. Federal standards for design, construction, operation, maintenance, and closure of hazardous product and petroleum USTs are found in 40 CFR 280 and 40 CFR 112. Standards for design, construction, operation, maintenance, and closure of tanks that contain hazardous wastes (both aboveground and underground) are the subject of RCRAregulations in 22CCR Chapter 15 (Division 4.5) and 40CFR 265. DTSC regulates aboveground hazardous and mixed waste tanks that hold fewer than 19,000liters and that store hazardous or mixed waste for under 90days; however, these types of tanks do not need RCRA permits.

In-Service Tanks

Underground tanks contain diesel fuel, gasoline, waste oil, and contaminated wastewater; aboveground tanks contain diesel fuel, insulating oil, trichloroethene, and contaminated wastewater. Some of the wastewater systems are a combination of underground storage tanks and aboveground storage tanks (ASTs). **Table 2-2** tabulates tank status as of December 31, 1993.

The number of USTs requiring tank permit fees during all or part of 1993 at the Livermore site decreased by 16, from 49 in 1992 to 33 in 1993. The 33 tanks for which fees were paid consisted of the 31 permitted USTs noted in the table, along with two additional tanks that were removed in 1993. The 16 fewer USTs for 1993 consisted of four USTs that were replaced with double-walled aboveground tanks with leak detection, five USTs that were removed pending installation of aboveground tanks, and seven USTs that were removed with no replacement tanks planned.

At the end of 1993, Site 300 had a total of 13 underground petroleum product tanks in service: 11 diesel storage tanks and two gasoline storage tanks. Fees were paid for 15 tanks during 1993. These comprised the 13 permitted USTs noted in the table, along with two other diesel USTs that were removed in 1993 but not replaced.

Tank Integrity Testing

Under the tank leak-tightness testing program, 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. Three diesel fuel USTs at the Livermore site and three diesel fuel USTs at Site 300, which have capacities in excess of 7600liters, were tested on a monthly basis throughout the year. One other diesel UST of greater than 7600liters was gauged weekly during the summer months because it was removed from service. The results of the testing were forwarded to the respective regulatory agencies.

Five diesel USTs, two gasoline USTs, and one oily waste UST at the Livermore site, and two gasoline USTs at Site 300 were tested in 1993 as part of the state and federal requirements for annual testing for single-walled USTs. Testing of petroleum tanks in 1993 revealed two system failures at the Livermore site. Both failures were caused by leaks in the upper access ways. No product was released due to the failures. There were no failures of the two gasoline USTs at Site 300.

No underground wastewater retention systems were tested in 1993 because there were no single-walled, underground, hazardous, or mixed wastewater retention tank systems that were inuse.

Closure and Leak Documentation

Closure requirements for hazardous USTs include the preparation and approval of a closure plan for closing the system, quarterly reports if leaks have been identified, and a closure 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.

A total of 52 closure plans was prepared in 1993 for tanks systems (or portions of systems) that were taken out of service, previously removed (but not officially closed), or expected to be removed from service. Thirty-three of these closure plans were for hazardous product, hazardous waste, or mixed waste tank systems; 19 of these plans progressed to regulatory approval and 14 are pending county approval in 1994. The 19 remaining closure plans were prepared for non-hazardous waste tank systems to conform with LLNL’s Best Management Practices.

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. Four closure reports for hazardous product USTs were submitted to regulatory agencies for review in 1993. An additional five closure reports for hazardous product USTs were in preparation at year’s end.

In 1993, LLNL submitted unauthorized release (leak)/contamination site reports to the regulatory agencies for three diesel USTs. Unauthorized release/contamination from two diesel USTs located at the Livermore site were discovered, excavated, and removed the same day as part of county-approved closure activities. The unauthorized release/contamination for the third diesel UST, which is located at Site 300, was discovered during an attempt to replace the embrittled plastic standpipe of the UST. Upon discovery of the release, the UST was removed from service and is scheduled for closure in 1994. An unauthorized release (leak)/contamination report to a regulatory agency for the release of diesel from a day tank at Building 271 was not mandated although the incident and cleanup activities were reported to DOE.

Tank Improvement Projects

In fiscal year 1990, LLNL received funding to upgrade, close, or replace 18 of the most critical tank systems at LLNL under the Environmental Safety and Health budget. The projects for the last six tank systems were completed in 1993. Five of the tank systems are wastewater retention tank systems at the Livermore site. Two wastewater retention tank systems were upgraded to meet RCRA regulatory requirements for hazardous waste tanks; the piping of one tank system was upgraded; two tanks were modified to remain in service as emergency-use tanks. The sixth tank is an underground diesel tank at Site300 that was removed and replaced with a heat pump.

In fiscal year 1992, LLNL received funding for four 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 (nonhazardous, hazardous, mixed, and radioactive) and product retention tanks (including 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, giving a revised total of 214 tanks or transformers being closed or upgraded. As of December 1993, construction was completed for 12 tanks; construction is in progress for 25tanks; design was completed for 47tanks; and design is in progress for 87tanks. Overflow and spill protection design and construction for the remaining tanks and transformers will begin in 1994.

Remedial Activities

LLNL continued to monitor tritium activities in the unsaturated and saturated zones of the Building 292 Area in the northwestern part of the Livermore site. The objective of this investigation is to evaluate the impact of a tritiated rinse water leak from an underground tank near the southeast corner of Building 292; the tank was sealed in December 1990. The assessment and monitoring tasks LLNL is conducting to characterize tritium movement in this area are summarized in the September *Ground Water Quarterly Progress Report* (Ziagos et al. 1994b).

The highest level of tritium activities was detected next to the suspected leak point near the base of the tank (about 3 meters below ground); the activity decreased with depth. Ground water samples were collected in the Building 292 Area in February, July, and October of 1993. In addition, monthly ground water samples were collected from the piezometer nearest the tank leak. Ground water monitoring results for tritium showed a general decrease in 1993. Results ranged from <37 Bq/L (<1000 pCi/L, or below the detection limit) to 74 Bq/L (2000pCi/L) in all piezometers and wells in the vicinity, except for one; results for the piezometer nearest to the UST showed an increase in tritium activity from 140 Bq/L (3,800 pCi/L) in February to 700 Bq/L (19,000 pCi/L) in November. However, these are the results of screening tests; further samples will be taken to verify the results. As a comparison, the maximum contaminant level for tritium in drinking water is 740 Bq/L (20,000 pCi/L). The possible reasons for this increase, the hydraulic properties of the sediments surrounding the piezometer, and the impact of alternative treatment scenarios are being investigated.

In December 1992, the underground diesel fuel tank at Building 298 showed a leak in the fuel supply line. The tank system and the associated impacted soil were removed in accordance with a Corrective Action Plan approved by Alameda County Environmental Health Services, and the site received a declaration of clean closure from them in January 1994.

Soil samples collected from the base of the excavation during closure of a diesel fuel tank at Site 300's Building 877 showed diesel fuel contamination. A Corrective Action Plan approved by San Joaquin County Public Health Services was completed under the oversight of their Site Mitigation/Local Oversight Program. The site received a statement of closure in May 1993.

At Site 300's Building 879 automotive fleet facility, a release of mineral oil through an underground casing for the ram of the hydraulic hoist system was detected and reported in 1992. Contaminated soil was removed in April 1993, according to a procedure established with the Central Valley RWQCB.

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 Site300) participates. For 1993, there was a total of 13 inspections by the former and 3 inspections by the latter.

With the exception of the April 14, 1993, inspection by San Joaquin County Public Health Services, no Notices of Violation or Notices of Deficiency were received as a result of any of these inspections. A field Notice of Violation was issued during the April14,1993, inspection at Site 300 because the monitoring of five diesel USTs did not conform to regulatory requirements. Two of the five USTs were empty and clean, but were not being monitored. They have since been removed under approved closure plans. The other three USTs are scheduled for closure, but in the interim they are being tested on a monthly basis, which is an acceptable regulatory monitoring program.

On March 24, 1993, the San Francisco Bay RWQCB conducted an inspection of petroleum product aboveground storage tanks at the Livermore site for compliance with federal Spill Prevention Control and Countermeasure Plan regulations and the State of California's Aboveground Storage Tank Law. No violations were identified and LLNL was noted to be generally doing an excellent job. The inspector noted that two of the tanks, 168-T101 and 341-T1A1, should undergo closure or upgrade. Both of these tanks are being closed under LLNL's Tank Upgrade Project.

National Environmental Policy Act (NEPA) and California Environmental Quality Act (CEQA)

NEPA

NEPA (42 U.S.C. 4321 et seq.) establishes federal policy for protecting environmental quality. The major method for achieving established NEPA goals is the requirement of an Environmental Impact Statement (EIS) for any major federal or federally funded project that may have significant impact on the quality of the human environment. If the need for an EIS is not clear, or 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 in-depth NEPA review (i.e., preparation of either an EA or EIS). DOE NEPA Implementing Procedures identify those Categorical Exclusions. If a proposed project does not clearly fit one of the exclusion categories, an Action Description Memorandum is prepared to determine which type of assessment document may be needed.

In 1993, LLNL prepared 58 Categorical Exclusion documents for DOE review for compliance with the NEPA. DOE issued a Finding of No Significant Impact for the EA on the Verification, International Security, and Technology Analysis Center and a Record of Decision for the *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). No EAs for proposed projects were submitted to DOE for NEPA determination in 1993.

CEQA

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 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, 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.

In November 1992, the University of California and LLNL made a commitment to implement 67 mitigation measures identified by the 1992 EIS/EIR and to provide annual reports on their implementation. The measures are being implemented and the first annual report was published in March 1994.

No Initial Study or EIR documents were submitted to local, regional, or state decision-making agencies in 1993.

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 policy

(10CFR1022) is to implement these Executive Orders through existing NEPA review procedures. 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 policy (10 CFR 1022.12), 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 1993, there were no proposed LLNL actions that required such separate assessments.

Endangered Species Act

Under the U.S. Endangered Species Act and the California Endangered Species Act, lists are prepared of endangered or threatened species and other species of concern that may exist or are known to exist at the LLNL sites. In 1993, for a proposed project at Site 300, LLNL conducted 13 surveys for potential dens of one of these species, the San Joaquin kit fox (*Vulpes microtis mutica*), and known burrows of two other sensitive species, the American badger (*Taxidea taxus*) and the burrowing owl (*Athene cunicularia).* No active kit fox dens or known burrows of the burrowing owl were noted during these surveys, but one active American badger den was found. The badger den was not impacted by Site 300 operations.

In the fall of 1992, LLNL investigators began a project to establish two 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 is funded through a Laboratory Directed Research and Development grant and is being conducted in collaboration with Mills College (representing the California Department of Fish and Game) and the University of California at Davis, with the approval of the U.S. Fish and Wildlife Service.

Researchers from Mills College and U.C. Davis made numerous trips to Site300 between October 1992 and May 1993 to work with LLNL personnel to establish the experimental populations near the natural population 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. On April 19, 1993, LLNL personnel counted 301mature plants in the Drop Tower population, down from the 546 plants observed in 1992. (Reductions in plant numbers were also observed at experimental populations established by the California Department of Fish and Game at other locations, and may have been related to the extremely wet, cool weather pattern.) On May 4, 1993, LLNL personnel counted 28 mature plants in the Draney Canyon population. The census information was provided to the California Department of Fish and Game. A combined total of 135 plants was successfully re-established into the two experimental populations. Work on the experimental populations will continue through 1994.

National Historic Preservation Act

In accordance with the provisions of the January 1993 DOE Record of Decision on the 1992 EIS/EIR for continued operation of LLNL, a Cultural Resource Management Plan is being prepared to further implement the requirements of the National Historic Preservation Act. In addition, efforts were begun in 1993 to revalidate the identification of resource locations (sites) at Site300 (previously noted in the 1992 EIS/EIR and earlier documents); these efforts will continue in 1994.

Clean Water Act and State Programs—NPDES/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 surface waterways. In addition, the State of California requires permits, known as Waste Discharge Requirements (WDRs), for any discharges of wastes that could adversely affect the beneficial uses of waters of the state. The Regional Water Quality Control Boards are responsible for issuance and enforcement of both permit types. The Livermore Water Reclamation Plant requires permits for wastewater discharges to the city sanitary sewer system. Finally, the California Department of Fish and Game requires streambed alteration agreements for any work that may disturb or impact rivers, streams, or lakes.

LLNL does not currently have any projects subject to permitting under Section 404 (wetlands) of the Clean Water Act, administered by the Army Corps of Engineers.

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. The treated ground water is discharged from monitoring wells used in the ground water investigation and ground water treatment facilities. On December 13, 1993, LLNL sent a letter to the San Francisco Bay RWQCB notifying them that, under CERCLA Section 121, LLNL will now follow only the substantive requirements of this permit as Applicable, Relevant and Appropriate

Requirements adopted into the CERCLA Record of Decision. The administrative requirements of WDR Order No. 88-075 will no longer be followed, including reporting, payment of fees, and permit renewal. The self-monitoring programs required by it and the CERCLA Record of Decision are described in Chapter 13 on Nonradiological Impact.

Both the Livermore site and Site 300 operate under the California General Industrial Storm Water Activity NPDES Permit issued by the State Water Resources Control Board and implemented by the RWQCBs. On March 27, 1992, LLNL submitted Notices of Intent to discharge storm water associated with industrial activity at both sites. The general industrial activity permit that allows this became effective October1, 1992. In addition, LLNL continued construction operations for three projects, affecting more than 2 hectares, under the California General Construction Activity Storm Water NPDES Permit. Notices of Intent for these three projects were submitted to the State Water Resources Control Board on September 30, 1992. The projects are Building 132 at the Livermore site, and the Roadway Improvement Project and closure of landfill Pits 1 and 7 at Site 300. The latter two projects were both completed during 1993, and two Notices of Termination of coverage under the general construction activity permit are being prepared for submittal to the RWQCB in the first quarter of 1994.

Both the Livermore site and Site 300 are implementing draft Storm Water Pollution Prevention Plans (SWPPPs). The storm water monitoring programs were implemented by January 1, 1993, as required by the California General Industrial Activity Permit. LLNL will also obtain permits to cover non-storm water discharges discovered during LLNL’s investigation of drain connections. This is necessary to meet SWPPP certification requirements for both the Livermore site and Site 300.

Site 300 has four additional permits issued by the Central Valley RWQCB: WDR Order No. 93-100 amends WDR Order No. 80-184 and pertains to ongoing post-closure monitoring requirements for landfill Pits 1 and 7. WDR Order No.82-105 applies to the discharges to surface water from 15 cooling towers. This permit was continued by the Central Valley RWQCB in 1990; a permit renewal application was submitted in 1991, to cover 3 of the 15 discharges located at Buildings 801, 836A, and 865. The Central Valley RWQCB is in the process of renewing this permit. The remaining discharges will be engineered to discharge to ground at the request of the agency and will be covered under a separate WDR Order (NPDES Permit No. CA0081396). WDR Order No. 85-188 is a permit for operation of the sewer lagoon, septic tanks, leach fields, and the ClassII surface impoundment for high-explosive rinse water. WDR Order No.91 -052 (NPDES Permit No. CA0082651) is a permit to discharge treated ground water from the eastern General Services Area ground water treatment facility to Corral Hollow Creek.

Additionally, two ground water treatment facilities at Site 300 (central General Services Area 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 these permits are also discussed in Chapters 6 and 13.

Storm water from the Central Drainage Basin is discharged under the authority of the CERCLA Record of Decision through the reference to WDR Order No. 91-091. The self-monitoring agreement submitted to the San Francisco Bay RWQCB for discharges from the Central Drainage Basin is detailed in Chapter 13.

Wastewater Permits

A Wastewater Discharge Permit from the Livermore Water Reclamation Plant provides for the continued discharge of LLNL sanitary and industrial effluent to the city sewer system. Permit No. 1250(92–93) was in effect from September 1992 through September 1993, and renewal Permit No. 1250(93-94) is effective from September 1993 to September 1994. Under the provisions of this permit, LLNL conducts a self-monitoring program at its outfall into the Livermore sewer system. Daily and monthly effluent sampling are performed to satisfy permit compliance requirements. The daily samples are composited to represent weekly values. The monitoring results of the total LLNL effluent are reported monthly to the Livermore Water Reclamation Plant. In accordance with federal pretreatment regulations, additional quarterly and semiannual sampling is required of all identified categorical processes. These additional monitoring results are reported semiannually to the Plant. The self-monitoring program for wastewater is detailed in Chapters 5 and 13. No wastewater permit violations occurred in 1993.

Streambed Alteration Agreements

Two streambed alteration agreements were issued by the California Department of Fish and Game for maintenance and construction projects impacting the natural drainage at Livermore site and Site 300. The projects were the Mocho Water Line Installation Systems Modification (Livermore site) and the removal of vegetative growth from Corral Hollow Creek, which were a result of discharging treated ground water from the eastern General Services Area treatment facility (Site 300).

Inspections

Livermore Water Reclamation Plant personnel spent five days on site during 1993 (in March, April, June, October, and November), inspecting and sampling pretreatment discharges. LLNL was granted three Discharge Permits by the Plant for discharge to the sanitary sewer during 1993: (1)ground water discharge Permit No. 1508G for discharge of sewerable waste from Treatment Facility F, (2)ground water discharge Permit No.1510B for an Environmental Restoration Division treatability study, and (3) wastewater discharge Permit No. 1250(93-94) for site-wide discharge of wastewater. There were no Notices of Violation issued by the Livermore Water Reclamation Plant to LLNL in 1993.

California Department of Fish and Game personnel inspected the Livermore site on February 5, 1993, to determine the need for a streambed alteration agreement for proposed work to reinforce the Arroyo Seco bank where it crosses the southwestern corner of the Livermore site. In addition, the Mocho Line project was inspected on June 16, 1993, to determine streambed alteration agreement requirements. On August 17, 1993, the portion of Corral Hollow Creek behind the California Department of Forestry facility south of Site300 was also inspected to determine streambed alteration agreement requirements. A follow-up inspection was conducted in January 1994. No findings or violations were issued as a result of these inspections.

Clean Air Act/Air Quality Management Activities

The Clean Air Act is the federal law that authorizes the EPA to set air quality standards and to assist local and state governments in developing and executing air pollution prevention and control programs. The Bay Area Air Quality Management District is the agency responsible for enforcing these standards, as well as the local and state standards, for air emissions from stationary sources in the San Francisco Bay Area, including the Livermore site. The San Joaquin Valley Unified Air Pollution Control District is the agency responsible for enforcing these standards in San Joaquin County, including Site 300.

In compliance with the Air Toxics “Hot Spots” Information and Assessment Act of 1987 (AB2588, California Health and Safety Code Section 44360 et seq.), LLNL completed a screening assessment of the potential impact of toxic air emissions on the area surrounding the Livermore site. The risk associated with the emissions was below the threshold values that would trigger further evaluation. These results were reported to the Bay Area Air Quality Management District in the fall of 1990.

After LLNL’s AB 2588 inventory for Site 300 was submitted in June 1990, the San Joaquin Valley Unified Air Pollution Control District requested that LLNL provide additional emissions data for a small burner called the “Iron Horse,” used for disposal of explosive waste. Test results were sent to the District in March 1993, and amended test results were submitted on May 14, 1993, and July2, 1993, in response to technical comments received from the District on April 19, 1993. On September 24, 1993, the District approved the amended Iron Horse Emissions Test Report, which thereby completed the AB2588 inventory for Site 300. While LLNL had secured off-site treatment and disposal options for its explosive waste, this on-site capability is far less expensive and avoids the safety issues ofadditional handling, packaging, and transportation associated with the off-siteoption.

These emission inventories are required to be updated at least every two years; the Site 300 inventory was submitted during the summer of 1992. The Bay Area Air Quality Management District uses the Annual Permit Renewal Update Sheets to update the inventories each year.

Air Permits

Air permits are obtained from the Bay Area Air Quality Management District for the Livermore site and from the San Joaquin Valley Unified Air Pollution Control District for Site 300. In 1993, the former issued 37 permits to operate, 32 letters of exemption, and 163 permit renewals for the Livermore site. In 1993, the latter issued 7 permits to operate, 1 letter of exemption, and 37 permit renewals for Site 300.

Inspections

Bay Area Air Quality Management District personnel conducted 11 days of inspections at the Livermore site during 1993. The District issued a Notice of Violation on January 21, 1993, for the use of adhesives without a permit at the Building 511 carpenters shop; on May 18, 1993, three notices were issued for the use of noncompliant paint in three paint booths in the Building 418 paint shop; and on May 19, 1993, a notice was issued for exceeding a source test condition during a startup source test of Treatment Facility F (ground water treatment facility). Each of these notices has been appropriately addressed.

The San Joaquin Valley Unified Air Pollution Control District conducted one inspection at Site 300 in April 1993, and no Notices of Violations were issued.

National Emission Standards for Hazardous Air Pollutants (NESHAPs)

In August 1993, DOE and EPA signed a Federal Facility Compliance Agreement whereby LLNL would undertake measures to demonstrate compliance with NESHAPs for radionuclide emissions (Radionuclide NESHAPs, 40 CFR 61, Subpart H). The agreement contained a compliance schedule, required quarterly reporting, and documented the work that LLNL needed to perform to demonstrate compliance with these regulations. EPA notified DOE and LLNL in April 1994 that all requirements of the Agreement had been met, and that LLNL had demonstrated compliance with NESHAPs regulations.

The applicable NESHAPs regulations require that all potential sources of radionuclide air emissions be evaluated to determine the possible effective dose equivalent to the maximally exposed individual member of the public (MEI). These evaluations may include modeling based on inventory data, measurements of the emissions, or both. 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 μSv/y (10 mrem/y). Second, all emission points with the potential for unmitigated emissions resulting in an MEI 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 1993 NESHAPs annual report (Harrach et al. 1994) reported to DOE and EPA the total calculated site-wide MEI effective dose equivalents for the Livermore site and Site 300 as 0.66 μSv/y (0.066 mrem/y) and 0.37 μSv/y (0.037 mrem/y), respectively. The values include contributions from both point sources and diffuse sources. 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 12). The total calculated 1993 MEI effective dose equivalents for the Livermore site and Site 300 are comparable to those reported for 1992, when the effective dose equivalent values were 0.79 μSv/y (0.079 mrem/y) for the Livermore site and 0.21 μSv/y (0.021 mrem/y) for Site 300.

During the first quarter of 1993, LLNL completed its evaluation of all emission points for the Livermore site and Site 300, meeting the schedule in the Federal Facility Compliance Agreement. From these evaluations, LLNL identified three buildings where continuous monitoring is required—Building 331, Building 332, and the hardened portion of Building 251. Continuous monitoring already exists in these buildings. They and five other buildings where continuous monitoring systems are in place will continue to be monitored. To improve the sampling and monitoring in these systems, LLNL made some minor flow rate adjustments. Inspections of these sampling systems indicated that representative sampling is being performed.

LLNL submitted two quarterly reports to EPA Region IX during 1993 (Biermann et al. 1993; Surano et al. 1993), detailing the efforts of the NESHAPs program. The March report reflected LLNL's demonstrated compliance with the NESHAPs regulations. In the second quarterly report, LLNL summarized the information in the 1992 NESHAPs annual report, described upgrades planned for existing sampling systems, reported on the status of the NESHAPs quality assurance program, and outlined the methods LLNL used to review proposed projects for compliance with NESHAPs and NEPA. In September1993, EPA Region IX rescinded the LLNL quarterly reporting requirement.

Department of Energy Tiger Team and Tiger Team Progress Assessment

DOE conducted a Tiger Team Assessment of LLNL ES&H programs in 1990. In November1992, it conducted a follow-up Tiger Team Progress Assessment, concluding that "LLNL management recognizes the importance that the Secretary of Energy places on ES&H excellence and has responded with improvements in all ES&H areas." Progress has been made in addressing the concerns identified in the 1990 Tiger Team Assessment. Although work remains to be done to address concerns in several areas, these concerns do not diminish the significance of the progress made since the 1990 Tiger Team Assessment.

In July 1993, a Draft Action Plan in response to the Tiger Team Progress Assessment was submitted to DOE; this plan is still under review. Once the action plan is approved, the actions may be incorporated as an addendum to the original Tiger Team Action Plan.

LLNL continues to undertake those activities identified in its original seven-year Tiger Team Action Plan, and significant progress has been made towards the 581 subtasks identified in it. Action items have been prioritized and are funded within budget constraints accordingly. As of December 31, 1993, approximately 76% of these subtasks have been completed, 1% are on schedule, and 18% are considered late, with 32 low priority subtasks (the remaining 5%) not funded. The majority of those subtasks behind schedule or late are a result of funding limitations.

Toxic Substances Control Act (TSCA)

TSCA regulations affecting the Livermore site are those that regulate the storage and disposal of polychlorinated biphenyls (PCBs) and asbestos wastes. 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. 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 Hazardous Waste Management for disposal at an approved site. Statistics for PCBs compiled in 1993 are kept on file, available for EPA inspection. Asbestos wastes are reported in the Hazardous Waste Report, which is required by DTSC under 22 CCR66264.75.

In 1993, LLNL requested EPA's approval to use an alternative method for changing the PCB classifications of transformers. Building 194 contained one transformer classified as a PCB transformer—the only one in operation at the

Livermore site— and one classified as PCB-contaminated. Both transformers had been drained, flushed, and retrofilled with non-PCB fluid in 1991, but had not been reclassified. Because the standard classification method involved testing the transformer under in-use load conditions for 90 days continuously, whereas the Building 194 transformers are used only intermittently, LLNL needed a variance from the regulations in the way they were to be tested for reclassification. EPA granted approval of LLNL's request in February 1994.

Other Major Environmental Issues and Actions

LLNL had several other notable projects under way as part of its regulatory compliance activities during 1993.

Air Emissions Tracking

In 1993, LLNL began implementing a comprehensive database, Emissions Measurement and Information Tracking System, to accurately sort all its emissions into various regulatory programs, including the Title III and Title V permit programs established under the 1990 Federal Clean Air Act Amendments, California's Air Toxics "Hot Spots" Act (AB2588), the "No-Net Increase" provisions of the Bay Area Air Quality Management District, and new federal rules on Ozone Depleting Substances. While not a large facility in terms of aggregate emissions, LLNL's emissions are numerous and extremely varied. The database will be a key tool for emissions management. Facilities in both the private and public sector have expressed interest in this database and LLNL is exploring its commercial potential.

In 1993, LLNL showed a decline in the use of ozone depleting substances (ODS). Because the phase-out of ODS must be fully completed by January 1, 1996 (with limited exceptions), several processes involving the use of ODS already have been modified to use non-ODS alternatives. Some very specialized uses of ODS currently have no identified alternatives, but LLNL continues to actively pursue alternatives for these specialized processes. LLNL's regulatory staff also continues to track and analyze all applicable ODS regulations, including those concerning recycling of refrigerants for motor vehicles and stationary air conditioning systems, labeling requirements, and EPA's Significant New Alternatives Program.

Closure of Hazardous Waste Facilities

In 1992, LLNL submitted closure plans to DTSC for LLNL's Building419 Size Reduction Unit and Building 419 Solidification Unit. These plans were retrieved from DTSC in 1993 for further review and reformatting. The plans will be revised and consolidated into one document, following the results of recent sampling, after which building closures will be planned.

Building Drain Investigation

In 1992, LLNL initiated a Building Drain Investigation Project, ultimately totaling a cost of $3.85 million, to document and test drains in all buildings and trailers at the Livermore site and Site300. LLNL completed the investigation in fiscal year 1993 with the identification and testing of nearly 20,000 drains. Two databases handle the data developed by the project: one to store and sort information on deficiencies, and one to store all documentation data, building drain key plans, building inspection forms, and logbooks.

The Building Drain Investigation Project identified “deficiencies” as any discharge to an incorrect sewer system or to the ground, including discharges of potable water such as that from safety showers. Deficiencies ranged from minor items such as safety showers and air conditioning condensate lines (which were the majority of the deficiencies) to concerns such as a sink drain connected to the storm sewer system. Significant, active deficiencies were immediately corrected in either a temporary or permanent manner whenever possible. LLNL received approval and funding in 1994 from DOE to perform permanent repairs to the deficiencies under a $2.1-million Building Drain Repair Project. This will require either permitting of continued discharges or redirection or elimination of a discharge.

Decontamination and Waste Treatment Facility and Mixed Waste Management Facility

The Decontamination and Waste Treatment Facility (DWTF) is a proposed facility to bring LLNL’s hazardous and radioactive waste handling capabilities in line with current technology. DWTF will be designed to handle efficiently and effectively the more problematic, site-generated waste streams, including mixed waste, which is a combination of RCRA hazardous waste and radioactive waste. Besides providing characterization, treatment, and storage facilities for newly generated radioactive waste (including mixed waste), facilities will be provided to characterize “legacy” radioactive waste (currently not certified for disposal) that has been stored in existing facilities.

The Mixed Waste Management Facility (MWMF) is a proposed pilot-scale demonstration facility. It will be used to evaluate a number of innovative processes for potential commercial-scale treatment of low-level mixed waste containing organic contaminants. Conceptual design has been completed on the MWMF project.

Mixed Waste Site Treatment Plan

The first of three iterations of LLNL’s Mixed Waste Site Treatment Plan was completed pursuant to requirements of the Federal Facilities Compliance Act of 1992. The first version, the conceptual plan, was submitted to both the EPA and the California DTSC. It contains descriptions of LLNL’s mixed waste streams and discussions of plans to treat mixed waste. The draft plan (to be submitted in August 1994) and the final plan (to be submitted in spring of 1995)will be progressively more specific about treatment options for LLNL's mixedwaste.

Waste Certification

In January 1993, LLNL submitted an application for disposal of low-level waste to the Nevada Test Site. The waste certification program was implemented in April. Four hundred people completed low-level waste certification training. In June, DOE-Nevada Operations completed an audit of the LLNL certification program. This audit had a successful close-out in September, resulting in resumption of low-level waste shipments to the Nevada Test Site in November.

Sanitary Sewer Rehabilitation Project

The LLNL sewer system is undergoing comprehensive rehabilitation in a three-part process: initial inspection, point repair / replacement, and pipe lining. The objectives of this work are based on regulatory requirements to eliminate the potential for exfiltration, contractual agreements to minimize infiltration, and programmatic necessity to maintain continuous operations.

A closed-circuit television inspection of the LLNL sewer collection system was conducted from September 1992 through January 1993, involving 710pipelines totaling approximately 27,340 meters of mainlines and building laterals. During the inspection, structural defects, lateral connections, abnormal conditions and other pertinent information were recorded on videotape and log sheets. Video inspection continued through the rest of 1993 for previously inaccessible lines.

A rehabilitation evaluation was performed to categorize defective pipelines into one of three repair categories: point repair, pipe replacement, or pipe lining. The results of the analysis on all videotaped lines identified approximately 106point repairs, 75 small replacement projects, and over 6100 meters of pipe lining. Conventional construction repairs were divided into three bid packages for which small disadvantaged business contractors competed. On-site maintenance personnel performed lateral point repairs.

The original condition assessment identified 121 pipelines as potential candidates for rehabilitation by inversion lining. After a six-month delay, the contract was awarded, and cured-in-place pipe lining of approximately 6100meters is expected to begin in 1994.

Environmental Occurrences

Notification of environmental occurrences is required under a number of environmental laws and regulations, including the 5000 series of DOE Orders: DOE Order 5000.3A, *Occurrence Reporting and Processing of Operations information*; and DOE Order 5484.1, *Environmental Protection, Safety, and Health Protection*

Information Reporting Requirements. DOE Order 5000.3A, issued in May 1990, provides guidelines to contractor facilities regarding categorization and reporting of environmental occurrences to DOE. The Order divides occurrences into three categories: emergency, unusual, and off-normal. DOE Order 5000.3B was issued with an effective date of February 22, 1993. The University of California accepted the Order on December 6, 1993, and will begin using its guidelines for categorization and reporting of environmental occurrences to DOE in 1994; however, many of the incidents that occurred in 1993 have in fact been reported to DOE using 5000.3B criteria.

The Environmental Protection Department (EPD) responds to all reports of spills or other environmental occurrences through a well established reporting process. EPD has established a 7-day, 24-hour, on-call, rotational position called the Environmental Duty Officer (EDO), accessible by pager or cellular phone at any time. The EDO determines reporting requirements; works with environmental analysts and Laboratory management on the process for notifying local, state, and federal regulatory agencies and DOE; and provides advice on immediate cleanup and monitoring necessary to protect the environment.

EPD responded to 15 incidents that required agency notification during the 1993 calendar year. Agencies notified of the incidents included DOE, Alameda County Department of Health Services, San Joaquin County Public Health Services, San Francisco Bay RWQCB, and the Office of Emergency services.

Only one of the incidents qualified as an unusual occurrence according to DOE Order 5000.3A; the others were reported as off-normal occurrences (any incident that requires notification of an environmental regulatory agency is considered an off-normal occurrence). None of the incidents caused any adverse impact to human health or the environment. **Table 2-3** is a tabulation of these incidents.

Table 2-1. Summary of permits.

Type of Permit	Livermore site	Site 300
Air	200 permits (various equipment)	44 permits (various equipment)
Water	WDR Order No. 88-075	WDR Order No. 93-100 (amended 80-184)
	WDR Order No. 91-091, NPDES Permit No. CA0029289	WDR Order No. 82-105, NPDES Permit No. CA0081396
		WDR Order No. 85-188
		WDR Order No. 91-052, NPDES Permit No. CA0082651
	WDR Order No. 91-13-DWQ (as amended by Order No. 92-12-DWQ) NPDES General Permit No. CAS000001	WDR Order No. 91-13-DWQ (as amended by Order No. 92-12-DWQ) NPDES General Permit No. CAS000001
	WDR Order No. 92-08-DWQ NPDES General Permit No. CAS000002 Site ID. No. Bldg. 132 2015300881	WDR Order No. 92-08-DWQ NPDES General Permit No. CAS000002 Site ID. Nos. 5B395300882 Main Gate Road Improvement Pits 1 and 7 Closure 5B395300882
Hazardous waste	ISD CA2890012584	Part B CA2890090002
	DTSC Permit No. 2-13640 for disposal of extremely hazardous waste	ISD CA2890090002
	Hazardous waste transport registration 1351	
	Authorization to perform Waste Resin Mixing in Unit CE231-1 and Unit CE443-1 under *Condition Exemption* tier	
Sewer	Discharge Permit Nos. 1250(93-94), 1508G, and 1510G	
Tanks	Fees paid for 33 tanks	Fees paid for 15 tanks
Other	FFA, ground water investigation/ remediation; ACEHS medical waste permits for treatment and storage	

Table 2-2. Status of in-service tanks, December 31, 1993.

Tank type	Livermore site Permitted	Livermore site No permits required	Livermore site Total	Site 300 Permitted	Site 300 No permits required	Site 300 Total
UST						
Petroleum						
Diesel	14	1	15	11	0	11
Gas	2	0	2	2	0	2
Oil	1	0	1	0	0	0
Wastewater	14	75	89	0	11	11
Sub-Total	**31**	**76**	**107**	**13**	**11**	**24**
AST						
Diesel	0	23	23	0	8	8
Wastewater	7[a]	90	97	0	12	12
Sub-Total	**7**	**113**	**120**	**0**	**20**	**20**
TOTAL	**38**	**189**	**227**	**13**	**31**	**44**

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

Table 2-3. Tabulation of environmental occurrences, 1993.

Date	Occurrence category	Description
Mar. 30	Unusual	Approximately 11,400 liters of dishwashing wastewater discharged to soil beneath the Central Cafeteria as a result of a failed coupling in a sanitary sewage line. Sinks and dishwasher discharging through the broken sewage line were immediately taken out of use. Plant Engineering pumped standing wastewater back into sanitary sewer, ventilated crawl space beneath the cafeteria, and sprayed affected soil with disinfectant.
Aug. 5	Off-normal	Review of June 1993 daily inventory data of an underground gasoline storage tank at Building 879 showed an excess of the allowable storage variation on June 11. Tank gauging on this day was performed by inexperienced personnel, so it is likely that this measurement is imprecise, causing a large daily variation that in turn resulted in a monthly variation exceeding that allowed by the California Underground Tank Regulations. Subsequent measurements show the tank to be leak-tight.
Aug. 12	Off-normal	Release of diesel fuel was discovered beneath the vent line of the diesel tank system at the southwest corner of Building 271. Release was traced to the supporting day tank that automatically fills from the underground diesel tank. The overfill prevention float in the tank system malfunctioned, resulting in the release. The contaminated soil was removed and placed in a roll-off box for disposal pending analytical results.
Sept. 8	Off-normal	Radon was emitted from a stack on Building 251 at a rate above historic levels, but not high enough to constitute a health hazard. This emission resulted from experimental work in a glove box where thorium was being extracted from uranium. The glove box was cleaned up, decontaminated, and had a charcoal filter installed on its exhaust to further minimize emissions.
Sept. 10 and 11	Off-normal	Approximately 1.9 million liters of Hetch Hetchy water were released into Arroyo Mocho along Mines Road in Livermore. The water line break resulted from a stress crack in a 30-year-old cast iron water line. Earth movement was determined to be the cause of the break.
Sept. 14	Off-normal	8–11 liters of diesel fuel were released from a backup generator on the south side of Trailer 1601. Approximately one liter of diesel fuel was released to the soil on the east side of the generator concrete pad. Fuel in the suction piping expanded due to heat, passing the control valve in the piping and continuing to flow to the generator even while the generator was not operating, thus spilling over to the concrete pad and soil. The contaminated soil and the absorbents used to contain the spillage were removed and taken to the Building 160 waste accumulation area.
Sept. 21	Off-normal	Diesel contamination was discovered in the gravel fill surrounding the 829-D1U1 tank top. The drum lid had a hole, apparently resulting from a puncture made at the time of closure excavation. The contaminated fill material was probably the result of historical overfilling. Amount of fuel released was estimated to be 4 liters or less.

…continued

Table 2-3. Tabulation of environmental occurrences, 1993 (*concluded)*.

Date	Occurrence category	Description
Sept. 22	Off-normal	A Plant Engineering crane bumped into a large metal barrier, scraping and rupturing a diesel fuel tank. Immediate personnel response made it possible to containerize most of the diesel fuel. Of the approximately 370 liters, approximately 265 liters were containerized and approximately 105 liters spilled to the ground.
Sept. 22	Off-normal	Approximately 236,000 liters of low conductivity water were released from a cooling tower into a utility trench used for electrical and communication cables. The release was caused by the failure of the basin water control float valve to shut off water, thus overfilling the basin. Approximately 68,000 liters were recovered from the trench and pumped to sanitary sewer.
Oct. 8	Unusual downgraded to off-normal	When the diesel tank at Building 511 was removed, diesel contamination was observed at the bottom of the excavation trench. Soil samples were submitted for TPH-D (total petroleum hydrocarbons as diesel) analysis. Contamination was probably the result of historical overfilling; total amount of released diesel fuel was unknown.
Oct. 12	Off-normal	A vent valve broken during construction and installation of a new water line caused a release of about 2650 liters of Hetch Hetchy water to an area adjacent to Mines Road near its intersection with Tesla Road. A dam of hay bales prevented the water from directly entering Arroyo Mocho. The valve was repaired and water service restored.
Oct. 13	Off-normal	A gate valve leading to fire hydrant #392 failed, releasing approximately 3400 liters of potable water into a storm drain near the hydrant. The water was contained within a sump in the storm drainage system and no water was released off site. The valve was replaced and the water restored to the fire hydrant line on Oct. 15.
Oct. 14	Off-normal	A maximum of 22,700 liters of potable water was released from the fire suppression sprinkler system outside Building 435. The sprinkler did not appear to be activated by fire or explosion; it was taken out of service and had a new valve installed in it. The released water traveled west and entered a storm drain at the northwest corner of Building 436. The storm drain outfall from Buildings 435 and 436 going into Arroyo Las Positas was inspected for evidence of the discharged water. Stagnant water was observed in the Arroyo and in the open ditch, but none of the discharged water migrated off site.
Nov. 9	Off-normal	A sanitary sewer pipeline broken during excavation caused the release of 1140 liters of sewage into a trench. The release was stopped by inserting a pipe bladder upstream of the damaged pipeline section. The pipeline was repaired and the sewer line was put back into normal operation the same day.
Dec. 20	Off-normal	When diesel tank 431-D1U1 at Building 431 was removed, diesel contamination was observed in the excavation trench. Soil samples were collected and analyzed for TPH-D (total petroleum hydrocarbons as diesel) analysis. Benzene, toluene, ethyl benzene, xylene, and 13,000 ppm of TPH-D were detected in the samples. The contamination was probably the result of holes on top of the tank and some historical overfilling. Total fuel released was unknown.

3. Environmental Program Information

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Introduction

LLNL has a substantial commitment to environmental compliance and accountability. During the course of each year, the Environmental Protection Department (EPD) monitors the environment surrounding the Livermore site and Site300 through a sampling and analysis program. In 1993, over 190,000 analyses of environmental samples were performed. This effort, which is conducted in accordance with DOE Orders 5400.1, 5400.5, 5484.1, and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), has four purposes: (1) to assess the effectiveness of pollution control programs, (2) to assess compliance with applicable environmental laws and regulations, (3)to evaluate the impact of operations on the environment, and (4)to support CERCLA investigations and cleanup. Data are produced from sampling of air, sewage, ground water, surface water, soil, vegetation, foodstuff, and environmental radiation; the type of samples collected at a specific location depends on the site and the potential pollutants to be monitored. Details on the monitoring activities can be found in the specific chapters herein for each environmental medium. These chapters also document a special study of tritium in rain and storm water runoff, discussed in Chapter 6 on Surveillance Water Monitoring. Summary information on monitoring activities can be found in Chapter 12 on Radiological Dose Assessment and Chapter 13 on Self-Monitoring Programs.

Although its monitoring activities are quite comprehensive, EPD's main mission is to interact with LLNL programs to ensure that operations are conducted in a manner that limits environmental impacts to levels consistent with regulatory guidelines. The specific activities required by environmental statutes have been described in the preceding chapter. This chapter describes the divisions comprising EPD and the activities they carry out as mandated by DOE, environmental regulations, and / or LLNL management.

Environmental Protection Department

EPD is the Laboratory's environmental support organization. Principal functions of EPD operations include preparing and maintaining LLNL environmental plans and guidelines, informing management about pending changes in environmental regulations pertinent to LLNL, representing LLNL in day-to-day interactions with regulatory agencies, assessing the effectiveness of pollution control programs, and monitoring the environment to determine the impact of LLNL operations. EPD also helps LLNL programs to 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; and responds to emergencies so as to minimize any impact on the environment.

Training is an important component of EPD’s work. Major efforts are ongoing to provide LLNL employees with training on environmentally related topics and improve their ability to comply with environmental regulations. Training tasks address both specialized training for environmental professionals in EPD and training in a variety of environmental topics for employees at all levels throughout LLNL.

EPD is divided into four operating divisions: Operations and Regulatory Affairs Division (ORAD), Hazardous Waste Management Division (HWM), Environmental Restoration Division (ERD), and Environmental Monitoring and Analysis Division (EMAD). EPD has also established Environmental Support Teams, composed of various environmental discipline specialists from the four divisions, who work with LLNL staff to identify and address compliance issues.

Operations and Regulatory Affairs Division

ORAD specializes in environmental compliance issues. The ORAD staff consult with program personnel on regulatory requirements, permitting issues, waste minimization, pollution abatement, inspections, and preconstruction monitoring. They help identify and mitigate potential environmental contamination so existing and planned projects can be performed in accordance with regulations.

In their permitting activities, the ORAD staff interpret pertinent environmental regulations and requirements; analyze existing operations and evaluate new facilities and operations during planning stages to identify environmental concerns and permitting needs; and obtain the necessary environmental permits. After a permit has been obtained, ORAD staff assist programs in evaluating environmental protection controls, procedures, and documentation requirements so that they can be properly implemented.

Other permitting activities include guiding LLNL program staff through the regulatory process to help ensure that regulatory requirements are met; meeting and conferring with regulators on permitting and compliance issues; and coordinating regulatory requirements for tank systems. ORAD staff also respond to emergencies and other urgent concerns to advise on environmental cleanup, sampling, and regulatory reporting.

ORAD prepares and maintains many types of documents for LLNL programs. ORAD staff issue guidance documents that describe how environmental laws, regulations, and DOE Orders are implemented at LLNL; issue templates for operational plans for tank systems and provide guidance and assistance to the programs in the preparation of these plans; develop and maintain chemical tracking databases; and prepare permits and regulatory documents, including documentation for compliance with the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA). In addition, ORAD staff work with a Training and Development Group to prepare and present in-house training programs for LLNL employees on environmental issues, sampling methodologies, and waste handling protocols.

Hazardous Waste Management Division

All hazardous, radioactive, and mixed wastes generated at all LLNL facilities are managed by HWM in accordance with state and federal waste regulations. HWM staff process, store, package, solidify, treat, or prepare waste for shipment and disposal, recycling, or discharge to the sanitary sewer.

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

Currently, HWM is developing a new waste data management system and new waste treatment capabilities, and is automating the controls of existing tank treatment units. In the fall of 1993, HWM initiated the Chemical Exchange Warehouse to minimize excess chemical product and reagent wastes atLLNL.

HWM is actively involved in locating and evaluating facilities that may accept mixed waste for storage or disposal, and subsequently ensuring that shipments from LLNL meet the acceptance criteria of any selected site.

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. These past practices and spills have resulted in environmental contamination that is being addressed by ERD remedial actions. In addressing CERCLA compliance issues, the ERD staff plan, direct, and conduct 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.

The ERD staff investigate 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. Finally, as part of its CERCLA activities, ERD is responsible for interacting with the community.

Environmental Monitoring and Analysis Division

The effluent and surveillance monitoring functions of EMAD cover a number of environmental media and include these activities: sampling and analysis, risk assessment, impact modeling and analysis, and reporting.

EMAD is responsible for monitoring the environmental effects, both radiological and nonradiological, of effluent streams of air, sewage, and storm water runoff. This monitoring is performed by sampling point-source discharges in accordance with federal regulations. Effluent monitoring of wastewater is also performed. EMAD staff are working with other LLNL programs to prepare storm water pollution prevention plans and eliminate illicit wastewater discharges; they are also providing regulatory guidance and permitting assistance on storm water / wastewater issues.

The surveillance monitoring program includes direct radiation monitoring as well as radiological and nonradiological surveillance monitoring of air, soil, water, ground water, vegetation, and foodstuff.

EMAD staff support LLNL site waste generators, as well as HWM, in performing chemical and radiological analysis to identify, characterize, and certify waste for proper disposal. Risk assessment and impact modeling and analysis are part of this work.

EMAD is responsible for producing this annual LLNL Environmental Report, as well as for radionuclide effluent reporting under the National Emission Standards for Hazardous Air Pollutants (NESHAPs) of the Clean Air Act; the Quarterly Ground Water Report and Annual Ground Water Report for the Regional Water Quality Control Board (RWQCB), Central Valley Region; the Semiannual Wastewater Report; and a number of other documents including those dealing with wastewater management for regulatory compliance, permit applications, monitoring reports, and compliance plans.

Self-Monitoring Programs

At both the Livermore site and Site 300, a number of self-monitoring programs are required by the permits and regulations governing projects and activities. The National Pollution Discharge Elimination System Permits require self-monitoring of storm water discharges associated with industrial activity (covered under the California General Industrial Activity Storm Water Permit) and of construction projects that are 2 hectares and greater (covered under the General Construction Activity Storm Water Permit).

Also at both sites, self-monitoring of pretreated, nondomestic, industrial-source wastewater is required by the Livermore Water Reclamation Plant, under the authority of the San Francisco Bay RWQCB, for wastewater that will be discharged from LLNL into the City of Livermore sewer system. The standards for pretreated water are defined in 40 CFR 403.

In addition, at the Livermore site, self-monitoring is required by the San Francisco Bay RWQCB for discharge of treated ground water to a percolation pond, to the surface drainage system, or for on-site reuse. Similarly, self-monitoring programs at Site 300 are required by permits issued by the Central Valley RWQCB for discharges of cooling tower blowdown water to surface waters, for discharges of treated ground water from the eastern General Services Area treatment facility, and for surveillance monitoring of landfills at the site. In addition, self-monitoring programs are required by substantive requirements (under CERCLA), issued by the Central Valley RWQCB for discharges of treated ground water from the central General Services Area treatment facility and the Building 834 treatment facility.

Waste Minimization and Pollution Abatement

Waste Minimization and Pollution Prevention Awareness Plan

The combined *Waste Minimization and Pollution Prevention Awareness Plan* was prepared in accordance with DOE Order 5400.1 and was published on April25, 1994. The plan was originally issued on May31, 1991, and prior to this latest publication had been updated on May31, 1992, after significant changes in regulatory requirements affected Laboratory operations.

Some changes involved new laws: California passed a law requiring reporting of recycled non-RCRA wastes; the California Hazardous Waste Management and Source Reduction Review Act led LLNL to identify its largest hazardous waste streams and select waste minimization options for them, along with a commitment for their implementation; the Pollution Prevention Act of 1990 required significant modifications to the existing LLNL hazardous waste data reporting procedures; and the Land Ban placed new restrictions on the generation of mixed wastes.

Other changes resulted from new definitions, requirements, and restrictions. These include the reduction by DOE of the level of radioactivity that defines waste as radioactive or mixed; new offset requirements for local air emissions that have increased the difficulty of obtaining air permits; an Executive Order issued in September 1991 that requires new emphasis on the use of recycled materials by all federal facilities; California's increased restrictions on the quantities of nonhazardous wastes that may be disposed of in landfills; and the directives by the DOE Secretary to participate in the EPA 33/50 program to reduce emissions of 17 priority chemicals and to submit progress reports on the program, as well as to phase out Class I ozone-depleting chemicals by the end of 1995 and to submit progress reports on this phase-out.

LLNL is continuing to address these changes and to follow the strategies proposed in the original 1991 Waste Minimization and Pollution Prevention Awareness Plan. The plan includes the following three actions: first, each Laboratory program is continuing to conserve resources, minimize waste generation, and prevent pollution. This 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 be barriers to waste minimization; and integrating and coordinating waste generators and waste managers on waste minimization issues.

The second action is to enhance communication of waste minimization goals and ideas. This has involved developing and implementing employee pollution prevention awareness activities, including regular articles in *Newsline* (the LLNL biweekly newspaper) or other periodicals; collecting and disseminating waste minimization information through technology transfer and outreach, and through presentations at conferences and internal LLNL meetings.

The third action involves characterizing waste streams and developing a baseline of waste generation data.

LLNL conducted a number of activities in support of the plan. LLNL continued to communicate management's commitment to curtail pollution and publicized the goals of pollution prevention through posters and articles in *Newsline*. LLNL conducted formal training on pollution prevention and on the responsibilities of waste generators. Pollution prevention displays and handouts were presented during Earth Week, at three Earth Day Fairs, and at an on-site Energy Fair. Environmental Alerts (one-page flyers) were published and distributed to all LLNL employees, conveying information on environmental concerns and possible solutions, on recommended practices, and on pertinent environmental regulatory issues. Changes and additions to regulatory requirements, new technologies, and management changes related to environmental issues continued to be conveyed in 1993 by the environmental analysts assigned to specific site areas.

Waste Minimization Activities

The Waste Minimization Project (WMP), assisted by program representatives, prepared the *Annual Report on Waste Generation and Waste Minimization Progress* for DOE. The WMP also updated the 1991 Livermore-site hazardous waste source reduction report (SB14 report) and submitted a report to Alameda County concerning recycling of non-RCRA hazardous wastes, which described LLNL's waste minimization achievements and successes.

The reduction of waste has been a major effort at LLNL. A significant part of this effort was to reduce hazardous organic solvents, which are disposed of as liquid hazardous waste or which may evaporate into the air. LLNL is undertaking an alternative solvent and coolants research project to minimize the use of ozone-depleting chemicals, halogenated hydrocarbons, and material with volatile organic compounds. The WMP solicits LLNL programs for parts that are currently cleaned with toxic solvents. After cleaning these parts with alternative solvents, the WMP returns them to the programs with suggestions for alternative solvent use. Substituting less toxic cleaning materials minimizes environmental management and waste management costs, minimizes employee health risk exposures, reduces potential impact to the environment, and correlates well with guidance and objectives from EPA.

LLNL evaluated the effectiveness of more than 70 alternative solvents for cleaning grease, oil, and dirt from commonly used substrates such as optical glass, aluminum, other machined metals, printed wiring boards, and plastic. Advanced spectrometry methods are used to quantify cleanliness achieved with the various solvent cleaners. In addition, aquatic toxicity tests are conducted on materials that provide promising cleaning results. Several alternative solvents have proved to be not only less hazardous but also better cleaners than the more toxic materials previously used.

Some of this year's solvent substitutions include the following: Site 300 paint shop is using lacquer thinner as a cleaner instead of paint thinner. The spent lacquer thinner is then recycled and reused. Estimated waste reduction is 85%. Hydrocarbon solvents have also been eliminated in many automotive repair operations. Engineering and Technical Transfer converted from acetone parts degreasers to citrus-based solvents and an aqueous-based detergent solution. It also converted from semiaqueous plus volatile organic compound solvents to a fully aqueous solvent for dry film developing, and reduced its use of 1,1,1-trichloroethane by switching to nonchlorinated, nonpetroleum-based solvents. Furthermore, it purchased a printed circuit board cleaning unit that eliminated Freon degreasing of the boards. Overall, permitted solvents use was reduced from 5700 liters to fewer than 570 liters per year by switching to alternative cleaning products that do not require permits. The Advanced Technology Program in Physical Sciences began using biodegradable degreasers in place of hazardous material solvents.

A variety of chemical substitutions have been implemented, displacing environmentally dangerous materials with more benign alternatives. Defense Systems/Nuclear Systems has substituted a nonhazardous cutting oil for INVOL-42, a hazardous hydrocarbon cutting fluid, and solidification agents Envirostone and Portland Cement have been replaced by Petroset/Aquaset, cutting transuranic waste volume by approximately 40%–50%. Engineering andTechnical Transfer converted to alternative chemistries that eliminate chrome from many of its waste streams. By consolidating similar metal finishing processes in two facilities, it eliminated 3400 liters per year of spent chemicalwaste.

The volume of hazardous wastewater produced at LLNL has also been reduced. This has been done through the use of Transportable Treatment Units (TTUs) to process hazardous wastewater from retention tanks. Since mid-1992, TTUs have treated approximately 200,000 liters of metal-contaminated wastewater from Building 141. Treated wastewater is discharged to the sewer system instead of being hauled off site for disposal, and has already resulted in a cost savings of more than $100,000. LLNL has initiated procurement actions to extend this service to all other qualified wastestreams.

The Hazardous Waste Management Division of EPD established a Chemical Exchange Warehouse (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. The program was established in October 1993 with DOE funds; savings from reduced disposal expenses are expected to break even with operational costs in 1994.

Property Management’s Donation, Utilization, and Sales (DUS) Group, in conjunction with CHEW, is recycling unused, unopened containers of chemicals. If LLNL staff cannot use the chemicals, DUS tries to find other DOE or federal agencies or contractors who can reuse them. The chemicals are ultimately sold if no one picks them up for reuse.

Additional waste minimization activities include recycling and changes in solid materials handling. These programs are described below.

The Hazardous Waste Management Division sent 180kilograms of metallic lead bricks, hammers, and shot to LLNL salvage operations for off-site recycling.

The Environmental Restoration Division has covered its waste accumulation yard with a weatherproof tent so that sampling of accumulated storm water is not needed during the rainy season. These sampling, analytical, and disposal costs have thus been eliminated. The Division has also investigated carbon regeneration and/or recycling from ground water treatment facilities, which will result in savings, including hazardous waste disposal costs. Furthermore, it has developed a system to remove volatile organic compounds from ground water that also contains tritium below the mixed-waste threshold. After the volatile organic compounds are removed, the ground water is reinjected into nearby wells (within the same aquifer) containing tritium concentrations. Also, the Environmental Restoration Division has begun ion exchange column regeneration for resins used in hexavalent chromium reduction operations. This eliminates hazardous waste disposal costs.

The Chemistry and Materials Science Department has implemented a rechargeable battery program for departmental pagers in Building 235, which will significantly reduce the number of alkaline batteries disposed of as waste. It has diverted 678surplus chemicals from the hazardous waste stream to CHEW. It has also recycled approximately 426 liters of acetone that were used in a process to displace water from aerogel. The acetone is driven from the aerogel, captured, and distilled for reuse.

The Lasers Directorate has modified procedures for refurbishing Freon in equipment, reducing the potential for Freon emissions during maintenance by about 5700 liters per year. Other waste reductions were made by joining the CHEW program; by installing a biodegradable, water-based dye penetrant inspection station for radioactive contaminated parts so that mixed waste was not generated during the inspection process; and by eliminating production of deionized water, which reduced by 31,000 liters the volume of water sent to the hazardous waste retention system. New laser designs are being investigated that will eliminate the use of chlorofluorocarbon coolants with oil-based materials.

Engineering and Technology Transfer reduced its generation of wastewater by 108,000 liters and spent chemicals by 13,120 liters by transferring its printed circuit board manufacturing to off-site vendors. This Directorate also implemented a pilot pager battery recycling program.

Site 300 staff have developed and implemented procedures for controlling the generation of energetic materials and wastes and have a recycling system for those that are generated. Similarly, they have instituted ways to reduce waste sources and control inventories to limit waste generation. These include removal of TCE using the Building 834 brine system and sending the brine off site to a resource recovery operation; transferring sixteen 55-gallon drums (3400liters) of surplus insulating oil to another facility that can use it; eliminating use of aerosol containers; reducing cleaning solvent inventory to only two types; processing wood products into energy instead of disposing of them at a landfill; using removed road asphalt as fill for on-site construction instead of disposing of it at a landfill; and recycling rags.

The Automotive Fleet Division of Business Services at Site 300 has substituted aerosol cans with reusable stainless steel containers that use pressurized air, providing an 80% reduction in generated waste. Also, compressor and generator lubricating oils are now changed only when analyses show high metal content; previously, oil changes followed a time schedule. The Motor Pool started using recapped tires instead of buying new ones for certain vehicles.

Like Site 300, Defense Systems/Nuclear Design has also developed and implemented procedures for controlling generation of excess energetic materials and wastes and put in place a system for recycling energetic materials. Their other waste minimization practices include changing a testing process to minimize use of materials that create mutagenic soot; removing aerosol products from the supply room; generating graphics electronically so that photoprocessing wastes are avoided; reconditioning and redistributing office supplies; recycling cardboard; replacing lead tamper-detection tags with plastic ones; developing a waste parcel air evacuation system that reduces low-level waste by about 40%–50%; changing solidification agents to reduce transuranic waste volume by approximately 40%–50%; using recyclable Kaufmann cans to store plutonium chips, thus reducing transuranic waste volume and enhancing safety; and recycling booties instead of disposing of them, reducing low-level waste volume by more than 90%. Finally, a portable tritium processing system has been designed that reduces the possibility of releases and personnel exposures during tritium transfer operations.

The Energy Directorate implemented procedures for minimizing on-hand process chemicals and began separating hazardous from nonhazardous waste which had previously been put together in containers, thereby contaminating the nonhazardous waste.

Biology and Biotechnology Research reduced its radioactive waste by using fewer long-half-life radioisotopes. It also stopped using hazardous solvents as disinfectants for cleaning bench tops and biosafety cabinets.

The Hazards Control Division's Calibration and Standards Laboratory now tests battery life rather than automatically throwing batteries away during the repair and maintenance of instruments. As other groups at LLNL have done, the Division has installed a battery reclamation center.

Overall, during 1993 hazardous waste generation declined by 303,000kilograms, or 32%, at the Livermore site and by 18,800kilograms, or 21%, at Site300. Mixed waste generation decreased by about 46,400 kilograms, or 41%, at the Livermore site, while Site 300 had a 100% reduction from 172 kilograms to none.Mixed transuranic waste decreased by 254 kilograms, or 88%, at the Livermore site. No transuranic waste is created at Site 300.

Nonhazardous Materials Recycling

In 1991, LLNL implemented a site-wide white paper recycling program that collected 242 metric tons of paper in its first year. In 1993, 355 metric tons were collected and recycled, which included destroyed classified as well as nonclassified paper wastes.

The Waste Minimization Project completed the second of two nonhazardous waste stream assessments, in which solid wastes from over a hundred dumpsters were sampled and categorized according to their types. Total paper waste constituted approximately 50% (by weight) of the material sampled. The paper waste was categorized as white paper, cardboard, newsprint, colored paper, coated paper, computer (green bar) paper, and paper towels. Quantities of white paper observed during the assessment indicated that the white paper recycling program is successful, but showed the need for additional awareness programs that would increase participation even more.

Cardboard comprises the largest single waste stream category. LLNL has implemented a pilot program for cardboard recycling with Biology and Biotechnology, Business Operations, Engineering, Shipping, and Salvage and is planning on implementing a site-wide program in fiscal year 1995.

LLNL has established a Buy Recycle Committee in response to Executive Order12873 which mandates federal facilities to increase use of recycled materials. LLNL Stores now carries white photocopier and printer paper containing 50% recycled fiber content (with 10%–25% post-consumer waste), refillable bottles that replace aerosol cans, aqueous-based correction fluid, low alkalinity dishwashing compound, rechargeable batteries, and refurbished laser printer toner cartridges. The Technical Information Department demonstrated that recycled paper could be used in most copiers and laser printers, stimulating acceptance by many other departments.

Property Management’s DUS Group has a project to divert scrap material from being dumped into landfills and make it available for LLNL reuse at no cost to the programs. The most common types of reuse items are moving boxes, wooden pallets, box pallets, office supplies, and general hardware such as nuts, bolts, and screws. Scrap metals that are not picked up for reuse are sold under term contracts, as are tires, cardboard, telephone books, electronic scrap, and baled paper. Pilot programs have been implemented to recycle magazines and newspapers. During 1993, DUS recycled over 1200 metric tons of scrap material. DUS is working closely with the Waste Minimization Project to explore new avenues of recycling.

In 1993, LLNL received a national award from DOE commending the Laboratory’s nonhazardous waste stream assessment and its outstanding contribution to solid waste recycling.

Compliance Activities

The Environmental Operations Group within the Operations and Regulatory Affairs Division is responsible for working closely with LLNL programs and departments to implement environmental requirements so that planned and current operations and experiments comply with local, state, and federal environmental regulations. The group consists of environmental analysts assigned to specific LLNL programs and departments to assist in day-to-day environmental activities. In addition to advising LLNL staff, analysts review and verify that proper procedures are followed for the management of hazardous wastes and for the implementation of appropriate pollution abatement controls. These analysts maintain and verify compliance status and keep abreast of existing and planned activities, review construction documents, inspect facilities, and assess waste management procedures.

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 health, safety, and environmental discipline specialists who assist LLNL staff to maintain compliance with ES&H requirements.

The inspections scrutinize proper handling and management of hazardous and radioactive wastes and waste streams, management and maintenance of waste accumulation areas (WAAs), potential release pathways to the environment (e.g., storm and sanitary sewer drains), hazardous product storage areas, wastewater retention systems, operating equipment (e.g., vacuum pumps, transformers, capacitors, and baghouses), and laboratory and machine shop areas. An inspection report is prepared for the program or department, and follow-up checks are conducted to ensure implementation of recommendations or corrections. Walk-through inspections are conducted on an as-needed basis. During 1993, the ES&H Teams conducted 122 formal building inspections at the Livermore site. At Site 300, the team conducted 9 formal building inspections. The Environmental Protection Department conducted 10 audits of the Hazardous Waste Management facilities at the Livermore site and 10 audits of the Hazardous Waste Management facilities at Site300.

Waste Accumulation Area Inspections

Program representatives conducted inspections at least weekly at all WAAs to ensure that WAAs are operated in compliance with regulatory requirements. An inspection checklist is completed and corrective actions are implemented. In addition, EPD staff conducted biweekly routine checks at all WAAs to help ensure that programs manage their WAAs and wastes in compliance with state and federal requirements. During 1993, 992 biweekly WAA routine checks were conducted at the Livermore site, 14biweekly checks at the Livermore Airport, and 247 biweekly checks at Site300. Chapter 2 provides additional information under the subsection on Waste Accumulation Areas.

Spill Response

Investigation, sampling, and evaluation of all spills and leaks that are potentially hazardous to the environment are conducted when necessary. The spill response process includes identifying the spill or leak, shutting off the source (if safe to do so), eliminating ignition sources, contacting appropriate emergency personnel, cordoning off the area, containing the spill or leak, absorbing and neutralizing the spill or leak, assisting in cleanup of the spill or leak, determining if a spill or leak must be reported to regulatory agencies, and verifying that cleanup (including decontaminating and replenishing spill equipment) is complete. Environmental analysts also provide guidance to the programs on preventing spill recurrence.

Spill Reporting

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 negotiated a spill reporting procedure with the San Francisco Bay RWQCB to replace an existing requirement to report minor spills. The new procedure identifies what types of spills must be reported and when the spills are considered to be of so little consequence that records can be kept on file rather than reported. A letter requesting formal approval of this procedure was submitted to RWQCB in February 1994. Should a spill occur of a reportable quantity of material or one that is not contained, the appropriate agencies are contacted immediately.

Site Evaluations Prior to Construction

Soil and debris from construction sites are sampled and analyzed for potential contamination. Soil is disposed of according to established procedures, based on analytical results. During 1993, environmental analysts conducted preconstruction site evaluations for 104 construction projects.

Environmental Training

In 1993, the Environmental Protection Department sponsored training, including RCRA and SARA/OSHA programs, for 4041people for a total of 15,870 contact hours. These statistics include all courses offered by the Environmental Protection Department Training Section. All courses are assigned a unique course number and are tracked in the Laboratory Repository of Completed Courses. These Training Program statistics do not include the number of hours devoted to on-the-job training, which is handled separately by each organization. Additionally, the Environmental Protection Department routinely participates in briefings to orient all new employees concerning approved environmental practices and procedures, including persons to contact during emergencies.

To meet the U.S. Department of Transportation final rule of docket HM126F, “Training for Safe Transportation of Hazardous Materials,” which was issued on May 15, 1992, the Hazardous Waste Management Division implemented approximately 40 hours of new training for transportation activities. This training consisted of both classroom and formal on-the-job training in topics such as hazardous material identification, packaging, container marking and labeling, vehicle placarding, and emergency response. Although most of the training materials were provided by DOE as part of their program to assist in compliance with these new requirements, on-the-job materials specific to operations in the Hazardous Waste Management facilities were developed in-house to ensure that specific laboratory needs were addressed. All of the training was conducted in-house by trained and qualified transportation specialists.

4. Air Monitoring

Paula J. Tate

Introduction

Air surveillance monitoring is performed to evaluate compliance with local, state, and federal regulations, which ensure that human health and the environment are protected from hazardous air emissions. LLNL complies with all appropriate local, state, and federal environmental air quality laws and DOE regulations including: 22 CCR 67264.700 and 66265.710, *Environmental and Compliance Monitoring*; 40 CFR 61, the National Emissions Standards for Hazardous Air Pollutants (NESHAPs) section of the Clean Air Act; *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.* In general, LLNL analyzes for most constituents at levels that are far below regulatory standards in order to determine if there is 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. Air monitoring involves measurement of particles collected on filters or of vapor chemically trapped on a collection medium. Concentrations of various airborne radionuclides (including particulates 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.

Methods

LLNL maintains eight continuously operating, high-volume, air particulate samplers on the Livermore site (**Figure 4-1**), eleven in the Livermore Valley (**Figure4-2**), eight at Site 300, and one in Tracy (**Figure4 -3**). The samplers are positioned to ensure reasonable probability that any significant concentration of particulate effluents from LLNL operations will be detected. Geographical details of particulate sampling locations are outlined in a written procedure that is included in Appendix B of the *Environmental Monitoring Plan* (Gallegos et al. 1992b).

Each air particulate sampler pulls air continuously at a constant rate of 400 liters per minute through a 20.3 cm ×25.4 cm Whatman-41 cellulose filter. The flow is maintained at better than the DOE requirement of ±20% of the nominal flow by using a mass flow controller that adjusts motor speed. These flow rates are verified at regular intervals with a portable field calibration unit. If a sampler fails, it is repaired and then calibrated with a spirometer that itself was calibrated using a unit traceable to the National Institute for Standards and Technology.

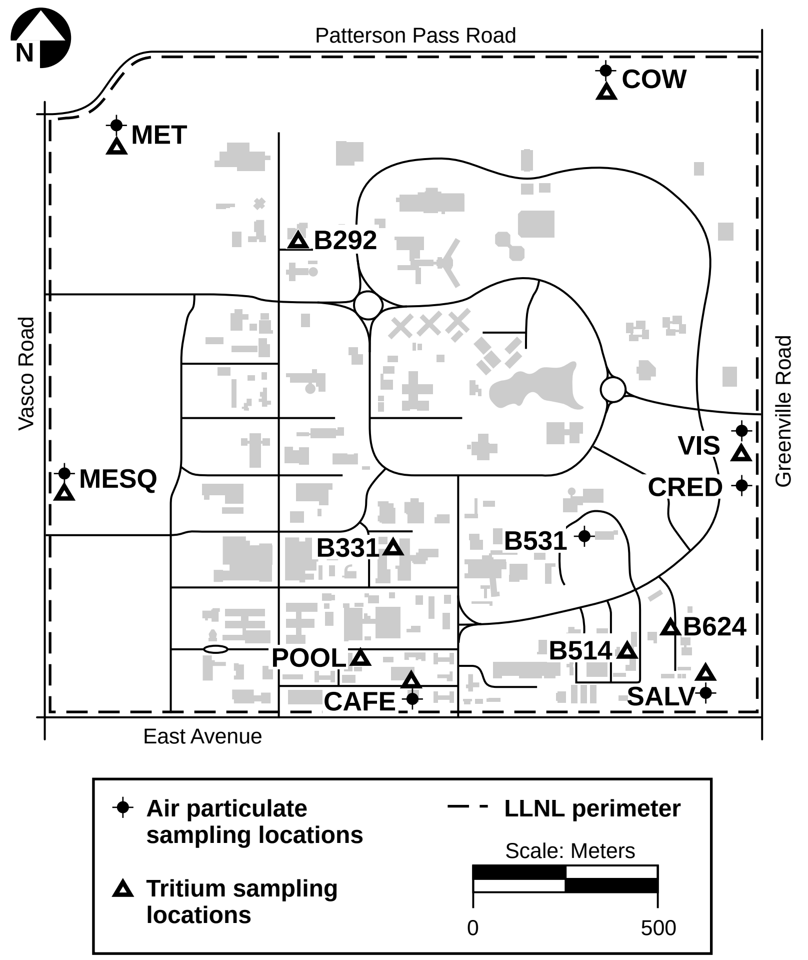

Figure 4-1. Air particulate and tritium sampling locations, Livermore site, 1993.

An easily dissolvable filter with a low trace-metal background is required for airborne beryllium analyses. Whatman-41 filters provide a balance between such requirements and particulate collection efficiency (Lindeken et al. 1963).

Particulate filters are changed each week at all locations. After each particulate filter is removed from a sampler, it is identified by location, date on, date off, elapsed time, and flow rate, and is given a sample identifier (a four-field code) that accompanies it throughout the analysis. Filters are then placed in glassine envelopes and the sample information is recorded in a field tracking notebook. After a four-day delay for decay of the radon-thoron daughters, gross alpha and gross beta activities on the filters are determined with a gas flow proportional counter. The gross alpha, gross beta, and beryllium analyses are completed by a contract laboratory. In March 1993, LLNL selected a new outside analytical contract laboratory to perform this work. The analytical methods of the new contract laboratory and a brief description of the differences between the new and previous contract laboratories are discussed below.

The new analytical laboratory uses ^{241}Am and ^{137}Cs as calibration sources to determine alpha and beta counting efficiencies, respectively. Cross checks utilizing ^{230}Th and ^{90}Sr are also completed periodically. These standards are certified by EPA. Counting-efficiency measurements are made for each set of counted filters. A background count is taken at the beginning of each run and between each set of twenty samples. Records are kept of background and counting-efficiency variations that occur in the counting equipment. The previous laboratory, which analyzed the January and February filters, used ^{239}Pu and ^{90}Sr as calibration sources and ran background counts between each set of ten samples. The new analytical laboratory reports the actual instrumentation values, including negative results, whereas the previous laboratory only reported a less-than-detection-limit value. The gross alpha and gross beta data from both laboratories are comparable.

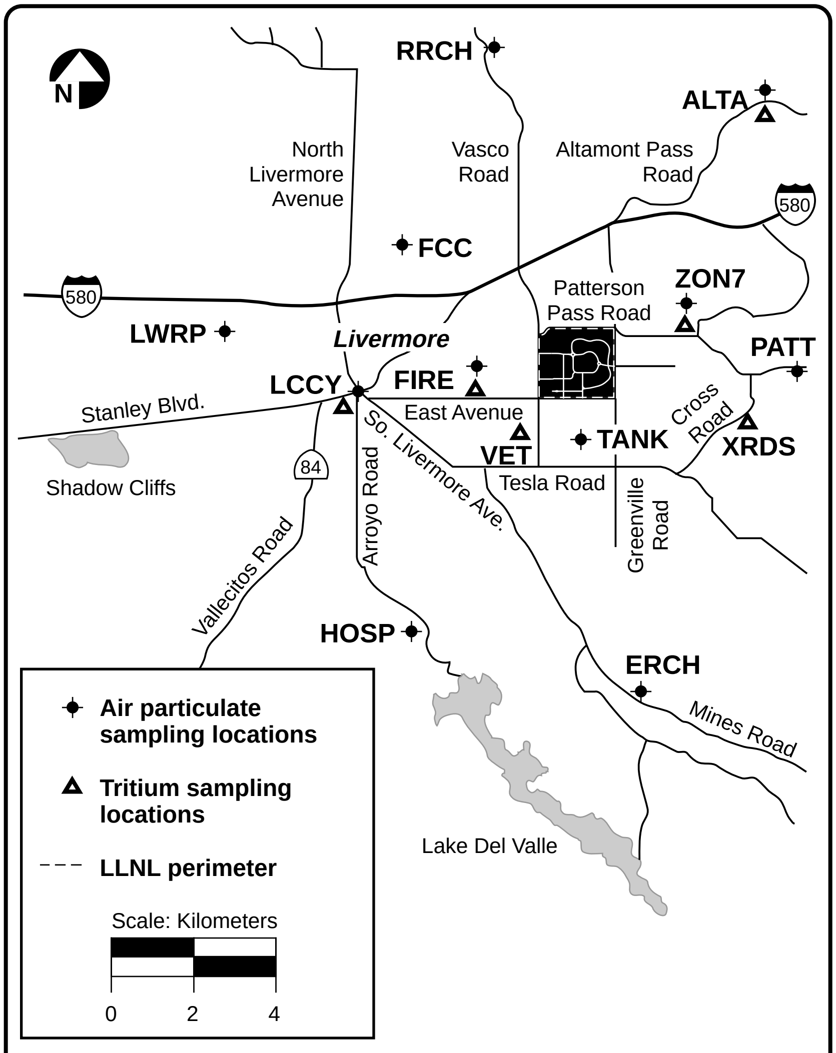

Figure 4-2. Air particulate and tritium sampling locations, Livermore Valley, 1993.

Monthly composites of filters from each of the Livermore-site perimeter locations (SALV, MESQ, CAFE, MET, VIS, and COW) are placed into individual plastic bags. The six bags are then combined and sealed in a 214-cm^3 aluminum can and are counted for gamma-emitting radionuclides using low-background Ge(Li) detectors. The Site 300 filters are sealed and counted in a similar manner. Following gamma counting, the composited filters from each Livermore-site perimeter location are analyzed by LLNL's Radiation Analytical Sciences laboratory for the presence of ^{239}Pu, ^{235}U, and ^{238}U. The off-site samples from the Livermore Valley are analyzed for ^{239}Pu, and all of the Site 300 samples are composited and analyzed for ^{239}Pu, ^{235}U, and ^{238}U. The filters are ashed and then dissolved in a mixture of nitric acid and hydrochloric and/or hydrofluoric acids. Plutonium and uranium are separated by an ion-exchange process. Each separated element is purified further by ion exchange. Then plutonium is electroplated onto a stainless steel disk and submitted for alpha spectrometry, while uranium solutions are submitted for analysis by mass spectrometry.

Replicate samples are processed to confirm the results obtained from the samplers. In addition, a duplicate quality assurance/quality control (QA/QC) sampler is operated for two months in parallel with the permanent sampler at a given site. The QA/QC filters also are exchanged weekly, and both filter sets are submitted for analysis in the usual manner. After two months, the QA/QC sampler is rotated to another location.

A total volume of approximately 4 million liters of air is sampled at each location each week. The details of air particulate sampling and sample change-out are described in Appendix B of the *Environmental Monitoring Plan* (Gallegos et al. 1992b). Details of high-volume sampler flow calibration are also discussed in an Environmental

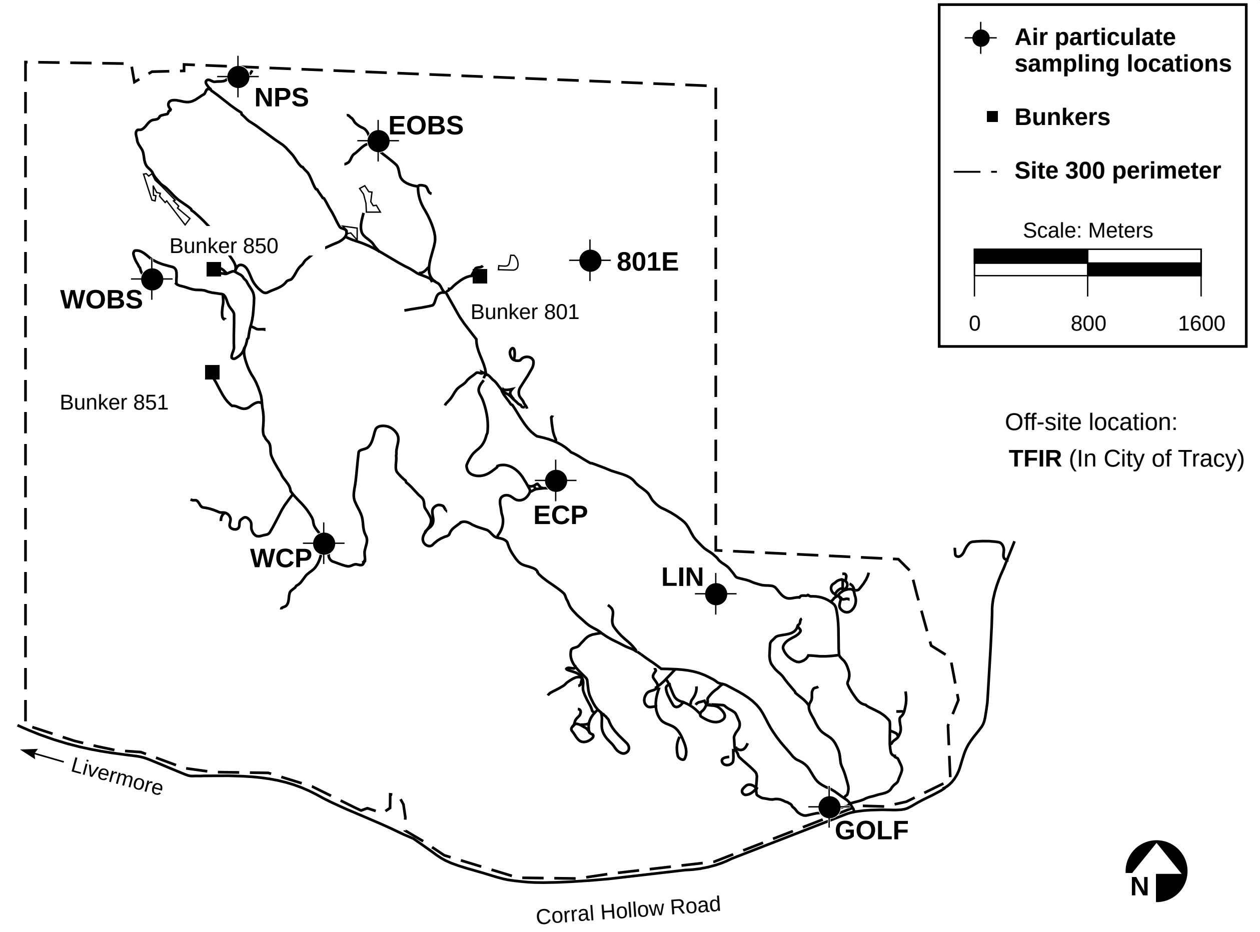

Figure 4-3. Air particulate sampling locations, Site 300, 1993.

Monitoring Section procedure, and details of air sample analysis procedures are outlined in Hall and Edwards (1994).

As outlined in U.S. Department of Energy (1991), gross alpha and gross beta air filter results are used only as trend indicators; specific radionuclide analysis is done for plutonium, uranium, and all 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 are present or may be present in the air sample. Particle size distributions are not determined because the estimated effective dose equivalent to the maximally exposed individual is well below the 0.01mSv (1 mrem) allowable limit.

Beryllium measurements are made on portions of each of the weekly air filters from the Livermore-site perimeter and Site 300 samplers that are composited by sampling location every month. The new analytical laboratory adds 40 milliliters of 10% nitric acid to each composite. The solution is heated for 30 minutes and decanted into a separate beaker where more nitric acid is added. This step is repeated two more times and the solution is evaporated to less than 20 milliliters (careis taken to prevent the samples from boiling or baking dry). The samples are diluted to 20milliliters with deionized water. Quantification is accomplished by graphite furnace atomic absorption. This method is different from that used by the previous analytical laboratory, wherein filters were wet ashed with a mixture of 80% nitric acid and 20% perchloric acid.

LLNL also maintains 11 continuously operating airborne tritium samplers on the Livermore site (**Figure 4-1**) and 6 samplers in the Livermore Valley (**Figure 4-2**). Four of the Livermore site locations (B331, B292, B514, and B624) monitor diffuse source emissions. The tritium sample locations are detailed in Appendix B of the *Environmental Monitoring Plan* (Gallegos et al. 1992b). The tritium samplers, operating at a flow rate of 700milliliters per minute, use silica gel in flasks to collect water vapor. These flasks are changed every two weeks, and the samples are identified by location, date on, date off, elapsed sampling time, and flow rate. The flow rate is the average of the initial and final flow rates, which are measured biweekly with a rotometer that is calibrated once a year. Each sample is given a sample identifier that accompanies it through analysis. Two additional samplers are rotated among the locations at two-month intervals to provide a duplicate QA/QC sample. Details of the actual tritium sampling and a description of tritium sampler calibration can be found in Appendix B of the *Environmental Monitoring Plan* (Gallegos etal. 1992b).

Once the samples are taken, the water is separated from the silica gel by freeze-dried vacuum distillation and the tritium concentration in the water is determined by liquid-scintillation counting. Airborne tritium sample analysis is done by LLNL's Radiation Analytical Sciences laboratory. All analytical results are reported as a measured concentration per unit volume of air flow through the sampling medium. Details of the analytical procedure are described in Hall and Edwards (1994).

Results

Livermore Site

Airborne Radioactivity. **Table 4-1** shows the weekly gross alpha and gross beta minimum, maximum, mean, and standard deviation for all Livermore-site perimeter and Livermore Valley sampling locations. The negative values are not considered detections. The weekly mean gross alpha and gross beta concentrations in air are plotted in **Figure 4-4**. The gross beta results seem to be much more variable and higher during the fall and winter. This apparent seasonal pattern is similar to 1992 data. The values reported for gross alpha and gross betaactivities are similar to those observed in previous years and show no significant differences between samples taken at the Livermore-site perimeter and Livermore Valley. Most of the gross alpha determinations were at or near the detection limit of the method. Typical gross alpha activity is less than 3.0×10^{-11} Bq/mL ($<8.1 \times 10^{-16}$ µCi/mL), and typical beta activity is 5.6×10^{-10} Bq/mL (1.5×10^{-14} µCi/mL). The primary sources of observed alpha and beta activity are the naturally occurring radioisotopes of uranium and thorium and their decay products.

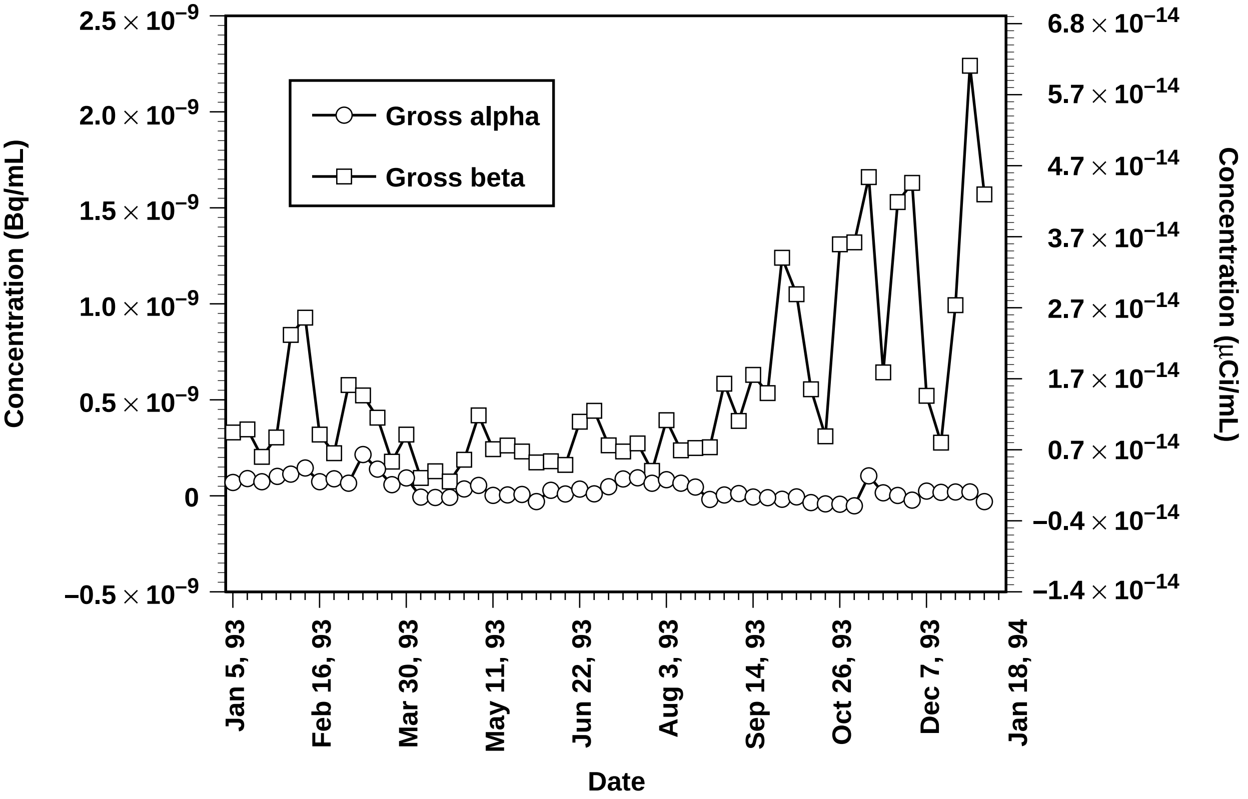

Figure 4-4. Weekly mean gross alpha and gross beta concentrations on air filters from Livermore Valley and Livermore-site perimeter sampling locations.

Table 4-2 lists the activities of gamma-emitting radionuclides that contribute to the activity in the Livermore-site perimeter samples. 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. An investigation to determine the source of ^{22}Na has begun.

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 **Table4 -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 a 1 mSv/y (100mrem/y) effective dose equivalent (DOE Order 5400.5). (Chapter 12 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 the low levels of gamma activity present at the Livermore-site perimeter.

Table 4-3 shows the concentration of plutonium on air filter samples collected in the Livermore Valley. The highest off-site average concentration of ^{239}Pu occurred at location LWRP (at the Livermore Water Reclamation Plant). Soils near the LWRP contain some detectable plutonium, principally resulting from sludge-spreading operations following an estimated 32 mCi release to the sewer in 1967 (see also Chapter 9 on Soil and Sediment Monitoring). Resuspension of these soils probably accounts for the slightly higher average ^{23}Pu in air concentrations observed. However, the mean observed value is less than one ten-thousandth of the DCG.

Table 4-4 shows the concentrations of airborne ^{239}Pu, ^{235}U, and ^{238}U (depleted uranium) on air filter samples from the Livermore-site perimeter. For these data, the DCG is based on the typical environmental oxide chemical form. The May sample for location CAFE, which is on the south perimeter of the Livermore site, registered the highest concentrations of ^{239}Pu in air of all perimeter sampling locations. The concentration reported for this sample, 7.7×10^{-14} Bq/mL (2.1×10^{-18} µCi/mL), represents 0.0001 of the DCG. The annual mean concentration of ^{239}Pu at location CAFE was 3.6×10^{-14} Bq/mL (9.8×10^{-19} µCi/mL). No other statistically significant differences between locations or samples were noted, and the overall ^{239}Pu levels were lower than those reported in 1992. The maximum measured concentrations of ^{238}U are less than 0.0008 of the DCG (DOE Order 5400.5). All ^{235}U/^{238}U ratios are as expected for naturally occurring uranium.

Figure 4-5 shows the annual mean concentrations of ^{239}Pu for locations SALV (on site) and FCC (off site) from 1982 to 1993. Location FCC represents a typical upwind background location and SALV represents the perimeter location having the highest annual average for most of this 12-year period. The higher values in the past at SALV may be attributed to historical activities at LLNL.

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 airand surface soil in the southeast quadrant of the Livermore site (see the Soil and Sediment Monitoring chapter in the 1991 environmental annual report for general background on this study [Gallegos et al. 1992a]). These sampling locations are now part of our routine monitoring network and provide data for diffuse source dose assessments. **Table4-5** shows the monthly concentrations ofairborne ^{239}Pu at these two locations. The average concentration of 2.7×10^{-13} Bq/mL (7.4×10^{-18} µCi/mL) at location B531 is higher than the average concentration for any of the other air particulate sampling locations but is still only 0.0004 of the DCG.

Table 4-6 shows the average biweekly concentrations of tritiated water-vapor that were observed at the Livermore-site perimeter sampling locations. The highest annual mean concentration was observed at location POOL, which was 3.4×10^{-7} Bq/mL (9.1×10^{-12} µCi/mL), or 0.00009 of the DCG.

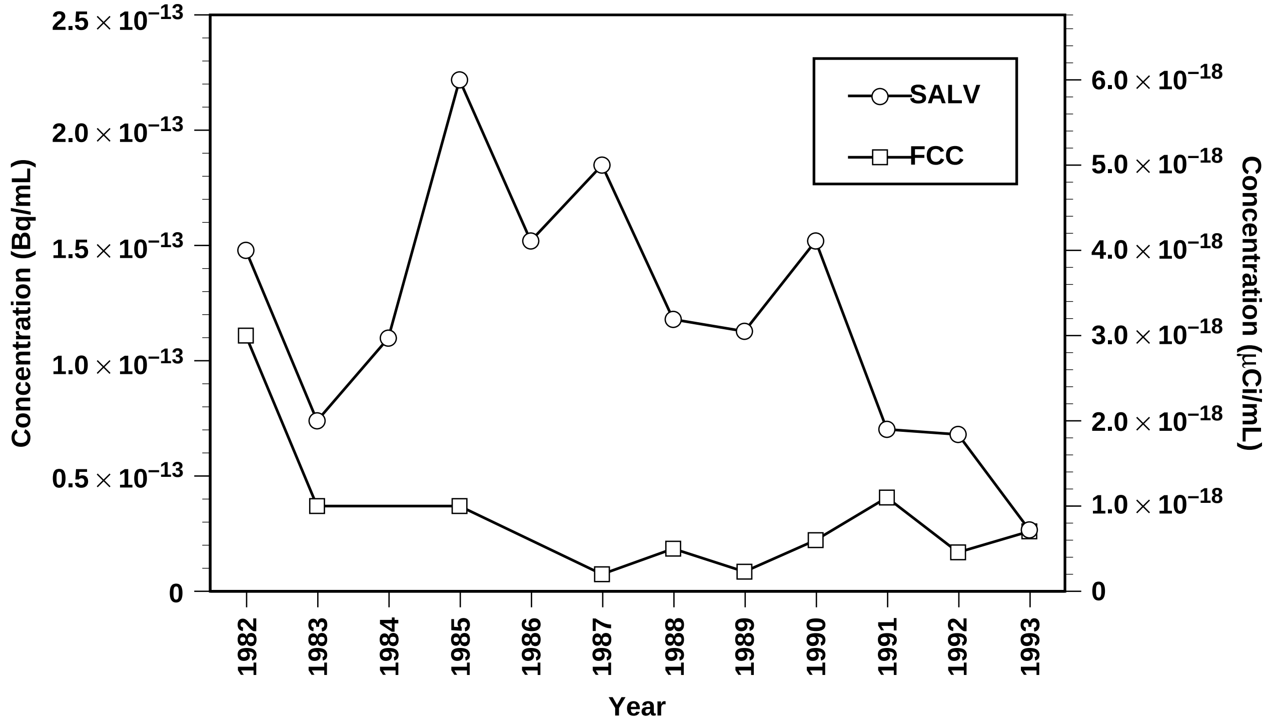

Figure 4-5. Mean plutonium concentrations on air monitors at two locations, SALV and FCC, 1982 to 1993.

Diffuse sources of tritium on the Livermore site are monitored at air tritium sampling locations B331, B292, B514, and B624. **Table 4-7** shows the average biweekly concentrations oftritiated water-vapor for these sampling locations. The highest averageconcentration was observed at location B331. This concentration was 1.9×10^{-6} Bq/mL (5.2×10^{-11} µCi/mL) and represents 0.0005 of the DCG. Three elevated biweekly tritium concentrations were observed in February and March at location B331. The highest of these biweekly tritium concentrations, 2.4×10^{-5} Bq/mL (6.5×10^{-10} µCi/mL) was observed in the sample period of February 11 to February 25. This concentration (if a yearly average) represents 0.0065 of the DCG. A rain sample taken during this period also had elevated levels of tritium (see Chapter 6 on Surface Water Monitoring). The B331 location is near the Tritium Facility (Building 331). This facility has ceased operations except for inventory reduction and cleanup activities. During this process, tritium-contaminated equipment slated for disposal is removed from the building, packaged in a waste accumulation area, and sent to Hazardous Waste Management facilities. During 1993, outgassing from such waste processing released an estimated 0.11×10^{12} Bq/L (3 Ci) of tritium to the atmosphere outside of Building 331. Furthermore, approximately half of this total was released during an eight-week period in February and March. The B292 location is near an underground retention tank that had previously leaked (see the section on Tank Systems Management in Chapter 2 for information regarding the B292 area). 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 1993 average concentrations at B292 and B624 are lower than the average concentrations in 1992.

Table 4-8 shows the average biweekly concentrations of tritiated water-vapor for the Livermore Valley sampling locations. The highest annual average concentrations were observed at locations ZON7 and VET. At approximately 7.1×10^{-8} Bq / mL (1.9×10^{-12} µCi / mL), this concentration represents 0.00002 of the DCG. The highest biweekly concentration was observed in February at ZON7 and in March at VET. This concentration, 1.8×10^{-7} Bq / mL (4.9×10^{-12} µCi / mL), if a yearly average, would be 0.00005 of the DCG. The 1993 tritium values generally are lower than those reported last year.

Beryllium in Air. The average monthly concentrations of airborne berylliumfor the Livermore-site perimeter sampling locations are shown in **Table 4-9**. The highest values of 137pg / m^3 and 68.2pg / m^3 occurred in the November composites at locations CAFE and MESQ, respectively. In both cases, only half of the samples were available for the composite. Consequently, these samples have a higher detection limit. The mean concentrations are less than 0.0014 of the monthly ambient concentration limit of 10,000 pg / m^3 established by the Bay Area Air Quality Management District (BAAQMD).

Figure 4-6 is a plot of the average beryllium concentration at the Livermore-site perimeter from 1974 through 1993 (the medians of 1981, 1989, and 1990 values are shown because some of the varying analytical techniques have high detection limits). The average concentration was calculated to be 0.003 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 Site300 were at or near the analytical limit of detection for the method. **Table 4-10** shows the weekly gross alpha and gross beta minimum, maximum, mean, and standard deviation of all Site 300 sampling locations. The weekly average gross alpha and gross beta concentrations are shown in **Figure 4-7**. The Site 300 gross beta results show a similar pattern to that of the Livermore-site results. Typical gross alpha activity is less than 3.0×10^{-11} Bq / mL ($<8.1 \times 10^{-16}$ µCi / mL). Typical beta activity is 5.6×10^{-10}Bq / mL (1.5×10^{-14} µCi / mL). The primary sources of observed gross alpha and gross beta activity are naturally occurring radioisotopes of uranium and thorium and their decay products.

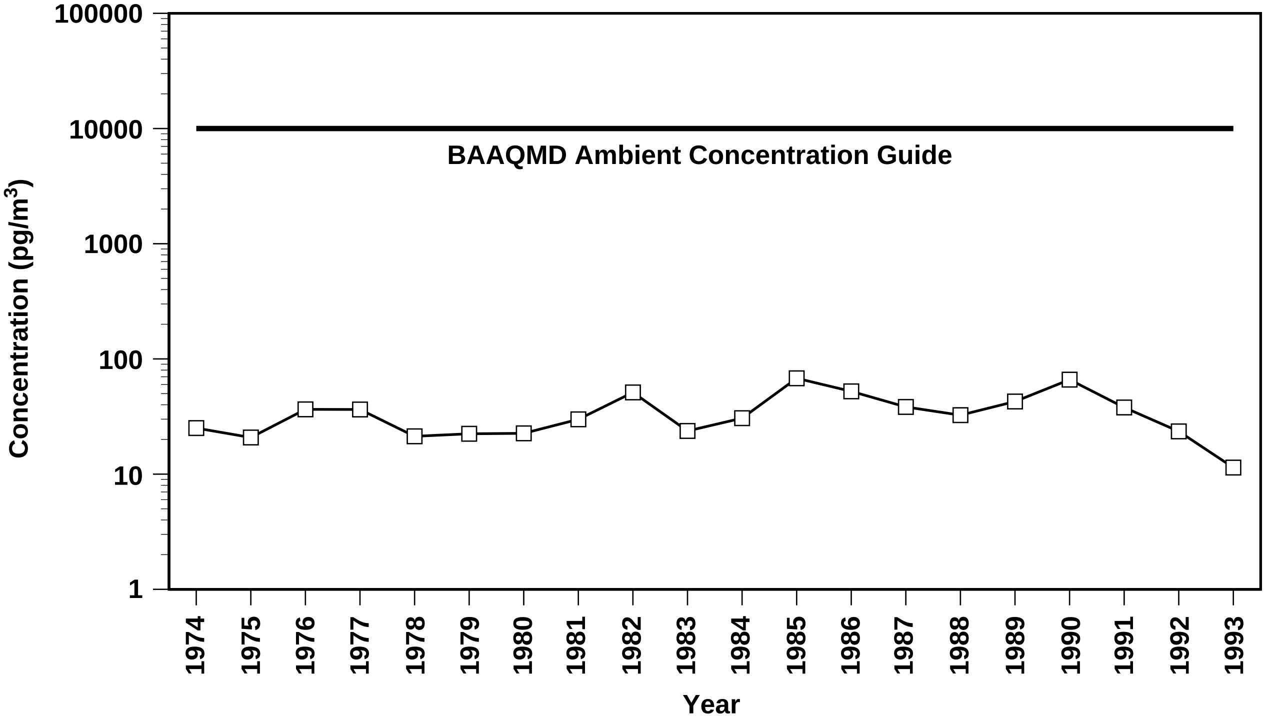

Figure 4-6. Mean concentration of beryllium on air filters, Livermore-site perimeter, 1974 to 1993. (Median used in 1981, 1989, and 1990.)

Table 4-11 lists the activities, as well as the DCGs, of gamma-emitting radionuclides in samples from Site300 and Tracy. 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 fallout resuspension. An investigation to determine the source of ^{22}Na has begun.

Table 4-12 shows the concentration of ^{239}Pu, ^{238}U, and ^{235}U on air filter samples collected from Site 300. The highest concentrations of ^{239}Pu were observed in the April and November composites at a level of 7.3×10^{-15}Bq / mL (2.0×10^{-19} µCi / mL, or 0.00001 of the DCG). The highest concentration of ^{238}U was observed in the April composite at a level of 1.6×10^{-4} µg / m^3 (0.0005 of the DCG). The highest concentration of ^{235}U was observed in the November composite at a level of 7.6×10^{-7} 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 as an indicator of 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 ^{238}U. Because LLNL uses ^{238}U at Site 300, but does not use ^{235}U, it follows that if the ratio remains

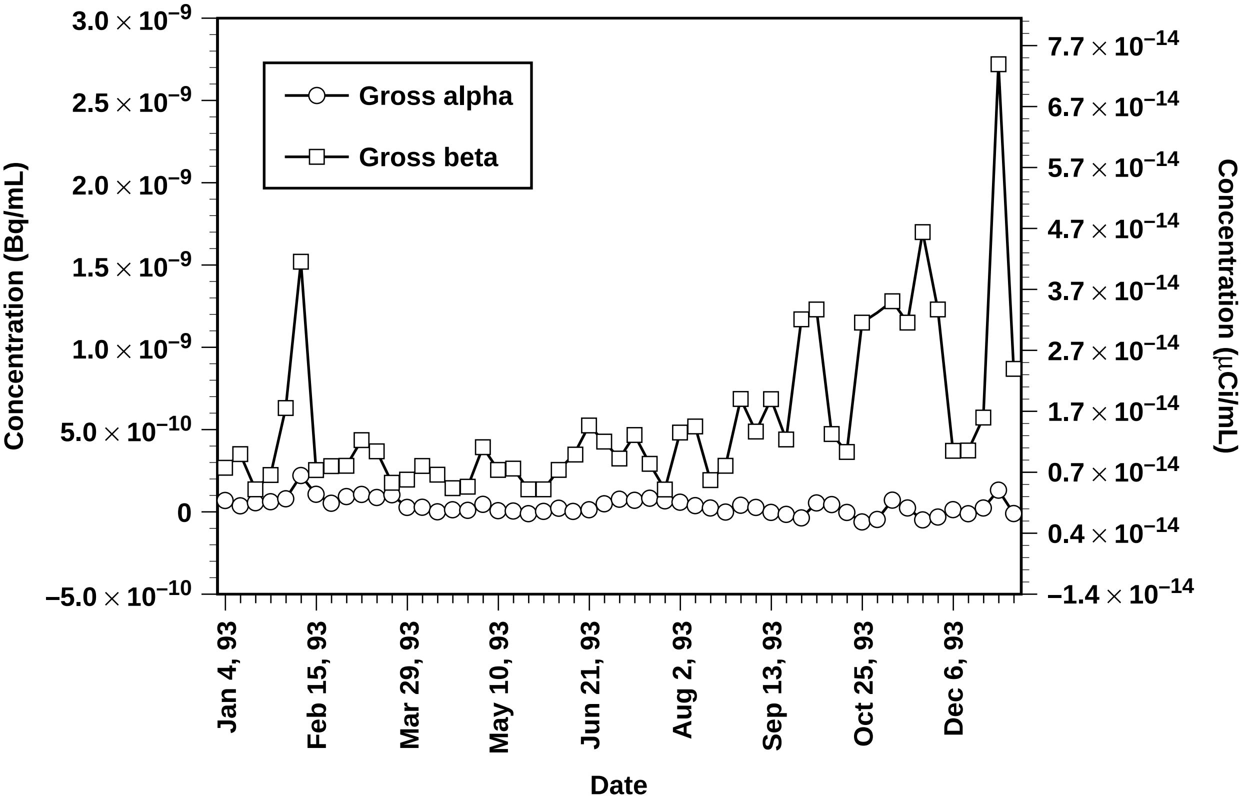

Figure 4-7. Weekly mean gross alpha and gross beta on air filters from Site 300.

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 ratio for April and October show statistically significant deviations from the natural ratio, indicating the presence of airborne depleted uranium from Site 300 operations. The measured concentrations of ^{238}U for 1993, however, are only 0.00024 of the DCG (DOE Order 5400.5).

Beryllium in Air. The average monthly concentrations of airborne beryllium for the Site300 sampling locations are shown in **Table4 -13**. The highest beryllium concentrations of 109pg/m^3 and 103pg/m^3 occurred in December at locations ECP and EOBS. In December, many samples were lost due to the weather conditions (thick ice on filters). Both locations had only half of the samples available for the composite. In November, locations EOBS and NPS also had elevated levels of beryllium. Both of these locations were without power for three of the four weeks in November. Although some of the November and December concentrations were elevated, the concentrations average 0.001 or less (with the highest value being 0.01) of the BAAQMD concentration limit, which is 10,000pg/m^3.

Environmental Impact

Radioactive Effluents

Most of the tritium discharged to the atmosphere by LLNL in 1993 came from the Tritium Facility (Building 331). In 1993, its operations released a total of 8.7×10^{12} Bq (237 Ci) of tritium to the atmosphere. Of this, approximately 4.2×10^{12} Bq (114Ci) were released as tritiated water (HTO). The remaining tritium was elemental tritium gas (HT). The highest single biweekly stack emission from the facility was 5.4×10^{11} Bq (14.7 Ci), of which 3.0×10^{11} Bq (8.1Ci) was HT. This stack emission was measured between January 16 and February 11, 1993.

Once released to the environment, the potential dose from tritium gas is approximately 25,000 times lower than a dose from a comparable release of tritiated water. Therefore, the tritiated hydrogen gas did not contribute significantly in calculations of the overall dose.

Other operations at LLNL released 0.22×10^{12} Bq (5.9 Ci) of HTO during 1993. The diffuse tritium sources at B292, B331, B514, and B624 have a localized effect; no high tritium concentrations were detected at the site perimeter or offsite.

Releases of the short-lived radionuclides ^{13}N and ^{15}O from Building 194 (the electron-positron linear accelerator) totaled 2.6×10^{11} Bq (7 Ci). Releases of radioactive effluents at LLNL during the 12-year period from 1981 through 1993 are shown in **Table 4-14**. The radioactive atmospheric emissions from LLNL operations during 1993 were larger than 1992 but much lower than previous years.

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. The ^{235}U/^{238}U ratios in April and October shown in **Table 4-12** are less than the ratio of naturally occurring concentrations of these isotopes, which suggests the presence of LLNL-induced depleted uranium in air samples from Site 300, although the actual concentrations are not statistically elevated over background. These kinds of results can occur when tests using depleted uranium are conducted at Site 300.

Nonradioactive Effluents

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 $\mu g/m^3$ of particulates. Using a value of 50 $\mu g/m^3$ 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 averages for the Livermore site and Site 300 are 11.2 pg/m^3 and

13.0pg/m ^{3}, respectively. These data are well below the standards and do not indicate the presence of a threat to the environment or public health.

The estimated releases from exempt and permitted sources of air pollutants at the Livermore site can be compared to the most recent estimated 1993 daily release of air pollutants for the entire Bay Area. For example, the total emissions of oxides of nitrogen (NOx) released in the Bay Area is approximately 505 metric tons per day compared to an estimate for LLNL releases of 0.064 metric tons per day (0.0001 of total Bay Area emissions). The BAAQMD estimate for reactive organic emissions (ROG) is at 592 metric tons/day, versus Livermore site's estimated releases of 0.03metric tons/day (0.00005 of total Bay Area emissions) in 1993.

Table 4-15 lists the estimated LLNL 1993 total releases for organic precursor and nonprecursor compounds, chlorofluorocarbons (an organic nonprecursor), and other LLNL airborne emissions.

Certain equipment operations at Site 300 require permits from San Joaquin County. Total estimated emissions are reported to the San Joaquin Valley Unified Air Pollution Control District. The total estimated air emissions during 1993 from permitted equipment operations at Site 300 are given in **Table 4-15**.

Table 4-1. Gross alpha and gross beta (Bq/mL) in air particulate samples summarized by week, Livermore, 1993.

Week	Detection frequency	Minimum[a]	Maximum[a]	Mean[a]	Std dev
Gross alpha					
1/5/93	0/17	$<2.73 \times 10^{-11}$	$<1.45 \times 10^{-10}$	$<6.95 \times 10^{-11}$	4.24×10^{-11}
1/12/93	0/16	$<4.15 \times 10^{-11}$	$<2.58 \times 10^{-10}$	$<8.98 \times 10^{-11}$	5.52×10^{-11}
1/19/93	0/16	$<3.88 \times 10^{-11}$	$<1.88 \times 10^{-10}$	$<7.34 \times 10^{-11}$	4.76×10^{-11}
1/26/93	0/15	$<4.58 \times 10^{-11}$	$<2.60 \times 10^{-10}$	$<1.03 \times 10^{-10}$	5.40×10^{-11}
2/2/93	0/17	$<4.47 \times 10^{-11}$	$<2.47 \times 10^{-10}$	$<1.13 \times 10^{-10}$	6.04×10^{-11}
2/9/93	2/16	$<4.47 \times 10^{-11}$	$<2.87 \times 10^{-10}$	$<1.45 \times 10^{-10}$	8.30×10^{-11}
2/16/93	0/17	$<3.16 \times 10^{-11}$	$<1.76 \times 10^{-10}$	$<7.35 \times 10^{-11}$	3.67×10^{-11}
2/23/93	0/16	$<3.53 \times 10^{-11}$	$<1.68 \times 10^{-10}$	$<8.86 \times 10^{-11}$	4.00×10^{-11}
3/2/93	0/16	$<2.56 \times 10^{-11}$	$<1.43 \times 10^{-10}$	$<6.58 \times 10^{-11}$	3.13×10^{-11}
3/9/93[b]	17/17	3.70×10^{-11}	4.23×10^{-10}	2.15×10^{-10}	9.85×10^{-11}
3/16/93	17/17	1.72×10^{-11}	2.85×10^{-10}	1.40×10^{-10}	6.19×10^{-11}
3/23/93	12/17	-3.80×10^{-11}	1.52×10^{-10}	4.50×10^{-11}	5.98×10^{-11}
3/30/93	16/16	3.60×10^{-11}	1.48×10^{-10}	9.31×10^{-11}	4.02×10^{-11}
4/6/93	9/17	-8.97×10^{-11}	9.79×10^{-11}	-6.72×10^{-12}	5.38×10^{-11}
4/13/93	6/17	-6.38×10^{-11}	7.33×10^{-11}	-8.69×10^{-12}	3.88×10^{-11}
4/20/93	7/17	-8.59×10^{-11}	1.19×10^{-10}	-8.09×10^{-12}	5.93×10^{-11}
4/27/93	11/16	-2.48×10^{-11}	1.37×10^{-10}	3.58×10^{-11}	4.76×10^{-11}
5/4/93	14/17	-2.89×10^{-11}	1.57×10^{-10}	5.42×10^{-11}	5.39×10^{-11}
5/11/93	7/17	-3.19×10^{-11}	5.67×10^{-11}	2.38×10^{-12}	2.98×10^{-11}
5/18/93	10/17	-3.84×10^{-11}	8.11×10^{-11}	4.76×10^{-12}	2.64×10^{-11}
5/25/93	9/16	-6.75×10^{-11}	1.08×10^{-10}	7.02×10^{-12}	4.90×10^{-11}
6/1/93	6/17	-1.09×10^{-10}	4.01×10^{-11}	-3.01×10^{-11}	4.64×10^{-11}
6/8/93	14/17	-4.17×10^{-11}	1.16×10^{-10}	2.88×10^{-11}	3.86×10^{-11}
6/15/93	9/16	-5.29×10^{-11}	6.82×10^{-11}	9.55×10^{-12}	3.18×10^{-11}
6/22/93	12/17	-4.36×10^{-11}	1.69×10^{-10}	3.50×10^{-11}	5.96×10^{-11}
6/29/93	10/16	-4.78×10^{-11}	6.74×10^{-11}	1.03×10^{-11}	3.31×10^{-11}
7/6/93	14/16	-3.12×10^{-11}	7.56×10^{-11}	3.16×10^{-11}	2.75×10^{-11}
7/13/93	8/16	-3.74×10^{-11}	1.33×10^{-10}	2.38×10^{-11}	5.25×10^{-11}
7/20/93	8/17	-7.66×10^{-11}	1.10×10^{-10}	1.98×10^{-11}	5.87×10^{-11}
7/27/93	10/17	-3.41×10^{-11}	7.76×10^{-11}	1.52×10^{-11}	2.86×10^{-11}
8/3/93	6/17	-7.99×10^{-11}	1.17×10^{-10}	-1.40×10^{-11}	4.72×10^{-11}
8/10/93	12/16	-4.30×10^{-11}	1.36×10^{-10}	5.88×10^{-11}	5.75×10^{-11}
8/17/93	13/17	-2.83×10^{-11}	1.13×10^{-10}	4.56×10^{-11}	4.84×10^{-11}
8/24/93	5/17	-7.65×10^{-11}	3.95×10^{-11}	-1.89×10^{-11}	3.33×10^{-11}
8/31/93	9/17	-5.48×10^{-11}	7.52×10^{-11}	4.43×10^{-12}	3.45×10^{-11}

…continued

Table 4-1. Gross alpha and gross beta (Bq/mL) in air particulate samples summarized by week, Livermore, 1993 *(continued).*

Week	Detection frequency	Minimum[a]	Maximum[a]	Mean[a]	Std dev
9/7/93	6/17	-6.47×10^{-11}	9.93×10^{-11}	1.17×10^{-11}	5.69×10^{-11}
9/14/93	7/15	-8.49×10^{-11}	8.68×10^{-11}	-6.23×10^{-12}	5.19×10^{-11}
9/21/93	6/16	-8.74×10^{-11}	5.09×10^{-11}	-9.70×10^{-12}	3.87×10^{-11}
9/28/93	6/15	-1.07×10^{-10}	9.01×10^{-11}	-1.79×10^{-11}	6.06×10^{-11}
10/5/93	9/17	-9.93×10^{-11}	8.85×10^{-11}	-5.63×10^{-12}	6.32×10^{-11}
10/12/93	3/17	-1.09×10^{-10}	5.27×10^{-11}	-3.53×10^{-11}	4.32×10^{-11}
10/19/93	1/17	-9.89×10^{-11}	3.03×10^{-11}	-4.19×10^{-11}	3.21×10^{-11}
10/26/93	6/17	-1.37×10^{-10}	9.65×10^{-11}	-4.38×10^{-11}	6.99×10^{-11}
11/2/93	3/16	-1.20×10^{-10}	2.74×10^{-11}	-5.20×10^{-11}	5.13×10^{-11}
11/9/93	11/12	-1.73×10^{-11}	1.74×10^{-10}	1.04×10^{-10}	5.66×10^{-11}
11/16/93	10/17	-6.07×10^{-11}	2.02×10^{-10}	1.56×10^{-11}	6.54×10^{-11}
11/23/93	7/15	-9.60×10^{-11}	1.01×10^{-10}	1.94×10^{-12}	5.96×10^{-11}
11/30/93	4/15	-6.27×10^{-11}	3.48×10^{-11}	-2.25×10^{-11}	2.74×10^{-11}
12/7/93	11/16	-7.57×10^{-11}	1.09×10^{-10}	2.46×10^{-11}	5.94×10^{-11}
12/14/93	11/17	-3.41×10^{-11}	1.13×10^{-10}	1.81×10^{-11}	3.86×10^{-11}
12/21/93	9/14	-6.40×10^{-11}	1.24×10^{-10}	2.00×10^{-11}	5.26×10^{-11}
12/28/93	9/17	-9.05×10^{-11}	1.85×10^{-10}	2.05×10^{-11}	7.89×10^{-11}
1/4/94	4/16	-1.36×10^{-10}	7.08×10^{-11}	-3.02×10^{-11}	5.62×10^{-11}
Gross beta					
1/5/93	12/17	$<2.12 \times 10^{-10}$	5.52×10^{-10}	3.30×10^{-10}	1.03×10^{-10}
1/12/93	16/16	1.58×10^{-10}	5.11×10^{-10}	3.46×10^{-10}	9.43×10^{-11}
1/19/93	7/16	1.20×10^{-10}	$<2.88 \times 10^{-10}$	$<2.03 \times 10^{-10}$	4.83×10^{-11}
1/26/93	8/15	$<1.30 \times 10^{-10}$	4.99×10^{-10}	3.04×10^{-10}	1.14×10^{-10}
2/2/93	17/17	3.40×10^{-10}	1.26×10^{-9}	8.38×10^{-10}	2.72×10^{-10}
2/9/93	16/16	5.84×10^{-10}	1.26×10^{-9}	9.28×10^{-10}	1.82×10^{-10}
2/16/93	9/17	$<1.32 \times 10^{-10}$	5.50×10^{-10}	3.19×10^{-10}	9.27×10^{-11}
2/23/93	3/16	$<1.15 \times 10^{-10}$	$<3.10 \times 10^{-10}$	$<2.22 \times 10^{-10}$	5.20×10^{-11}
3/2/93	16/16	2.79×10^{-10}	2.99×10^{-9}	5.77×10^{-10}	6.51×10^{-10}
3/9/93[b]	17/17	2.90×10^{-10}	6.73×10^{-10}	5.23×10^{-10}	1.13×10^{-10}
3/16/93	17/17	2.74×10^{-10}	5.70×10^{-10}	4.07×10^{-10}	8.42×10^{-11}
3/23/93	17/17	3.74×10^{-11}	3.00×10^{-10}	1.78×10^{-10}	7.55×10^{-11}
3/30/93	16/16	1.80×10^{-10}	5.11×10^{-10}	3.19×10^{-10}	1.07×10^{-10}
4/6/93	11/17	-8.30×10^{-11}	3.54×10^{-10}	9.30×10^{-11}	1.46×10^{-10}
4/13/93	15/17	-8.09×10^{-11}	4.26×10^{-10}	1.28×10^{-10}	1.37×10^{-10}
4/20/93	14/17	-1.39×10^{-10}	2.62×10^{-10}	7.47×10^{-11}	1.15×10^{-10}
4/27/93	14/16	-1.98×10^{-11}	4.96×10^{-10}	1.88×10^{-10}	1.58×10^{-10}

…continued

Table 4-1. Gross alpha and gross beta (Bq/mL) in air particulate samples summarized by week, Livermore, 1993 *(concluded).*

Week	Detection frequency	Minimum[a]	Maximum[a]	Mean[a]	Std dev
5/4/93	17/17	2.31×10^{-10}	6.08×10^{-10}	4.19×10^{-10}	1.18×10^{-10}
5/11/93	17/17	8.13×10^{-12}	4.57×10^{-10}	2.43×10^{-10}	1.17×10^{-10}
5/18/93	17/17	1.36×10^{-10}	4.86×10^{-10}	2.62×10^{-10}	8.56×10^{-11}
5/25/93	16/16	8.87×10^{-11}	3.39×10^{-10}	2.31×10^{-10}	8.28×10^{-11}
6/1/93	17/17	3.03×10^{-11}	4.62×10^{-10}	1.74×10^{-10}	1.08×10^{-10}
6/8/93	17/17	2.03×10^{-11}	2.76×10^{-10}	1.80×10^{-10}	7.95×10^{-11}
6/15/93	16/16	3.34×10^{-11}	3.56×10^{-10}	1.61×10^{-10}	9.62×10^{-11}
6/22/93	17/17	1.16×10^{-10}	5.51×10^{-10}	3.86×10^{-10}	1.09×10^{-10}
6/29/93	16/16	3.33×10^{-10}	5.60×10^{-10}	4.43×10^{-10}	6.20×10^{-11}
7/6/93	16/16	8.43×10^{-11}	4.84×10^{-10}	2.63×10^{-10}	1.30×10^{-10}
7/13/93	16/16	4.10×10^{-11}	4.20×10^{-10}	2.31×10^{-10}	1.02×10^{-10}
7/20/93	17/17	8.02×10^{-11}	4.96×10^{-10}	2.73×10^{-10}	1.04×10^{-10}
7/27/93	16/17	-1.14×10^{-11}	1.92×10^{-10}	1.19×10^{-10}	6.14×10^{-11}
8/3/93	17/17	2.37×10^{-10}	6.83×10^{-10}	3.94×10^{-10}	1.18×10^{-10}
8/10/93	16/16	3.25×10^{-11}	4.58×10^{-10}	2.37×10^{-10}	1.35×10^{-10}
8/17/93	17/17	1.39×10^{-10}	4.16×10^{-10}	2.49×10^{-10}	8.09×10^{-11}
8/24/93	17/17	2.51×10^{-11}	5.14×10^{-10}	2.53×10^{-10}	1.20×10^{-10}
8/31/93	17/17	3.10×10^{-10}	9.05×10^{-10}	5.84×10^{-10}	1.67×10^{-10}
9/7/93	17/17	1.72×10^{-10}	7.69×10^{-10}	3.90×10^{-10}	1.74×10^{-10}
9/14/93	15/15	4.23×10^{-10}	8.76×10^{-10}	6.30×10^{-10}	1.33×10^{-10}
9/21/93	16/16	2.94×10^{-10}	8.48×10^{-10}	5.35×10^{-10}	1.56×10^{-10}
9/28/93	14/15	-4.85×10^{-10}	1.80×10^{-9}	1.24×10^{-9}	5.26×10^{-10}
10/5/93	17/17	8.33×10^{-10}	1.41×10^{-9}	1.05×10^{-9}	1.61×10^{-10}
10/12/93	17/17	3.64×10^{-10}	8.08×10^{-10}	5.55×10^{-10}	1.11×10^{-10}
10/19/93	17/17	5.06×10^{-11}	4.74×10^{-10}	3.10×10^{-10}	1.13×10^{-10}
10/26/93	17/17	9.34×10^{-10}	1.60×10^{-9}	1.31×10^{-9}	1.81×10^{-10}
11/2/93	16/16	8.28×10^{-10}	1.66×10^{-9}	1.32×10^{-9}	2.00×10^{-10}
11/9/93	12/12	9.67×10^{-10}	2.22×10^{-9}	1.66×10^{-9}	3.45×10^{-10}
11/16/93	17/17	8.03×10^{-11}	8.23×10^{-10}	6.43×10^{-10}	1.78×10^{-10}
11/23/93	15/15	1.04×10^{-9}	1.95×10^{-9}	1.53×10^{-9}	2.93×10^{-10}
11/30/93	15/15	1.15×10^{-9}	2.18×10^{-9}	1.63×10^{-9}	2.73×10^{-10}
12/7/93	16/16	3.61×10^{-10}	7.12×10^{-10}	5.21×10^{-10}	1.21×10^{-10}
12/14/93	17/17	6.14×10^{-11}	4.46×10^{-10}	2.77×10^{-10}	1.06×10^{-10}
12/21/93	14/14	5.84×10^{-10}	1.47×10^{-9}	9.93×10^{-10}	2.28×10^{-10}
12/28/93	17/17	1.33×10^{-9}	3.09×10^{-9}	2.24×10^{-9}	4.05×10^{-10}
1/4/94	16/16	1.07×10^{-9}	1.92×10^{-9}	1.57×10^{-9}	2.36×10^{-10}

[a] Negative values are not considered detections.

[b] A new analytical laboratory began the gross alpha and gross beta analysis in the second week of March.

Table 4-2. Gamma activity on air filters, Livermore-site perimeter, 1993.[a]

	[10^{-9} Bq/mL]	[10^{-12} Bq/mL]					
Month	**^{7}Be**	**^{40}K**	**^{137}Cs**	**^{22}Na**	**^{226}Ra**	**^{228}Ra**	**^{228}Th**
Jan.	3.8 ± 0.061	<4.59	<0.17	<0.18	<0.36	<0.83	0.97 ± 0.71
Feb.	4.6 ± 0.073	<7.14	<0.23	<0.29	<0.49	<1.1	<0.59
Mar.	3.8 ± 0.068	<5.44	<0.19	<0.21	<0.40	<0.82	<0.44
Apr.	4.4 ± 0.071	<5.51	<0.19	0.75 ± 0.57	<0.39	1.8 ± 1.5	<0.47
May	5.0 ± 0.079	<6.66	<0.22	<0.26	<0.49	<1.1	<0.57
June	4.4 ± 0.071	<6.85	<0.23	<0.26	<0.49	<2.5	<0.54
July	4.3 ± 0.069	<4.59	0.42 ± 0.34	0.50 ± 0.38	<0.34	1.7 ± 1.4	1.2 ± 0.58
Aug.	5.1 ± 0.11	<7.44	<0.26	<0.29	1.7 ± 1.1	<1.3	<0.67
Sept.	6.7 ± 0.15	21.4 ± 14.5	<0.27	<0.27	<0.54	<1.2	<0.69
Oct.	6.9 ± 0.15	27.2 ± 12.5	<0.21	<0.22	1.1 ± 0.78	2.6 ± 2.0	<0.59
Nov.	9.9 ± 0.16	<8.25	<0.27	<0.30	<0.57	2.1 ± 2.1	<0.76
Dec.	5.0 ± 0.11	<5.07	<0.16	0.39 ± 0.33	<0.35	<0.74	<0.43
Median	**5.3**[b]	**<6.75**	**<0.22**	**<0.28**	**<0.49**	**<1.27**	**<0.59**
MAD[c]	**1.8**[d]	**—**[e]	**—**[e]	**—**[e]	**—**[e]	**—**[e]	**—**[e]
DCG[f] **(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}**
Fraction of DCG	**3.5×10^{-6}**	**$<2.0 \times 10^{-7}$**	**$<1.5 \times 10^{-8}$**	**$<7.6 \times 10^{-9}$**	**$<1.3 \times 10^{-5}$**	**$<1.2 \times 10^{-5}$**	**$<3.9 \times 10^{-4}$**
				[µCi/mL]			
Median	**1.4×10^{-13}**[b]	**$<1.8 \times 10^{-16}$**	**$<6.1 \times 10^{-18}$**	**$<7.5 \times 10^{-18}$**	**$<1.3 \times 10^{-17}$**	**$<3.4 \times 10^{-17}$**	**$<1.6 \times 10^{-17}$**
MAD[c]	**4.7×10^{-14}**[d]	**—**[e]	**—**[e]	**—**[e]	**—**[e]	**—**[e]	**—**[e]
DCG[f]	**4×10^{-8}**	**9×10^{-10}**	**4×10^{-10}**	**1×10^{-9}**	**1×10^{-12}**	**3×10^{-12}**	**4×10^{-14}**

Note: Radionuclide results are reported $\pm 2\sigma$; see Quality Assurance chapter.

[a] All Livermore-site perimeter samples were composited.

[b] Mean value reported to meet QA requirements; see Quality Assurance chapter.

[c] Median Absolute Deviation.

[d] Standard deviation reported to meet QA requirements; see Quality Assurance chapter.

[e] No measure of dispersion calculated; see Quality Assurance chapter.

[f] Derived Concentration Guide.

Table 4-3. Plutonium-239 activity on air filters (in 10^{-13} Bq/mL), Livermore Valley, 1993.

	Sampling location[a]					
Month	**TANK**	**ZON7**	**FCC**	**HOSP**	**LWRP**	**FIRE**
Jan.	0.051 ± 0.067	0.017 ± 0.034	<0.13	<0.20	<0.22	<0.16
Feb.	0.031 ± 0.056	0.041 ± 0.055	<0.23	0.022 ± 0.044	1.4 ± 0.36	0.015 ± 0.031
Mar.	<0.18	<0.18	<0.20	<0.18	0.15 ± 0.20	<0.14
Apr.	0.13 ± 0.13	0.25 ± 0.22	0.18 ± 0.14	0.036 ± 0.10	0.59 ± 0.20	0.50 ± 0.19
May	0.69 ± 0.33	0.061 ± 0.18	1.6 ± 0.34	0.061 ± 0.12	0.82 ± 0.31	3.1 ± 0.56
June	–0.015 ± 0.12	–0.024 ± 0.13	0.22 ± 0.15	–0.028 ± 0.16	0.44 ± 0.20	–0.089 ± 0.093
July	0.028 ± 0.094	–0.014 ± 0.24	0.026 ± 0.22	–0.12 ± 0.23	0.23 ± 0.17	–0.0071 ± 0.10
Aug.	0.20 ± 0.19	0.12 ± 0.19	0.21 ± 0.15	0.024 ± 0.16	0.86 ± 0.26	0.17 ± 0.15
Sept.	0.16 ± 0.13	0.046 ± 0.13	0.14 ± 0.14	0.096 ± 0.094	0.46 ± 0.26	0.11 ± 0.27
Oct.	0.087 ± 0.12	0.0035 ± 0.097	0.11 ± 0.096	–0.037 ± 0.068	0.0099 ± 0.070	–0.0090 ± 0.018
Nov.	–0.087 ± 0.11	0.067 ± 0.13	0.075 ± 0.090	0.0047 ± 0.047	—[b]	—[b]
Dec.	0.15 ± 0.12	0.0067 ± 0.048	0.034 ± 0.062	–0.052 ± 0.066	0.56 ± 0.23	–0.0019 ± 0.063
Median	**0.11**	**0.044**	**0.16**	**0.023**	**0.46**	**0.11**
MAD[c]	**—[d]**	**0.039**	**—[d]**	**0.056**	**—[d]**	**—[d]**
Fraction of DCG[e]	**1.5×10^{-5}**	**5.9×10^{-6}**	**2.1×10^{-5}**	**3.1×10^{-6}**	**6.2×10^{-5}**	**1.5×10^{-5}**
	[μCi/mL]					
Median	**2.9×10^{-19}**	**1.2×10^{-19}**	**4.3×10^{-19}**	**6.3×10^{-20}**	**1.2×10^{-18}**	**3.0×10^{-19}**
MAD[c]	**—[d]**	**1.1×10^{-19}**	**—[d]**	**1.5×10^{-19}**	**—[d]**	**—[d]**

…continued

Table 4-3. Plutonium-239 activity on air filters (in 10^{-13} Bq/mL), Livermore Valley, 1993 (*concluded*).

	Sampling location[a]					
Month	**TFIR**	**ALTA**	**ERCH**	**LCCY**	**RRCH**	**PATT**
Jan.	0.083 ± 0.085	0.0082 ± 0.016	<0.18	<0.28	<0.38	—[b]
Feb.	0.0086 ± 0.017	<0.17	0.032 ± 0.058	<0.32	0.013 ± 0.026	<0.12
Mar.	0.039 ± 0.12	<0.18	0.0038 ± 0.079	<0.24	<0.24	<0.32
Apr.	0.11 ± 0.16	0.051 ± 0.21	2.1 ± 0.38	0.12 ± 0.12	–0.058 ± 0.14	1.9 ± 0.35
May	1.3 ± 0.30	0.12 ± 0.13	0.69 ± 0.27	–0.31 ± 0.36	0.30 ± 0.17	1.3 ± 0.32
June	0.060 ± 0.13	0.074 ± 0.14	0.012 ± 0.12	0.12 ± 0.19	–0.091 ± 0.13	0.074 ± 0.12
July	0.0069 ± 0.13	0.10 ± 0.24	0.14 ± 0.19	0.51 ± 0.31	0.0000070 ± 0.15	0.016 ± 0.16
Aug.	0.11 ± 0.098	0.48 ± 0.75	0.25 ± 0.19	0.41 ± 0.22	–0.030 ± 0.13	–0.027 ± 0.099
Sept.	0.086 ± 0.11	–0.043 ± 0.10	0.47 ± 0.18	0.20 ± 0.15	0.016 ± 0.11	–0.041 ± 0.19
Oct.	0.12 ± 0.085	0.068 ± 0.076	0.050 ± 0.095	–0.021 ± 0.095	0.15 ± 0.13	0.021 ± 0.11
Nov.	–0.020 ± 0.28	0.13 ± 0.10	0.12 ± 0.11	0.13 ± 0.14	–0.028 ± 0.039	0.040 ± 0.33
Dec.	—[b]	0.041 ± 0.15	0.063 ± 0.094	0.078 ± 0.076	0.031 ± 0.11	–0.054 ± 0.096
Median	**0.17[f]**	**0.088**	**0.13**	**0.16**	**0.014**	**0.040**
MAD[c]	**0.38[g]**	**0.044**	**—[d]**	**—[d]**	**—[d]**	**—[d]**
Fraction of DCG[e]	**2.4 × 10^{-5}**	**1.2 × 10^{-5}**	**1.8 × 10^{-5}**	**2.2 × 10^{-5}**	**1.9 × 10^{-6}**	**5.4 × 10^{-6}**
	[μCi/mL]					
Median	**4.7 × 10^{-19}[f]**	**2.4 × 10^{-19}**	**3.5 × 10^{-19}**	**4.4 × 10^{-19}**	**3.9 × 10^{-20}**	**1.1 × 10^{-19}**
MAD[c]	**1.0 × 10^{-18}[g]**	**1.2 × 10^{-19}**	**—[d]**	**—[d]**	**—[d]**	**—[d]**

Note: Radionuclide results are reported $\pm 2\sigma$; see Quality Assurance chapter.

[a] See Fig. 4-2 for sampling locations. Location TFIR is in the city of Tracy.

[b] No data; see Quality Assurance chapter.

[c] Median Absolute Deviation.

[d] No measure of dispersion calculated; see Quality Assurance chapter.

[e] Derived Concentration Guide (DCG) = 7.4 × 10^{-10} Bq/mL for ^{239}Pu activity in air (2 × 10^{-4} μCi/mL).

[f] Mean value reported to meet QA requirements; see Quality Assurance chapter.

[g] Standard deviation reported to meet QA requirements; see Quality Assurance chapter.

Table 4-4. Plutonium and uranium activity on air filters, Livermore-site perimeter, 1993.

		[10^{-13} Bq/mL]	[10^{-5} µg/m^3]	[10^{-7} µg/m^3]	[10^{-3}]
Location[a]	**Month**	**^{239}Pu**	**^{238}U**	**^{235}U**	**^{235}U/^{238}U**
SALV	Jan.	0.18 ± 0.13	2.16	1.53	7.08
	Feb.	0.44 ± 0.35	2.31	1.56	6.76
	Mar.	0.39 ± 0.18	2.91	2.12	7.27
	Apr.	0.11 ± 0.11	3.12	2.14	6.83
	May	0.29 ± 0.21	3.87	2.75	7.11
	June	0.22 ± 0.19	3.94	2.84	7.21
	July	0.36 ± 0.22	4.70	5.06	10.8
	Aug.	0.36 ± 0.18	6.30	4.60	7.31
	Sept.	0.19 ± 0.17	8.49	6.41	7.55
	Oct.	0.19 ± 0.14	3.55	2.70	7.60
	Nov.	0.34 ± 0.19	8.30	5.85	7.05
	Dec.	0.13 ± 0.13	2.81	2.09	7.43
MESQ	Jan.	0.27 ± 0.12	2.32	1.67	7.19
	Feb.	0.12 ± 0.12	2.62	1.87	7.14
	Mar.	0.17 ± 0.13	4.18	3.02	7.22
	Apr.	0.063 ± 0.12	3.56	2.76	7.77
	May	0.14 ± 0.22	3.78	2.72	7.21
	June	0.35 ± 0.17	4.84	3.63	7.50
	July	0.17 ± 0.34	6.64	6.04	9.08
	Aug.	0.42 ± 0.21	6.95	5.22	7.50
	Sept.	0.31 ± 0.22	7.92	5.54	7.00
	Oct.	0.12 ± 0.14	3.88	2.72	7.01
	Nov.	0.25 ± 0.20	6.84	4.36	6.38
	Dec.	0.17 ± 0.12	4.60	3.23	7.02
CAFE	Jan.	0.18 ± 0.10	4.02	2.89	7.19
	Feb.	0.17 ± 0.13	4.02	2.93	7.28
	Mar.	0.33 ± 0.19	7.58	5.45	7.20
	Apr.	0.18 ± 0.15	6.40	4.57	7.14
	May	0.77 ± 0.30	6.76	5.04	7.46
	June	0.27 ± 0.19	5.75	4.20	7.31
	July	0.15 ± 0.35	8.92	7.05	7.90
	Aug.	0.50 ± 0.22	10.4	7.39	7.11
	Sept.	0.48 ± 0.20	9.98	6.99	7.00
	Oct.	0.29 ± 0.15	6.41	4.49	7.01
	Nov.	0.38 ± 0.29	8.50	5.25	6.18
	Dec.	0.65 ± 0.20	4.97	3.37	6.77

…continued

Table 4-4. Plutonium and uranium activity on air filters, Livermore-site perimeter, 1993 (*continued*).

Location[a]	Month	[10^{-13} Bq/mL]	[10^{-5} μg/m^3]	[10^{-7} μg/m^3]	[10^{-3}]
		^{239}Pu	^{238}U	^{235}U	^{235}U/^{238}U
MET	Jan.	0.088 ± 0.066	1.86	1.37	7.37
	Feb.	0.33 ± 0.15	22.8	16.0	7.01
	Mar.	0.16 ± 0.18	3.23	2.40	7.42
	Apr.	0.17 ± 0.13	3.00	2.31	7.68
	May	0.20 ± 0.20	3.86	2.78	7.19
	June	0.22 ± 0.23	4.24	3.18	7.50
	July	0.20 ± 0.27	6.41	4.68	7.31
	Aug.	0.33 ± 0.16	6.55	4.79	7.31
	Sept.	0.13 ± 0.11	7.78	5.19	6.66
	Oct.	0.19 ± 0.13	3.59	2.55	7.11
	Nov.	0.27 ± 0.19	8.66	5.93	6.85
	Dec.	0.091 ± 0.094	2.99	2.02	6.74
VIS	Jan.	0.13 ± 0.10	1.74	1.19	6.81
	Feb.	0.15 ± 0.10	1.58	1.13	7.18
	Mar.	0.26 ± 0.18	2.50	1.86	7.43
	Apr.	0.20 ± 0.13	2.64	2.16	8.20
	May	0.26 ± 0.36	2.91	2.11	7.25
	June	0.41 ± 0.23	4.84	3.35	6.91
	July	0.29 ± 0.49	5.31	3.51	6.62
	Aug.	0.40 ± 0.17	5.47	4.00	7.31
	Sept.	0.17 ± 0.16	8.88	6.41	7.22
	Oct.	0.11 ± 0.13	2.86	2.06	7.21
	Nov.	0.20 ± 0.17	7.24	5.10	7.04
	Dec.	0.16 ± 0.14	2.94	2.20	7.46
COW	Jan.	0.23 ± 0.14	2.40	1.75	7.29
	Feb.	0.023 ± 0.041	2.45	1.77	7.22
	Mar.	0.15 ± 0.26	3.82	2.74	7.18
	Apr.	0.23 ± 0.14	5.61	4.10	7.31
	May	0.30 ± 0.16	5.70	3.86	6.76
	June	0.14 ± 0.19	6.65	4.72	7.11
	July	–0.027 ± 0.30	7.79	5.23	6.71
	Aug.	0.58 ± 0.25	9.78	7.14	7.31
	Sept.	0.38 ± 0.20	11.7	8.16	6.97
	Oct.	0.10 ± 0.16	5.98	4.08	6.81
	Nov.	0.24 ± 0.21	9.16	6.56	7.16
	Dec.	0.22 ± 0.14	3.46	2.52	7.27

...continued

Table 4-4. Plutonium and uranium activity on air filters, Livermore-site perimeter, 1993 (*concluded*).

Sampling location[a]	SALV	MESQ	CAFE	MET	VIS	COW
^{239}Pu						
Mean (10^{-13} Bq/mL)	**0.27**	**0.21**	**0.36**	**0.20**	**0.23**	**0.21**
Std dev (10^{-13} Bq/mL)	**0.11**	**0.11**	**0.20**	**0.08**	**0.10**	**0.16**
Fraction of DCG[b]	**3.6×10^{-5}**	**2.9×10^{-5}**	**4.9×10^{-5}**	**2.7×10^{-5}**	**3.1×10^{-5}**	**2.9×10^{-5}**
Mean (10^{-18} µCi/mL)	**0.72**	**0.57**	**0.98**	**0.53**	**0.62**	**0.57**
Std dev (10^{-18} µCi/mL)	**0.30**	**0.29**	**0.55**	**0.22**	**0.27**	**0.43**
^{238}U						
Mean (10^{-5} µg/m^3)	**4.37**	**4.84**	**6.98**	**6.25**	**4.08**	**6.21**
Std dev (10^{-5} µg/m^3)	**2.19**	**1.82**	**2.15**	**5.63**	**2.29**	**2.97**
Fraction of DCG[c]	**1.5×10^{-4}**	**1.6×10^{-4}**	**2.3×10^{-4}**	**2.1×10^{-4}**	**1.4×10^{-4}**	**2.1×10^{-4}**
^{235}U						
Mean (10^{-7} µg/m^3)	**3.30**	**3.56**	**4.97**	**4.43**	**2.92**	**4.39**
Std dev (10^{-7} µg/m^3)	**1.71**	**1.43**	**1.56**	**3.91**	**1.61**	**2.08**
Fraction of DCG[d]	**7.0×10^{-6}**	**7.6×10^{-6}**	**1.1×10^{-5}**	**9.4×10^{-6}**	**6.2×10^{-6}**	**9.3×10^{-6}**

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] See Fig. 4-1 for sample locations.

[b] Derived Concentration Guide (DCG) = 7.4×10^{-10} Bq/mL for ^{239}Pu activity in air (2×10^{-14} µCi/mL).

[c] Derived Concentration Guide = 0.3 µg/m^3 for ^{238}U activity in air.

[d] Derived Concentration Guide = 0.047 µg/m^3 for ^{235}U activity in air.

Table 4-5. Plutonium-239 activity on air filters (in 10^{-13} Bq/mL), locations near diffuse sources, 1993.

	Sampling location[a]	
Month	**B531**	**CRED**
Jan.	1.5 ± 0.35	0.038 ± 0.058
Feb.	1.3 ± 0.36	0.055 ± 0.073
Mar.	3.1 ± 0.51	<0.26
Apr.	1.3 ± 0.27	0.40 ± 0.17
May	1.2 ± 0.33	0.37 ± 0.21
June	6.8 ± 0.73	0.26 ± 0.24
July	3.5 ± 0.49	0.27 ± 0.15
Aug.	5.6 ± 0.64	0.31 ± 0.18
Sept.	6.4 ± 0.70	0.30 ± 0.15
Oct.	0.85 ± 0.22	0.0091 ± 0.13
Nov.	1.1 ± 0.31	0.11 ± 0.11
Dec.	0.17 ± 0.13	0.021 ± 0.085
Mean	**2.7**	**0.26**[b]
Std dev	**2.3**	**—**[c]
Fraction of DCG[d]	**3.7×10^{-4}**	**3.5×10^{-5}**
	[µCi/mL]	
Mean	**7.4×10^{-18}**	**6.9×10^{-19}**
Std dev	**6.3×10^{-18}**	**—**[c]

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] See Fig. 4-1 for sample locations.

[b] Median value reported to meet QA requirements; see Quality Assurance chapter.

[c] No measure of dispersion calculated; see Quality Assurance chapter.

[d] Derived Concentration Guide (DCG) = 7.4×10^{-10} Bq/mL for ^{239}Pu activity in air (2×10^{-14} µCi/mL).

Table 4-6. Tritium in air (in 10^{-7} Bq/mL), Livermore-site perimeter, 1993.

	Sample location[a]			
	SALV	**MESQ**	**CAFE**	**MET**
Jan.	—[b]	0.585 ± 0.175	1.62 ± 0.196	0.562 ± 0.155
	0.951 ± 0.128	1.41 ± 0.213	1.76 ± 0.185	0.636 ± 0.190
Feb.	1.14 ± 0.175	1.01 ± 0.144	1.92 ± 0.202	0.781 ± 0.186
	—[b]	2.95 ± 0.221	9.25 ± 0.352	2.15 ± 0.234
Mar.	1.60 ± 0.149	3.33 ± 0.226	6.48 ± 0.265	1.42 ± 0.163
	2.60 ± 0.244	1.32 ± 0.184	2.38 ± 0.212	1.27 ± 0.194
Apr.	—[b]	0.588 ± 0.182	1.36 ± 0.177	0.426 ± 0.148
	0.907 ± 0.142	0.544 ± 0.151	1.41 ± 0.179	0.365 ± 0.120
May	2.25 ± 0.198	1.18 ± 0.205	1.68 ± 0.194	0.562 ± 0.147
	3.85 ± 0.223	1.07 ± 0.172	1.64 ± 0.171	0.555 ± 0.133
June	1.65 ± 0.187	0.400 ± 0.177	0.847 ± 0.168	0.448 ± 0.160
	3.69 ± 0.225	0.869 ± 0.238	1.82 ± 0.206	0.488 ± 0.161
July	1.86 ± 0.158	1.17 ± 0.159	2.37 ± 0.168	0.895 ± 0.147
	0.803 ± 0.157	< 0.149	0.548 ± 0.176	0.259 ± 0.158
	1.24 ± 0.169	0.511 ± 0.260	1.13 ± 0.213	0.241 ± 0.172
Aug.	1.15 ± 0.247	0.500 ± 0.182	0.899 ± 0.213	0.392 ± 0.150
	1.28 ± 0.189	0.544 ± 0.179	1.54 ± 0.212	0.496 ± 0.170
Sept.	1.35 ± 0.152	0.736 ± 0.160	2.02 ± 0.216	0.611 ± 0.164
	1.13 ± 0.152	0.290 ± 0.129	0.910 ± 0.177	< 0.148
Oct.	1.28 ± 0.156	0.777 ± 0.149	1.24 ± 0.182	0.514 ± 0.145
	1.20 ± 0.172	1.52 ± 0.228	2.26 ± 0.228	1.00 ± 0.182
Nov.	0.369 ± 0.137	—[b]	1.32 ± 0.184	0.844 ± 0.183
	0.718 ± 0.103	1.67 ± 0.201	1.50 ± 0.157	0.847 ± 0.138
Dec.	0.651 ± 0.107	1.00 ± 0.149	0.947 ± 0.135	0.592 ± 0.112
	0.984 ± 0.181	0.770 ± 0.169	1.15 ± 0.192	0.500 ± 0.190
	0.374 ± 0.080	0.696 ± 0.0981	0.596 ± 0.0995	1.11 ± 0.121
Mean[c]	**1.44**	**0.777[d]**	**1.95**	**0.562[d]**
Std dev	**0.907**	**0.278[e]**	**1.85**	**0.184[e]**
Fraction of DCG[f]	**3.88×10^{-5}**	**2.10×10^{-5}**	**5.26×10^{-5}**	**1.52×10^{-5}**
Dose (mSv)	**3.1×10^{-5}**	**1.7×10^{-5}**	**4.2×10^{-5}**	**1.2×10^{-5}**
	[µCi/mL]			
Mean	**3.88×10^{-12}**	**2.10×10^{-12}[d]**	**5.26×10^{-12}**	**1.52×10^{-12}[d]**
Std dev	**2.45×10^{-12}**	**7.51×10^{-13}[e]**	**5.01×10^{-12}**	**4.97×10^{-13}[e]**
Dose (mrem)	**3.1×10^{-3}**	**1.7×10^{-3}**	**4.2×10^{-3}**	**1.2×10^{-3}**

...continued

Table 4-6. Tritium in air (in 10^{-7} Bq/mL), Livermore-site perimeter, 1993 (*concluded*).

	Sampling location[a]		
	VIS	**COW**	**POOL**
Jan.	1.34 ± 0.196	0.951 ± 0.188	1.67 ± 0.169
	1.30 ± 0.199	0.980 ± 0.176	2.54 ± 0.216
Feb.	1.49 ± 0.195	1.28 ± 0.184	2.95 ± 0.215
	4.66 ± 0.266	6.40 ± 0.320	10.2 ± 0.359
Mar.	2.27 ± 0.200	1.20 ± 0.156	14.1 ± 0.409
	2.60 ± 0.242	1.55 ± 0.196	3.96 ± 0.281
Apr.	1.42 ± 0.196	1.56 ± 0.265	2.87 ± 0.247
	1.24 ± 0.188	1.35 ± 0.156	—[b]
May	1.57 ± 0.193	1.35 ± 0.179	3.08 ± 0.240
	1.85 ± 0.185	1.25 ± 0.159	2.97 ± 0.231
June	1.35 ± 0.202	1.01 ± 0.173	2.11 ± 0.238
	2.00 ± 0.218	1.37 ± 0.190	3.56 ± 0.257
July	1.74 ± 0.158	0.980 ± 0.133	4.70 ± 0.249
	1.32 ± 0.198	1.03 ± 0.185	1.64 ± 0.207
	1.72 ± 0.226	0.888 ± 0.189	1.95 ± 0.240
Aug.	1.22 ± 0.202	0.585 ± 0.172	—[b]
	1.15 ± 0.191	0.773 ± 0.176	2.28 ± 0.198
Sept.	1.68 ± 0.203	0.929 ± 0.168	3.32 ± 0.229
	2.11 ± 0.289	0.603 ± 0.145	1.47 ± 0.158
Oct.	1.22 ± 0.174	0.618 ± 0.181	1.60 ± 0.167
	1.79 ± 0.230	0.918 ± 0.172	2.97 ± 0.234
Nov.	0.326 ± 0.183	< 0.147	3.66 ± 0.227
	0.762 ± 0.136	0.407 ± 0.117	2.03 ± 0.140
Dec.	0.958 ± 0.150	0.315 ± 0.105	1.17 ± 0.106
	0.888 ± 0.186	0.451 ± 0.142	2.35 ± 0.226
	0.352 ± 0.107	0.186 ± 0.086	1.57 ± 0.129
Mean[c]	**1.55**	**0.966[d]**	**3.36**
Std dev	**0.826**	**0.355[e]**	**2.91**
Fraction of DCG[f]	**4.19×10^{-5}**	**2.61×10^{-5}**	**9.09×10^{-5}**
Dose (mSv)[g]	**3.3×10^{-5}**	**2.1×10^{-5}**	**7.2×10^{-5}**
		[µCi/mL)	
Mean	**4.19×10^{-12}**	**2.61×10^{-12}[d]**	**9.09×10^{-12}**
Std dev	**2.23×10^{-12}**	**9.59×10^{-13}[e]**	**7.86×10^{-12}**
Dose (mrem)[g]	**3.3×10^{-3}**	**2.1×10^{-3}**	**7.2×10^{-3}**

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] See Fig. 4–1 for sampling locations.

[b] No data; see Quality Assurance chapter.

[c] Overall average = 1.6×10^{-7} Bq/mL.

[d] Median value reported to meet QA requirements; see Quality Assurance chapter.

[e] Median Absolute Deviation (MAD) reported to meet QA requirements; see Quality Assurance chapter.

[f] Derived Concentration Guide (DCG) = 3.7×10^{-3} Bq/mL (1×10^{-7} µCi/mL).

[g] This is the effective dose equivalent.

Table 4-7. Tritium in air (in 10^{-7} Bq/mL), locations near diffuse sources, 1993.

	Sampling location[a]			
	B292	**B331**	**B514**	**B624**
Jan.	8.18 ± 0.311	3.52 ± 0.229	2.77 ± 0.197	5.22 ± 0.277
	9.84 ± 0.344	2.31 ± 0.177	3.32 ± 0.216	6.48 ± 0.272
Feb.	10.7 ± 0.374	33.0 ± 0.593	3.20 ± 0.227	10.4 ± 0.373
	11.5 ± 0.369	242 ± 1.69	4.48 ± 0.242	11.8 ± 0.365
Mar.	14.0 ± 0.351	64.0 ± 0.704	—[b]	10.7 ± 0.311
	11.3 ± 0.385	7.77 ± 0.326	2.83 ± 0.220	9.32 ± 0.364
Apr.	11.2 ± 0.405	6.22 ± 0.274	1.51 ± 0.160	6.48 ± 0.369
	11.8 ± 0.365	5.11 ± 0.230	1.15 ± 0.151	5.88 ± 0.247
May	25.4 ± 0.610	8.73 ± 0.323	2.20 ± 0.194	8.03 ± 0.305
	11.1 ± 0.334	6.40 ± 0.275	2.85 ± 0.202	10.1 ± 0.322
June	8.33 ± 0.391	7.22 ± 0.317	1.94 ± 0.195	8.81 ± 0.352
	12.0 ± 0.382	7.99 ± 0.304	1.90 ± 0.190	7.81 ± 0.250
July	22.2 ± 0.465	9.77 ± 0.303	2.35 ± 0.176	13.9 ± 0.363
	—[b]	9.92 ± 0.377	0.899 ± 0.167	7.84 ± 0.337
	3.06 ± 0.257	7.99 ± 0.368	1.27 ± 0.185	5.99 ± 0.294
Aug.	9.25 ± 0.342	9.69 ± 0.388	1.35 ± 0.198	9.40 ± 0.367
	4.51 ± 0.316	6.70 ± 0.301	1.30 ± 0.178	8.44 ± 0.329
Sept.	—[b]	6.66 ± 0.400	2.70 ± 0.208	27.4 ± 0.548
	2.50 ± 0.243	5.81 ± 0.285	1.27 ± 0.166	31.5 ± 0.598
Oct.	2.56 ± 0.205	7.10 ± 0.305	2.07 ± 0.182	13.7 ± 0.382
	11.8 ± 0.447	6.73 ± 0.337	2.39 ± 0.203	11.9 ± 0.393
Nov.	9.81 ± 0.314	4.03 ± 0.242	2.28 ± 0.192	12.7 ± 0.305
	35.2 ± 0.598	2.42 ± 0.158	1.30 ± 0.122	6.96 ± 0.292
Dec.	3.15 ± 0.176	2.24 ± 0.217	—[b]	7.88 ± 0.292
	4.11 ± 0.296	3.65 ± 0.241	1.52 ± 0.169	6.92 ± 0.298
	7.10 ± 0.234	—[b]	—[b]	4.29 ± 0.172
Mean[c]	**10.9**	**19.1**	**2.12**	**10.4**
Std dev	**7.58**	**48.1**	**0.87**	**6.20**
Fraction of DCG[d]	$\mathbf{2.93 \times 10^{-4}}$	$\mathbf{5.16 \times 10^{-4}}$	$\mathbf{5.74 \times 10^{-5}}$	$\mathbf{2.80 \times 10^{-4}}$
Dose (mSv)[e]	$\mathbf{2.3 \times 10^{-4}}$	$\mathbf{4.1 \times 10^{-4}}$	$\mathbf{4.6 \times 10^{-5}}$	$\mathbf{2.2 \times 10^{-4}}$
	[μCi/mL]			
Mean	$\mathbf{2.93 \times 10^{-11}}$	$\mathbf{5.16 \times 10^{-11}}$	$\mathbf{5.74 \times 10^{-12}}$	$\mathbf{2.80 \times 10–^{11}}$
Std dev	$\mathbf{2.05 \times 10^{-11}}$	$\mathbf{1.30 \times 10^{-10}}$	$\mathbf{2.36 \times 10^{-12}}$	$\mathbf{1.67 \times 10^{-11}}$
Dose (mrem)[e]	$\mathbf{2.3 \times 10^{-2}}$	$\mathbf{4.1 \times 10^{-2}}$	$\mathbf{4.6 \times 10^{-3}}$	$\mathbf{2.2 \times 10^{-2}}$

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] See Fig. 4–1 for sampling locations.

[b] No data; see Quality Assurance chapter.

[c] Overall average = 1.1×10^{-6} Bq/mL.

[d] Derived Concentration Guide (DCG) = 3.7×10^{-3} Bq/mL (1×10^{-7} μCi/mL).

[e] This is the effective dose equivalent.

Table 4-8. Tritium in air (in 10^{-7} Bq/mL), Livermore Valley, 1993.

	Sampling location[a]		
	ZON7	**ALTA**	**LCCY**
Jan.	0.470 ± 0.131	0.224 ± 0.188	0.200 ± 0.124
	0.796 ± 0.234	<0.129	0.330 ± 0.150
Feb.	<0.143	<0.165	1.52 ± 0.197
	1.82 ± 0.255	0.818 ± 0.126	0.411 ± 0.105
Mar.	0.903 ± 0.143	0.437 ± 0.124	0.536 ± 0.120
	1.16 ± 0.199	0.633 ± 0.201	<0.151
Apr.	0.703 ± 0.158	0.265 ± 0.116	0.115 ± 0.082
	0.426 ± 0.154	0.377 ± 0.142	0.139 ± 0.124
May	0.655 ± 0.137	0.514 ± 0.166	0.142 ± 0.109
	0.818 ± 0.142	0.481 ± 0.131	0.241 ± 0.119
June	0.736 ± 0.167	0.298 ± 0.144	<0.141
	1.35 ± 0.257	0.306 ± 0.135	0.285 ± 0.157
July	1.14 ± 0.179	0.339 ± 0.108	0.279 ± 0.117
	0.766 ± 0.182	0.346 ± 0.147	0.181 ± 0.160
	0.729 ± 0.193	0.176 ± 0.156	0.259 ± 0.180
Aug.	0.422 ± 0.168	0.145 ± 0.139	—[b]
	0.574 ± 0.173	0.171 ± 0.138	<0.153
Sept.	0.807 ± 0.174	0.429 ± 0.139	0.295 ± 0.164
	0.537 ± 0.165	<0.124	<0.149
Oct.	0.699 ± 0.150	0.288 ± 0.118	0.381 ± 0.144
	0.858 ± 0.194	0.492 ± 0.165	0.240 ± 0.170
Nov.	<0.151	<0.139	<0.164
	0.184 ± 0.131	<0.0884	0.226 ± 0.092
Dec.	0.418 ± 0.135	0.115 ± 0.103	0.283 ± 0.112
	0.324 ± 0.121	<0.101	—[b]
	0.166 ± 0.0905	<0.080	0.374 ± 0.123
Median[c]	**0.701**	**0.276**	**0.241**
MAD[d]	**0.216**	**—[e]**	**—[e]**
Fraction of DCG[f]	**1.90×10^{-5}**	**7.47×10^{-6}**	**6.50×10^{-6}**
Dose (mSv)[g]	**1.5×10^{-5}**	**5.9×10^{-6}**	**5.2×10^{-6}**
		[μCi/mL]	
Median	**1.90×10^{-12}**	**7.47×10^{-13}**	**6.50×10^{-13}**
MAD[d]	**5.84×10^{-13}**	**—[e]**	**—[e]**
Dose (mrem)[g]	**1.5×10^{-3}**	**5.9×10^{-4}**	**5.2×10^{-4}**

...continued

Table 4-8. Tritium in air (in 10^{-7} Bq/mL), Livermore Valley, 1993 (*concluded*).

	Sampling location[a]		
	FIRE	**XRDS**	**VET**
Jan.	0.315 ± 0.131	0.422 ± 0.201	0.944 ± 0.163
	0.324 ± 0.141	0.781 ± 0.233	1.48 ± 0.182
Feb.	—[b]	0.350 ± 0.146	1.31 ± 0.209
	0.910 ± 0.172	0.555 ± 0.219	1.10 ± 0.187
Mar.	0.803 ± 0.181	0.936 ± 0.242	1.82 ± 0.177
	0.299 ± 0.152	0.914 ± 0.221	—[b]
Apr.	0.175 ± 0.147	0.299 ± 0.258	0.451 ± 0.142
	0.230 ± 0.137	0.363 ± 0.180	0.292 ± 0.152
May	0.223 ± 0.118	0.337 ± 0.175	—[b]
	0.511 ± 0.137	0.651 ± 0.145	—[b]
June	0.249 ± 0.162	—[b]	0.106 ± 0.097
	0.388 ± 0.170	0.644 ± 0.194	0.518 ± 0.166
July	0.566 ± 0.134	0.718 ± 0.131	1.33 ± 0.150
	0.258 ± 0.172	<0.174	<0.172
	0.343 ± 0.187	0.633 ± 0.218	0.522 ± 0.205
Aug.	0.352 ± 0.178	0.317 ± 0.184	0.525 ± 0.177
	<0.162	0.203 ± 0.166	0.736 ± 0.188
Sept.	0.433 ± 0.172	0.688 ± 0.184	1.27 ± 0.208
	0.299 ± 0.162	0.361 ± 0.183	0.293 ± 0.173
Oct.	0.355 ± 0.148	0.437 ± 0.171	0.662 ± 0.158
	0.358 ± 0.173	0.529 ± 0.219	0.847 ± 0.224
Nov.	<0.165	<0.175	1.17 ± 0.192
	0.322 ± 0.121	0.488 ± 0.142	0.666 ± 0.123
Dec.	0.254 ± 0.115	0.315 ± 0.140	0.714 ± 0.137
	0.184 ± 0.156	0.296 ± 0.160	0.225 ± 0.156
	0.514 ± 0.105	0.481 ± 0.114	0.818 ± 0.120
Median	**0.322**	**0.437**	**0.714**
MAD[d]	**0.073**	**0.137**	**0.389**
Fraction of DCG[f]	$\mathbf{8.71 \times 10^{-6}}$	$\mathbf{1.18 \times 10^{-5}}$	$\mathbf{1.93 \times 10^{-5}}$
Dose (mSv)[g]	$\mathbf{6.9 \times 10^{-6}}$	$\mathbf{9.4 \times 10^{-6}}$	$\mathbf{1.5 \times 10^{-5}}$
		[μCi/mL]	
Median	$\mathbf{8.71 \times 10^{-13}}$	$\mathbf{1.18 \times 10^{-12}}$	$\mathbf{1.93 \times 10^{-12}}$
MAD[d]	$\mathbf{1.97 \times 10^{-13}}$	$\mathbf{3.70 \times 10^{-13}}$	$\mathbf{1.05 \times 10^{-12}}$
Dose (mrem)[g]	$\mathbf{6.9 \times 10^{-4}}$	$\mathbf{9.4 \times 10^{-4}}$	$\mathbf{1.5 \times 10^{-3}}$

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] See Fig. 4-2 for sampling locations.

[b] No data; see Quality Assurance chapter.

[c] Livermore Valley overall average = 4.8×10^{-8} Bq/mL.

[d] Median Absolute Deviation.

[e] No measure of dispersion calculated; see Quality Assurance chapter.

[f] Derived Concentration Guide (DCG) = 3.7×10^{-3} Bq/mL (1×10^{-7} μCi/mL).

[g] This is the effective dose equivalent.

Table 4-9. Beryllium on air filters (in pg/m^3), Livermore-site perimeter, 1993.

Month	Sampling location[a]					
	SALV	MESQ	CAFE	MET	VIS	COW
Jan.	<5.4	7.9	13.9	6.0	<4.1	8.7
Feb.	9.9	8.6	13.1	<4.9	<4.9	<4.9
Mar.	4.9	5.1	7.5	5.0	<2.7	5.0
Apr.	<3.5	6.0	7.3	5.0	<3.5	7.1
May	5.0	5.0	<4.5	<4.5	<3.5	9.0
June	9.2	7.0	<5.1	7.2	6.0	10.1
July	5.8	9.3	5.0	<1.9	6.3	8.7
Aug.	7.0	8.2	6.6	6.5	<3.1	9.1
Sept.	12.4	162	20.2	18.6	14.2	22.4
Oct.	13.0	19.1	22.1	14.0	14.3	29.8
Nov.	12.1	68.2[b]	137[b]	21.8	16.6	13.8
Dec.	<1.6	<2.7	<3.5	<1.7	<1.0	<1.5
Median[c]	**6.4**	**8.1**	**7.4**	**5.5**	**<4.5**	**8.9**
MAD[d]	**—[e]**	**2.5**	**—[e]**	**—[e]**	**—[e]**	**2.8**

Note: The monthly ambient concentration guide (ACG) set by the BAAQMD is 10,000 pg/m^3. To determine the fraction each value is of the monthly standard, divide the reported value for the month by 10,000; e.g., 35.0 ÷ 10,000 = 0.0035.

[a] See Fig. 4-1 for sampling locations.

[b] Only half of the composite was available for this sample.

[c] Livermore-site perimeter overall annual average is 11.2 pg/m^3.

[d] Median Absolute Deviation.

[e] No measure of dispersion calculated; see Quality Assurance chapter.

Table 4-10. Gross alpha and gross beta (Bq/mL) in air particulate samples summarized by week, Site 300, 1993.

Week	Detection frequency	Minimum[a]	Maximum[a]	Mean[a]	Std dev
Gross alpha					
1/4/93	0/8	$<2.62 \times 10^{-11}$	$<1.24 \times 10^{-10}$	$<6.93 \times 10^{-11}$	3.01×10^{-11}
1/11/93	0/9	$<2.32 \times 10^{-11}$	$<6.94 \times 10^{-11}$	$<3.68 \times 10^{-11}$	1.52×10^{-11}
1/19/93	0/9	$<2.96 \times 10^{-11}$	$<1.04 \times 10^{-10}$	$<5.56 \times 10^{-11}$	2.21×10^{-11}
1/25/93	0/8	$<1.11 \times 10^{-11}$	$<1.66 \times 10^{-10}$	$<6.17 \times 10^{-11}$	4.68×10^{-11}
2/1/93	0/9	$<4.79 \times 10^{-11}$	$<1.13 \times 10^{-10}$	$<7.96 \times 10^{-11}$	2.39×10^{-11}
2/8/93	5/9	7.57×10^{-11}	$<4.27 \times 10^{-10}$	$<2.21 \times 10^{-10}$	9.50×10^{-11}
2/16/93	0/8	$<4.06 \times 10^{-11}$	$<1.77 \times 10^{-10}$	$<1.07 \times 10^{-10}$	5.39×10^{-11}
2/22/93	0/8	$<2.25 \times 10^{-11}$	$<1.05 \times 10^{-10}$	$<5.25 \times 10^{-11}$	2.83×10^{-11}
3/1/93	0/9	$<1.78 \times 10^{-11}$	$<1.65 \times 10^{-10}$	$<9.30 \times 10^{-11}$	4.64×10^{-11}
3/8/93[b]	9/9	7.19×10^{-11}	1.84×10^{-10}	1.06×10^{-10}	4.29×10^{-11}
3/15/93	9/9	3.66×10^{-11}	1.88×10^{-10}	8.74×10^{-11}	4.64×10^{-11}
3/22/93	8/9	-5.96×10^{-11}	2.25×10^{-10}	7.53×10^{-11}	8.14×10^{-11}
3/29/93	3/9	-8.63×10^{-11}	7.51×10^{-11}	2.51×10^{-12}	5.26×10^{-11}
4/5/93	6/9	-2.47×10^{-11}	8.83×10^{-11}	2.82×10^{-11}	3.97×10^{-11}
4/13/93	2/9	-3.97×10^{-11}	2.49×10^{-11}	-1.19×10^{-11}	2.43×10^{-11}
4/19/93	4/8	-5.25×10^{-11}	4.15×10^{-11}	-4.81×10^{-12}	3.28×10^{-11}
4/26/93	6/9	-1.29×10^{-11}	3.51×10^{-11}	9.36×10^{-12}	1.77×10^{-11}
5/3/93	8/8	8.82×10^{-13}	1.32×10^{-10}	4.58×10^{-11}	4.53×10^{-11}
5/10/93	6/9	-1.94×10^{-11}	3.19×10^{-11}	7.35×10^{-12}	2.02×10^{-11}
5/17/93	4/9	-3.08×10^{-11}	7.08×10^{-11}	5.24×10^{-12}	3.31×10^{-11}
5/24/93	3/8	-3.33×10^{-11}	8.67×10^{-12}	-1.09×10^{-11}	1.68×10^{-11}
5/31/93	3/9	-3.15×10^{-11}	9.30×10^{-11}	3.03×10^{-12}	3.96×10^{-11}
6/7/93	6/9	-3.85×10^{-11}	1.00×10^{-10}	2.22×10^{-11}	4.84×10^{-11}
6/14/93	5/9	-5.48×10^{-11}	6.06×10^{-11}	4.52×10^{-12}	3.64×10^{-11}
6/21/93	5/9	-5.05×10^{-11}	1.63×10^{-10}	1.30×10^{-11}	6.10×10^{-11}
6/28/93	9/9	4.23×10^{-12}	1.80×10^{-10}	4.92×10^{-11}	6.54×10^{-11}
7/6/93	6/9	-1.82×10^{-11}	1.25×10^{-10}	3.71×10^{-11}	4.58×10^{-11}
7/12/93	7/9	-3.02×10^{-11}	1.72×10^{-10}	3.99×10^{-11}	6.60×10^{-11}
7/19/93	4/8	-3.62×10^{-11}	8.93×10^{-11}	1.90×10^{-11}	4.74×10^{-11}
7/26/93	7/9	-4.07×10^{-11}	1.44×10^{-10}	3.44×10^{-11}	5.43×10^{-11}
8/2/93	7/9	-1.86×10^{-11}	1.68×10^{-10}	3.10×10^{-11}	5.47×10^{-11}
8/9/93	9/9	7.54×10^{-12}	1.30×10^{-10}	3.80×10^{-11}	3.80×10^{-11}
8/16/93	7/9	-2.16×10^{-11}	1.26×10^{-10}	2.37×10^{-11}	4.45×10^{-11}
8/23/93	3/8	-4.18×10^{-11}	6.42×10^{-11}	-1.05×10^{-12}	3.33×10^{-11}
8/30/93	8/8	3.40×10^{-12}	1.18×10^{-10}	4.04×10^{-11}	4.08×10^{-11}

…continued

Table 4-10. Gross alpha and gross beta (Bq/mL) in air particulate samples summarized by week, Site 300, 1993 (*continued*).

Week	Detection frequency	Minimum[a]	Maximum[a]	Mean[a]	Std dev
9/7/93	4/9	-7.02×10^{-11}	2.15×10^{-10}	2.71×10^{-11}	8.73×10^{-11}
9/13/93	2/9	-5.02×10^{-11}	9.06×10^{-11}	-3.03×10^{-12}	4.69×10^{-11}
9/20/93	3/9	-7.06×10^{-11}	1.45×10^{-11}	-1.51×10^{-11}	2.70×10^{-11}
9/27/93	2/9	-1.41×10^{-10}	2.36×10^{-11}	-3.66×10^{-11}	5.29×10^{-11}
10/4/93	6/9	-6.53×10^{-11}	2.08×10^{-10}	5.44×10^{-11}	8.14×10^{-11}
10/11/93	5/9	-5.16×10^{-11}	1.63×10^{-10}	4.43×10^{-11}	8.16×10^{-11}
10/18/93	3/9	-8.11×10^{-11}	9.49×10^{-11}	-3.32×10^{-12}	5.07×10^{-11}
10/25/93	0/9	-1.21×10^{-10}	-2.09×10^{-11}	-6.10×10^{-11}	3.47×10^{-11}
11/1/93	1/9	-1.12×10^{-10}	2.79×10^{-11}	-4.61×10^{-11}	4.81×10^{-11}
11/8/93	7/7	2.95×10^{-11}	1.44×10^{-10}	7.14×10^{-11}	4.20×10^{-11}
11/15/93	4/7	-7.55×10^{-11}	7.93×10^{-11}	2.38×10^{-11}	5.90×10^{-11}
11/22/93	1/7	-1.39×10^{-10}	2.44×10^{-11}	-4.87×10^{-11}	5.52×10^{-11}
11/29/93	2/6	-1.00×10^{-10}	1.31×10^{-10}	-3.13×10^{-11}	9.03×10^{-11}
12/6/93	3/7	-4.08×10^{-11}	1.01×10^{-10}	1.36×10^{-11}	4.94×10^{-11}
12/13/93	3/9	-6.61×10^{-11}	4.03×10^{-11}	-1.12×10^{-11}	3.22×10^{-11}
12/20/93	2/4	-2.66×10^{-11}	8.67×10^{-11}	2.36×10^{-11}	4.91×10^{-11}
12/27/93	2/2	3.85×10^{-11}	2.25×10^{-10}	1.32×10^{-10}	1.32×10^{-10}
1/3/94	2/5	-6.17×10^{-11}	3.72×10^{-11}	-1.02×10^{-11}	4.16×10^{-11}
Gross beta					
1/4/93	2/8	$<1.88 \times 10^{-10}$	$<3.86 \times 10^{-10}$	$<2.68 \times 10^{-10}$	7.05×10^{-11}
1/11/93	6/9	$<2.86 \times 10^{-10}$	4.58×10^{-10}	3.51×10^{-10}	5.77×10^{-11}
1/19/93	7/9	$<8.97 \times 10^{-11}$	2.14×10^{-10}	1.37×10^{-10}	3.87×10^{-11}
1/25/93	2/8	$<1.36 \times 10^{-10}$	$<3.41 \times 10^{-10}$	$<2.24 \times 10^{-10}$	6.99×10^{-11}
2/1/93	8/9	$<3.38 \times 10^{-10}$	1.31×10^{-9}	6.31×10^{-10}	2.78×10^{-10}
2/8/93	9/9	9.11×10^{-10}	2.69×10^{-9}	1.52×10^{-9}	5.54×10^{-10}
2/16/93	2/8	$<1.44 \times 10^{-10}$	4.33×10^{-10}	2.54×10^{-10}	8.91×10^{-11}
2/22/93	2/8	1.56×10^{-10}	$<5.92 \times 10^{-10}$	$<2.78 \times 10^{-10}$	1.43×10^{-10}
3/1/93	7/9	2.43×10^{-10}	$<3.64 \times 10^{-10}$	$<2.80 \times 10^{-10}$	4.00×10^{-11}
3/8/93[b]	9/9	2.21×10^{-10}	5.90×10^{-10}	4.36×10^{-10}	1.08×10^{-10}
3/15/93	9/9	2.65×10^{-10}	4.76×10^{-10}	3.68×10^{-10}	7.63×10^{-11}
3/22/93	9/9	3.76×10^{-11}	4.13×10^{-10}	1.77×10^{-10}	1.01×10^{-10}
3/29/93	9/9	1.13×10^{-10}	3.00×10^{-10}	1.96×10^{-10}	5.53×10^{-11}
4/5/93	9/9	1.79×10^{-10}	4.06×10^{-10}	2.79×10^{-10}	7.76×10^{-11}
4/13/93	9/9	1.11×10^{-10}	3.55×10^{-10}	2.26×10^{-10}	7.78×10^{-11}
4/19/93	7/8	-8.35×10^{-12}	3.21×10^{-10}	1.44×10^{-10}	9.38×10^{-11}
4/26/93	9/9	4.57×10^{-11}	2.98×10^{-10}	1.53×10^{-10}	7.95×10^{-11}

...continued

Table 4-10. Gross alpha and gross beta (Bq/mL) in air particulate samples summarized by week, Site 300, 1993 (*concluded*).

Week	Detection frequency	Minimum[a]	Maximum[a]	Mean[a]	Std dev
5/3/93	8/8	2.86×10^{-10}	5.22×10^{-10}	3.93×10^{-10}	8.86×10^{-11}
5/10/93	9/9	4.79×10^{-11}	4.21×10^{-10}	2.55×10^{-10}	1.10×10^{-10}
5/17/93	9/9	1.60×10^{-10}	3.52×10^{-10}	2.63×10^{-10}	6.44×10^{-11}
5/24/93	7/8	-9.27×10^{-11}	2.27×10^{-10}	1.37×10^{-10}	1.08×10^{-10}
5/31/93	8/9	-3.80×10^{-11}	2.04×10^{-10}	1.37×10^{-10}	7.46×10^{-11}
6/7/93	9/9	6.18×10^{-11}	4.95×10^{-10}	2.55×10^{-10}	1.32×10^{-10}
6/14/93	9/9	2.43×10^{-10}	4.99×10^{-10}	3.48×10^{-10}	8.41×10^{-11}
6/21/93	9/9	3.02×10^{-10}	7.41×10^{-10}	5.25×10^{-10}	1.48×10^{-10}
6/28/93	9/9	1.23×10^{-10}	7.91×10^{-10}	4.27×10^{-10}	1.89×10^{-10}
7/6/93	9/9	1.04×10^{-10}	5.39×10^{-10}	3.24×10^{-10}	1.21×10^{-10}
7/12/93	9/9	3.00×10^{-10}	6.69×10^{-10}	4.67×10^{-10}	1.13×10^{-10}
7/19/93	8/8	1.72×10^{-10}	4.75×10^{-10}	2.92×10^{-10}	1.01×10^{-10}
7/26/93	9/9	3.01×10^{-11}	3.84×10^{-10}	1.36×10^{-10}	1.26×10^{-10}
8/2/93	9/9	3.57×10^{-10}	5.97×10^{-10}	4.82×10^{-10}	9.87×10^{-11}
8/9/93	9/9	4.40×10^{-10}	6.21×10^{-10}	5.19×10^{-10}	6.47×10^{-11}
8/16/93	9/9	7.01×10^{-11}	3.17×10^{-10}	1.93×10^{-10}	8.92×10^{-11}
8/23/93	8/8	8.82×10^{-11}	4.14×10^{-10}	2.80×10^{-10}	9.50×10^{-11}
8/30/93	8/8	3.88×10^{-10}	1.01×10^{-9}	6.86×10^{-10}	2.02×10^{-10}
9/7/93	9/9	3.13×10^{-10}	7.50×10^{-10}	4.88×10^{-10}	1.33×10^{-10}
9/13/93	9/9	5.57×10^{-10}	8.67×10^{-10}	6.85×10^{-10}	1.25×10^{-10}
9/20/93	9/9	1.79×10^{-10}	6.43×10^{-10}	4.40×10^{-10}	1.51×10^{-10}
9/27/93	9/9	9.50×10^{-10}	1.33×10^{-9}	1.17×10^{-9}	1.35×10^{-10}
10/4/93	9/9	7.98×10^{-10}	1.62×10^{-9}	1.23×10^{-9}	2.75×10^{-10}
10/11/93	9/9	3.53×10^{-10}	7.54×10^{-10}	4.73×10^{-10}	1.20×10^{-10}
10/18/93	9/9	1.94×10^{-10}	5.12×10^{-10}	3.64×10^{-10}	1.21×10^{-10}
10/25/93	9/9	7.44×10^{-10}	1.70×10^{-9}	1.15×10^{-9}	2.88×10^{-10}
11/1/93	9/9	4.11×10^{-10}	1.43×10^{-9}	1.21×10^{-9}	3.11×10^{-10}
11/8/93	6/7	-2.36×10^{-10}	1.73×10^{-9}	1.28×10^{-9}	6.88×10^{-10}
11/16/93	7/7	9.42×10^{-10}	1.35×10^{-9}	1.15×10^{-9}	1.71×10^{-10}
11/23/93	7/7	1.13×10^{-9}	2.12×10^{-9}	1.70×10^{-9}	3.58×10^{-10}
11/30/93	5/6	-1.46×10^{-10}	1.79×10^{-9}	1.23×10^{-9}	7.30×10^{-10}
12/6/93	7/7	2.72×10^{-10}	6.06×10^{-10}	3.71×10^{-10}	1.25×10^{-10}
12/13/93	9/9	1.20×10^{-10}	9.38×10^{-10}	3.73×10^{-10}	2.30×10^{-10}
12/20/93	4/4	2.83×10^{-10}	8.34×10^{-10}	5.73×10^{-10}	2.29×10^{-10}
12/27/93	2/2	2.34×10^{-9}	3.11×10^{-9}	2.72×10^{-9}	5.44×10^{-10}
1/3/94	5/5	5.63×10^{-10}	1.29×10^{-9}	8.69×10^{-10}	3.01×10^{-10}

[a] Negative values are not considered detections.

[b] A new analytical laboratory began the gross alpha and gross beta analysis in the second week of March.

Table 4-11. Gamma activity on air filters, Site 300, 1993.[a]

	[10^{-9} Bq/mL]	[10^{-12} Bq/mL]					
Month	**^{7}Be**	**^{40}K**	**^{137}Cs**	**^{22}Na**	**^{226}Ra**	**^{228}Ra**	**^{228}Th**
Jan.	2.7 ± 0.059	<4.1	<0.16	<0.17	<0.33	<0.72	<0.38
Feb.	4.1 ± 0.066	<4.3	<0.16	0.40 ± 0.31	<0.33	<0.67	<0.39
Mar.	3.4 ± 0.076	<5.0	<0.19	0.80 ± 0.52	<0.39	<0.84	<0.47
Apr.	4.5 ± 0.072	<3.3	0.30 ± 0.23	0.54 ± 0.32	<0.25	<0.52	<0.34
May	4.9 ± 0.079	<4.1	<0.15	0.65 ± 0.40	<0.32	<0.65	<0.40
June	5.8 ± 0.092	<4.1	<0.15	0.59 ± 0.39	<0.30	<2.0	<0.41
July	5.6 ± 0.12	<4.4	<0.17	0.68 ± 0.38	<0.33	<0.78	<0.46
Aug.	5.8 ± 0.092	<4.4	<0.16	0.63 ± 0.34	0.89 ± 0.51	2.2 ± 1.2	<0.44
Sept.	7.2 ± 0.11	15 ± 11	0.56 ± 0.36	0.59 ± 0.38	<0.32	2.0 ± 1.3	0.95 ± 0.71
Oct.	6.0 ± 0.095	<12	<0.13	0.39 ± 0.28	0.75 ± 0.69	1.6 ± 1.3	<0.48
Nov.	11 ± 0.21	<6.7	<0.25	0.92 ± 0.75	<1.3	<1.1	<0.74
Dec.	2.8 ± 0.050	<6.3	<0.22	<0.23	<0.46	0.97	<0.47
Median	**5.3[b]**	**<4.4**	**<0.16**	**0.59**	**<0.33**	**<0.92**	**<0.45**
MAD[c]	**2.2[d]**	**—[e]**	**—[e]**	**0.14**	**—[e]**	**—[e]**	**—[e]**
DCG[f] (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}**
Fraction of DCG	**3.5×10^{-6}**	**$<1.3 \times 10^{-7}$**	**$<1.1 \times 10^{-8}$**	**1.6×10^{-8}**	**$<8.9 \times 10^{-6}$**	**$<8.2 \times 10^{-6}$**	**$<3.0 \times 10^{-4}$**
	[µCi/mL]						
Median	**1.4×10^{-13}[b]**	**$<1.2 \times 10^{-16}$**	**$<4.4 \times 10^{-18}$**	**1.6×10^{-17}**	**$<8.9 \times 10^{-18}$**	**$<2.4 \times 10^{-17}$**	**$<1.2 \times 10^{-17}$**
MAD[c]	**5.9×10^{-14}[d]**	**—[e]**	**—[e]**	**3.8×10^{-18}**	**—[e]**	**—[e]**	**—[e]**
DCG[f]	**4×10^{-8}**	**9×10^{-10}**	**4×10^{-10}**	**1×10^{-9}**	**1×10^{-12}**	**3×10^{-12}**	**4×10^{-14}**

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] All Site 300 perimeter samples composited.

[b] Mean value reported to meet QA requirements; see Quality Assurance chapter.

[c] Median Absolute Deviation.

[d] Standard deviation reported to meet QA requirements; see Quality Assurance chapter.

[e] No measure of dispersion calculated; see Quality Assurance chapter.

[f] Derived Concentration Guide.

Table 4-12. Plutonium and uranium activity on air filters, Site 300, 1993.[a]

	[10^{--13} Bq/mL]	[10^{-5} μg/m^3]	[10^{-7} μg/m^3]	[10^{-3}]
Month	**^{239}Pu**	**^{238}U**	**^{235}U**	**^{235}U/^{238}U**
Jan.	0.0081 ± 0.0094	0.90	0.65	7.2
Feb.	0.027 ± 0.023	1.8	1.3	7.2
Mar.	0.0094 ± 0.026	2.6	1.9	7.2
Apr.	0.073 ± 0.028	16	4.1	2.7
May	–0.095 ± 0.16	3.6	2.7	7.4
June	0.052 ± 0.024	4.9	3.4	6.9
July	0.066 ± 0.025	6.4	4.1	6.4
Aug.	0.071 ± 0.054	9.3	5.7	6.1
Sept.	0.067 ± 0.030	12	6.7	5.8
Oct.	0.068 ± 0.027	14	3.4	2.4
Nov.	0.073 ± 0.067	13	7.6	5.8
Dec.	0.044 ± 0.031	2.1	1.5	7.0
Mean	**0.039**	**7.2**	**3.6**	
Std dev	**0.046**	**5.3**	**2.2**	
Fraction of DCG	**5.2×10^{-6}[b]**	**2.4×10^{-4}[c]**	**7.6×10^{-6}[d]**	
	[μCi/mL]			
Mean	**1.0×10^{-19}**			
Std dev	**1.3×10^{-19}**			

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] Composite of all Site 300 samples. See Fig. 4-3 for sample locations.

[b] Derived Concentration Guide (DCG) = 7.4×10^{-10} Bq/mL for ^{239}Pu activity in air (2×10^{-14} μCi/mL).

[c] Derived Concentration Guide = 0.3 μg/m^3 for ^{238}U activity in air.

[d] Derived Concentration Guide = 0.047 μg/m^3 for ^{235}U activity in air.

Table 4-13. Beryllium on air filters (in pg/m^3), Site 300, 1993.

	Sampling location[a]								
Month	**EOBS**	**ECP**	**WCP**	**LIN**	**GOLF**	**TFIR[b]**	**NPS**	**WOBS**	**801E**
Jan.	<4.0	<3.9	<4.0	<4.0	9.9	8.9	<5.1	<3.9	<4.0
Feb.	<5.0	9.8	9.8	<4.9	15.3	18.4	13.5	<4.9	17.1[c]
Mar.	5.0	5.0	<2.5	5.0	<2.5	5.0	<2.5	<2.5	<2.5
Apr.	<4.4	<4.4	<3.9	5.9	<3.9	6.0	<4.3	<2.9	<4.4
May	5.0	6.6	7.6	12.2	7.1	13.5	7.4	6.0	13.1
June	11.0	10.1	8.1	8.4	10.0	14.1	9.1	6.2	11.6
July	6.9	8.8	10.2	<2.1	<0.6	<4.4	<2.5	<1.9	5.7
Aug.	15.7	<4.5	6.0	9.7	5.1	8.8	8.6	6.0	8.7
Sept.	13.6	14.3	18.3	17.7	20.2	27.1	15.7	13.6	20.0
Oct.	11.0	14.1	22.4	18.1	14.0	25.2	16.0	10.8	15.1
Nov.	62.2[c]	6.9	11.8	9.2	12.9	31.8	98.1[c]	9.9	53.4
Dec.	103[c]	109[c]	10.0	31.6	6.8	8.8	15.1[c]	<8.0[c]	<1.3
Median[d]	**8.9**	**7.9**	**8.9**	**8.8**	**8.5**	**11.2**	**8.9**	**6.0**	**10.2**
MAD[e]	**—[f]**	**—[f]**	**2.9**	**—[f]**	**—[f]**	**5.7**	**—[f]**	**—[f]**	**—[f]**

Note: The monthly ambient concentration guide (ACG) set by the BAAQMD is 10,000 pg/m^3. To determine the fraction each value is of the monthly standard, divide the reported value for the month by 10,000; e.g., 14.1 ÷ 10,000 = 0.00141.

[a] See Fig. 4-3 for sampling locations.

[b] Location TFIR is in the city of Tracy.

[c] Only one-fourth to one-half of the filters were available to composite.

[d] Site 300 overall annual average is 13.0 pg/m^3.

[e] Median Absolute Deviation.

[f] No measure of dispersion calculated; see Quality Assurance chapter.

Table 4-14. Radioactive airborne effluent releases from the Livermore site, 1981 through 1993.

	Airborne effluents			
Year	^{3}H (GBq)[a]	^{3}H (Ci)	^{13}N and ^{15}O (GBq)	^{13}N and ^{15}O (Ci)
1981	96,900	2,619	12,700	344
1982	74,520	2,014	21,600	584
1983	120,100	3,245	31,600	855
1984	272,100	7,354	3,000	81
1985	81,550	2,204	19,200	520
1986	46,400	1,254	4,180	113
1987	101,800	2,751	2,300	62
1988	147,400	3,983	1,100	30
1989	109,200	2,952	1,600	42
1990	47,430	1,282	1,800	48
1991	41,140	1,112	440	12
1992	6,550	177	0	0
1993	8,770	237	259	7

[a] Tritium values are from Building 331 only; an additional 220 GBq were released during 1993 from other operations and diffuse sources.

Table 4-15. Nonradioactive air emissions, Livermore site and Site 300, 1993.

	Estimated releases [metric tons/day]	
Pollutant	Livermore site	Site 300
Carbon monoxide	0.01095	0.00225
Chlorofluorocarbons	0.02710	0.00076
Organic compounds	0.03042	0.00400
Oxides of nitrogen	0.06446	0.00470
Oxides of sulfur	0.000879	0.00023
Particulates	0.01008	0.00042

5. Sewage Monitoring

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Introduction

The Livermore site discharges approximately 1.1 million liters per day of wastewater to the City of Livermore sewer system, an amount that constitutes less than 7% of the total flow to the system. This volume includes wastewater generated by Sandia National Laboratories, California (SNL/CA), 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. 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. During the summer months, June through August, deliveries are taken primarily 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. For the remainder of the year, LLNL's water usually is supplied from the Hetch-Hetchy Aqueduct. Water quality parameters for these 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. Environmental Protection Department 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 both at the point of generation and point of discharge to the municipal sewer system.

5. Sewage Monitoring

To ensure the integrity of the wastewater collection system, LLNL recently has pursued an aggressive assessment and rehabilitation program. During 1992 and 1993, all building drains that could be identified were tested to determine their points of discharge. Identified deficiencies were classified and are being corrected; major deficiencies were immediately remedied. The retention tank infrastructure at LLNL is undergoing comprehensive evaluation and rehabilitation. Finally, preparatory to relining with a synthetic sock, the major laterals of the sanitary sewer system itself have been videotaped and evaluated. Major line failures have been repaired. The relining work commenced in 1993.

For facilities with installed retention tank systems, collected wastewater is discharged to the sanitary sewer only if 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 DOE Order 5400.5 and LWRP discharge limits.

LLNL's sanitary sewer discharge permit requires continuous monitoring of the effluent flow rate and pH. A flow-proportional composite sampler collects samples that are analyzed for metals, radioactivity, toxic chemicals, and water quality parameters. In addition, the outflow to the municipal collection system is sampled continuously and analyzed for conditions that may 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. Ifconcentrations 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 aredetected. Trained staff respond to all alarms to evaluate the cause.

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 isretained at LLNL, thereby protecting the LWRP and minimizing any requiredcleanup. Up to 775,000 liters 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, and its contamination level may first be adjusted, depending on analytical results), shipped for off-site disposal, or treated at LLNL's Hazardous Waste Management Facility.

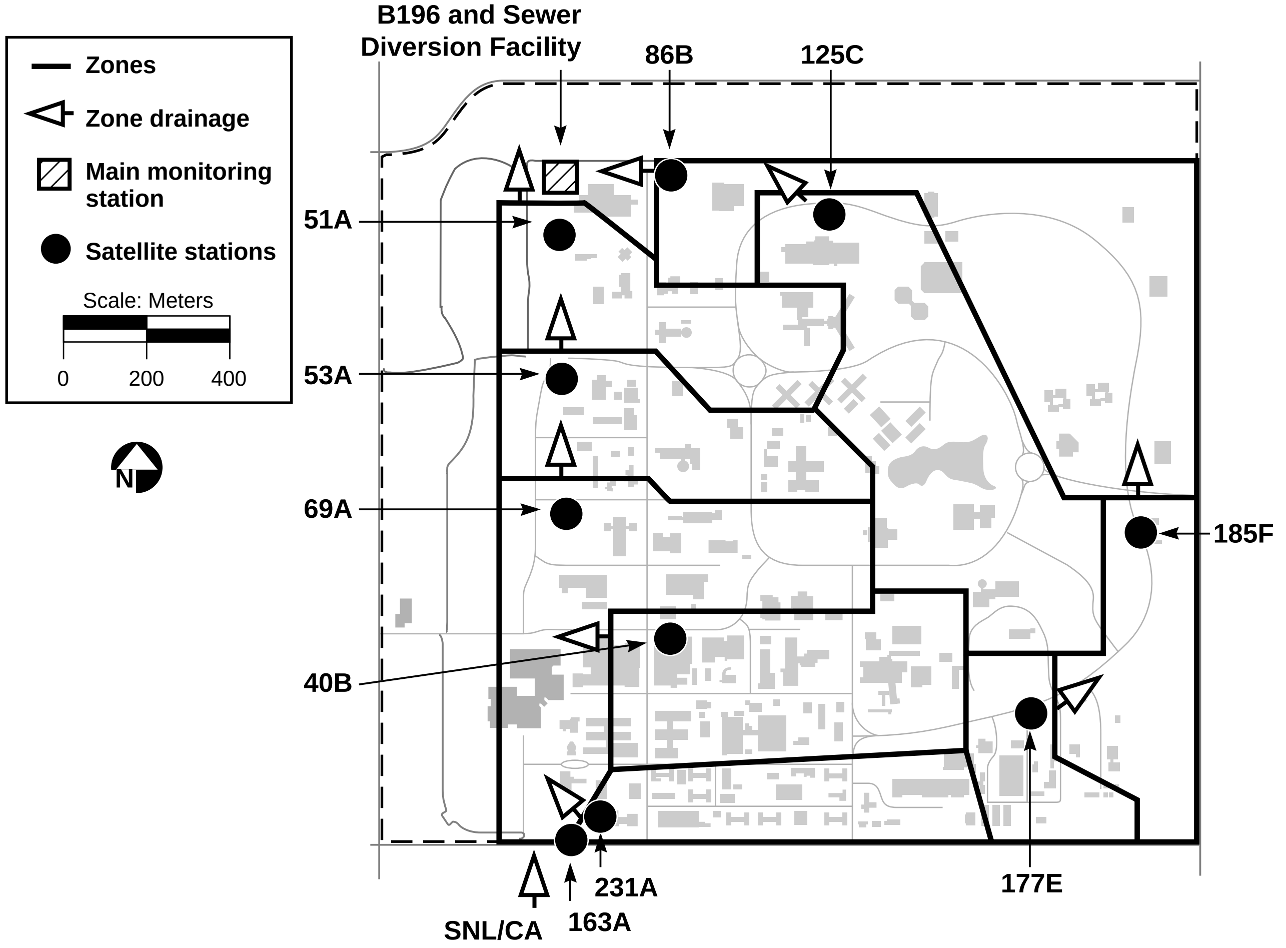

Figure 5-1. Sewer monitoring network, 1993.

LLNL has also implemented a system of satellite monitoring stations that operates in conjunction with the sewer monitoring system (**Figure 5-1**). The satellite monitoring stations are positioned at strategic locations within the main sewer system to help pinpoint the area on site from which a release might have originated. Each station consists of an automatic sampler that collects samples on a time-proportional basis. In the event of a release, these samples are analyzed. On the basis of the continuous monitoring data, during 1993 there were no releases of corrosive, metallic, or radioactive contaminants that warranted a sewer diversion. This contrasts markedly with the results for 1991 and 1992, when 15 and 13 such releases (respectively) were detected.

Methods

A 24-hour composite of Livermore-site sewage effluent is collected daily by a peristaltic pump that functions for 4 seconds for every 3875 liters of effluent. Aliquots of this composite are transferred to polyethylene bottles and submitted for analysis. Treated effluent from LWRP is collected daily by LWRP employees. Aliquots are placed in 500-milliliter polyethylene bottles, which are retained for weekly collection by LLNL. Composite samples from the LWRP digesters are collected monthly. The composites consist of aliquots taken from the circulating sludge three times a week.

Standard quality control and quality assurance procedures are followed. When each sewage field sample is collected, it is labeled with the sampling location and date of sampling. In the laboratory, each sample is assigned a number that accompanies that sample during analysis.

The daily composite samples are analyzed for gross alpha, gross beta, and tritium activity. A monthly composite of the Livermore-site and LWRP effluents is analyzed for ^{137}Cs and ^{239}Pu using ion-exchange and gamma or alpha spectroscopy (respectively). Weekly composites of LLNL effluent are analyzed for metals. In addition, composite samples from the LWRP digesters are analyzed monthly for gross radioactivity and metals; composites of the monthly samples are analyzed quarterly for plutonium and cesium content and for gamma-emitting radionuclides.

Water quality parameters and organic compounds are also monitored. Once each month, a 24-hour composite sample and an instantaneous grab sample of the LLNL sewage effluent are subjected to an extensive set of analyses. These analyses include parameters specified on LWRP’s National Pollutant Discharge Elimination System permit, including metals, nutrients, pesticides, and priority pollutants. The federal priority pollutants are measured using EPA Methods 624 and 625 to establish baseline information for these parameters. As part of this monthly sampling program, four oil and grease grab samples are acquired at 4-hour intervals during the day. The analytical results are averaged to obtain a representative measure of the daily oil and grease concentration.

Quarterly samples were collected at the point of discharge of specified metal finishing and electrical (and electronic) component processes to assure compliance with EPA discharge limits for those processes. LLNL reports the results of these analyses semi-annually to the LWRP, the agency delegated by EPA to implement those regulations. The results are reviewed in Chapter 13 on Compliance Self-Monitoring.

Two changes in the sampling program were made in 1993. In July, LLNL changed its primary contractor for environmental analytical services. In the months immediately following the change-over, certain specialized services that had been established with the previous analytical laboratory were not available. Additionally, minor variations in the analysis and reporting of analytical results, and specifically the limit of sensitivity for some analyses, were significantly higher. Secondly, as of December, analysis of the LWRP effluent for gross alpha and gross beta radioactivity and tritium is performed on weekly composites of the daily samples, instead of individual samples. This change was implemented as an efficiency measure following a determination that the weekly analysis would adequately support analysis of contaminant transport through the LWRP treatment process.

Results

Radioactivity in Sewage

Determination of the total radioactivity released as 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 5-1**). The combined releases of tritium, alpha, and beta radiation is 10.1 gigabequerels (GBq = 10^9Bq), or 0.27curie (Ci). The total is based on the results shown in **Table 5-1**, reduced by reported SNL/CA tritium releases of 2.5 GBq (0.07 Ci). The annual average concentration of tritium in LLNL sanitary sewer effluent was 0.024 Bq/mL (0.65pCi/mL). **Figure 5-2** shows the historical trend in the monthly average concentration of tritium. **Figure 5-3** shows the average monthly plutonium and cesium concentrations in sewage since 1973. The annual average concentration of ^{137}Cs was 2.7 µBq/mL (7.3×10^{-5} pCi/mL); the annual average ^{239}Pu concentration was 0.55 µBq/mL (1.5×10^{-5} pCi/mL).

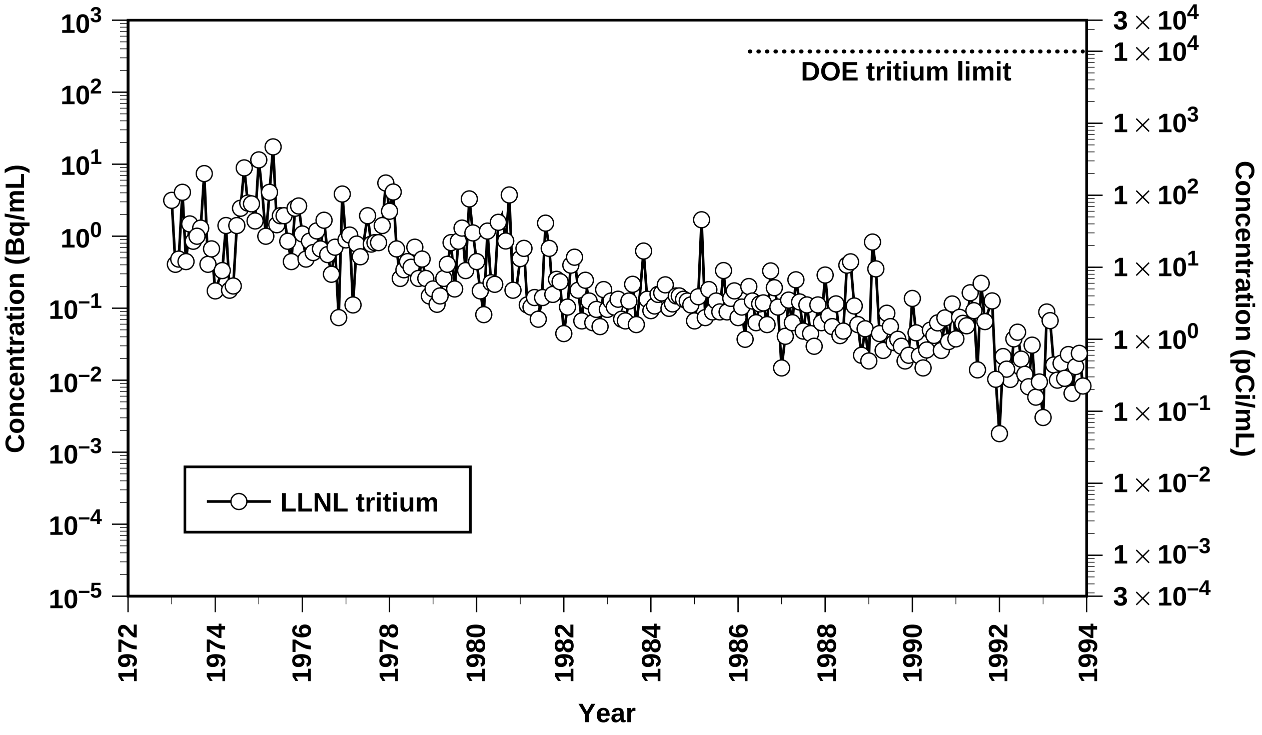

Figure 5-2. LLNL monthly average tritium concentration in sewage.

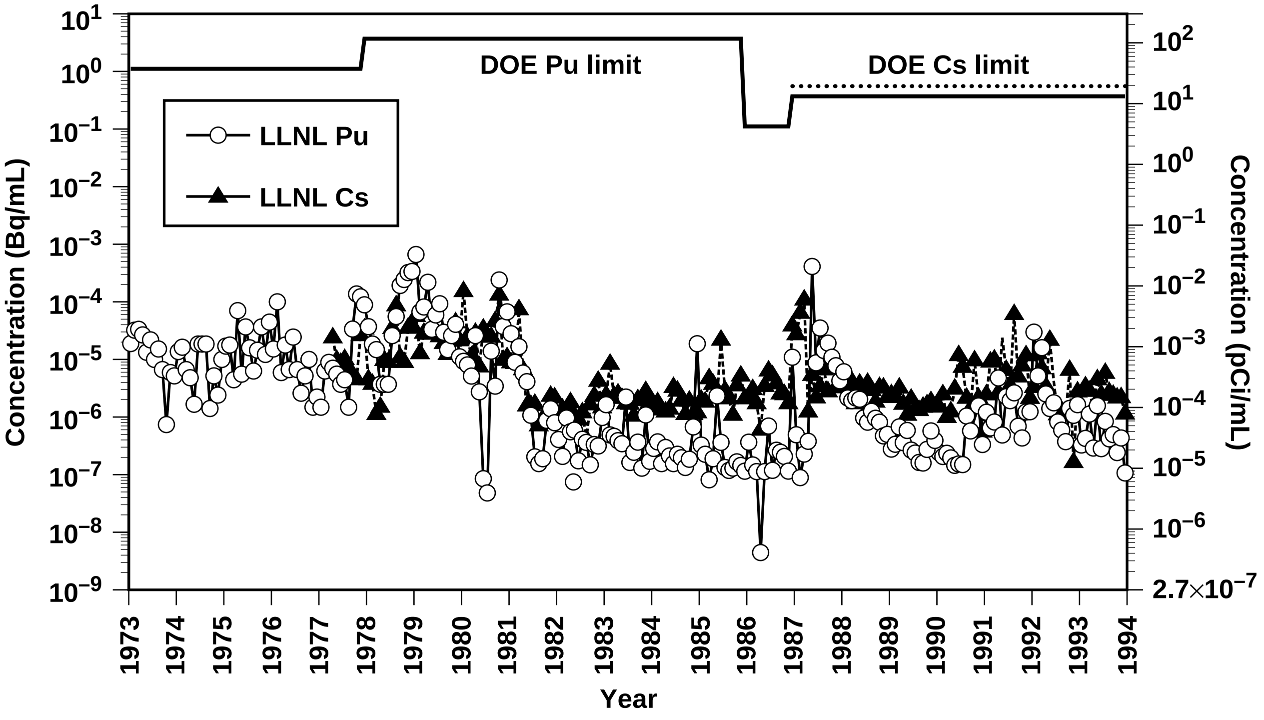

Figure 5-3. LLNL monthly average plutonium and cesium concentrations in sewage.

The concentrations of ^{239}Pu, ^{137}Cs, and tritium measured in the sanitary sewer effluent from LLNL and LWRP are presented in **Table 5-2**. 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 laboratory that provides tritium analysis reported that, for sewage samples received between June and November 1993, the results may be slightly low due to the use of an unstable scintillation cocktail. This was discovered when the results for November from the EPA Environmental Monitoring Systems Laboratory Intercomparison Studies program showed a 28% discrepancy from the actual value. Assuming that the cocktail changed immediately following the June test, the annual totals reported here would require a 7% upward adjustment. The actual adjustment is far lower because the change in yield would have occurred over an extended period. At any rate, the expected correction was lower than the sensitivity of the analysis, so no adjustment to the data was made.

Nonradioactive Pollutants in Sewage

As discussed in the Methods section above, LLNL changed its primary nonradiological analytical laboratory during 1993. The transition between laboratories resulted in some fluctuation in the analytical limits of detection and minor inconsistencies in the reported suite of analytes. Effects of the transition are visible in **Table 5-3**, where the detection limit for nickel varies between 0.005 and 0.1mg/L, and in **Table 5-4**, where the statistics for detection frequency for several of the analytes shows that they were reported for only five or six months during theyear.

Table 5-3 presents monthly average metal concentrations in LLNL‘s sanitary sewer effluent. The averages were obtained by a time-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 number of days in the month that fell during the period that the sample was collected. The results are quite typical of the values seen during previous years, with the exception of arsenic, which was present in slightly higher concentrations.

Results of monthly monitoring for metals and other physical and chemical characteristics of the sanitary sewer effluent are provided in **Table 5-4**. We note that, although the samples were analyzed for cyanide and the full suite of organochlorine pesticides, those analytes were not detected in any sample acquired during 1993, and so are not presented in the table. The results are again quite typical of those seen in previous years.

Environmental Impact

Radioactivity in Sewage

During 1993, there were no inadvertent releases that exceeded any discharge limits for release of radioactive materials to the sanitary sewer system.

DOE requires that radiological releases to the sanitary sewer comply with local and state regulations. The most stringent of these limits is applied by Title17of the California Code of Regulations. As a federal facility, LLNL is formally exempt from the requirements of Title17, but follows those requirements under the guidance of DOE. Title17 contains a limit on discharges of radioactivity in sewage of 37GBq (1 Ci) each year; it also lists limits on the daily, monthly, and annual concentration for each specific radionuclide. **Table 5-5** summarizes the discharge requirements of Title17, including the total activity that could be discharged by LLNL during a given period (daily, monthly, and annually), assuming typical flow rates. As is obvious from the table, for facilities such as LLNL that generate wastewater in large volumes, the Title17 concentration limits are essentially overridden by the limit on total activity discharge during a single year. In 1993, the total LLNL releases (**Table 5- 1**), in the form of alpha and beta emitters (including tritium), were 27% of the Title17 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 Guidelines,” or DCGs) limit the concentration of each specific radionuclide that is discharged to publicly-owned treatment works (the DOE limits are more stringent than the specific radioisotopic limits of Title 17). 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. **Table5-5** presents the DCGs for the specific radioisotopes of most interest at LLNL.

The annual average concentration of tritium in LLNL sanitary sewer effluent was 0.000065 (that is, 0.0065%) of the DOE DCG, the annual average concentration of ^{137}Cs was 0.0000047 oftheDOE DCG, and the annual average ^{239}Pu concentration was 0.0000015 of the DOE DCG. The combined discharges were therefore 0.000071 of the DCG. In calculating the contribution from plutonium, we assume that the plutonium in LLNL effluent is in the insoluble form (the DCG for soluble forms of plutonium is seventy times less than the DCG for insoluble plutonium). This assumption is supported by the experience during the recent sewer system evaluation, when increased cleaning led to higher plutonium concentrations in LLNL sewage (*Environmental Report for 1992*, Gallegos et al. 1993). This indicates that the bulk of plutonium discharged is liberated from deposits on the sewer pipes. These deposits are, by their nature, insoluble.

LLNL also compares annual discharges against historical values to evaluate the effectiveness of ongoing discharge control programs. **Table 5-6** summarizes the radioactivity in liquid effluent released over the past ten years. During 1993, a total of 12.6 GBq (0.34 Ci) of tritium was discharged to the sanitary sewer. This is the combined release from the Livermore site and from SNL/CA, whose records account for 2.5 GBq (0.07 Ci) of this amount; LLNL therefore released 10.1GBq (0.27 Ci), an amount that is well within environmental protection standards and is generally less than the range reported in the past. We note that DOE did not require compliance with the 37 GBq limit of Title17 until 1990.

Figure 5-3 summarizes the ^{239}Pu monitoring data since 1973. The historical levels observed since 1981 are approximately 0.37 Bq/mL (1×10^{-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 one-millionth (0.000001) 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. Theplutonium concentration observed in 1993 sludge (**Table 5-2**), 2.1mBq/dry g (0.06pCi/dryg), is more than two hundred times lower than the proposed EPA guideline for unrestricted use of soil (480mBq/dry g).

As first discussed in the *Environmental Report for 1991* (Gallegos et al. 1992a), concentrations of plutonium and cesium 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. Cleaning activity around the site was less extensive during 1993 as utilities personnel worked to complete their assessment of the condition of the sewer system. This has been reflected in slightly lower plutonium and cesium concentrations in LLNL effluent during 1993.

Nonradioactive Liquid Effluents

Table 5-3 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, mercury, and lead at 12%, 10%, and 10%, respectively, of the discharge concentrations.

Although arsenic concentrations were well below discharge limits, the slightly elevated levels first seen during the summer of 1992 were the subject of an extended investigation during 1993. Daily composite samples from satellite stations and portable samplers finally localized the source along the southern border of the laboratory. The only known source of arsenic in that region, from a gas pad cleanup operation, was stable and well monitored, and seemed to account for the majority of the observed arsenic. The concentration was therefore unlikely to increase to levels that would result in a violation of the permit limit, and the investigation was terminated.

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 the City’s treatment plant. The results demonstrate across-the-board compliance with the effluent pollutant limitations of LLNL’s sewer permit, and are generally consistent (with the exception of arsenic, discussed above) with values seen in the past. Oil and grease concentrations are substantially reduced from levels in 1992, when LLNL received a Notice of Violation for grease discharges. The continuous monitoring system did not detect any inadvertent discharges during 1993, as compared to 13 such discharges in 1992.

Table 5-1. Estimated total radioactivity in sanitary sewer effluent, LLNL, 1993.

Radioactive emitter	Estimate based on effluent concentration [GBq][a]	Limit of sensitivity [GBq][a]
Tritium	12.6[b]	0.8
Alpha radiation	0.040	0.004
Beta radiation	0.30	0.003

[a] GBq = 10^9 Bq, or 0.027 Ci.

[b] 12.6 GBq includes 10.1 GBq from LLNL plus 2.5 GBq from SNL/CA.

Table 5-2. Various radionuclides in sanitary sewer effluents, LLNL and LWRP, 1993.

	^{3}H (mBq/mL)		^{137}Cs (µBq/mL)		^{239}Pu (nBq/mL)		^{239}Pu (mBq/gm)
Month	**LLNL**	**LWRP**	**LLNL**	**LWRP**	**LLNL**	**LWRP**	**LWRP sludge**[a]
Jan.	3 ± 1	1.1 ± 0.9	1.3 ± 0.4	<0.5	330 ± 50	40 ± 20	
Feb.	89 ± 5	5.3 ± 1.5	3.4 ± 0.6	<0.6	430 ± 70	26 ± 16	
Mar.	67 ± 5	6.2 ± 1.5	2.8 ± 0.5	<0.7	1130 ± 70	<15	2.7 ± 0.3
Apr.	16 ± 2	2.8 ± 1.2	1.4 ± 0.3	<0.3	290 ± 40	1 ± 6	
May	10 ± 2	3.8 ± 1.3	4.4 ± 0.6	0.6 ± 0.3	1580 ± 150	2 ± 16	
June	17 ± 2	1.8 ± 1.0	2.4 ± 0.4	<0.5	280 ± 40	-6 ± 10	1.7 ± 0.1
July	11 ± 2	1.4 ± 0.9	5.7 ± 0.6	0.4 ± 0.2	840 ± 100	2 ± 9	
Aug.	23 ± 3	0.5 ± 0.8	2.7 ± 0.5	<0.3	420 ± 60	5 ± 14	
Sept.	7 ± 2	1.2 ± 1.0	2.4 ± 0.5	<0.7	500 ± 50	13 ± 10	1.4 ± 0.1
Oct.	16 ± 2	2.5 ± 1.1	2.1 ± 0.6	<0.8	240 ± 50	3 ± 10	
Nov.	24 ± 3	1.3 ± 1.0	2.2 ± 0.4	<0.5	430 ± 70	6 ± 8	
Dec.	8 ± 2	-0.6 ± 0.6	1.1 ± 0.3	0.5 ± 0.4	110 ± 30	-3 ± 10	2.7 ± 0.2
Mean	**24**	**2.3**	**2.7**	**<0.5**[b]	**550**	**7**	**2.1**
Std dev	**53**	**4.0**	**2.7**		**85**	**25**	**1.3**
	pCi/mL						**pCi/dry g**
Mean	**0.65**	**0.06**	**72×10^{-6}**	**$<14 \times 10^{-6}$**	**15×10^{-6}**	**0.19×10^{-6}**	**0.06**
Std dev	**1.42**	**0.11**	**72×10^{-6}**		**23×10^{-6}**	**0.66×10^{-6}**	**0.03**

	Annual total discharges by radioisotope			
	^{3}H	**^{137}Cs**	**^{239}Pu**	**Total**
Bq/y	10×10^{9}[c]	1.3×10^{6}	2.6×10^{5}	10×10^{9}[c]
Ci/y	0.27	3.6×10^{-5}	7.1×10^{-6}	0.27
Fraction of limit				
DOE	6.5×10^{-5}	4.7×10^{-6}	1.5×10^{-6}	7.1×10^{-5}
Title 17	0.27	3.6×10^{-5}	7.1×10^{-6}	**0.27**

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] Sludge from LWRP digesters is dried prior to analysis. The resulting data indicate the plutonium concentration of the sludge prepared by LWRP workers for disposal at the Livermore Sanitary Landfill.

[b] Due to the large number of nondetects, the median rather than the mean is presented, and the standard deviation from the mean is omitted; see Quality Assurance chapter.

[c] Not including SNL/CA discharges of 2.5×10^{9} Bq (0.068 Ci).

Table 5-3. Metals discharged to sanitary sewer system (in mg/L), 1993 summary.

Month	Ag	Al	As	Be	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Zn
Jan.	0.015	<0.3	0.0034	<0.0002	0.0014	0.025	0.06	0.87	0.0012	0.006	0.010	0.14
Feb.	0.018	0.53	0.0037	<0.0002	0.0015	0.033	0.11	1.53	0.0007	0.008	0.014	0.20
Mar.	0.022	0.47	0.0031	<0.0002	0.0010	0.035	0.12	1.26	0.0007	0.009	0.021	0.24
Apr.	0.028	<0.3	0.0036	<0.0002	0.0018	0.055	0.12	1.41	0.0011	0.009	0.027	0.25
May	0.028	0.52	0.0029	<0.0002	0.0009	0.072	0.10	1.54	0.0005	0.006	0.022	0.19
June	<0.050	0.41	<0.005	<0.0002	<0.0070	<0.05	0.14	1.09	0.0006	<0.05	0.013	0.18
July	0.023	0.52	<0.005	<0.005	<0.01	<0.05	0.16	1.06	0.0010	<0.1	0.048	0.21
Aug.	0.018	0.71	<0.002	<0.0005	<0.0011	0.043	0.16	1.67	0.0011	<0.1	0.030	0.27
Sep.	0.014	0.35	0.0043	<0.0005	<0.0016	0.027	0.12	1.09	0.0003	0.006	0.016	0.16
Oct.	0.017	0.30	0.0055	<0.0005	<0.01	0.027	0.13	1.08	0.0011	0.006	0.019	0.24
Nov.	0.011	0.31	<0.002	<0.0005	<0.01	0.016	0.08	0.84	0.0027	<0.005	0.011	0.19
Dec.	0.012	0.30	0.0035	<0.0005	0.0008	0.014	0.07	0.81	0.0005	<0.005	0.007	0.22
Mean	**0.015[a]**	**0.43**	**0.0036[a]**	**<0.0005**	**0.0014[a]**	**0.036**	**0.12**	**1.2**	**0.0010**	**0.006**	**0.020**	**0.21**
Std dev	**0.005[a]**	**0.19**	**0.0014[a]**	**—[b]**	**0.0008[a]**	**0.027**	**0.05**	**0.5**	**0.0011**	**—[b]**	**0.016**	**0.08**
DCL[c]	**0.2**	**—[d]**	**0.06**	**—[d]**	**0.14**	**0.62**	**1.0**	**—[d]**	**0.01**	**0.61**	**0.2**	**3.0**
Fraction of DCL	**0.075**	**—[d]**	**0.06**	**—[d]**	**0.01**	**0.06**	**0.12**	**—[d]**	**0.10**	**0.01**	**0.10**	**0.07**

[a] Rather than the mean and the standard deviation from the mean, the numbers presented are the median and median absolute deviation of the weekly values; see Quality Assurance chapter.

[b] The number presented as a mean is the median of the annual values. Due to the large number of nondetects, the standard deviation could not be calculated for these analytes; see Quality Assurance chapter.

[c] Discharge Concentration Limit (City of Livermore Ordinance 13.32).

[d] No established limit for analyte.

Table 5-4. Positively detected parameters in LLNL sanitary sewer effluent, 1993**.**

Positively detected parameter	Detection[a] frequency	Minimum	Maximum	Mean[b]	Std dev[b]
Physical and chemical (mg/L)					
Biochemical oxygen demand	10/10	32	180	101	98
Chemical oxygen demand	12/12	140	330	216	142
Settlable solids (mL/L)	6/6	0.1	6.5	2.4	6.1
Total dissolved solids	12/12	180	600	328	222
Total solids	5/5	240	540	404	239
Total suspended solids	12/12	22	120	63	59
Volatile solids	7/7	54	310	165	166
Ammonia nitrogen (as N)	12/12	21	38	31	12
Chloride	12/12	3.3	150	61	81
Fluoride	2/2	0.16	0.36		
Nitrate plus nitrite (as N)	1/6	<0.1	0.22	<0.1	
Nitrate plus nitrite (as NO_3)	1/6	<0.4	0.88	<0.4	
Nitrite nitrogen (as N)	3/9	<0.01	0.1	0.052	
Nitrite nitrogen (as NO_2)	3/9	<0.03	5	0.18	
Sulfate	12/12	13	100	49	58
Bicarbonate alkalinity (as $CaCO_3$)	12/12	160	280	202	88
Total Kjeldahl nitrogen (as N)	12/12	21	50	36	17
Total phosphorus (as P)	11/11	1.1	10	4.7	4.7
Total phosphorus (as PO_4)	6/6	3.5	20	13	11
Aluminum	8/12	<0.2	0.62	0.32	0.30
Arsenic	8/12	<0.002	0.0051	0.0035	0.0025
Boron	4/6	<0.2	0.63	0.35	0.36
Cadmium	6/12	<0.0005	0.0018	0.0007	
Calcium	12/12	8.7	38	19	18
Chromium	10/12	0.0087	0.062	0.026	0.037
Copper	10/12	<0.05	0.11	0.07	0.04
Iron	12/12	0.35	1.4	0.68	0.64
Lead	11/12	<0.002	0.02	0.009	0.009
Magnesium	12/12	1.9	17	6.4	8.8
Mercury	7/12	<0.0002	0.0047	0.0008	0.0024
Nickel	4/12	<0.005	<0.1	<0.005	
Potassium	11/11	12	23	16	6
Selenium	2/12	<0.002	0.0043	<0.002	
Silver	8/12	<0.0005	0.055	0.015	
Sodium	12/12	26	120	55	53
Zinc	11/12	<0.05	0.43	0.17	0.20
Organic compounds (mg/L)					
Oil and grease	12/12	6.5	27	18.5	6.2
Phenolics	9/11	<0.005	0.24	0.09	0.14
Total organic carbon	12/12	28	58	42	21

...continued

Table 5-4. Positively detected parameters in LLNL sanitary sewer effluent, 1993 *(concluded)*.

Positively detected parameter	Detection[a] frequency	Minimum	Maximum	Mean[b]	Std dev[b]
Organochloride pesticides (EPA Method 608, μg/L)[c]					
(None detected)					
Purgeable-extractable pollutants (EPA Methods 624/625, μg/L)					
2,4-Dimethylphenol	2/12	<4	24	<10	
2-Methylphenol	1/12	<3	23	<10	
4-Methylphenol	6/7	<4	53	26	39
Acetone	5/12	<5	720	<10	
Benzene	4/12	<0.5	5.7	<1	
Benzoic acid	4/12	<10	140	<50	
Benzyl alchohol	6/12	<10	2500	21	
Bis(2-ethylhexyl)phthalate	3/12	<10	17	<10	
Bromodichloromethane	3/12	<0.5	3	<0.1	
Butoxy ethanol phosphate	2/12	—	400[c]	—	
Butylbenzylphthalate	2/12	<3	41	<10	
Chloroform	12/12	1	33	17	19
Cholestanol	5/12	—	600[c]	—	
Cholesten-3-ol	5/12	—	600[c]	—	
cis-1,2-Dichloroethane	1/6	<0.5	0.8	<0.5	
Dibromochloromethane	2/12	<0.5	2	<0.1	
Dibromomethane	1/6	<1	2	<1	
Dibutylphthalate	1/6	<5	15	<5	
Diethylphthalate	1/12	<3	15	<10	
Ethanol	2/2	6	20	13	20
Ethylbenzene	2/12	<0.5	3.9	<1	
Freon-113	1/12	<1	1	<1	
Methyl ethyl ketone	2/6	<5	20	<5	
Methylene chloride	7/12	0.6	2.3	1	1
m- and p-Cresol	2/5	<10	33	22	
Napthalene	1/12	<3	3	<10	
Phenol	2/12	<5	27	<10	
Tetrachloroethene	1/12	<0.5	10	<1	
Toluene	6/12	<0.5	15	<1	
Total xylene isomers	3/12	<0.5	31	<2	
Trichloroethene	1/12	<0.5	4.7	<0.5	

[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] Standard deviation is 2σ. Where the detection frequency is less than 50%, the median is presented and the standard deviation from the mean is omitted.

[c] Semiquantified result. The analytical laboratory does not usually report a result for this compound, and no detection limit has been established.

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

		^3H	^{137}Cs	^{239}Pu
CA Title 17 concentrations used to establish release limits		3.7×10^3 Bq/mL	15 Bq/mL	30 Bq/mL
CA Title 17	**Daily**	37 GBq[a]	20 GBq[a]	37 GBq[a]
	Monthly	37 GBq[b]	37 GBq[b]	37 GBq[b]
	Yearly	37 GBq[a]	37 GBq[a]	37 GBq[a]
DOE annualized discharge limit for application of BAT[c]		370 Bq/mL	0.55 Bq/mL	0.37 Bq/mL

[a] CA Title 17 regulations impose a 37-GBq (1-Ci) combined limit on the total of all radiation released, 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.

[b] Limits similar to those applied to daily releases except total releases for the month must not exceed these quantities.

[c] The DOE annualized discharge limit for application of Best Available Technology is five times the DCG (ingested water) for each radionuclide released.

Table 5-6. Radioactive liquid effluent releases from the Livermore site, 1984–1993.

	Liquid effluents (GBq)	
Year	**^3H (LLNL and SNL/CA)**	**^{239}Pu**
1984	63	1.2×10^{-4}
1985	133	1.8×10^{-4}
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}

[a] Year that DOE first required compliance with the 37-GBq (1-Ci) limit of California Title 17.

6. Surface Water Monitoring

William G. Hoppes

Introduction

Lawrence Livermore National Laboratory performs surface water monitoring at the Livermore site, in surrounding regions of the Livermore Valley, and at Site300 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. Water samples are analyzed for radionuclides and a wide range of nonradioactive constituents. At Site 300, surface water monitoring encompasses spring-fed creeks and rainfall. These water samples are analyzed for radionuclides.

Surface water monitoring is driven by the requirements in EH-0173T, *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.* Changes in Section 402 of the Federal Clean Water Act led to LLNL's revision of the storm water monitoring program during 1993.

Methods

Livermore-Site and Livermore Valley Surface Water

Surface and drinking water near the Livermore site and in the Livermore Valley (**Figure 6-1**) are sampled according to procedures EMP-W-L and EMP-W-S in AppendixB of the *Environmental Monitoring Plan* (Gallegos et al. 1992b). Sampling locations DEL, ZON7, DUCK, ALAG, SHAD, and CAL are surface water sources; GAS, PALM, and ORCH are drinking water outlets. LLNL samples these locations quarterly for gross alpha, gross beta, and tritium. LLNL technicians use a tethered pail to collect water samples from surface sources; other locations are sampled directly from the outfall. Samples for tritium analysis are collected in 250-mL, argon-flushed glass containers; those for other radiological analyses are collected in 1000-mL polyethylene bottles.

The on-site swimming pool and drinking water source (POOL and TAP; **Figure 6-1**) are sampled, as described above, for gross alpha, gross beta, and tritium. POOL is sampled monthly, TAP quarterly.

Livermore-Site and Livermore Valley Rainfall

Tritium in rainfall near the Livermore site and in the Livermore Valley (**Figure 6-2**) is sampled according to procedures EMP-RA-L and EMP-RA-S in Appendix B of the *Environmental Monitoring Plan* (Gallegos et al. 1992b). Rainwater collected in stainless steel buckets is decanted into 250-mL argon-flushed glass containers fitted with ground-glass stoppers.

To eliminate redundant sampling and reduce analytical costs, the rain network underwent a significant reduction in sampling locations and sampling frequency during 1993. Sampling changed from "every rainstorm with measurable precipitation" to "monthly, concurrent with runoff." Based on this new directive, LLNL sampled five storms in 1993, compared to 20 in 1991 and 25 in 1992. We also reviewed historic rainfall data and found that tritium levels in rain dropped to background (<3.5Bq/L) at about 3kilometers from the Livermore site. In the fall of 1993, we eliminated eight of nine locations at this distance or farther from the Livermore site (DEL7, VINE, PARK, FCC, ALTA, PATT, BVA, and GTES). A single remote location, SLST, still provides background samples; it was kept because it is secure and easily accessible to LLNL staff. In summary, during 1993 rain samples were collected from 19 locations during spring (7 on site and 12 off site) and 11 locations (7 on site and 4 off site) during fall.

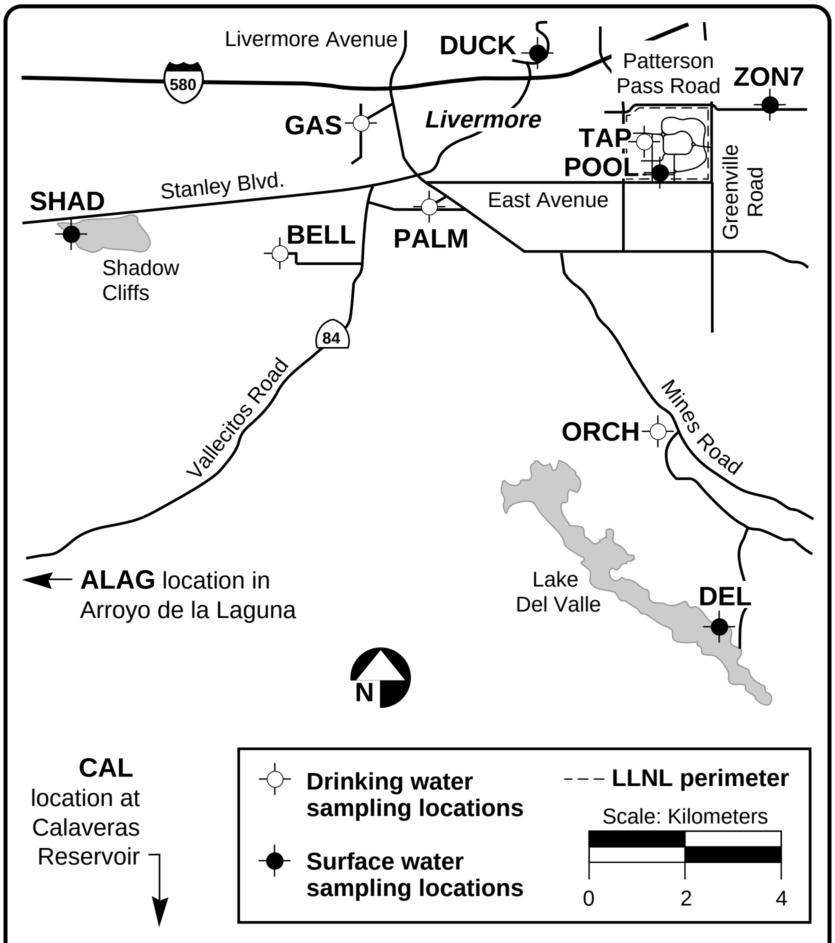

Figure 6-1. Surface and drinking water sampling locations, Livermore Valley, 1993.

Storm Water

Storm water runoff monitoring provides a broad measure of the efficacy of LLNL operational procedures that prevent, or contain and remediate, inadvertent spills of hazardous wastes or products onto the ground within the Livermore site and at 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 (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. Because no runoff

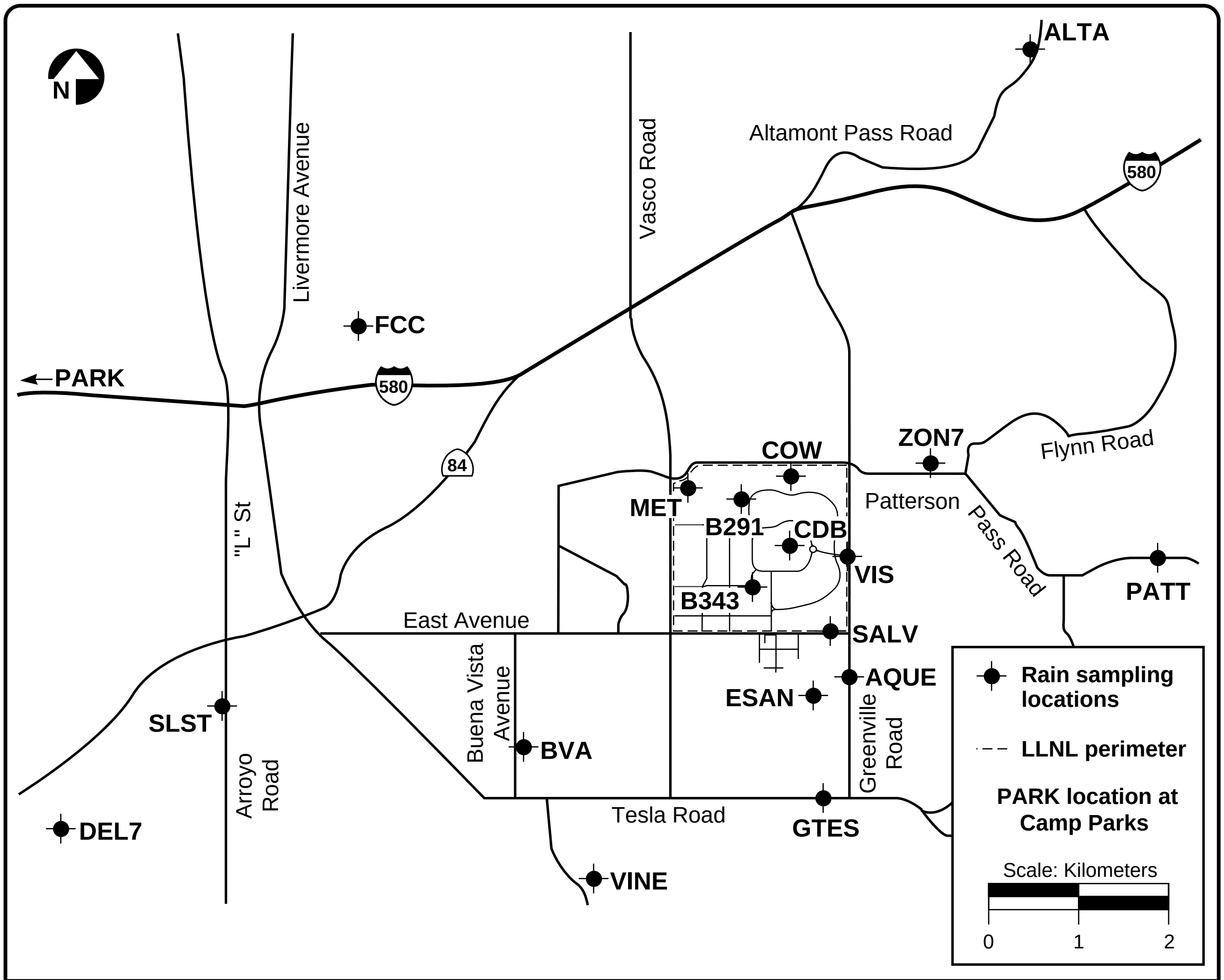

Figure 6-2. Rain sampling locations, Livermore site and Livermore Valley, 1993.

occurred at the Site 300 monitoring stations in the remainder of 1993, after the stations were established, we collected no samples and no further discussion of the Site300 network appears here.

About one-fourth of the storm water runoff generated within the Livermore site drains into the Central Drainage Basin, a lined depression turned into man-made lake through the collection of runoff and treated ground water (CDB; **Figure 6-3**). 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.

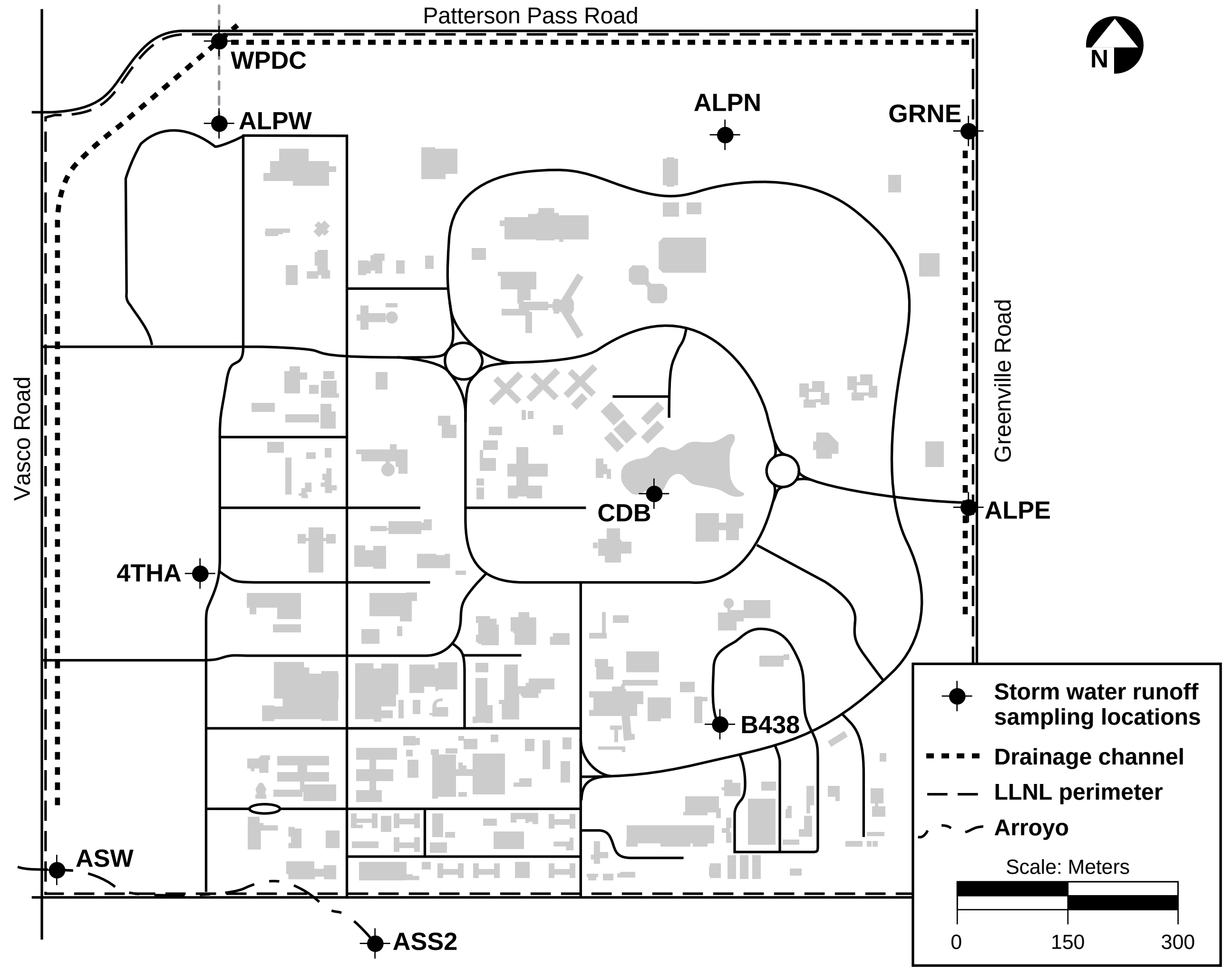

Figure 6-3. Storm water runoff sampling locations, Livermore site and vicinity, 1993.

In January 1993, the Livermore-site storm water sampling network consisted of ten locations. Five locations characterize storm water either entering (influent: ALPE, GRNE, and ASS2) or exiting (effluent: WPDC and ASW) the Livermore site. The remaining five characterize on-site runoff, some from locations with potential to introduce significant contaminants to storm water runoff. Location CDB characterizes runoff from the southeastern quadrant of the Livermore site entering the Central Drainage Basin. Location ALPN samples outflow from the Central Drainage Basin at its confluence with the Arroyo Las Positas. ALPW samples on-site runoff from a ditch along Avenue A where it enters the Arroyo Las Positas. Location 4THA samples runoff from the on-site Plutonium and Tritium Facilities. Location B438 samples runoff from the shops area and the Hazardous Waste Management facilities.

Storm water sampling occurred on seven dates during 1993. We obtained samples from all ten locations on January 6, February 8, and March 25. An unusually late season storm on June 4 brought about storm water flow and thus sampling at ALPN, ALPW, CDB, and GRNE.

To reduce analytical costs, the storm water network underwent a significant reduction in the number of sampling locations beginning in the fall of 1993. Four of the five on-site locations (ALPN, 4THA, B438, and ALPW) were dropped from the program. This enabled us to continue sampling all influent and effluent locations and CDB. We retained CDB because so much of the site runoff enters the Central Drainage Basin.

One of the requirements of the NPDES General Permit is to sample the first storm of the rainy season (beginning on July 1 and ending on June 30 of the following year). We made two attempts during October: on October 5, flow was present only at WPDC, and on October 15, at ASS2 and CDB. The first and only fall storm with runoff from all six remaining locations occurred on November 10.

In November 1992, the California Department of Water Resources cleaned the 120-million-liter Patterson Reservoir, located 2 kilometers northeast of the Livermore site, and discharged approximately 3000 m^3 of a sediment-slurry mixture into the arroyo that enters the Livermore site at ALPE. The slurry deposited fine textured, black sediments in the storm channel from GRNE to WDPC, and backed-up the storm channel leading from GRNE to ALPE. LLNL technicians collected samples of water and sediments at the time of the event. Analysis of the samples showed the slurry was nonhazardous for organics and metals. Analysis did indicate, however, that sediments contained concentrations of some metals above background, most significantly, copper. We also found during the analysis of the “black sludge event” that we did not routinely analyze for copper in our storm water samples. Beginning in March 1993, we added copper to our requested analyses.

Also between the spring and fall rainy seasons we switched analytical laboratories. We then found that the cost for a suite of analyses called “General Minerals” was less than the total cost of the individual analyses we had previously requested. Thus, beginning with the November 10 storm, we obtained “General Minerals” reports that included constituents such as aluminum, magnesium, potassium, and zinc, in addition to those such as specific conductance and nitrate (as N) that we had always requested. The current list of analyses requested for storm water samples is given in **Table 6-1**.

EMP-RO-L and EMP-RO-S in Appendix B of the *Environmental Monitoring Plan* (Gallegos et al. 1992b) describe storm water sampling procedures and locations. LLNL technicians collect storm water samples for nonradiological analysis directly into sample bottles for storm water runoff grab samples. Samples analyzed for tritium are collected in 250-mL, argon-flushed glass containers; samples for gross alpha and gross beta measurements are collected in 1000-mL polyethylene bottles. Finally, pH is determined with a calibrated meter.

Site300 Surface Water and Rainfall

LLNL collects quarterly surface water samples at Site 300 in Corral Hollow Creek (GEOCRK) and in a small, spring-fed creek near Bunker 812 (812CRK; **Figure 6-4**). We analyze these samples for gross alpha, gross beta and tritium. Procedures EMP-GW-L and EMP-GW-SP in Appendix B of the *Environmental Monitoring Plan* (Gallegos et al. 1992b) describe sampling procedures and locations. Samples analyzed for tritium are collected in 250-mL, argon-flushed glass containers; samples for gross alpha and gross beta measurements are collected in 1000-mL polyethylene bottles.

Rainfall at one location (RAIN; **Figure 6-4**) is composited each month and analyzed for tritium as described in EMP-RA-L and EMP-RA-S in Appendix B of the *Environmental Monitoring Plan* (Gallegos et al. 1992b).

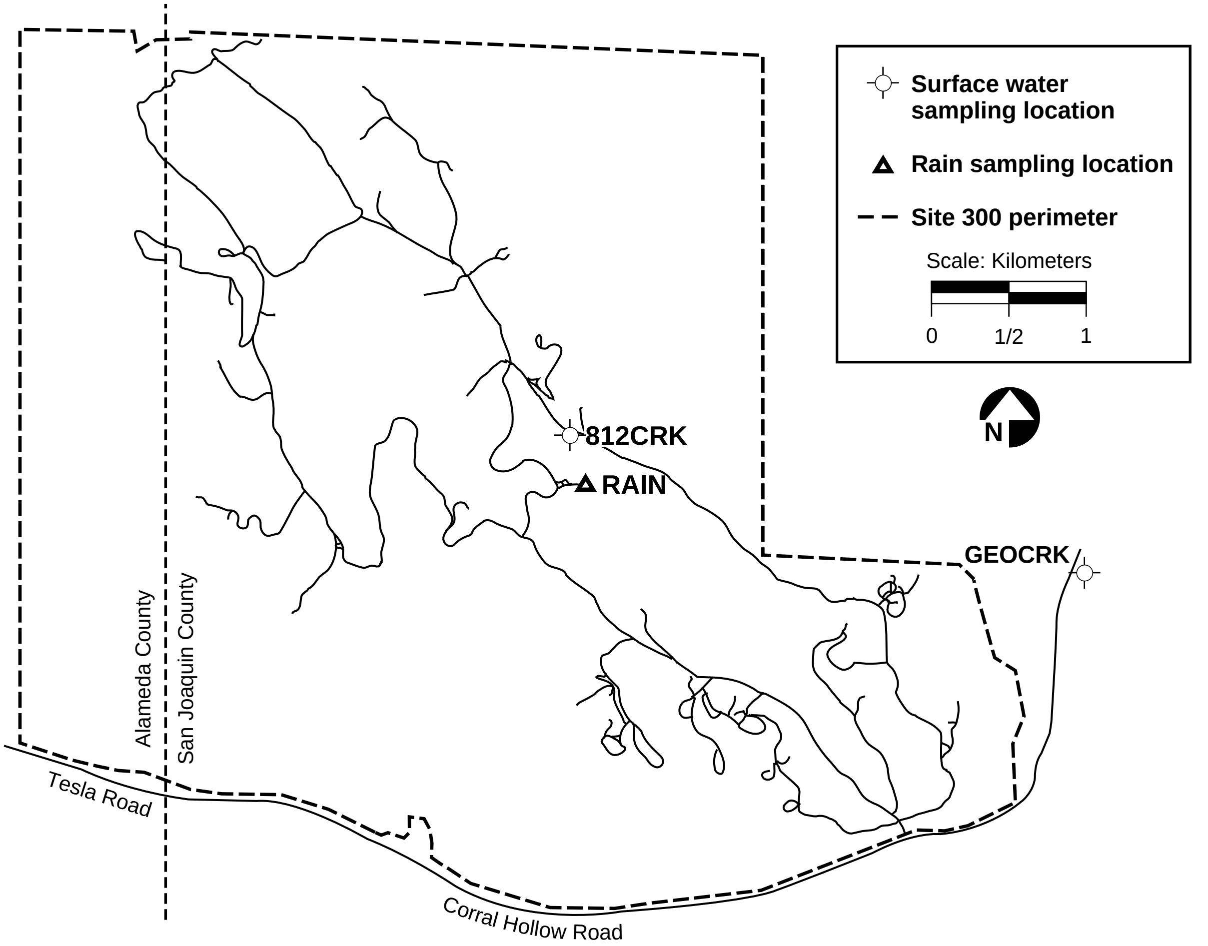

Figure 6-4. Surface water sampling locations and access roads, Site 300 and vicinity, 1993.

Results

Livermore Site and Livermore Valley

Gross Alpha and Gross Beta. Gross alpha and gross beta levels in surface water samples (**Table 6-2**) averaged less than 1% of the drinking water maximum contaminant levels (MCLs; 0.56 Bq/L or 15pCi/L, gross alpha, and 1.85 Bq/L or 50pCi/L, gross beta). Storm water gross alpha and gross beta samples also were well below MCLs, except for samples collected February 8 and November10 at ALPE and June 4 and November 10 at GRNE, which showed gross alpha and gross beta levels above drinking water MCLs (**Table6 -3**). Because both ALPE and GRNE are influent locations, the gross alpha and gross beta sources were upstream and off the Livermore site. The origin of this off-site source is unknown. There is no pattern in the 1993 air particulate gross alpha and gross beta sampling east of the Livermore site that would tie this result to airborne emissions from LLNL (see Chapter 4 on Air Monitoring). Contemporaneous storm water effluent measurements on February 8 and November 10 at WPDC (there was no June 4 runoff at WPDC) also showed higher-than-average values of gross alpha (42% of MCL) and gross beta (24% of MCL).

Tritium. Mean tritium activity at surface and drinking water locations in the Livermore Valley (2.07 Bq/L [55.9 pCi/L]) was less than 1% of the drinking water MCL (**Table 6-2**). Water in the LLNL swimming pool had the highest mean value and individual measurement. The mean tritium value at POOL for 1993 was 6.52 Bq/L (176 pCi/L), compared to 16.96 Bq/L in 1992, with both values less than 1% of the drinking water MCL. The highest single observation for POOL was 10.3 Bq/L (275 pCi/L), compared to 22.98Bq/L (620 pCi/L) in1992.

We collected rainfall samples from five storms in 1993. The mean rainfall tritium concentration for all locations for 1993 was 99.3 Bq/L (2680 pCi/L; **Table6 -4**), less than 15% of the drinking water MCL. Some observed tritium levels, however, were much higher in 1993 than in previous years. The highest rainfall tritium activity measured in 1993 was 5439 Bq/L (147,000 pCi/L) in a sample collected at B331 during a February 8–20 rainy period. This is over seven times the drinking water MCL, and seven times higher than the previous highest single value, 722 Bq/L (19,500 pCi/L) at location CDB in 1990.

Six of seven on-site locations also recorded their highest 1993 tritium levels during the February 8–20 period. Compared to levels at B331, the next highest value was 426 Bq/L (11,502 pCi/L) at CDB. Off site, three of twelve locations had their highest 1993 tritium values during this period The highest off-site value, however, was 29.0 Bq/L (783 pCi/L), indicating that the high level of tritium rainout during this storm did not extend off site. Interestingly, elevated air tritium values were also measured at this time (see Chapter 4 on Air Monitoring).

Rain sampling location B331 adjoins LLNL’s Tritium Facility. This facility completed various decommissioning actions during 1993 that resulted in diffuse tritium emissions. Modeling, discussed in both Chapter 4 on Air Monitoring and Chapter 12 on Radiation Dose Assessment, determined that a release of 6.3×10^{10}Bq (1.7 Ci) over eight weeks from the B331 yard could account for the observed levels of tritium in air and rain at the B331 sampling station. This level of diffuse emission can be expected from routine decommissioning operations in the B331 yard (Harrach et al. 1994). The dose to the theoretical person having the greatest possible exposure from this event is about 0.02 µSv (0.002 mrem).

Tritium levels in storm water runoff were low, averaging 6.5 Bq/L (175pCi/L), or less than 1% of the drinking water MCL (**Table6-3**). The highest tritium activity measured in storm water runoff during 1993 was 19.7Bq/L (531pCi/L) at influent location ASW. This sample was collected on February 8, the beginning of the February 8–20 rainy period that resulted in the elevated rainfall tritium sample at B331. By comparison, tritium at B438, the storm water sampling location closest to the B331 yard, was 13.1 Bq/L (354pCi/L) for that date, the highest value for that location for 1993.

Livermore Site and Livermore Valley, Nonradioactive Pollutants in Storm Water

Sulfate, a common constituent of agricultural chemicals, equaled or exceeded the secondary standard of 250 ppm set by the State of California for drinking water (with the highest value at 490 ppm) in samples at influent location ALPE on January 6, February 8, and March 25. Samples from influent location GRNE also contained sulfate at levels as high as 220ppm on these dates. On-site storm water sampling locations were at the detection limit for sulfate on those dates **(Table 6-5)**.

Sample results of copper in storm water effluent from WPDC and ASW on March 25 exceeded the numerical water quality objective (0.0075 mg/L) of the California Inland Surface Water Plan for protecting aquatic life. The highest value, 0.013 mg/L at GRNE (influent) is probably a residual effect from the “black sludge event” of November 1992. Effluent values for copper at ASW and WPDC ranged to within 95% of the water quality objective during subsequent runoff events. Other commonly detected metals in storm water runoff were arsenic, barium, cadmium, nickel, and lead. Soils at the Livermore site contain naturally elevated levels of arsenic and barium. Cadmium, nickel, and lead are commonly found in storm water runoff from areas associated with auto use, such as parking lots and roads. Bearing, brushing, tire and brake lining wear, diesel and gasoline exhaust, and spilled motor oil release these metals. During 1993, storm water samples contained these metals at levels less than the corresponding drinking water MCLs. Other metals, such as aluminum, antimony, iron, magnesium, mercury, manganese, silver, and zinc, were found four or fewer times in storm water runoff, all at levels below their respective drinking water MCL.

Of possible organic contaminants, only three measurements of bis(2-ethylhexyl)phthalate exceeded the drinking water MCL of 4 ppb. The three measurements were from locations ASS2 (34 ppb), ASW (12 ppb), and WPDC (13ppb). This plasticizer is ubiquitous in the environment and is known to be used on site (LLNL Wastewater Discharge permit application, 1993–1994). Other detected organic pollutants included acetone (five observations), chloromethane (one observation), hexanal (one observation), and butylbenzylphthalate (one observation). The herbicide 2,4-D was found in storm water at influent locations ALPE and GRNE.

Site300, Radioactivity in Surface Water

No measured value of radioactivity in rain or surface water at Site 300 exceeded drinking water MCLs for gross alpha, gross beta, or tritium (**Table 6-6**). Mean gross alpha and gross beta values at the two surface water locations, GEOCRK and 812CRK, were less than 36% of the MCL. Mean tritium activity in the two surface water locations and in rain at Site 300 was very low, less than 1% of the MCL, at levels associated with natural background.

Environmental Impact

Livermore Site and Livermore Valley

Copper in samples of storm water effluent from one February storm exceeded the California Inland Surface Water Plan's numerical water quality objective for the protection of aquatic life (0.0089 mg/L at WPDC, compared to the objective of 0.0075 mg/L). Salmonids, a fish found in San Francisco Bay water and commonly used in bioassay tests, suffer lethal effects from copper at 0.0023mg/L (Davies et al. 1976; Sauter et al. 1976; Cusimano et al. 1986). Leland and Carter (1984) have observed a significant negative effect on algae growth at levels as low as 0.005 mg/L. Samples from storm water runoff the fall following this storm contained copper well below the aquatic life objective. Although some 1993 storm water runoff contained copper above the aquatic life objective, the overall impact to biota in Arroyo Las Positas was probably minor.

Storm water runoff also contained low levels of bis(2-ethylhexyl)phthalate and other organics at various locations. No other nonradiological pollutants in Livermore-site storm water effluent were observed above a regulatory limit.

As is clear by the results from the February 8–20 rainfall event, tritium emissions from the Livermore site can result in elevated tritium levels in rain.

Although off-site tritium rainfall levels are well below the drinking water MCL, they are elevated above background levels (background ranges from 3–4 Bq/L). We estimated the potential impact of such tritium levels in rainfall through the effective dose equivalent (EDE). Appendix B presents the method to calculate dose. Of all off-site waters measured, the maximum tritium activity, 50.7 Bq/L (1369 pCi/L), occurred in rain sampled at ESAN during a March 22 rainstorm. The EDE to an adult who ingested two liters of this rain water per day for one year would be 0.0007 mSv (0.07mrem), which is less than 0.1% of the DOE standard allowable dose of 1.0mSv/yr (100 mrem). All other off-site waters, if ingested at the 2-liter-per-day rate, would result in even lower EDEs. The data from waters sampled during 1993 and the estimated potential maximal dose demonstrates a minimal impact ofLLNL operations on valley waters resulting from releases of radionuclides to the atmosphere.

Site300

The highest observed tritium value at Site 300 was a 1.14 Bq/L (28pCi/L) measurement from surface water at GEOCRK. Humans do not currently consume this water; this level poses no significant impact to the environment or human health.

Table 6-1. Requested analyses for storm water samples**.**

EPA Method 624	Gross alpha/beta
EPA Method 625	Metals
Drinking water pesticides	Total organic carbon
Oil and grease	Anions
General minerals	Tritium
Chemical oxygen demand	

Table 6-2. Radioactivity in water, Livermore Valley (in Bq/L), 1993.

Location[a]	Date	Tritium	Gross alpha	Gross beta
DEL	1Q	0.85 ± 0.09	0.05 ± 0.07	0.07 ± 0.06
	2Q	0.31 ± 0.13	0.02 ± 0.03	0.35 ± 0.08
	3Q	0.74 ± 0.12	0.05 ± 0.01	0.08 ± 0.01
	4Q	0.70 ± 0.12	0.04 ± 0.01	0.10 ± 0.01
ZON7	1Q	1.44 ± 0.14	0.04 ± 0.08	0.21 ± 0.07
	2Q	1.07 ± 0.17	0.06 ± 0.04	0.19 ± 0.07
	3Q	0.75 ± 0.13	0.08 ± 0.01	0.09 ± 0.01
	4Q	0.54 ± 0.14	0.06 ± 0.01	0.08 ± 0.01
DUCK	1Q	2.00 ± 0.24	0.16 ± 0.15	0.19 ± 0.07
	2Q	3.15 ± 0.25	0.05 ± 0.10	0.18 ± 0.10
	3Q	2.00 ± 0.17	0.15 ± 0.03	0.35 ± 0.05
	4Q	1.48 ± 0.18	0.28 ± 0.06	0.29 ± 0.04
CAL	1Q	0.71 ± 0.09	0.00 ± 0.05	0.09 ± 0.06
	2Q	0.52 ± 0.08	0.01 ± 0.01	0.06 ± 0.04
	3Q	0.53 ± 0.12	0.01 ± 0.01	0.06 ± 0.01
	4Q	0.39 ± 0.09	0.01 ± 0.01	0.06 ± 0.01
ALAG	1Q	1.28 ± 0.13	–0.05 ± 0.24	0.51 ± 0.15
	2Q	1.47 ± 0.19	0.09 ± 0.08	0.12 ± 0.09
	3Q	1.56 ± 0.15	0.07 ± 0.02	0.08 ± 0.01
	4Q	0.93 ± 0.17	–0.01 ± 0.01	0.03 ± 0.01
SHAD	1Q	3.07 ± 0.27	0.05 ± 0.10	0.08 ± 0.05
	2Q	2.76 ± 0.18	0.06 ± 0.05	0.11 ± 0.07
	3Q	3.07 ± 0.20	0.09 ± 0.03	0.15 ± 0.02
	4Q	2.92 ± 0.25	0.07 ± 0.02	0.14 ± 0.01
POOL	1Q1	2.08 ± 2.08	0.01 ± 0.04	0.07 ± 0.04
	1Q2	5.51 ± 2.30	0.01 ± 0.07	0.11 ± 0.04
	1Q3	10.25 ± 1.83	0.02 ± 0.08	0.10 ± 0.05
	2Q1	7.25 ± 1.85	0.01 ± 0.03	0.13 ± 0.08
	2Q2	9.69 ± 2.02	0.02 ± 0.06	0.05 ± 0.05
	2Q3	9.40 ± 2.01	0.07 ± 0.08	0.12 ± 0.07
	3Q	7.40 ± 2.19	0.03 ± 0.03	0.18 ± 0.02
	4Q	2.46 ± 1.94	—[b]	—[b]
GAS	1Q	1.55 ± 0.16	0.00 ± 0.05	0.12 ± 0.05
	2Q	0.31 ± 0.14	0.00 ± 0.02	0.04 ± 0.05
	3Q	1.36 ± 0.13	0.02 ± 0.02	0.10 ± 0.01
	4Q	1.40 ± 0.17	0.01 ± 0.01	0.04 ± 0.01

...continued

Table 6-2. Radioactivity in water, Livermore Valley (in Bq/L), 1993 *(concluded)*.

Location[a]	Date	Tritium	Gross alpha	Gross beta
TAP	1Q	1.20 ± 0.13	0.17 ± 0.07	0.13 ± 0.05
	2Q	0.60 ± 0.11	0.00 ± 0.01	0.04 ± 0.03
	3Q	0.58 ± 0.11	0.01 ± 0.004	0.05 ± 0.01
	4Q	0.33 ± 0.09	0.05 ± 0.01	0.08 ± 0.01
PALM	1Q	1.78 ± 0.17	–0.02 ± 0.06	0.12 ± 0.05
	2Q	0.90 ± 0.11	0.05 ± 0.04	0.09 ± 0.05
	3Q	0.68 ± 0.12	0.04 ± 0.02	0.09 ± 0.01
	4Q	0.61 ± 0.10	0.01 ± 0.01	0.07 ± 0.01
BELL	1Q	1.91 ± 0.57	–0.01 ± 0.07	0.03 ± 0.05
	2Q	0.76 ± 0.13	–0.01 ± 0.02	0.05 ± 0.06
	3Q	0.67 ± 0.11	0.01 ± 0.01	0.25 ± 0.01
	4Q	0.41 ± 0.10	0.03 ± 0.01	0.09 ± 0.01
ORCH	1Q	1.52 ± 0.16	–0.06 ± 0.24	0.65 ± 0.23
	2Q	1.32 ± 0.13	0.06 ± 0.08	0.77 ± 0.17
	3Q	0.84 ± 0.13	0.12 ± 0.03	0.23 ± 0.02
	4Q	0.51 ± 0.10	0.05 ± 0.01	0.28 ± 0.02
Mean		**2.07**	**0.042**	**0.15**
Std dev		**2.45**	**0.057**	**0.15**
Mean without POOL		**1.22**	**0.044**	**0.16**
Std dev		**0.80**	**0.061**	**0.16**
Mean of POOL		**6.76**	**0.02**	**0.11**
Std dev		**3.17**	**0.02**	**0.04**
			(pCi/L)	
Mean		**55.9**	**1.1**	**4.1**
Std dev		**66.2**	**1.5**	**4.1**
Mean without POOL		**33.0**	**1.2**	**4.3**
Std dev		**21.6**	**1.6**	**4.3**
Mean of POOL		**183**	**0.5**	**3.0**
Std dev		**85.7**	**0.5**	**1.1**

Note: Results are reported ±2σ; see Quality Assurance chapter.
For very low counts, subtraction of background values may yield a negative number for gross alpha and gross beta (U.S. Department of Energy 1991).

[a] See Fig. 6-1 for sampling locations.

[b] Sample not taken; see Quality Assurance chapter.

Table 6-3. Radioactivity in storm water runoff (in Bq/L), 1993.

Location[a]	Date	Tritium	Gross alpha	Gross beta
4THA	Jan. 6	2.79 ± 2.01	0.03 ± 0.03	0.11 ± 0.03
	Feb. 8	<1.96	0.003 ± 0.09	0.09 ± 0.07
	Mar. 25	5.00 ± 1.71	0.06 ± 0.02	0.13 ± 0.03
ALPE	Jan. 6	<1.97	0.24 ± 0.28	0.83 ± 0.21
	Feb. 8	3.47 ± 2.04	0.97 ± 0.46	2.37 ± 0.25
	Mar. 25	5.55 ± 1.68	0.17 ± 0.16	0.45 ± 0.18
	Nov. 10	2.30 ± 1.91	1.6 ± 0.11	1.39 ± 0.06
ALPN	Jan. 6	<1.95	0.05 ± 0.05	0.19 ± 0.04
	Feb. 8	16.17 ± 2.47	0.03 ± 0.06	0.21 ± 0.06
	Mar. 25	6.96 ± 1.78	0.12 ± 0.05	0.23 ± 0.04
	June 4	5.11 ± 1.68	0.04 ± 0.02	0.11 ± 0.03
ALPW	Jan. 6	2.29 ± 2.00	0.03 ± 0.04	0.17 ± 0.05
	Feb. 8	3.44 ± 2.03	0.11 ± 0.10	0.33 ± 0.10
	Mar. 25	5.18 ± 1.57	0.10 ± 0.03	0.13 ± 0.03
	June 4	<21.61	0.15 ± 0.06	0.37 ± 0.05
	Oct. 5	5.40 ± 1.92	0.10 ± 0.01	0.20 ± 0.01
	Oct. 15	9.18 ± 2.06	0.39 ± 0.03	0.54 ± 0.01
ASS2	Jan. 6	13.84 ± 2.39	0.11 ± 0.08	0.34 ± 0.05
	Feb. 8	6.99 ± 2.16	0.08 ± 0.09	0.32 ± 0.09
	Mar. 25	7.62 ± 1.80	0.22 ± 0.08	0.36 ± 0.05
	Oct. 15	12.32 ± 2.23	0.04 ± 0.01	0.13 ± 0.01
	Nov. 10	2.75 ± 1.92	0.18 ± 0.01	0.32 ± 0.01
ASW	Jan. 6	12.91 ± 2.39	0.01 ± 0.02	0.11 ± 0.02
	Feb. 8	19.65 ± 2.59	0.40 ± 0.20	0.77 ± 0.16
	Mar. 25	8.84 ± 1.84	0.05 ± 0.02	0.24 ± 0.04
	Nov. 10	11.40 ± 2.20	0.16 ± 0.01	0.38 ± 0.01
B438	Feb. 8	13.10 ± 2.38	0.04 ± 0.11	0.29 ± 0.13
	Mar. 25	6.51 ± 1.76	0.05 ± 0.02	0.12 ± 0.03
CDB	Jan. 6	4.81 ± 2.09	0.05 ± 0.04	0.25 ± 0.05
	Feb. 8	12.03 ± 2.33	–0.03 ± 0.10	0.07 ± 0.06
	Mar. 25	6.51 ± 1.76	0.09 ± 0.03	0.18 ± 0.04
	June 4	10.25 ± 1.86	0.06 ± 0.02	0.19 ± 0.04
	Oct. 15	<1.87	0.10 ± 0.01	0.23 ± 0.01
	Nov. 10	4.55 ± 1.98	0.22 ± 0.02	0.31 ± 0.01

...continued

Table 6-3. Radioactivity in storm water runoff (in Bq/L), 1993 (*concluded*).

Location[a]	Date	Tritium	Gross alpha	Gross beta
GRNE	Jan. 6	2.94 ± 2.02	0.21 ± 0.20	0.54 ± 0.09
	Feb. 8	5.40 ± 2.11	0.06 ± 0.21	0.48 ± 0.14
	Mar. 25	5.51 ± 1.73	0.19 ± 0.15	0.26 ± 0.09
	June 4	2.60 ± 1.59	0.63 ± 0.25	0.63 ± 0.12
	Nov. 10	2.28 ± 1.90	4.07 ± 0.30	3.38 ± 0.15
WPDC	Jan. 6	2.80 ± 2.03	0.05 ± 0.05	0.19 ± 0.04
	Feb. 8	6.92 ± 2.17	0.08 ± 0.08	0.20 ± 0.10
	Mar. 25	7.18 ± 1.79	0.05 ± 0.28	0.15 ± 0.35
	Oct. 5	3.85 ± 1.96	—[b]	—[b]
	Oct. 15	—[b]	0.28 ± 0.03	0.57 ± 0.01
	Nov. 10	7.10 ± 1.97	0.39 ± 0.03	0.68 ± 0.02
Mean		**6.47**	**0.27**	**0.44**
Std dev		**4.21**	**0.65**	**0.60**
			pCi/L	
Mean		**174.69**	**7.38**	**12.01**
Std dev		**113.67**	**17.56**	**16.22**

Note: Results are reported ±2σ; see Quality Assurance chapter.
Gross alpha and gross beta sampled quarterly; Quality Assurance duplicates also reported.
For very low counts, subtraction of background count may yield a negative number for gross alpha and gross beta (U.S. Department of Energy 1991).

[a] See Fig. 6-3 for sampling locations.

[b] No sample; see Quality Assurance chapter for explanation.

Table 6-4. Tritium in rain, Livermore site and Livermore Valley (in Bq/L), 1993.

Sampling location[a]	Jan 12	Feb 22	Mar 22	Oct 6	Nov 11
On site					
B343	26.1 ± 2.58	5440 ± 27.20	82.1 ± 3.78	—[b]	17.6 ± 2.28
CDB	19.1 ± 2.41	426 ± 7.66	42.6 ± 2.94	29.9 ± 2.69	5.70 ± 1.88
B291	24.6 ± 2.49	79.9 ± 3.76	59.6 ± 3.28	—[b]	8.58 ± 1.99
VIS	15.6 ± 2.25	51.8 ± 3.21	23.0 ± 2.44	19.5 ± 2.41	8.66 ± 2.00
SALV	19.3 ± 2.36	13.4 ± 2.22	28.2 ± 2.57	—[b]	9.40 ± 2.04
MET	5.29 ± 1.94	13.9 ± 2.27	6.25 ± 1.97	< 1.65	3.32 ± 1.79
COW	12.1 ± 2.14	132 ± 4.62	15.1 ± 2.20	13.7 ± 2.20	3.56 ± 1.80
Mean	**17.5**	**879.4**	**36.7**	**16.2**	**8.1**
Std dev	**6.7**	**1866.1**	**24.7**	**10.2**	**4.5**
Off site					
ESAN	42.2 ± 2.99	18.2 ± 2.37	50.7 ± 3.14	—[b]	15.2 ± 2.32
AQUE	28.1 ± 2.67	17.8 ± 2.36	39.6 ± 2.85	—[b]	22.6 ± 2.45
ZON7	8.29 ± 2.09	29.0 ± 2.58	12.0 ± 2.15	—[c]	4.48 ± 2.54
GTES	9.10 ± 2.06	7.10 ± 2.01	7.47 ± 1.97	—[c]	—[c]
BVA	5.03 ± 1.98	6.22 ± 2.01	5.22 ± 1.90	—[c]	—[c]
VINE	3.55 ± 1.94	3.49 ± 1.93	< 1.78	—[c]	—[c]
PATT	3.56 ± 1.92	2.85 ± 1.83	5.25 ± 1.92	—[c]	—[c]
FCC	< 1.84	—[b]	4.07 ± 1.90	—[c]	—[b]
SLST	< 1.84	< 1.72	4.33 ± 1.88	—[c]	3.03 ± 1.79
ALTA	2.62 ± 1.90	5.18 ± 1.94	4.77 ± 1.91	—[c]	—[c]
DEL7	2.83 ± 1.89	< 1.78	2.09 ± 1.89	—[c]	—[c]
PARK	< 1.87	< 1.75	2.92 ± 1.80	—[c]	—[c]
Mean	**9.2**	**8.6**	**11.7**		**11.3**
Std dev	**12.2**	**8.6**	**15.4**		**8.0**

Note: Results are reported $\pm 2\sigma$; see Quality Assurance chapter.

[a] See Fig. 6-2 for sampling locations.

[b] Sample unavailable; see Quality Assurance chapter.

[c] Dropped from program.

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993.

Parameters[a]	Storm date	4THA	ALPE	ALPN	ALPO	ALPW	ASS2
Metals and minerals[b] (mg/L)							
Aluminum	Nov. 10		<0.2				<0.2
	Dec. 10						
Ammonia nitrogen (as N)	Dec. 10						
Antimony	Jan. 4						
	Dec. 10						
Aquatic bioassay, survival (%)	Dec. 10						
Arsenic	Jan. 4						
	Jan. 6	<0.002	0.0031	<0.002		<0.002	<0.002
	Feb. 8	0.0034	0.0043	<0.002		<0.002	<0.002
	Mar. 10				0.0057		
	Mar. 25	0.0032	0.0041	<0.002		0.002	<0.002
	June 4			<0.002		<0.002	
	Oct. 5					0.0054	
	Oct. 15					<0.002	<0.002
	Nov. 10		<0.002				<0.002
	Dec. 10						
Barium	Jan. 6	<0.05	0.11	<0.05		<0.05	<0.05
	Feb. 8	<0.05	0.32	<0.05		<0.05	<0.05
	Mar. 10				0.08		
	Mar. 25	0.013	0.11	0.046		0.027	0.029
	June 4			0.022		0.017	
	Oct. 5					0.085	
	Oct. 15					<0.05	<0.05
	Nov. 10		<0.05				<0.05
Bicarbonate alkalinity (as $CaCO_3$)	Jan. 6	11	200	27		15	27
	Feb. 8	8.4	330	45		10	13
	Mar. 25	13	280	44		28	31
	Oct. 5					43	
	Nov. 10		63				32
	Dec. 10						
Boron	Jan. 4						
	Dec. 10						
Cadmium	Jan. 4						
	Jan. 6	<0.0005	<0.0005	<0.0005		<0.0005	<0.0005
	Feb. 8	<0.0005	<0.0005	<0.0005		<0.0005	<0.0005
	Mar. 10				<0.05		
	Mar. 25	0.0005	<0.0005	<0.0005		<0.0005	<0.0005
	June 4			<0.0005		<0.0005	
	Oct. 5					0.0011	
	Oct. 15					<0.0005	0.0005
	Nov. 10		<0.0005				0.0019
	Dec. 10						
Calcium	Nov. 10		15				18
	Dec. 10						

...continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm date	ASW	B438	CDB	GRNE	WPDC
Metals and minerals[b] (mg/L)						
Aluminum	Nov. 10	<0.2		<0.2	0.33	<0.2
	Dec. 10					
Ammonia nitrogen (as N)	Dec. 10					
Antimony	Jan. 4					
	Dec. 10					
Aquatic bioassay, survival (%)	Dec. 10					
Arsenic	Jan. 4					
	Jan. 6	<0.002		<0.002	0.0045	<0.002
	Feb. 8	<0.002	0.002	<0.002	0.0038	<0.002
	Mar. 10					
	Mar. 25	0.0029	0.0024	0.0022	0.0038	<0.002
	June 4			<0.002	0.0038	
	Oct. 5					0.0054
	Oct. 15			<0.002		
	Nov. 10	0.002		<0.002	<0.002	<0.002
	Dec. 10					
Barium	Jan. 6	<0.05		<0.05	0.11	<0.05
	Feb. 8	<0.05	<0.05	<0.05	0.051	<0.05
	Mar. 10					
	Mar. 25	0.038	0.018	0.018	0.088	0.046
	June 4			0.017	0.065	
	Oct. 5					0.081
	Oct. 15			<0.05		
	Nov. 10	<0.05		<0.05	0.085	<0.05
Bicarbonate alkalinity (as $CaCO_3$)	Jan. 6	15		14	170	18
	Feb. 8	11	14	7.2	82	27
	Mar. 25	46	14	18	160	55
	Oct. 5					72
	Nov. 10	26		9.1	35	24
	Dec. 10					
Boron	Jan. 4					
	Dec. 10					
Cadmium	Jan. 4					
	Jan. 6	<0.0005		<0.0005	<0.0005	<0.0005
	Feb. 8	<0.0005	0.0007	<0.0005	<0.0005	<0.0005
	Mar. 10					
	Mar. 25	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	June 4			<0.0005	<0.0005	
	Oct. 5					0.001
	Oct. 15			0.001		
	Nov. 10	0.001		<0.0005	<0.0005	0.0012
	Dec. 10					
Calcium	Nov. 10	10		3.3	5.7	8.9
	Dec. 10					

...continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm date	4THA	ALPE	ALPN	ALPO	ALPW	ASS2
Carbonate alkalinity (as $CaCO_3$)	Jan. 6	<1	<1	<1		<1	<1
	Feb. 8	<1	<1	<1		<1	<1
	Mar. 25	<1	40	<1		<1	<1
	Oct. 5					<1	
	Nov. 10		<1				<1
	Dec. 10						
Chemical oxygen demand	Jan. 6	25	80	20		35	40
	Feb. 8	40	240	25		25	35
	Mar. 25	50	120	60		50	40
	June 4			28		90	
	Oct. 5					280	
	Oct. 15					83	79
	Nov. 10		100				150
	Dec. 10						
Chloride	Jan. 6	<1	340	<1		<1	1
	Feb. 8	<1	510	2.8		<1	<1
	Mar. 10				300		
	Mar. 25	<1	350	<1		14	5.5
	June 4			3		4	
	Oct. 5 (mg/kg)					7.4	
	Oct. 15					5.4	6.2
	Nov. 10		13				5.6
	Dec. 10						
Chlorophyll a	Dec. 10						
Chromium	Jan. 4						
	Jan. 6	<0.005	<0.005	<0.005		<0.005	<0.005
	Feb. 8	0.0082	0.0068	0.0053		0.0063	0.0065
	Mar. 10				<0.005		
	Mar. 25	<0.005	<0.005	<0.005		<0.005	<0.005
	June 4			<0.005		<0.005	
	Oct. 15					<0.01	<0.01
	Dec. 10						
Copper	Jan. 4						
	Mar. 25	0.0075	0.0072	<0.005		0.0083	0.007
	June 4			<0.02		<0.02	
	Oct. 5					0.078	
	Nov. 10		<0.01				<0.01
			<0.05				0.052
	Dec. 10						
Fecal coliform (MPN/100mL)	Dec. 10						

...continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm date	ASW	B438	CDB	GRNE	WPDC
Carbonate alkalinity (as $CaCO_3$)	Jan. 6	<1		<1	<1	<1
	Feb. 8	<1	<1	<1	<1	<1
	Mar. 25	<1	<1	<1	20	<1
	Oct. 5					<1
	Nov. 10	<1		<1	<1	<1
	Dec. 10					
Chemical oxygen demand	Jan. 6	20		50	90	25
	Feb. 8	40	45	25	80	70
	Mar. 25	40	80	60	70	60
	June 4			70	36	
	Oct. 5					240
	Oct. 15			90		
	Nov. 10	210		70	62	120
	Dec. 10					
Chloride	Jan. 6	<1		<1	220	1
	Feb. 8	<1	<1	<1	56	3.5
	Mar. 10					
	Mar. 25	19	<1	<1	210	24
	June 4			4	3	
	Oct. 5 (mg/kg)					14
	Oct. 15			3.5		
	Nov. 10	4.9		1.6	7.7	7.2
	Dec. 10					
Chlorophyll a	Dec. 10					
Chromium	Jan. 4					
	Jan. 6	<0.005		<0.005	<0.005	<0.005
	Feb. 8	0.0059	0.0063	0.0067	0.008	<0.005
	Mar. 10					
	Mar. 25	<0.005	<0.005	<0.005	<0.005	<0.005
	June 4			0.0085	<0.005	
	Oct. 15			<0.01		
	Dec. 10					
Copper	Jan. 4					
	Mar. 25	0.0077	0.01	0.0064	0.013	0.0089
	June 4			<0.02	0.03	
	Oct. 5					0.071
	Nov. 10	<0.01		<0.01	<0.01	<0.01
		<0.05		<0.05	<0.05	<0.05
	Dec. 10					
Fecal coliform (MPN/100mL)	Dec. 10					

...continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm date	4THA	ALPE	ALPN	ALPW	ASS2
Fluoride	Jan. 6	<0.1	0.53	<0.1	<0.1	<0.1
	Feb. 8	<0.1	1.6	<0.1	<0.1	<0.1
	Mar. 10					
	Mar. 25	<0.1	1.1	<0.1	0.12	<0.1
	June 4			0.11	0.05	
	Oct. 5				0.08	
	Oct. 15				0.059	0.065
	Nov. 10		0.075			0.064
			<0.05			0.058
	Dec. 10					
Hardness, total (as $CaCO_3$)	Nov. 10		48			55
	Dec. 10					
Iron	Jan. 4					
	Nov. 10		<0.1			<0.1
	Dec. 10					
Lead	Jan. 4					
	Jan. 6	<0.002	<0.002	<0.002	<0.002	<0.002
	Feb. 8	<0.002	<0.002	<0.002	0.0021	<0.002
	Mar. 10					
	Mar. 25	<0.002	<0.002	<0.002	<0.002	0.0021
	June 4			<0.002	<0.002	
	Oct. 5				0.0048	
	Oct. 15				<0.002	<0.002
	Nov. 10		<0.002			<0.002
	Dec. 10					
Magnesium	Nov. 10		2.5			2.5
	Dec. 10					
Manganese	Jan. 4					
	Nov. 10		<0.03			0.16
	Dec. 10					
Mercury	Jan. 4					
	Jan. 6	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
	Feb. 8	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
	Mar. 10					
	Mar. 25	0.0002	<0.0002	0.0002	<0.0002	<0.0002
	June 4			<0.0005	<0.0005	
	Oct. 5				<0.0002	
	Nov. 10		<0.0002			<0.0002
	Dec. 10					

...continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm date	ASW	B438	CDB	GRNE	WPDC
Fluoride	Jan. 6	<0.1		<0.1	0.55	<0.1
	Feb. 8	<0.1	<0.1	<0.1	0.29	<0.1
	Mar. 10					
	Mar. 25	<0.1	<0.1	<0.1	0.67	0.12
	June 4			0.08	0.7	
	Oct. 5					0.11
	Oct. 15			0.051		
	Nov. 10	0.058		<0.05	0.14	0.073
		<0.05		<0.05	0.099	0.087
	Dec. 10					
Hardness, total (as $CaCO_3$)	Nov. 10	35		12	22	34
	Dec. 10					
Iron	Jan. 4					
	Nov. 10	0.27		<0.1	0.22	<0.1
	Dec. 10					
Lead	Jan. 4					
	Jan. 6	<0.002		<0.002	<0.002	<0.002
	Feb. 8	<0.002	0.0027	<0.002	<0.002	<0.002
	Mar. 10					
	Mar. 25	<0.002	<0.002	<0.002	<0.002	<0.002
	June 4			<0.002	0.0028	
	Oct. 5					0.0038
	Oct. 15			<0.002		
	Nov. 10	<0.002		0.0025	0.0023	<0.002
	Dec. 10					
Magnesium	Nov. 10	2.4		0.83	1.9	2.9
	Dec. 10					
Manganese	Jan. 4					
	Nov. 10	0.21		<0.03	<0.03	0.25
	Dec. 10					
Mercury	Jan. 4					
	Jan. 6	<0.0002		<0.0002	<0.0002	<0.0002
	Feb. 8	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
	Mar. 10					
	Mar. 25	<0.0002	<0.0002	0.0003	<0.0002	<0.0002
	June 4			<0.0005	<0.0005	
	Oct. 5					<0.0002
	Nov. 10	<0.0002		<0.0002	<0.0002	<0.0002
	Dec. 10					

...continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm date	4THA	ALPE	ALPN	ALPW	ASS2
Nickel	Jan. 4					
	Mar. 25	0.0083	0.028	0.0093	0.0058	<0.005
	June 4			0.0082	0.0074	
	Oct. 5				0.024	
	Nov. 10		0.0069			0.012
			<0.1			<0.1
	Dec. 10					
Nitrate (as N)	Oct. 5				0.59	
	Oct. 15				1.6	0.79
	Nov. 10		2			1.8
	Dec. 10					
Nitrate plus nitrite (as N)	Mar. 10					
Nitrate plus nitrite (as NO_3)	Jan. 6	4	5.2	4.2	3.6	1.6
	Feb. 8	2.2	2.7	2.4	1.9	1.4
	Mar. 10					
	Mar. 25	3	5.8	4.2	3.5	2.4
	June 4			0.51	0.71	
Nitrite (as N)	Oct. 15				<0.1	<0.1
	Nov. 10		0.17			<0.1
	Dec. 10					
Oil and grease	Jan. 6	<5	6	<5	6	<5
	Feb. 8	<5	7	<5	<5	<5
	Mar. 25	<5	<5	<5	<5	<5
	June 4			<5	<5	
	Oct. 5				<5	
	Oct. 15				<5	<5
	Nov. 10		<5			<5
	Dec. 10					
pH (units)	Jan. 4					
	Nov. 10		8.4			6.9
	Dec. 10					
Potassium	Nov. 10		1.7			4.1
	Dec. 10					

...continued

Table 6-5 LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm date	ASW	B438	CDB	GRNE	WPDC
Nickel	Jan. 4					
	Mar. 25	0.0063	0.0057	0.0081	0.011	0.0075
	June 4			0.011	0.012	
	Oct. 5					0.021
	Nov. 10	0.016		0.0069	0.13	0.014
		<0.1		<0.1	<0.1	<0.1
	Dec. 10					
Nitrate (as N)	Oct. 5					1.8
	Oct. 15			1.4		
	Nov. 10	0.87		<0.5	1.2	1.3
	Dec. 10					
Nitrate plus nitrite (as N)	Mar. 10					
Nitrate plus nitrite (as NO_3)	Jan. 6	2.4		3.1	5.1	3.6
	Feb. 8	1.3	1.5	1.2	6.1	2.2
	Mar. 10					
	Mar. 25	4.4	1.8	3.4	4.3	4.5
	June 4			0.45	0.05	
Nitrite (as N)	Oct. 15			<0.1		
	Nov. 10	<0.1		<0.1	0.12	0.14
	Dec. 10					
Oil and grease	Jan. 6	<5		<5	<5	<5
	Feb. 8	<5	<5	<5	<5	<5
	Mar. 25	<5	<5	5	<5	<5
	June 4			<5	<5	
	Oct. 5					<5
	Oct. 15			<5		
	Nov. 10	<5		<5	<5	<5
	Dec. 10					
pH (units)	Jan. 4					
	Nov. 10	6.7		6.8	8.7	6.9
	Dec. 10					
Potassium	Nov. 10	5.7		1.7	<1	4.3
	Dec. 10					

…continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued)*.

Parameters[a]	Storm date	4THA	ALPE	ALPN	ALPW	ASS2
Silver	Jan. 4					
	Jan. 6	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Feb. 8	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Mar. 10					
	Mar. 25	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	June 4			<0.0005	<0.0005	
	Oct. 5				<0.01	
	Oct. 15				<0.01	<0.01
	Nov. 10		<0.01			<0.01
	Dec. 10					
Sodium	Nov. 10		4.2			5.4
	Dec. 10					
Specific conductance (µmhos/cm)	Jan. 4					
	Nov. 10		80			130
	Dec. 10					
Sulfate	Jane 6	<2	390	<2	<2	<2
	Feb. 8	<2	490	<2	<2	<2
	Mar. 10					
	Mar. 25	<2	250	<2	7.6	4.8
	June 4			35	66	
	Oct. 5 (mg/kg)				17	
	Oct. 15				7.6	10
	Nov. 10		6.7			25
	Dec. 10					
Total alkalinity (as $CaCO_3$)	Jan. 6	11	200	27	15	27
	Feb. 8	8.4	330	45	10	13
	Mar. 25	13	320	44	28	31
	June 4			23	15	
	Oct. 5				43	
	Nov. 10		63			32
	Dec. 10					
Total coliform (MPN/100mL)	Dec. 10					
Total dissolved solids	Jan. 4					
	Nov. 10		66			120
	Dec. 10					

…continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm Date	ASW	B438	CDB	GRNE	WPDC
Silver	Jan. 4					
	Jan. 6	<0.0005		0.0005	<0.0005	<0.0005
	Feb. 8	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	Mar. 10					
	Mar. 25	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	June 4			<0.0005	<0.0005	
	Oct. 5					<0.01
	Oct. 15			<0.01		
	Nov. 10	<0.01		<0.01	<0.01	<0.01
	Dec. 10					
Sodium	Nov. 10	5.2		1.6	17	7.9
	Dec. 10					
Specific conductance (μmhos/cm)	Jan. 4					
	Nov. 10	110		35	94	110
	Dec. 10					
Sulfate	Jan. 6	<2		<2	220	<2
	Feb. 8	<2	<2	<2	33	<2
	Mar. 10					
	Mar. 25	42	<2	<2	170	14
	June 4			59	100	
	Oct. 5 (mg/kg)					26
	Oct. 15			5.5		
	Nov. 10	7.8		2.5	5.2	7.7
	Dec. 10					
Total alkalinity (as $CaCO_3$)	Jan. 6	15		14	170	18
	Feb. 8	11	14	7.2	82	27
	Mar. 25	46	14	18	180	55
	June 4			10	150	
	Oct. 5					72
	Nov. 10	26		9.1	35	24
	Dec. 10					
Total coliform (MPN/100mL)	Dec. 10					
Total dissolved solids	Jan. 4					
	Nov. 10	110		19	85	95
	Dec. 10					

...continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm Date	4THA	ALPE	ALPN	ALPW	ASS2
Total organic carbon[c]	Jan. 4					
	Jan. 6	6.6	17	5.1	5.7	6.3
	Feb. 8	5.6	25	5.6	4.4	3.4
	Mar. 25	9.7	28	8.4	8.6	6.6
	June 4			13	19	
	Oct. 5				98	
	Oct. 15				30	30
	Nov. 10		11			46
	Dec. 10					
Total suspended solids	Jan. 4					
	Nov. 10		1700			230
	Dec. 10					
Zinc	Jan. 4					
	Nov. 10		<0.05			1.8
	Dec. 10					
EPA Method 524.2[d] (µg/L)						
Chloromethane	Jan. 4					
EPA Method 615[e] (µg/L)						
2,4-D	Oct. 5				<10	
	Oct. 15				<5	<5
	Nov. 10		2.6			<1
EPA Method 624[f] (µg/L)						
Acetone	Jan. 6	<5	<5	<5	<5	<5
	Feb. 8	<5	<5	<5	<5	<5
	Mar. 25	<5	<5	<5	<5	<5
	June 4			<5	<5	
	Oct. 5				<10	
	Oct. 15				27	<10
	Nov. 10		<10			18
Chloromethane	Jan. 6	<0.5	<0.5	<0.5	<0.5	<0.5
	Feb. 8	<0.5	<0.5	<0.5	<0.5	<0.5
	Mar. 25	0.5	<0.5	<0.5	<0.5	<0.5
	June 4			<0.5	<0.5	
	Oct. 5				<2	
	Oct. 15				<2	<2
	Nov. 10		<2			<2
Hexanal ($C_6H_{12}O$)	Feb. 8		3			

...continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm date	ASW	B438	CDB	GRNE	WPDC
Total organic carbon[c]	Jan. 4					
	Jan. 6	4.9		5.3	20	4.8
	Feb. 8	4.3	7.6	3.5	11	4.3
	Mar. 25	8.7	8.4	7.5	14	10
	June 4			19	9.6	
	Oct. 5					80
	Oct. 15			30		
	Nov. 10	73		15	7	47
	Dec. 10					
Total suspended solids	Jan. 4					
	Nov. 10	82		210	3300	940
	Dec. 10					
Zinc	Jan. 4					
	Nov. 10	0.33		0.14	<0.05	0.24
	Dec. 10					
EPA Method 524.2[d] (μg/L)						
Chloromethane	Jan. 4					
EPA Method 615[e] (μg/L)						
2,4-D	Oct. 5					<10
	Oct. 15			<2		
	Nov. 10	<1		<1	5.1	<1
EPA Method 624[f] (μg/L)						
Acetone	Jan. 6	<5		<5	<5	<5
	Feb. 8	<5	<5	<5	<5	<5
	Mar. 25	<5	<5	<5	<5	<5
	June 4			<5	<5	
	Oct. 5					<10
	Oct. 15			19		
	Nov. 10	16		<10	<10	17
Chloromethane	Jan. 6	<0.5		<0.5	<0.5	<0.5
	Feb. 8	<0.5	<0.5	<0.5	<0.5	<0.5
	Mar. 25	<0.5	<0.5	<0.5	<0.5	<0.5
	June 4			<0.5	<0.5	
	Oct. 5					<2
	Oct. 15			<2		
	Nov. 10	<2		<2	<2	<2
Hexanal ($C_6H_{12}O$)	Feb. 8					

…continued

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(continued).*

Parameters[a]	Storm date	4THA	ALPE	ALPN	ALPW	ASS2
EPA Method 625[g] (μg/L)						
Bis(2-ethylhexyl)phthalate	Jan. 4					
	Jan. 6	<10	<10	10	<10	<10
	Feb. 8	<10	<10	<10	<10	<10
	Mar. 25	<10	<10	<10	<10	<10
	June 4			<10	<10	
	Oct. 5				<10	
	Oct. 15				<10	<10
	Nov. 10		<10			34
	Dec. 10					
Butylbenzylphthalate	Jan. 4					
	Jan. 6	<3	<3	<3	<3	<3
	Feb. 8	<3	<3	<3	<3	<3
	Mar. 25	<3	<3	<3	<3	<3
	June 4			<3	<3	
	Oct. 5				<10	
	Oct. 15				<10	<10
	Nov. 10		<10			31
	Dec. 10					
$C_{12}H_{18}O_6N_4S$	Jan. 6			10		
$C_{13}H_8ON_2Cl_4$	Jan. 6			10		
C_{16} Fatty acid	Jan. 6					
C_{25}–$C_3$5 Hydrocarbon matrix	Jan. 6	600	300	300	500	
$C_9H_{13}O_2N_2Br$	Jan. 6			80		
Total C_{20}–C_{35} hydrocarbons	Feb. 8					
EPA Method 8015[h] (μg/L)						
C_{10}–C_{22} Hydrocarbons as diesel	Jan. 4					

[a] Other analyses requested EPA Method 504, EPA Method 601, EPA Method 602, and EPA Method 608. However, all values for those analyses were below detection limits. EPA Method 504 includes 1,2-dibromo-3-chloropropane and ethylene dibromide. EPA Method 601 includes 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-chloroethylvinylether; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,3-dichloropropene; dibromochloromethane; dichlorodifluoromethane; Freon-113; methylene chloride; tetrachloroethene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; and vinyl chloride. EPA Method 602 includes 1,2-dichlorobenzene; 1,3-dichlorobenzene; 1,4-dichlorobenzene; benzene; chlorobenzene; ethylbenzene; toluene; and total xylene isomers. EPA Method 608 includes 2,4,5-tp (Silvex); 2,4-d; Aldrin; bhc, alpha isomer; bhc, beta isomer; bhc, delta isomer; bhc, gamma isomer (Lindane); chlordane; dieldrin; endosulfan i; endosulfan ii; endosulfan sulfate; endrin; endrin aldehyde; heptachlor; heptachlor epoxide; methoxychlor; p,p'-ddd; p,p'-dde; p,p'-ddt; and toxaphene.

[b] Other metals and minerals for which analysis was performed include beryllium, bromide, hexavalent chromium, hydroxide alk (as $CaCO_3$), selenium, surfactant, thallium, total phosphate, and total phosphorus (as P).

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 (*continued*).

Parameters[a]	Storm date	ASW	B438	CDB	GRNE	WPDC
EPA Method 625[g] (µg/L)						
Bis(2-ethylhexyl)phthalate	Jan. 4					
	Jan. 6	<10		<10	<10	<10
	Feb. 8	<10	<10	<10	<10	<10
	Mar. 25	<10	<10	<10	<10	<10
	June 4			<10	<10	
	Oct. 5					<10
	Oct. 15			<10		
	Nov. 10	12		<10	<10	13
	Dec. 10					
Butylbenzylphthalate	Jan. 4					
	Jan. 6	<3		<3	<3	<3
	Feb. 8	<3	<3	<3	<3	<3
	Mar. 25	<3	<3	<3	<3	<3
	June 4			<3	<3	
	Oct. 5					<10
	Oct. 15			<10		
	Nov. 10	<10		<10	<10	<10
	Dec. 10					
$C_{12}H_{18}O_6N_4S$	Jan. 6					
$C_{13}H_8ON_2Cl_4$	Jan. 6					
C_{16} Fatty acid	Jan. 6	5				
C_{25}–$C_{3}5$ Hydrocarbon matrix	Jan. 6	400		400		600
$C_9H_{13}O_2N_2Br$	Jan. 6					
Total C_{20}–C_{35} hydrocarbons	Feb. 8		700			1000
EPA Method 8015[h] (µg/L)						
C_{10}–C_{22} Hydrocarbons as diesel	Jan. 4					

[c] Average of total organic carbon replicate samples taken.

[d] Other EPA Method 524.2 analytes for which analyses were performed include 1,1,1,2-tetrachloroethane; 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,1-dichloropropene; 1,2,3-trichlorobenzene; 1,2,3-trichloropropane; 1,2,4-trichlorobenzene; 1,2,4-trimethylbenzene; 1,2-dibromo-3-chloropropane; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloropropane; 1,3,5-trimethylbenzene; 1,3-dichlorobenzene; 1,3-dichloropropane; 1,4-dichlorobenzene; 2,2-dichloropropane; 2-chlorotoluene; 4-chlorotoluene; benzene; bromobenzene; bromochloromethane; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dibromomethane; dichlorodifluoromethane; ethylbenzene; ethylene dibromide; hexachlorobutadiene; isopropylbenzene; m- and p-xylene isomers; methylene chloride; n-butylbenzene; n-propylbenzene; naphthalene; o-xylene; p-isopropyl toluene; sec-butylbenzene; styrene; tert-butylbenzene; tetrachloroethene; toluene;trans-1,2-dichloroethylene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; and vinyl chloride. However, all values for those analyses were below detection limits.

Table 6-5. LLNL storm water runoff, nonradioactive parameters, 1993 *(concluded).*

[e] Other EPA Method 615 analytes for which analyses were performed include 2,4,5-T; 2,4,5-TP (Silvex); 4-(2,4-dichlorophenoxy)butyric acid; dalapon; dicamba; dichloroprop; dinoseb; MCPA; and MCPP. However, all values for those analyses were below detection limits.

[f] Other EPA Method 624 analytes for which analyses were performed include 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-butanone; 2-chloroethylvinylether; 2-hexanone; 4-methyl-2-pentanone; acrolein; acrylonitrile; benzene; bromodichloromethane; bromoform; bromomethane; carbon disulfide; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dibromomethane; dichlorodifluoromethane; ethylbenzene; Freon-113; methyl ethyl ketone; methylene chloride; styrene; tetrachloroethene; toluene; total xylene isomers; trans-1,2-dichloroethylene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; vinyl acetate; and vinyl chloride. However, all values for those analyses were below detection limits.

[g] Other EPA Method 625 analytes for which analyses were performed include 1,2,4-trichlorobenzene; 1,2-dichlorobenzene; 1,2-diphenylhydrazine; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2,4,5-trichlorophenol; 2,4,6-trichlorophenol; 2,4-dichlorophenol; 2,4-dimethylphenol; 2,4-dinitrophenol; 2,4-dinitrotoluene; 2,6-dinitrotoluene; 2-chloronaphthalene; 2-chlorophenol; 2-methyl phenol; 2-methyl-4,6-dinitrophenol; 2-methylnaphthalene; 2-nitroaniline; 2-nitrophenol; 3,3'-dichlorobenzidine; 3-nitroaniline; 4-bromophenylphenylether; 4-chloro-3-methylphenol; 4-chloroaniline; 4-chlorophenylphenylether; 4-methyl phenol; 4-nitroaniline; 4-nitrophenol; acenaphthene; acenaphthylene; aniline; anthracene; benzidine; benzo(a)anthracene; benzo(a)pyrene;benzo(b)fluoranthene; benzo(g,h,i)perylene; benzo(k)fluoranthene; benzoic acid; benzyl alcohol; bis(2-chloroethoxy)methane; bis(2-chloroethyl)ether; bis(2-chloroisopropyl)ether; chrysene; di-n-butylphthalate; di-n-octylphthalate; dibenzo(a,h)anthracene; dibenzofuran; dibutylphthalate; diethylphthalate; dimethylphthalate; fluoranthene; fluorene; hexachlorobenzene; hexachlorobutadiene; hexachlorocyclopentadiene; hexachloroethane; indeno(1,2,3-c,d)pyrene; isophorone; m- and p- cresol; n-nitrosodi-n-propylamine; n-nitrosodimethylamine; n-nitrosodiphenylamine; naphthalene; nitrobenzene; pentachlorophenol; phenanthrene; phenol; and pyrene. However, all values for those analyses were below detection limits.

[h] Other EPA Method 8015 analytes for which analyses were performed include C25-C35 hydrocarbon matrix; C_6 to C_{14} hydrocarbons-as-gasoline; diesel fuel; and gasoline fingerprint. However, all values for those analyses were below detection limits.

Table 6-6. Quarterly radioactivity in surface water (in Bq/L), Site 300, 1993.

	Sampling location[a]		
	GEOCRK	**RAIN**	**812CRK**
Tritium			
1st Quarter	1.14 ± 0.135	0.773 ± 0.119	0.292 ± 0.108
		0.870 ± 0.167	
		0.770 ± 0.124	
2nd Quarter	0.844 ± 0.104	0.714 ± 0.145	0.231 ± 0.066
		0.796 ± 0.123	
3rd Quarter	0.773 ± 0.154	—[b]	0.306 ± 0.122
4th Quarter	0.770 ± 0.149	0.744 ± 0.133	< 0.115
Gross alpha			
1st Quarter	0.129 ± 0.141		0.074 ± 0.103
2nd Quarter	0.128 ± 0.137		0.304 ± 0.124
3rd Quarter	0.120 ± 0.049		0.189 ± 0.026
4th Quarter	0.115 ± 0.015		0.232 ± 0.029
Gross beta			
1st Quarter	0.258 ± 0.094		0.244 ± 0.053
2nd Quarter	0.238 ± 0.078		0.040 ± 0.116
3rd Quarter	0.309 ± 0.031		0.307 ± 0.016
4th Quarter	0.321 ± 0.303		0.337 ± 0.017

[a] See Fig. 6-4 for sampling locations.

[b] No rain event this quarter.

7. Routine Ground Water Monitoring

Eric Christofferson

Introduction

Lawrence Livermore National Laboratory routinely monitors ground water in the Livermore Valley and at Site 300 in the Altamont Hills in order to detect and quantify any impacts of past and present Laboratory operations on water supplies. Routine ground water monitoring consists of surveillance monitoring and compliance monitoring. Area-wide surveillance monitoring is directed by DOE Orders 5400.1 and 5400.5. Additionally, DOE provides direction on radiological effluent monitoring in document DOE/EH-0173T (U.S. Department of Energy 1991). For surveillance monitoring purposes, the number and locations of sampling wells, the constituents to be monitored, and the frequency of sampling are prerogatives of LLNL. This allows LLNL to devise a comprehensive, cost-effective monitoring program. Fewer options are available to LLNL with regard to compliance ground water monitoring. Compliance monitoring requirements are specifically prescribed in Waste Discharge Requirements permits (WDRs) issued by the State of California Regional Water Quality Control Boards. The WDRs specify the wells to be monitored, the constituents to be measured, the frequency of measurement for each constituent of concern, and the frequency and form of required reports. Much of the data presented and discussed in this chapter are related to compliance monitoring activities at Site 300, LLNL's Experimental Test Site. These compliance data were previously submitted to the Central Valley Regional Water Quality Control Board in four quarterly reports covering the 1993 calendar year (Christofferson etal. 1993a, b, and 1994; Fisher et al. 1993).

To meet the intent of DOE orders and WDR permits, LLNL monitors tritium activity in ground water in the Livermore Valley and at Site300.Ground waters are sampled both from potable water supply wells and from wells that are used only for monitoring purposes.

Additional potential contaminants to ground water are monitored at Site 300, where compliance monitoring is associated with two Resource Conservation and Recovery Act (RCRA)-closed landfills, known as Pit 1 and Pit 7, and with two process water impoundments. Compliance monitoring is accomplished by measuring numerous specified constituents of concern and general contaminant indicator parameters. The sampled ground waters come from specific wells upgradient and downgradient from the landfills and the process water impoundments. Additionally, lysimeters that were placed beneath the process water impoundment liners to detect leakage are tested quarterly for the presence of water.

Surveillance monitoring at Site300 utilizes both on-site and off-site wells. Depending on their location and purpose, well waters at Site 300 are sampled monthly, quarterly, or annually and are analyzed for gross radioactivity, certain radioisotopes, and a wide range of nonradioactive inorganic and organic constituents of concern.

Surveillance Monitoring of the Livermore Valley

Potable Water Supply Wells and Irrigation Monitoring Wells

Rain and storm water runoff in the Livermore Valley recharge local aquifers. Rain and runoff contain small amounts of tritium from natural sources, from past atmospheric tests of nuclear weapons, and from atmospheric emissions from LLNL and Sandia National Laboratories, California (SNL/CA)—see Chapter 4 on Air Monitoring for further discussion on air emissions. A fraction of treated effluent from the City of Livermore Water Reclamation Plant (LWRP) is used to irrigate nearby municipal land. This effluent also contains low levels of tritium from natural sources and from permitted operational releases to the sanitary sewer system by LLNL and SNL/CA (total radionuclides in liquid effluents are limited to 3.7×10^{10} Bq [1 Ci] per year; see Chapter 5 for details of sanitary sewer releases). The Livermore Valley floor slopes westward, which directs surface stream flow and ground water flow generally to the west. Since 1977, annual tritium measurements have been made on water samples collected from monitoring wells and drinking water wells downgradient from LLNL to determine the extent of tritium migration into the ground from the LWRP irrigation water, from tritium washed out of the atmosphere by rain, and from tritium in storm water runoff that flows through the Arroyo Las Positas and recharges local aquifers (**Figure 7-1**).

Compliance Ground Water Monitoring at Site 300

Site 300, the LLNL Experimental Test Site, is located in the Altamont Hills approximately 15 kilometers southwest of the city of Tracy. Compliance ground water monitoring at Site 300 is governed by two Waste Discharge Requirements permits, WDR No. 85-188 and WDRNo. 93 -100 (CVRWQCB 1985; 1993) and a RCRA post-closure monitoring plan (Rogers/Pacific Corporation 1990). Compliance monitoring involves analyses of water samples drawn from 23wells associated with two closed landfills and two active process water impoundments. **Figure 7-2** shows the test site and locates closed landfills (pits), the two process water surface impoundments, and all of the on-site and off-site surveillance wells. A brief description of these areas and associated wells follows. A complete description of the stratigraphy and hydrogeologic

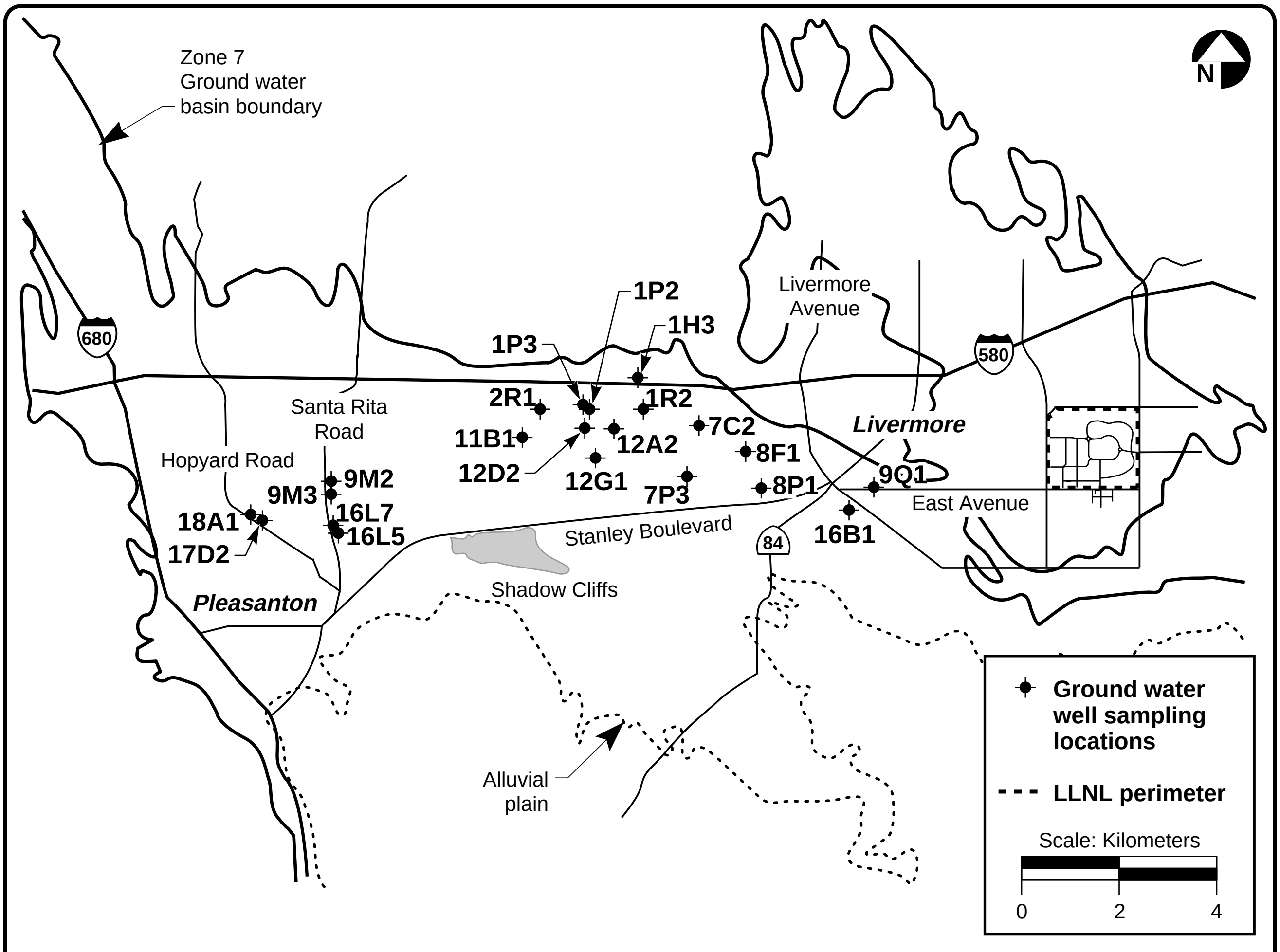

Figure 7-1. Ground water well sampling locations, Livermore Valley, 1993.

conditions at Site 300 can be found in the *Final Site-Wide Remedial Investigation* report (Webster-Scholten 1994), hereafter referred to as the Final SWRI report.

Pit 1 Area

Figure 7-3 shows the locations of Pit 1, the monitoring wells, an adjacent inactive landfill identified as Pit 2, and the Advanced Test Accelerator (ATA). Pit1 lies in the upper part of the Elk Ravine drainage area at an elevation of 330meters above sea level. Although the test site is in 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 discharged runoff flows to Elk Ravine. Subsurface water flow beneath Pit 1 is east-northeasterly and generally follows the dip of the underlying sedimentary rocks. Compliance monitoring wells K1-01C and K1-07 are hydrologically upgradient from Pit 1; K1-02B, K1-03,

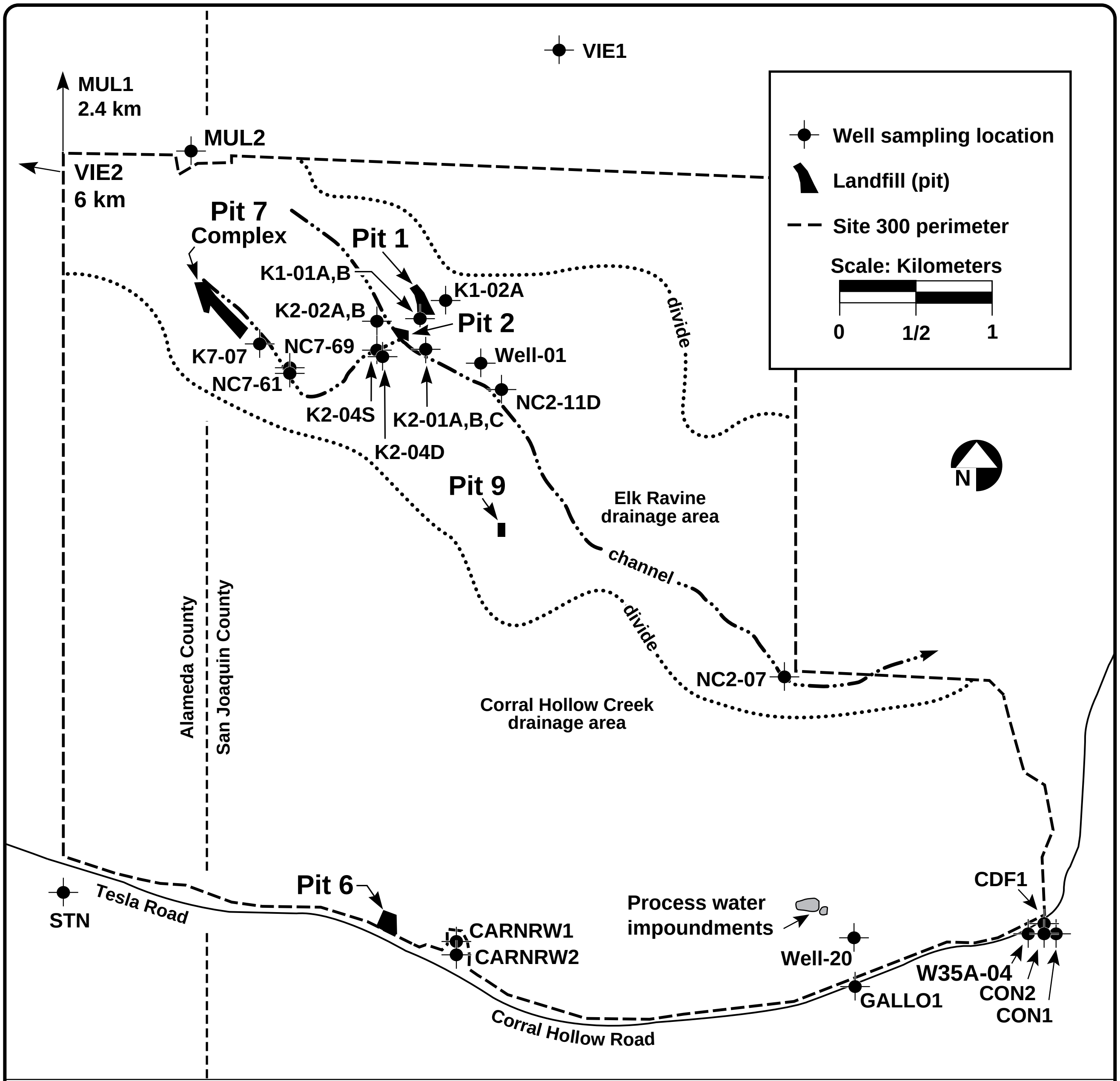

Figure 7-2. Site 300 and vicinity surveillance wells and pits.

K1-04, and K1-05 are downgradient; and K1-08 and K1-09 are cross-gradient. Pit2 is hydrologically upgradient from Pit 1 with respect to subsurface water flow, although it is downgradient from Pit 1 with respect to rain runoff into Elk Ravine. The ATA is upgradient from Pit 1 monitoring wells K1-05, K1-08, and K1-09.

The Pit 1 monitoring wells are completed near or at the contact between the Tertiary Neroly Formation lower blue sandstone member and the underlying

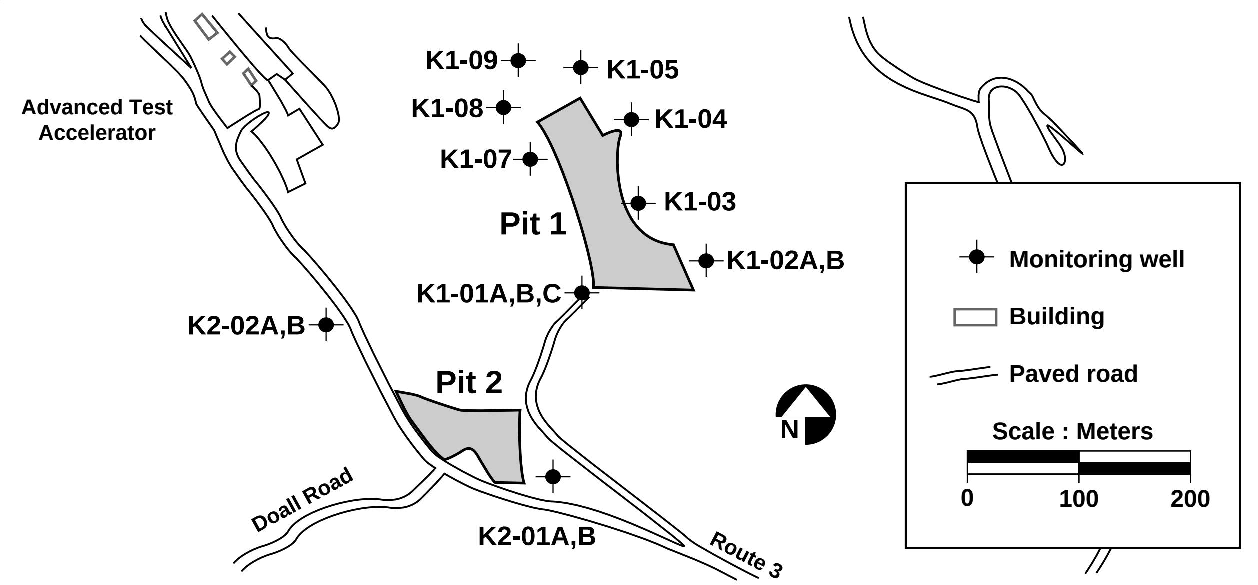

Figure 7-3. Pit 1 compliance wells and Pit 2 surveillance wells.

Mid-Miocene Cierbo Formation consisting of claystones and siltstones. The Tertiary Neroly and Cierbo sedimentary rock formations are the main water-bearing strata beneath the test site.

Pit 7 Complex Area

Nine wells monitor the Pit7 Complex, consisting of three inactive landfills (Pits3, 4, 5) and one closed RCRA landfill (Pit 7; **Figure7 -4**). The complex of closed landfills lies in the uppermost reaches of the Elk Ravine drainage area at an elevation of 425 meters above sea level. To combat erosion and to reduce local recharge, rain runoff from the Pit 7 RCRA cap is collected in several concrete channels. Pit 7 is nearly encircled by one concrete channel that collects rain runoff from the pit cap and directs it southeasterly into the Elk Ravine drainage system. An additional concrete channel lies to the west of Pit 7. Runoff entering this northerly directed diversion channel is sheet flow that develops on the hill slope immediately west of Pit 7. Subsurface water can flow in two directions through this area. With sufficient seasonal rainfall, a shallow, unconfined, southeastward flow can develop that follows the direction of thickening of the unconsolidated surficial Quaternary alluvial deposits. The predominant ground water flow, however, is east-northeasterly within the underlying Tertiary sedimentary rocks of the Neroly and Cierbo formations that dip east-northeast in this area. With respect to Pit7 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

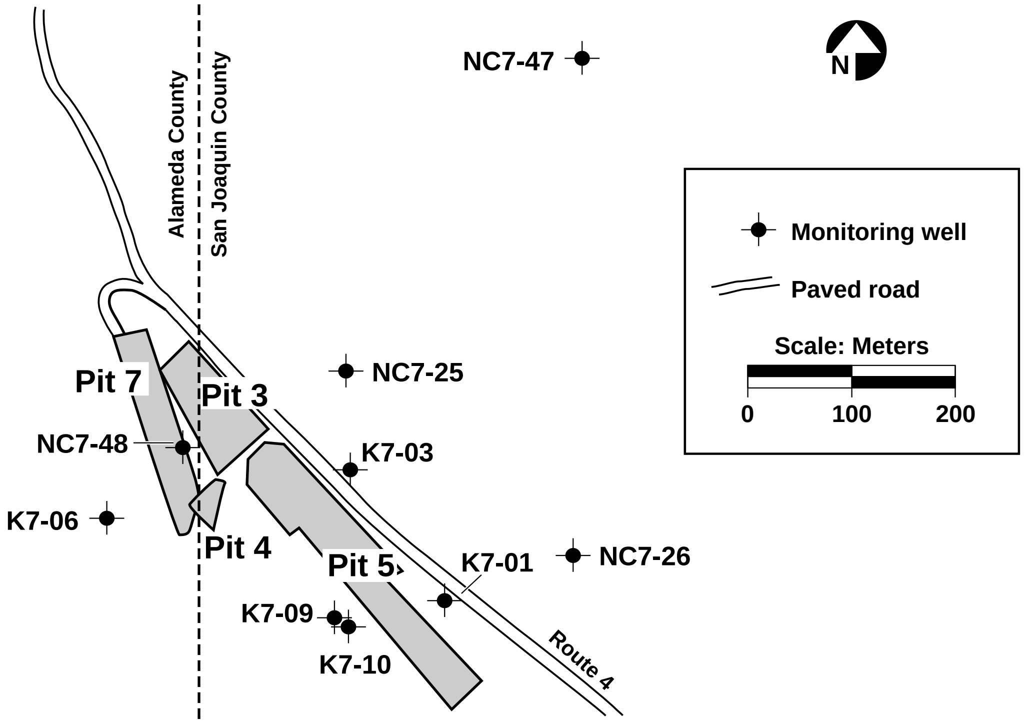

Figure 7-4. Pit 7 Complex compliance wells.

Formation that underlies much of the Pit 7 complex. The remaining wells are completed at the base of, or below, the Neroly and within the claystone and sandstone Mid-Miocene Cierbo Formation.

HE Process Area

Figure 7-5 shows the portion of the High Explosives (HE) Process Area that includes Building 817 (B-817), the two process water impoundments, and the five compliance monitoring wells. Compliance monitoring of the two impoundments to detect any release of process water to ground is specified in permit WDR No.85-188 issued by the Central Valley Regional Water Quality Control Board (CVRWQCB 1985). Not shown in **Figure 7-5** are the locations of six lysimeters that are installed between two impermeable liners beneath the process water impoundments. Three operational lysimeters are positioned beneath each of the two impoundments. Their primary purpose is leak detection. In addition to lysimeters, four compliance monitoring wells are completed in the underlying Neroly upper blue sandstone, a water-bearing formation. A fifth compliance monitoring 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

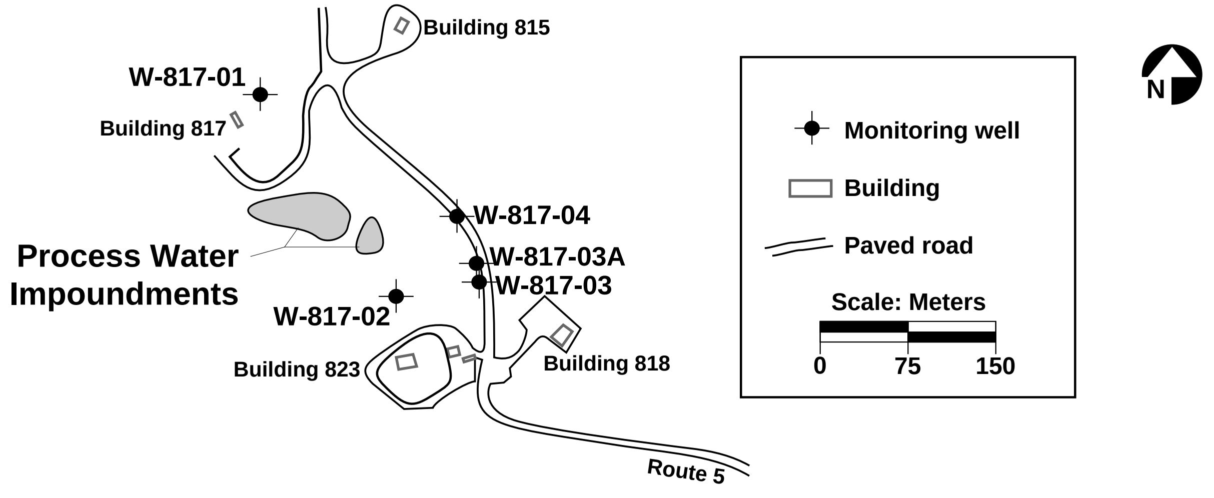

Figure 7-5. HE Process Area compliance wells.

perched water-bearing zone that is very restricted laterally and vertically. The direction of water flow in both formations is approximately south-southeasterly. Well W-817-01 is an upgradient well with respect to the impoundments. Wells W-817-02, -03, -03A, and -04 are downgradient wells.

Surveillance Ground Water Monitoring at Site 300

Thirty-five ground water wells are monitored at Site300 as part of the ground water surveillance program (**Figure 7-2**). Twenty-three wells are on site and twelve are off site. Methods of sampling and analysis are the same for surveillance wells and compliance monitoring wells, but the constituents monitored and the frequency of sampling may differ. Four of the twelve off-site surveillance wells are located next to Site 300 on the north where the Altamont Hills slope down to the San Joaquin Valley. The remaining eight off-site surveillance wells are located next to Site 300 on the south in the Corral Hollow Creek drainage area. Twelve of the twenty-three on-site surveillance wells are clustered about inactive landfill pits. Six wells monitor Pit 6 (**Figure 7-6**). Four wells monitor Pit 9 (**Figure7 -7**). Three multiple completion wells monitor Pit 2 (**Figure 7-3**). Nine of the ten remaining surveillance wells are strewn along the system of fault-marked ravines and valleys that comprise the Elk Ravine drainage area (**Figure 7-2**). Well 20 is a production well that provided potable water to Site 300 during 1993 (**Figure 7-2**). The wells are described below. A more complete description of the stratigraphy and the hydrogeologic conditions beneath the wells can be found in the Final SWRI report (Webster-Scholten 1994).

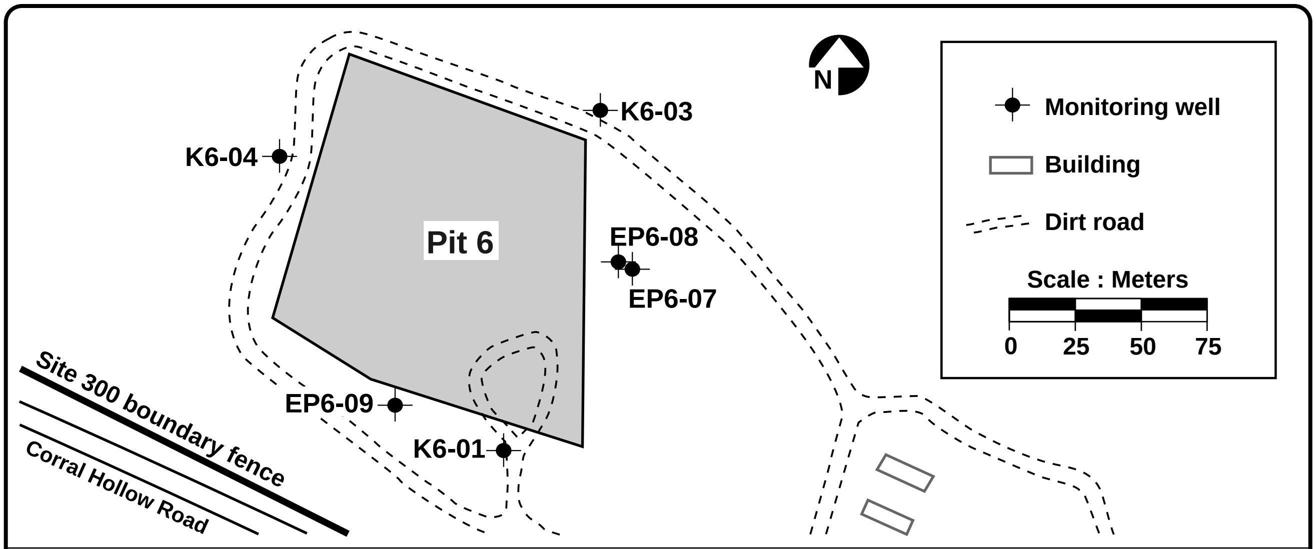

Figure 7-6. Pit 6 surveillance wells.

Pit 2

The inactive Pit 2 landfill lies in the upper portion of Elk Ravine at 320meters above sea level (**Figure 7-3**). 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, shown in **Figure 7-3**, 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, which is an upgradient monitoring point for Pit 1, by Barcad K1-01C. 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.

Pit 9

Inactive landfill Pit 9 is centrally located within Site 300 at an elevation of 340 meters 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. Surveillance 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 in the Neroly lower blue sandstone at its contact with the underlying Cierbo Formation. Wells K9-01, K9-03, and K9-04 are completed in the Cierbo Formation, just below its contact with the Neroly Formation.

Elk Ravine Drainage Area

The Elk Ravine drainage area includes most of northern Site 300, the area between the drainage divides shown on **Figure 7-2.** This semiarid area collects rare surface runoff from inactive landfill Pits 1, 2, 3, 4, 5, 7, 8, and 9. Surface runoff from the Pit 7 Complex area flows southeastward to Doall Road where it is deflected northeastward into Doall Ravine by a colluvial landslide deposit. At the northeastern end of Doall Ravine, the runoff combines with channeled runoff from the Advanced Test Accelerator area. From this confluence point the dry streambed 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 kilometers to its confluence with Corral Hollow Creek. Except for Doall Ravine, the runoff channels often traverse faults 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 within the drainage area) K7-07, NC7-61, NC7-69, K2-04D, K2-04S, K2-01C, Well 01, NC2-11D, andNC2-07. Individual wells are discussed below (see also the Methods and Results sections).

Well K7-07 is a shallow well, completed in the upper Neroly lower blue sandstone and the overlying Quaternary alluvium. The well had sufficient water for sampling and analysis only during the first two quarters of 1993. Wells NC7-61 and NC7-69 sample separate water-bearing zones beneath the upper reach of Doall Ravine, downstream from well K7-07. Well NC7-61 is completed in the shallower Neroly Formation lower blue sandstone and Well NC7-69 is completed in the deeper Cierbo Formation. Wells K2-04D, K2-04S, and Barcad K2-01C are located near the join between Elk Ravine and Doall Ravine. They are all completed in the upper Neroly Formation lower blue sandstone. Wells 01 and NC2-11D are located in Elk Ravine below its join with Doall Ravine. Formerly a drinking water production well, well 01 is now an emergency fire-suppression water well and is completed in the Neroly Formation lower blue sandstone. Well NC2-11D is completed at the boundary between the Cierbo and the overlying Neroly formations. The farthest downstream on-site well in the Elk Ravine drainage area is well NC2-07. It is completed in the Neroly Formation lower blue sandstone.

Pit 6

The inactive Pit 6 landfill is positioned along the southern boundary of Site300 at an elevation of 210 meters above sea level (**Figure 7-2**). It lies in Quaternary terrace deposits above and north of the Corral Hollow Creek floodplain. 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.

Six wells comprise the surveillance monitoring network at closed landfill Pit6 (**Figure 7-7**). Well K6-03 is hydrologically upgradient from Pit 6 and is completed 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 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 Pit6 and are completed in the vertically dipping Tertiary sedimentary rocks.

Well 20

This well supplied most of the potable water to Site300 during 1993. It is a deep, high production well that is completed in the Tertiary Neroly Formation lower blue sandstone. The well can produce up to 1500 liters of water per minute. Complete geologic and hydrogeologic information about well 20 is contained in the Final SWRI report (Webster-Scholten 1994).

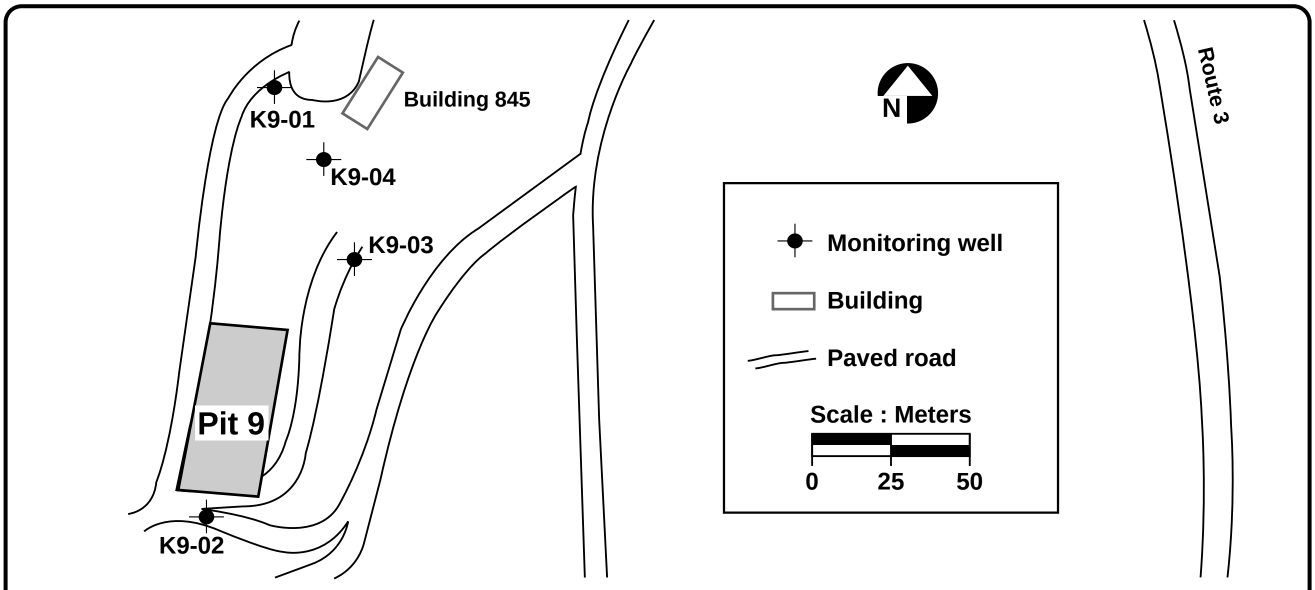

Figure 7-7. Pit 9 surveillance wells.

Off-Site Supply Wells

Twelve off-site potable water supply wells near Site300 were tested during 1993 as part of the Site 300 surveillance monitoring program. Four wells, MUL1, MUL2, VIE1, and VIE2, lie to the north of Site 300. Wells CARNRW1, CARNRW2, CDF1, CON1, CON2, GALLO1 STN, and W-35A-04 are located to the south of the test site (**Figure7-2**).

Methods

Livermore Valley Wells

Figure7-1 shows the locations of 21 ground water wells in the Livermore Valley that were sampled once during 1993 and analyzed for tritium activity. The wells are all hydrologically downgradient from LLNL and are located within the Alameda County Zone 7 Flood Control and Water Conservation District. Ten of the wells monitor ground water beneath municipal land near the Livermore Water Reclamation Plant (LWRP), where reclaimed water is used for irrigation. These monitoring-only wells are identified in **Figure 7-1** as 1H3, 1P2, 1P3, 1R2, 2R1, 7C2, 11B1, 12A2, 12D2, and 12G1. Five drinking water supply wells serving the City of Livermore were sampled and analyzed for tritium activity. These are identified as 7P3, 8F1, 8P1, 9Q1, and 16B1. Six drinking water supply wells serving the City of Pleasanton were sampled. These are identified as 9M2, 9M3, 16L5, 16L7, 17D2, and 18A1. Water samples for tritium analysis are collected in 250-milliliter, argon-flushed glass bottles. Measurements are made by LLNL using a liquid scintillation counting method with a detection limit of 1.85 Bq/L (50pCi/L). Samples with expected tritium activities below this detection limit may be concentrated by as much as fifty times using a method of electrolytic enrichment, resulting in a detection limit of 0.037Bq/L (1pCi/L). Four 50-minute counting intervals are used for all sample measurements.

Site 300 Pit 1 and Pit 7 Areas

Compliance monitoring of Pit 1 and Pit 7 changed during 1993 due to official RCRA-closure of these inactive landfills in February and the adoption in June of a new WDR permit, WDR No. 93-100, that was issued by the Central Valley Regional Water Quality Control Board (CVRWQCB 1993). Compliance ground water monitoring for the first three quarterly reporting periods in 1993 was conducted according to an Interim Status Document (California Department of Health Services 1981), an older WDR permit, WDR No. 80-184 (CVRWQCB 1980), and a post-closure monitoring plan (Rogers/Pacific Corporation 1990). LLNL began the new monitoring, analyses, and reporting required by WDR No. 93-100 on October1, 1993.

The WDR No. 93-100 permit for Pit 1 and Pit 7 requires measurements of general contaminant indicator parameters (pH, specific conductance, total organic carbon [TOC], and total organic halides [TOX]), as well as “specified constituents of concern,” including radioisotopes, which are identified as having been disposed of in Pit 1 or in Pit7. **Table7-1** lists the constituents of concern and their prescribed limits, which, if exceeded, require that the CVRWQCB be notified within seven days of the finding. The concentration limits for several new constituents of concern, such as cobalt and thorium, are to be statistically determined from 12 monthly measurements made over a one-year period in order to establish baseline data for comparison with future measurements (“TBD” in **Table 7-1**).

In order to obtain a representative sample from a water-bearing zone, wells are typically purged of stagnant water prior to sampling. All sampling equipment is maintained so that it does not contaminate the water sample. Containers and preservatives are used according to established protocols for the analytes of interest. Most of the analytical measurements are performed for LLNL by contract laboratories. Exceptions are water table elevation, water temperature, and tritium activity. **Tables 7-2** and **7-3** list the standard EPA methods used to measure various inorganic and organic constituents of concern that may be dissolved in ground water.

Pit 1 ground water samples were analyzed for constituents fulfilling the requirements of WDR No. 93-100 and a post-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 compounds HMX and RDX; general minerals; TOC; TOX; radioactivity (gross alpha and gross beta); radioisotopes of hydrogen (tritium), uranium, and thorium; herbicides and pesticides (EPA Methods 615 and 608); purgeable organic compounds (EPA Method 624); and extractable organic compounds (EPA Method 625).

Pit 7 ground water samples were also analyzed for constituents fulfilling the requirements of WDR No. 93-100 and a post-closure monitoring plan. Measurements were performed for water-table elevation; TDS; specific conductance; temperature; pH; metals; radioisotopes of hydrogen (tritium), radium, uranium and thorium; high-explosive compounds HMX and RDX; and a wide range of organic compounds.

HE Process Area

As required by the WDR No. 85-188 permit, the lysimeters underlying the process water surface impoundments in the B-817 HE Process Area were tested quarterly during 1993 for the presence of water.

Ground water samples were collected quarterly during 1993 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, minerals, TOC, TOX, pH, specific conductance, high-explosive compounds (RDX, HMX, and TNT), volatile organic compounds, and tritium. Samples from the shallow well W-817-03A were analyzed for volatile organic compounds, high-explosive compounds, and tritium.

Pit 2

Samples from the Barcad-fitted multiple completions were taken quarterly during 1993 and were analyzed for various metals; radioactivity (gross alpha and gross beta);and radioisotopes of hydrogen (tritium), radium (^{226}Ra), and uranium (^{234}U, ^{235}U, ^{238}U).

Pit 9

Pit 9 surveillance monitoring wells were sampled and analyzed once during 1993 forgeneral contaminant indicator parameters, general minerals, metals, radioactivity, radioisotopes, and a wide range of organic compounds, including pesticides and herbicides.

Elk Ravine Drainage Area

Ground water samples from all wells were analyzed for various metals, including beryllium (except NC2-07), radioactivity (gross alpha and gross beta), tritium activity, and volatile organic compounds (EPA Method 601). Samples from wells K7-07, NC7-61, and NC7-69 were additionally analyzed for uranium isotopes (^{234}U, ^{235}U, and ^{238}U). Samples from wells K2-04D, K2-04S, and K2-01C were additionally analyzed for nitrogen compounds. Samples from well K7-07 were additionally analyzed for barium, vanadium, and purgeable organic compounds (EPA Method 624).

Pit 6

Ground water samples from the Pit 6 surveillance wells were analyzed for metals; general minerals; organic compounds, including purgeable organic compounds (EPA Method 601), herbicides (EPA Method 615), and pesticides (EPA Method 608); the general contamination indicator parameters pH, specific conductivity, TOC, and TOX; radioactivity (gross alpha and gross beta); and radioisotopes of hydrogen (tritium), radium (^{226}Ra), and uranium (^{234}U, ^{235}U, ^{238}U). Quarterly sampling of Pit 6 surveillance wells was changed to semiannual sampling during the third quarter of 1993.

Well 20

Quarterly samples taken from this drinking water production well during 1993 were analyzed for the metals beryllium, chromium, copper, and lead; for gross alpha and gross beta radioactivity; and for tritium activity. Monthly well samples were also taken and were analyzed for volatile organic compounds using EPA Method 502.2 or 524.2.

Off-Site Water Supply Wells

Six wells were sampled quarterly during 1993. Of these, CARNRW1 and CON2 were tested for volatile organic compounds only (EPA Method 601), while CARNRW2, CDF1, CON1, and GALLO1 were tested for a large suite of inorganic and organic compounds. The remaining six wells, MUL1, MUL2, STN, VIE1, VIE2, and W-35A-04, were tested once during 1993 for a large suite of inorganic and organic compounds. All wells, except CARNRW1 and CON2, were tested at least once during 1993 for high-explosive compounds (HMX, RDX, and TNT), radioactivity (gross alpha and gross beta), and tritium activity.

Results

Livermore Valley Wells

Tritium activity measurements of water samples collected once during 1993 from 21 wells in the Livermore Valley are given in **Table 7-4**. Tritium activity levels measured in all well samples were very low compared to the EPA maximum contaminant level (MCL) for tritium activity in drinking water, which is 740 Bq/L (20,000 pCi). As in previous years, the highest tritium activity measured, 16.5 Bq/L (445 pCi/L), was in a water sample from irrigation monitoring well 11B1. The activity is essentially unchanged from 1992 when it measured 17.0Bq/L (460pCi/L). However, tritium activity in well 11B1 has decreased 23% since 1991, when it measured 23.4 Bq/L (630 pCi/L).

Site 300 Pit 1 Area

The results of analyses conducted on ground water samples taken from Pit1 compliance monitoring wells during 1993 are given in **Table 7-5**. As a result of new reporting requirements under WDR No. 93-100, LLNL notified the Central Valley Regional Water Quality Control Board (CVRWQCB) regarding “statistically significant evidence of a release” of uranium from Pit 1. However, the evidence does not indicate that such a release occurred during 1993.

Tritium activity has steadily increased in ground water samples from downgradient monitoring well K1-02B since 1989. It reached 130 Bq/L (3500pCi/L) in the fourth quarter of 1993. However, the tritium does not appear to originate from Pit 1. Most likely, the tritium signals the arrival of a plume of tritium-bearing ground water that is spreading northeastward from an upgradient source near Building 850 in the West Firing Area. This plume is described in the Final SWRI report (Webster-Scholten 1994). Historical ground water measurements for upgradient well K1-01C show slightly increasing tritium activities since 1991. Future elevated tritium activity in samples from this upgradient well would demonstrate that tritium-bearing ground water has been entering the Pit 1 area from an external source.

Since 1989, the specific conductance has remained steady in ground water samples from downgradient well K1-02B, while it uniformly decreased in the other wells of the Pit 1 monitoring network. The reasons for this shift are unknown but correlate with different concentrations of dissolved calcium, chloride, and sulfate in the ground water samples (Fischer et al. 1992). Under the new reporting requirements of WDR No. 93-100, this anomaly of specific conductance constituted “statistically significant evidence of a release “from Pit 1 and was reported to the CVRWQCB. However, the steady specific conductance at well K1-02B is more simply correlated with the tritium-bearing water that is flowing into the area from the southwest, as discussed above.

Under the new reporting requirements of WDRNo. 93 -100, a fourth quarter ^{235}U activity measurement of 0.009 Bq/L (0.24 pCi/L) in a sample from cross-gradient well K1-08 exceeded the 0.007 Bq/L (0.20 pCi/L) concentration limit (CL) and was reported to the CVRWQCB as statistical evidence of a release from Pit 1 even though this activity is within background levels and a release was unlikely. Uranium isotope activities in ground water samples collected from the upgradient monitoring well K1-01C have doubled since 1988 and now approach the CLs set for these isotopes in the WDR permit. It is possible that this upgradient water with a higher uranium content has reached well K1-08. Alternatively, the higher activity may be due to measurement error.

Measurements of low concentrations of ^{235}U by alpha spectroscopy show considerable variability between duplicate samples and between successive water samples taken from monitoring wells. Two subsequent measurements, 0.007Bq/L and 0.002Bq/L, for ^{235}U activity in samples from well K1-08 illustrate the high degree of variability in the alpha spectroscopy measurements. As allowed in the WDR No. 93-100 permit after the first year of monitoring, LLNL will propose revised uranium isotope CLs for Pit 1, based on new statistical analyses of increased uranium activities in the upgradient monitoring wells.

Gross alpha, gross beta, total uranium, radium, and tritium activities measured in water samples taken from Pit 1 compliance monitoring wells were all low and were indicative of natural background levels. The highest values, except for tritium, were measured in water samples taken from upgradient monitoring well K1-01C. The highest tritium value, 130 Bq/L (3500 pCi/L), was measured in a water sample from downgradient well K1-02B and is equal to 18% of the 740 Bq/L (20,000 pCi/L) drinking water MCL; the highest measured gross alpha value, 0.3 Bq/L (8 pCi/L), is equal to 54% of the 0.56 Bq/L (15 pCi/L) drinking water MCL; the highest measured gross beta value, 0.2 Bq/L (5.2pCi/L), is equal to 10% of the 1.85 Bq/L (50 pCi/L) MCL; the highest measured total uranium value, 0.36 Bq/L (9.9pCi/L), is equal to 50% of the 0.74Bq/L (20 pCi/L) MCL; and the highest measured radium value, 0.02 Bq/L (0.6pCi/L), is equal to 12% of the 0.19 Bq/L (5 pCi/L) MCL.

The compound 1,1,2-trichloro-1,2,2-trifluoroethane, commonly known as Freon-113, was detected during 1993 far below the California State Action Level of 1200 µg/L in ground water samples from wells K1-05, K1-08, and K1-09. These wells have a five-year history of Freon-113 detections. However, Pit 1 has no record of Freon disposal. The Pit 1 wells that yield ground water samples containing this Freon compound are downgradient from the Advanced Test Accelerator (**Figure 7-3**) where a Freon spill to ground occurred. LLNL is continuing to monitor the nature and extent of Freon in this area (Webster-Scholten 1994).

Pit 7 Complex Area

Analytical results from 1993 on ground water samples from the Pit 7 compliance monitoring wells are given in **Table 7-6**. The monitoring data for 1993 continue to show tritium and trichloroethene (TCE) from Pit 3 and Pit 5, respectively, from a release that occurred in 1983 (Webster-Scholten 1994). The initial releases resulted from higher-than-normal rainfall during the 1982–1983 rain season. Infiltrating rain water raised the local water table above the bases of the two unlined pits, allowing the ground water to become contaminated. The RCRA capping of Pit 7, completed in early 1993, is designed to prevent any further release from the landfill.

Although many measurements made during 1993 constituted statistical evidence of releases of several constituents of concern under the newly adopted WDRNo. 93-100, none of the data can be interpreted unequivocally to demonstrate that any release has occurred from Pit 7 since it was capped in early 1993. In question are certain measurements of total dissolved solids (TDS), specific conductance, pH, barium, lead, tritium, uranium isotopes, and TCE.

Initial measurements of TDS, specific conductance, and pH made on water samples collected during the fourth quarter of 1993 from Pit 7 monitoring network wells showed significant statistical differences among well samples (Christofferson et al. 1994). These findings are inconclusive with regard to causal mechanisms. However, under the requirements of WDR No. 93-100, these fourth quarter parameter measurements were reported to the CVRWQCB as statistical evidence of a release from Pit 7, even though they may simply reflect increasingdissolution of natural components contained in the underlying sedimentaryrocks.

Barium levels above the concentration limits were measured in samples from monitoring wells K7-01 and NC7-48 during 1993. Under the new reporting requirements of WDR No. 93-100, these measurements were reported to the CVRWQCB as statistical evidence of a release from Pit 7. However, since barium has been measured at similar levels in samples from well K7-01 since 1984 and in samples from well NC7-48 since early 1992, the barium is either natural, or was released prior to the completion of the Pit 7 capping in early 1993.

One lead concentration above the CL was measured in a ground water sample from well K7-01. This measurement was reported to the CVRWQCB as statistically significant evidence of a release from Pit 7. However, two subsequent measurements of water samples from this well showed lead to be less than the CL of 0.002 mg/L. These measurements nullify the statistical significance of the earlier elevated lead measurement.

Tritium activities continued above the CL defined by WDR No.93-100 in ground water samples from downgradient monitoring wells K7-01, K7-03, NC7-25, NC7-26, and NC7-48. Except for well NC7-48, the tritium is linked to known releases that occurred during 1983 from Pits 3 and 5 (Webster-Scholten 1994). Tritium activity slightly above the CL was measured in well NC7-48 during 1993 and was reported to the CVRWQCB as statistically significant evidence of a release from Pit 7. However, tritium activity steadily decreased in water samples taken from well NC7-48 during 1993 and fell below the concentration limit of 3.17 Bq/L (85.7pCi/L) during the first quarter of 1994. Tritium measurements do not indicate that tritium was ever released from Pit 7. Rather, the low tritium activity in samples from well NC7-48 may represent the higher (than present) activity of historical rains that recharged the water-bearing zone beneath the Pit 7 Complex.

Uranium isotope activities continued above their respective CLs in samples from monitoring wells K7-01, K7-03, K7-10, NC7-25, and NC7-48 during 1993. Under the new reporting requirements of WDR No. 93-100, these activities were reported to the CVRWQCB as statistically significant evidence of a release from Pit 7. Analysis of uranium isotopes by mass spectroscopy in three water samples from well NC7-48 detected depleted uranium, that is, uranium deficient in the ^{235}U isotope compared to natural uranium (Christofferson et al. 1993b). This uranium could only have come from Pit 7, but the release probably predated capping of the pit. Alpha spectroscopy ratios of ^{234}U to ^{238}U activities are much less than one-to-one in samples taken from well NC7-48 prior to and after capping. This low activity ratio, which is one-to-one in the natural element, suggests the presence of depleted uranium in the ground water prior to capping. Capping was deemed necessary to prevent any further release of potential contaminants from that unit.

Total uranium activity in two Pit 7 downgradient monitoring wells NC7-25 and NC7-48 continued during 1993 to exceed the U.S. and California drinking water MCL of 0.74 Bq/L (20 pCi/L). Samples taken from these two wells during 1993 also exceeded the 0.555 Bq/L (15 pCi/L) drinking water MCL for gross alpha activity, the 1.85 Bq/L (50 pCi/L) MCL for gross beta activity, and the 0.185 Bq/L (5 pCi/L) MCL for radium (**Table 7-6**). The highest value for total uranium activity measured during 1993 was 1.9 Bq/L (50 pCi/L) in well NC7-48, equal to 2.5 times the MCL; the highest value for gross alpha activity measured at this well was 5.6 Bq/L (152 pCi/L), which is equal to 10 times the MCL; the highest value for gross beta activity was 5.5 Bq/L (148 pCi/L), equal to 3 times the MCL; and the highest value for radium measured was 0.8 Bq/L (22pCi/L), which is equal to 4 times the MCL.

Trichloroethene and its breakdown product 1,2-dichloroethene were detected in downgradient wells K7-03 and K7-01 during 1993. The highest TCE value measured was 5.6 µg/L, which exceeded the 5 µg/L drinking water MCL. The TCE source is believed to be in Pit 5, adjacent to and downgradient of Pit 7. The occurrence of TCE in this area is described in the Final SWRI report (Webster-Scholten 1994).

HE Process Area

As required by the WDR No. 85-188 permit, the lysimeters underlying the process water surface impoundments in the Building 817 HE Process Area were tested quarterly during 1993 for the presence of water. No water was detected, confirming that the impoundment liners were not leaking.

Analytical results of ground water samples from the Building 817 HE Process Area compliance monitoring wells are given in **Table 7-7**. Water samples drawn from all the compliance monitoring wells in the Building 817 HE Process Area network in 1993 exhibited levels of arsenic, selenium, and nitrate that are near or above drinking water MCLs. Arsenic and selenium are believed to be the result of the dissolution of arsenopyrite and mafic minerals from the volcaniclastic-rich Neroly upper sandstone (Webster-Scholten 1994). The highest arsenic value measured was 67 µg/L in downgradient well W-817-02, as contrasted to the drinking water MCL of 50 µg/L. The highest selenium value measured was 0.1mg/L, also in well W-817-02. This is ten times the California Department of Health Services drinking water MCL of 0.01 mg/L for selenium. The highest nitrate value measured was 88 mg/L in well W-817-04, which is double the EPA drinking water MCL of 45 mg/L for nitrate. The origins of the nitrate are uncertain.

As expected from historical data, TCE continued above the MCL of 5 µg/L in ground water samples from all downgradient monitoring wells, except well W-817-02. A sample from shallow well W-817-03A showed the highest value of 63 µg/L, approximately thirteen times the 5 µg/L drinking water MCL. The TCE breakdown product cis-1,2-dichloroethene was detected at a concentration of 3.3 µg/L in a water sample from well W-817-03A. This is 55% of the 6 µg/L MCL for this compound. Tetrachloroethene, another solvent, was detected in a water sample taken from well W-817-02 at a concentration of 1.9 µg/L. This is 38% of the 5 µg/L MCL for this compound. The levels of halocarbon organic compounds measured in these water samples taken from the Building 817 HE Process Area monitoring wells are very consistent with the distribution of organic compounds described in the Final SWRI report (Webster-Scholten 1994).

The high-explosive compound RDX was observed often, but only in water samples drawn from well W-817-01. Obviously, the source of the RDX in well W-817-01 cannot be the process water impoundments that lie downgradient from it. The highest value measured for 1993 was 117 µg/L. An MCL has not been set for RDX.

Tritium activity, the single radiological parameter monitored in the Building817 HE Process Area compliance network wells, was at background levels (1.7 Bq/L) in samples from all five network monitoring wells.

Pit 2

The results of analyses made on ground water samples from Pit 2 surveillance monitoring wells during 1993 are given in **Table 7-8**. Of the metals, only arsenic, barium, and iron were measured above detection limits. The highest arsenic value was 0.044 mg/L in a sample from Barcad K2-02A. This value is 88% of the drinking water MCL for arsenic. The highest barium value was 0.053 mg/L in a sample from Barcad K1-01B and is 5% of the drinking water MCL for barium. Iron was detected in a sample from Barcad K2-02B. The value, 0.15 mg/L, is 50% of the secondary (esthetic) drinking water MCL for iron. No primary MCL for iron has been established. The metals levels are all within the range of natural background concentrations found in the ground water at Site 300 (Buddemeier et al. 1987).

The radioactivity and radioisotope measurements show only low background levels for gross alpha, gross beta, radium, tritium, and uranium isotopes. However, although tritium activities in samples from Barcad K2-01B are very low, they are approximately three times the activities measured in samples taken from the other six Barcads in this area. This relatively elevated activity probably defines the boundary of the plume of tritium-bearing water flowing into the Pit 2 area from a source 1 kilometer to the west near Building850 in the West Firing Area (Webster-Scholten 1994). The incursion of this tritium-bearing water into the Pit 2 and Pit 1 area is also seen in Pit 1 Barcad K1-02B ground water samples (**Table 7-5**). The plume appears to be confined to the lower blue sandstone aquifer within the Neroly Formation in the vicinity of Pit 2 and Pit 1.

Pit 9

The results of analyses made on ground water samples from Pit 9 surveillance monitoring wells during 1993 are given in **Table 7-9.** All of the organic compounds analyzed for were below reporting limits. Metals, general minerals, and radioisotope measurements were indistinguishable from normal background levels. None of the measurements indicates that Pit 9 released any potential contaminants to the ground water during 1993.

Elk Ravine Drainage Area

The results of analyses on ground water samples from the Elk Ravine drainage area surveillance monitoring wells during 1993 are given in **Table 7-10**.

Well K7-07. Beryllium and lead were not detected in samples from this well. Two quarterly barium measurements of 0.14 mg/L and 0.11 mg/L were above the new 0.09 mg/L CL set for Pit 7 by permit WDR No. 93-100. One of two samples measured showed vanadium at 0.019 mg/L. This is below the 0.05mg/L CL for vanadium set for Pit7 by the WDR permit. Vanadium occurs naturally in the area's ground water.

Trichloroethene at 0.9 µg/L and toluene at 0.9 µg/L were the only detected organic constituents of concern in samples from well K7-07. These measurements are below drinking water MCLs and are consistent with the distribution of solvents in the ground water following release from Pit 5 in 1982–1983, described in the Final SWRI report (Webster-Scholten 1994).

Gross alpha measurements were two to four times the drinking water MCL of 0.56 Bq/L and gross beta measurements were just above the 1.85 Bq/L MCL. The activity ratio of ^{234}U and ^{238}U was less than 1 for both measurements made during 1993. This strongly suggests that the uranium present in samples from well K7-07 contains depleted uranium.

The two tritium measurements made on samples from well K7-07 were 320Bq/L (8650 pCi/L) and 714 Bq/L (19,300 pCi/L). These values are below the

740 Bq/L (20,000 pCi/L) drinking water MCL and they are consistent with the description of a historical tritium release from Pit 5 that is described in the Final SWRI report (Webster-Scholten 1994).

Wells NC7-61, NC7-69. The analysis for four metals in these two wells (beryllium, chromium, copper, and lead), resulted in only single detects of beryllium at 0.0002 mg/L and chromium at 0.0044 mg/L in separate samples from well NC7-61. These levels represent 40% and 10% of the drinking water MCL, respectively. No volatile organic compounds were detected in either well.

Of the radioactivity and radioisotope measurements, only elevated tritium activity was seen in the Neroly Formation NC7-61 well samples. The mean of four quarterly tritium measurements, 8270Bq/L (224,000 pCi/L), is about eleven times the drinking water MCL for tritium. This tritium contamination in the Neroly lower blue sandstone has its source in the West Firing Area near Building850 and is described in the Final SWRI report (Webster-Scholten 1994). Tritium activity in the underlying Cierbo Formation was very low, close to 0Bq/L. The marked difference in tritium activity between these two wells suggests that the two water-bearing zones are not interconnected in this area.

Uranium isotope measurements by alpha spectroscopy of ground water samples from the Neroly and Cierbo Formation wells NC7-61 and NC7-69 do not suggest the presence of depleted uranium in either water-bearing zone in this area. The alpha activity ratios of ^{234}U and ^{238}U are greater than 1, suggesting a natural uranium source. Comparison of alpha spectroscopy results, however, indicates that the uranium activity in the Neroly is about thirty times the activity in the underlying Cierbo Formation. LLNL is conducting an investigation of uranium isotopes in this area using the more definitive mass spectroscopy method and will report those results in the environmental report for 1994.

Wells K2-04D, K2-04S, K2-01C. Three of four quarterly gross alpha measurements in Barcad K2-01C exceeded the 0.555 Bq/L (15 pCi/L) drinking water MCL, while the other wells showed relatively low gross alpha. Although uranium isotopic measurements are not made on water samples from well K2-01C, it is likely that the elevated alpha activity results from an elevated concentration of natural uranium in the ground water.

Elevated gross beta activity was measured in these three wells during the first quarter of 1993. Measurement errors are indicated because of the simultaneity of the occurrences and the fact that gross beta measurements made on three subsequent quarterly samples were consistently low. A change of contract analytical laboratory was made after the first quarter measurements were completed.

Elevated tritium activity was measured in all three wells. The tritium activity level in well K2-04D was approximately equal to the drinking water MCL, the level in well K2-04S was approximately double the MCL, and the level in K2-01C was approximately one-half the 740 Bq/L (20,000 pCi/L) MCL. These wells lie within the 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 near Building 850 in the West Firing Area (Webster-Scholten1994).

Nitrate measurements in the three wells approached, but did not exceed, the 45mg/L drinking water MCL for nitrate. The largest value, 42 mg/L in well K2-04S, is equal to 93% of the MCL. Elevated nitrate levels are common in Site 300 ground waters, including the previously discussed HE Process Area, but their origin is still uncertain.

Wells 01, NC2-11D. Metals and organic compounds were not detected in samples taken from these two wells. Both gross alpha and gross beta radioactivity measurements were far below drinking water MCLs. Only tritium activity was elevated in the samples from these wells. Activities of about one-half the drinking water MCL were measured in well 01, while measurements of about one-tenth the MCL were found in NC2-11D. Tritium activity increased in well 01 from 222 Bq/L (6000 pCi/L) in 1992 to 263 Bq/L (7100 pCi/L) in 1993, which is equal to 36% of the drinking water MCL. Tritium activity increased in well NC2-11D from a mean of 68.6 Bq/L (1850 pCi/L) in 1992 to a mean of 74.9Bq/L (2025 pCi/L) in 1993. These wells are located within the plume of tritium-bearing ground water that has been traced upgradient to Building 850 in the West Firing Area (Webster-Scholten, 1994).

Well NC2-07. No organic constituents of concern were detected in the samples taken in 1993. Gross alpha and gross beta measurements were low and cannot be distinguished from background levels in the Neroly Formation. Tritium activity measurements were also very low. This well presently lies far ahead of the plume of tritium-bearing ground water, discussed above, that is moving slowly southeastward in the Neroly Formation beneath Elk Ravine.

Pit 6

The results of analyses made on ground water samples from Pit 6 surveillance monitoring wells during 1993 are given in **Table 7-11**. Of the metals analyzed, arsenic, iron, and selenium were detected in Pit 6 well samples at concentrations consistent with natural levels in the area ground water (Buddemeier et al. 1987). Singular detections of lead and silver at extremely low levels from wells K6-04 and EP6-09 were followed by nondetections in samples taken the following two quarters.

Of the organic compounds, only the solvent TCE was detected above the 5 µg/L MCL for drinking water in ground water samples from well EP6-09. The highest value measured was 18 µg/L in the first quarter of 1993. Well EP6-09 lies within a shallow, elongated plume of water that is known to contain TCE. The plume extends only 100 meters east of Pit 6. TCE in the Pit 6 area is described in the Final SWRI report (Webster-Scholten 1994).

All of the radioactivity and radioisotope measurements for ground water samples from the Pit 6 area wells in 1993 gave low levels that are indistinguishable from natural background levels. No measurement was above the drinking water MCL.

Water Supply Well 20

The results of analyses made on ground water samples from well 20 during 1993 are given in **Table 7-12**. No metals of concern were detected in well 20 water samples during 1993. Radioactivity and tritium activity measurements of these samples in 1993 gave very low values that are indistinguishable from natural background levels.

On several occasions during 1993, the solvent 1,2-dichloroethane (1,2-DCA) was detected in samples from well 20 above the State of California MCL of 0.5 µg/L. Further sampling and analysis done by LLNL during 1994 has traced this 1,2-DCA and other minor contaminants to the hydrochloric acid used to preserve the water samples prior to analysis. Additional analyses in 1994 have shown well 20 to be free of contamination.

Off-Site Supply Wells

The results of analyses made on ground water samples from off-site surveillance monitoring wells during 1993 are given in **Table 7-13.** Only two inorganic compounds, sulfate and manganese, were detected above their MCL in any of the off-site monitoring wells. Three wells, STN, CON1, and MUL2, exceeded the 400 mg/L EPA drinking water MCL for sulfate. Two wells, CON1 and MUL2, exceeded the secondary (aesthetic) MCL of 50 µg/L for manganese. High concentrations of sulfate and manganese occur naturally in ground water in the Altamont Hills (Buddemeier et al. 1987).

Wells CARNRW1 and CON2 were sampled once in 1993 and analyzed for volatile organic compounds only. Because none were detected, these wells are not listed in **Table 7-13**.

Bromoform was detected in one of four quarterly water samples from well CARNRW2 during 1993. This compound and other trihalomethanes have been detected in water samples from this well in the past. The compounds result from chlorination. Although the water tap used to obtain samples is upstream from the chlorinating mechanism, some reverse flow probably occurs when the well pump is off.

Trichloroethene was reported at the detection limit of 0.2 µg/L in the first of four quarterly water samples from surveillance well GALLO1. Two similarly low detections were seen in this well during 1992. The GALLO1 well is not located near any known areas of TCE contamination at Site 300. The trace of organic solvents in this well may stem from an unknown source in the Corral Hollow Creek floodplain that is not associated with LLNL activities at Site 300.

None of the radioactivity or tritium measurements made on samples from the off-site surveillance wells showed levels above their drinking water MCL. All measurements gave very low values that are statistically equivalent to natural background levels in the Site 300 area.

Environmental Impacts

Livermore Valley

The highest tritium activity measured in a sample from a drinking water well serving the Livermore Valley during 1993 was 2.0 Bq/L (53 pCi/L; Livermore well 8P1). This activity was only 0.3% of the drinking water MCL. The highest tritium activity measured in a sampled drinking water well serving the City of Pleasanton during 1993 was 1.5 Bq/L (42 pCi/L) in well 16L5. This activity was only 0.2% of the drinking water MCL. We can calculate the potential environmental impact of 2 Bq/L (53 pCi/L) of tritium activity measured in a potable water supply well in terms of effective dose equivalent (EDE), based on an individual who ingests two liters of this water per day and who showers with this water 15minutes per day. Total water ingested is 730 liters per year. Total water inhaled while showering equals 4 liters per year. Total ingestion equals 1460 Bq (40,000 pCi) and total inhalation equals 8 Bq (210 pCi). Using the dose conversion factors contained in Appendix B, the EDE for ingested tritium is 0.000026 mSv (0.0026 mrem) and the EDE for tritium inhaled while showering is 0.0000002 mSv (0.00002 mrem). The inhalation dose is more than a hundred times smaller than the ingested dose and the ingested dose is less than 0.03% of the EPA standard allowable annual dose of 0.1 mSv (10 mrem).

Site 300

Several analyses of ground water samples from Pit 1 and Pit 7 monitoring wells became issues of compliance during 1993 under the newly adopted WDR No. 93-100 permit. However, the particular analytes of concern for Pit 1 correlate either with natural sources, such as the increasing uranium activity, or they correlate with sources outside the pit, such as tritium and Freon. Current and historicalground water data from Pit 1 indicate that the landfill did not release any potential contaminants to the ground water during 1993. Completion of the Pit 1 cap in early 1993 further assures that the waste material buried in the pit will be contained.

Under the newly adopted WDRNo. 93 -100, several analyses of ground water samples from Pit 7 monitoring wells constituted statistical evidence of non-compliance for several constituents of concern, but none of the data can be interpreted to demonstrate unequivocally that any release has occurred from Pit7 since it was capped in early 1993.

During 1993, tritium activities in three Pit 7 downgradient monitoring wells continued to exceed the U.S. and California drinking water MCL of 740 Bq/L

(20,000 pCi/L). Well K7-01 averaged 1590 Bq/L, about double the MCL, wellK7 -03 averaged 6930 Bq/L, about nine times the MCL, and well NC7-25 averaged 9820 Bq/L, about thirteen times the MCL. Fate and transport modeling of tritium with a half-life of 12.3 years indicates that the tritium released during flooding of Pit 3 and Pit 5 in 1983 will have decayed to a level far below the MCL by the time it reaches the Site 300 boundary (Webster-Scholten 1994). None of the tritium-bearing ground water in the area is used for irrigation or for consumption by animals and people; therefore, it presents no impact to the environment at Site300.

The perched ground water in Quaternary alluvium, located in the upper reaches of the Elk Ravine drainage area and downslope from the Pit 7 Complex area, contains barium, depleted uranium, tritium, and organic solvents that have been released from the complex of inactive landfills in the past. The extent of the tritium and TCE-bearing ground waters have been characterized in the Final SWRI report (Webster-Scholten 1994). The barium and depleted uranium data were discussed in reports to the Central Valley Regional Water Quality Control Board in 1993 (Christofferson et al. 1993b and 1994).

In response to exceeding several WDR No. 93-100 concentration limits in Pit 1 and Pit7 ground water samples during 1993, LLNL established an evaluation monitoring and assessment program. LLNL will continue to determine the nature and extent of uranium isotopes, tritium, and barium adjacent to Pit 1 and Pit 7 by sampling ground water from wells in addition to those specified in the WDR No. 93-100 monitoring networks, and by conducting additional data analyses. Fate and transport analysis and a risk assessment will be conducted for these substances. If the assessments indicate that the potential risks or hazards posed by these substances are significant, as defined by CERCLA, corrective actions will be incorporated into the CERCLA process.

No drinking water wells were contaminated by LLNL activities at Site 300 in the Altamont Hills during 1993. The 1,2-DCA measured in several samples from well 20 during 1993 was traced to the hydrochloric acid used to preserve the water samples prior to analysis. The surveillance monitoring data for 1993 demonstrate that the off-site radiological and nonradiological impact of LLNL operations at Site300 were minimal. LLNL is, however, continuing investigations of several areas of TCE-bearing ground water within the site. Investigations as to the extent and sources of organic solvents in Site300 ground water are discussed in the Final SWRI report (Webster-Scholten 1994).

Table 7-1. Constituents of concern and concentration limits, Pits 1 and 7.

Constituent of concern	Pit 1 Concentration limit	Pit 7 Concentration limit
Metals (mg/L)		
Arsenic	0.02	TBD[a]
Barium	0.05	0.09
Beryllium	0.0005	0.0005
Cadmium	0.0005	TBD[a]
Cobalt	TBD[a]	TBD[a]
Copper	0.07	TBD[a]
Lead	0.009	0.002
Nickel	0.10	TBD[a]
Vanadium	0.09	0.05
Zinc	0.06	TBD[a]
Radioisotopes (Bq/L)		
Radium-226	0.037 (1.0 pCi/L)	TBD[a]
Tritium	18.5 (500 pCi/L)	3.17 (85.7 pCi/L)
Uranium-234	0.23 (6.3 pCi/L)	0.078 (2.1 pCi/L)
Uranium-235	0.007 (0.2 pCi/L)	0.0037 (0.1 pCi/L)
Uranium-238	0.10 (2.76 pCi/L)	0.059 (1.6 pCi/L)
Thorium-228	TBD[a]	TBD[a]
Thorium-232	TBD[a]	TBD[a]
High explosives (µg/L)		
HMX	26	TBD[a]
RDX	30	TBD[a]

[a] TBD = To be determined. Concentration limit (CL) to be statistically determined from 12 monthly measurements beginning October 1993 due to insufficient or nonexistent historical data on which to base CL.

Table 7-2. List of ground water analyses showing inorganic constituent, EPA or other standard measurement method used, and typical lower limit of detection reported by analytical laboratory.

Parameter	Method	Reporting limit
Metals and minerals (mg/L)		
All alkalinities	EPA 310.1	1
Aluminum	EPA 200.7	0.02
Ammonia nitrogen (as N)	EPA 350.3	0.03
Antimony	EPA 200.7	0.06
Arsenic	EPA 206.2	0.002
Barium	EPA 200.7	0.05
Beryllium	EPA 210.2	0.0005
Cadmium	EPA 213.2	0.0005
Calcium	EPA 200.7	0.5
Chloride	EPA 325.3	1
Chromium	EPA 218.2	0.010
Cobalt	EPA 200.7	0.025
Copper	EPA 200.7	0.05
Fluoride	EPA 340.2	0.1
Hardness, total (as $CaCO_3$)	EPA 2320B	1
Iron	EPA 200.7	0.1
Lead	EPA 239.2	0.002
Magnesium	EPA 200.7	0.5
Manganese	EPA 200.7	0.03
Mercury	EPA 245.1	0.0002
Molybdenum	EPA 200.7	0.05
Nickel	EPA 249.2	0.005
Nitrate (as N)	EPA 353.2	0.1
Potassium	EPA 200.7	1
Selenium	EPA 270.2	0.002
Silver	EPA 272.2	0.010
Sodium	EPA 200.7	1
Sulfate	EPA 300.0	1
Surfactants	EPA 425.1	0.5
Thallium	EPA 279.2	0.005
Total dissolved solids	EPA 160.1	1
Total Kjeldahl nitrogen	EPA 351.4	0.2
Total suspended solids	EPA 160.2	1

…continued

Table 7-2. List of ground water analyses showing inorganic constituent, EPA or other standard measurement method used, and typical lower limit of detection reported by analytical laboratory (*concluded*).

Parameter	Method	Reporting limit
Metals and minerals (mg/L) (cont.)		
Vanadium	EPA 6010	0.05
Zinc	EPA 200.7	0.02
Phenolics (mg/L)		
Phenolics	EPA 420.1	0.005
General indicator parameters		
pH, units	EPA 150.1	none
Specific conductance (µmhos/cm)	EPA 120.1	1
Total organic carbon (mg/L)	EPA 415.1	0.5
Total organic halides (mg/L)	EPA 9020	0.01
Explosive compounds (µg/L)		
HMX	HPLC	20
RDX	HPLC	30
TNT	HPLC	30
Radioactivity (Bq/L)		
Gross alpha	EPA 900	0.06
Gross beta	EPA 900	0.05
Radioisotopes (Bq/L)		
Radium-226	EPA 903	0.00303
Thorium-228	U-NAS-NS-3050	0.009
Thorium-232	U-NAS-NS-3050	0.006
Tritium	LLNL-RAS-011	0.05
Uranium-234	U-NAS-NS-3050	0.004
Uranium-235	U-NAS-NS-3050	0.003
Uranium-238	U-NAS-NS-3050	0.004

Table 7-3. List of ground water analyses showing EPA Method, organic constituent, and typical lower limit of detection reported by analytical laboratory.

Method	Reporting limit (μg/L)
EPA Method 502.2	
1,1,1,2-Tetrachloroethane	0.2
1,1,1-Trichloroethane	0.2
1,1,2,2-Tetrachloroethane	0.2
1,1,2-Trichloroethane	0.2
1,1-Dichloroethane	0.2
1,1-Dichloroethene	0.2
1,1-Dichloropropene	0.2
1,2,3-Trichlorobenzene	0.2
1,2,3-Trichloropropane	0.2
1,2,4-Trichlorobenzene	0.2
1,2,4-Trimethylbenzene	0.2
1,2-Dichlorobenzene	0.2
1,2-Dichloroethane	0.2
1,2-Dichloropropane	0.2
1,3,5-Trimethylbenzene	0.2
1,3-Dichlorobenzene	0.2
1,3-Dichloropropane	0.2
1,4-Dichlorobenzene	0.2
2,2-Dichloropropane	0.2
2-Chlorotoluene	0.2
4-Chlorotoluene	0.2
Benzene	0.2
Bromobenzene	0.2
Bromochloromethane	0.2
Bromodichloromethane	0.2
Bromoform	0.2
Bromomethane	0.2
Carbon tetrachloride	0.2
Chlorobenzene	0.2
Chloroethane	0.2
Chloroform	0.2
Chloromethane	0.2
cis-1,2-Dichloroethene	0.2
cis-1,3-Dichloropropene	0.5
Dibromochloromethane	0.2
Dibromomethane	0.2
Dichlorodifluoromethane	0.2
Ethylbenzene	0.2
Freon-113	0.2
Hexachlorobutadiene	0.2
Isopropylbenzene	0.2
m- and p-Xylene isomers	0.2
Methylene chloride	0.2
n-Butylbenzene	0.2
n-Propylbenzene	0.2
Naphthalene	0.2
o-Xylene	0.2
Isopropyl toluene	0.2
sec-Butylbenzene	0.2
Styrene	0.2
tert-Butylbenzene	0.2
Tetrachloroethene	0.2
Toluene	0.2
trans-1,2-Dichloroethene	0.2
trans-1,3-Dichloropropene	0.2
Trichloroethene	0.2
Trichlorofluoromethane	0.2
Vinyl chloride	0.2
EPA Method 524.2	
1,1,1,2-Tetrachloroethane	1
1,1,1-Trichloroethane	1
1,1,2,2-Tetrachloroethane	1

…continued

Table 7-3. List of ground water analyses showing EPA Method, organic constituent, and typical lower limit of detection reported by analytical laboratory *(continued)*.

Method	Reporting limit (μg/L)	Method	Reporting limit (μg/L)
1,1,2-Trichloroethane	1	Dibromomethane	1
1,1-Dichloroethane	1	Dichlorodifluoromethane	2
1,1-Dichloroethene	1	Ethylbenzene	1
1,1-Dichloropropene	1	Ethylene dibromide	1
1,2,3-Trichlorobenzene	1	Freon-113	1
1,2,3-Trichloropropane	1	Hexachlorobutadiene	1
1,2,4-Trichlorobenzene	1	Isopropylbenzene	1
1,2,4-Trimethylbenzene	1	m- and p-Xylene isomers	1
1,2-Dibromo-3-chloropropane	2	Methylene chloride	1
1,2-Dichlorobenzene	1	n-Butylbenzene	1
1,2-Dichloroethane	1	n-Propylbenzene	1
1,2-Dichloropropane	1	Naphthalene	1
1,3,5-Trimethylbenzene	1	o-Xylene	1
1,3-Dichlorobenzene	1	Isopropyl toluene	1
1,3-Dichloropropane	1	sec-Butylbenzene	1
1,4-Dichlorobenzene	1	Styrene	1
2-Chlorotoluene	1	tert-Butylbenzene	1
4-Chlorotoluene	1	Tetrachloroethene	1
Benzene	1	Toluene	1
Bromobenzene	1	trans-1,2-Dichloroethene	1
Bromodichloromethane	1	trans-1,3-Dichloropropene	1
Bromoform	1	Trichloroethene	0.5
Bromomethane	2	Trichlorofluoromethane	1
Carbon tetrachloride	1	Vinyl chloride	2
Chlorobenzene	1		
Chloroethane	2	**EPA Method 601**	
Chloroform	1	1,1,1-Trichloroethane	0.5
Chloromethane	2	1,1,2,2-Tetrachloroethane	0.5
cis-1,2-Dichloroethene	1	1,1,2-Trichloroethane	0.5
cis-1,3-Dichloropropene	1	1,1-Dichloroethane	0.5
Dibromochloromethane	1	1,1-Dichloroethene	0.5

...continued

Table 7-3. List of ground water analyses showing EPA Method, organic constituent, and typical lower limit of detection reported by analytical laboratory (*continued*).

Method	Reporting limit (µg/L)
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
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
EPA Method 615	
2,4,5-T	0.5
2,4,5-TP (Silvex)	0.2

…continued

Table 7-3. List of ground water analyses showing EPA Method, organic constituent, and typical lower limit of detection reported by analytical laboratory (*continued*).

Method	Reporting limit (µg/L)	Method	Reporting limit (µg/L)
2,4-D	1	Carbon tetrachloride	1
2,4-Dichlorophenoxy acetic acid	2	Chlorobenzene	1
Dalapon	2	Chloroethane	2
Dicamba	1	Chloroform	1
Dichloroprop	2	Chloromethane	2
Dinoseb	1	cis-1,3-Dichloropropene	1
MCPA	250	Dibromochloromethane	1
MCPP	250	Dibromomethane	1
		Dichlorodifluoromethane	2
EPA Method 624		Ethylbenzene	1
1,1,1-Trichloroethane	1	Freon-113	1
1,1,2,2-Tetrachloroethane	1	Methylene chloride	1
1,1,2-Trichloroethane	1	Styrene	1
1,1-Dichloroethane	1	Tetrachloroethene	1
1,1-Dichloroethene	1	Toluene	1
1,2-Dichlorobenzene	1	Total xylene isomers	2
1,2-Dichloroethane	1	trans-1,3-Dichloropropene	1
1,2-Dichloroethene (total)	1	Trichloroethene	0.5
1,2-Dichloropropane	1	Trichlorofluoromethane	1
1,3-Dichlorobenzene	1	Vinyl acetate	10
1,4-Dichlorobenzene	1	Vinyl chloride	2
2-Butanone	10		
2-Chloroethylvinylether	10	**EPA Method 625**	
2-Hexanone	10	1,2,4-Trichlorobenzene	10
4-Methyl-2-pentanone	10	1,2-Dichlorobenzene	10
Acetone	10	1,3-Dichlorobenzene	10
Benzene	1	1,4-Dichlorobenzene	10
Bromodichloromethane	1	2,4,5-Trichlorophenol	10
Bromoform	1	2,4,6-Trichlorophenol	10
Bromomethane	2	2,4-Dichlorophenol	10
Carbon disulfide	1	2,4-Dimethylphenol	10

…continued

Table 7-3. List of ground water analyses showing EPA Method, organic constituent, and typical lower limit of detection reported by analytical laboratory (*concluded*).

Method	Reporting limit (μg/L)	Method	Reporting limit (μg/L)
2,4-Dinitrophenol	50	Bis(2-chloroethoxy)methane	10
2,4-Dinitrotoluene	10	Bis(2-chloroisopropyl)ether	10
2,6-Dinitrotoluene	10	Bis(2-ethylhexyl)phthalate	10
2-Chloronaphthalene	10	Butylbenzylphthalate	10
2-Chlorophenol	10	Chrysene	10
2-Methylphenol	10	Di-n-butylphthalate	10
2-Methyl-4,6-dinitrophenol	50	Di-n-octylphthalate	10
2-Methylnaphthalene	10	Dibenzo(a,h)anthracene	10
2-Nitroaniline	50	Dibenzofuran	10
2-Nitrophenol	10	Diethylphthalate	10
3,3'-Dichlorobenzidine	20	Dimethylphthalate	10
3-Nitroaniline	50	Fluoranthene	10
4-Bromophenylphenylether	10	Fluorene	10
4-Chloro-3-methylphenol	20	Hexachlorobenzene	10
4-Chloroaniline	20	Hexachlorobutadiene	10
4-Chlorophenylphenylether	10	Hexachlorocyclopentadiene	10
4-Nitroaniline	50	Hexachloroethane	10
4-Nitrophenol	50	Indeno(1,2,3-c,d)pyrene	10
Acenaphthene	10	Isophorone	10
Acenaphthylene	10	m- and p-Cresol	10
Anthracene	10	N-Nitrosodi-n-propylamine	10
Benzo(a)anthracene	10	N-Nitrosodiphenylamine	10
Benzo(a)pyrene	10	Naphthalene	10
Benzo(b)fluoranthene	10	Nitrobenzene	10
Benzo(g,h,i)perylene	10	Pentachlorophenol	50
Benzo(k)fluoranthene	10	Phenanthrene	10
Benzoic acid	50	Phenol	10
Benzyl alcohol	20	Pyrene	10

Table 7-4. Tritium activity in Livermore Valley wells (in Bq/L), 1993.

Well ID	Activity	% MCL
LWRP		
1H3	0.52 ± 0.14	0.1
1P2	4.8 ± 0.28	0.7
1P3	0.76 ± 0.11	0.1
1R2	2.6 ± 0.22	0.4
2R1	5.4 ± 0.29	0.7
7C2	3.8 ± 0.26	0.5
11B1	16 ± 0.54	2.2
12A2	5.7 ± 0.29	0.8
12D2	9.7 ± 0.39	1.3
12G1	7.5 ± 0.38	1.0
Mean	**5.7 (154 pCi/L)**	**0.8**
Std dev	**4.7 (127 pCi/L)**	
Livermore		
7P3	0.08 ± 0.08	0.0
8F1	1.8 ± 0.14	0.2
8P1	2.0 ± 0.16	0.3
9Q1	1.1 ± 0.13	0.2
16B1	1.5 ± 0.16	0.2
Mean	**1.3 (35 pCi/L)**	**0.2**
Std dev	**0.7 (19 pCi/L)**	
Pleasanton		
9M2	1.1 ± 0.15	0.1
9M3	1.1 ± 0.15	0.2
16L5	1.5 ± 0.15	0.2
16L7	0.90 ± 0.13	0.1
17D2	0.10 ± 0.080	0.0
18A1	0.40 ± 0.12	0.1
Mean	**0.9 (24 pCi/L)**	**0.1**
Std dev	**0.5 (14 pCi/L)**	

Table 7-5. Pit 1 well water analyses.

Parameter[a]	Well K1-01C	 K1-02B	 K1-03	 K1-04
Metals and minerals[b] (mg/L)				
Ammonia nitrogen (as N)	<0.03	<0.03	<0.03	<0.03
	0.060	0.076	0.057	0.12
	<0.1	<0.1	<0.1	<0.1
Arsenic	0.0095	0.0080	0.010	0.0093
	0.012	0.012	0.012	0.011
	0.013	0.012	0.014	0.012
	0.016	0.015	0.014	0.012
	0.014	0.014	0.013	0.013
	0.012	0.011	0.012	0.011
	0.011	0.010	0.012	0.013
Bicarbonate alkalinity (as $CaCO_3$)	150	150	150	150
	160	150	150	150
	200	200	200	210
	140	140	120	140
Cadmium	<0.0005	<0.0005	<0.0005	<0.0005
	<0.0005	<0.0005	<0.0005	<0.0005
	<0.001	<0.001	<0.001	<0.001
	<0.0005	<0.0005	<0.0005	<0.0005
Calcium	47	48	43	42
	40	44	39	40
	49	54	49	50
	49	55	33	46
Chloride	36	55	35	43
	42	56	43	40
	35	50	33	34
	31	51	31	32
Chromium	<0.005	<0.005	<0.005	<0.005
	<0.005	<0.005	<0.005	<0.005
	0.0012	0.0016	<0.001	<0.001
	<0.01	<0.01	<0.01	<0.01
Fluoride	0.40	0.34	0.32	0.39
	0.33	0.29	0.28	0.35
	0.34	0.31	0.29	0.38
	0.34	0.28	0.52	0.36
Hardness, total (as $CaCO_3$)	200	230	200	200
	200	240	140	180
Lead	0.0020	<0.002	<0.002	<0.002
	0.0062	0.0052	<0.002	<0.002
	<0.002	0.0026	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002

...continued

Table 7-5. Pit 1 well water analyses (*continued*).

	Well			
Parameter[a]	**K1-05**	**K1-07**	**K1-08**	**K1-09**
Metals and minerals[b] (mg/L)				
Ammonia nitrogen (as N)	<0.03	<0.03	<0.03	<0.03
	0.060	0.040	0.047	0.060
	<0.1	<0.1	<0.1	<0.1
Arsenic	0.012	0.011	0.012	0.012
	0.014	0.014	0.015	0.014
	0.016	0.014	0.015	0.014
	0.014	0.013	0.014	0.015
	0.014	0.014	0.016	0.015
	0.018	0.017	0.017	0.014
	0.016	0.016	0.016	0.016
Bicarbonate alkalinity (as $CaCO_3$)	130	140	130	130
	130	140	140	140
	180	190	180	170
	120	130	120	120
Cadmium	0.0006	<0.0005	<0.0005	<0.0005
	<0.0005	<0.0005	<0.0005	<0.0005
	<0.001	<0.001	<0.001	<0.001
	<0.0005	<0.0005	<0.0005	<0.0005
Calcium	35	39	36	37
	33	34	33	34
	40	42	43	41
	35	37	37	33
Chloride	37	35	36	36
	40	38	48	40
	34	33	34	34
	30	30	32	31
Chromium	<0.005	<0.005	<0.005	<0.005
	<0.005	<0.005	<0.005	<0.005
	<0.001	<0.001	<0.001	<0.001
	<0.01	<0.01	<0.01	<0.01
Fluoride	0.40	0.44	0.47	0.47
	0.42	0.42	0.42	0.42
	0.48	0.49	0.55	0.54
	0.45	0.41	0.45	0.52
Hardness, total (as $CaCO_3$)	180	190	190	180
	160	160	160	140
Lead	0.0038	<0.002	<0.002	0.0022
	0.010	<0.002	<0.002	0.0042
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002

…continued

Table 7-5. Pit 1 well water analyses (*continued*).

	Well			
Parameter[a]	K1-01C	K1-02B	K1-03	K1-04
Lead (cont.)	0.0037	0.061	<0.002	<0.002
	<0.005	<0.005	<0.005	<0.005
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
Magnesium	17	21	16	15
	16	20	15	21
	19	23	19	18
	18	24	15	17
Mercury	<0.0002	<0.0002	<0.0002	<0.0002
	<0.0002	<0.0002	<0.0002	<0.0002
	<0.0005	<0.0005	<0.0005	<0.0005
	<0.0002	0.00022	<0.0002	<0.0002
Nitrate (as N)	4.7	5.2	4.1	6.7
Nitrate plus nitrite (as N)	6.6	7.0	6.3	5.4
	6.8	6.9	5.9	4.6
Potassium	<5	<5	<5	<5
	4.5	2.9	2.6	2.9
	3.5	3.2	3.1	3.6
	2.9	2.8	2.8	3.8
Selenium	<0.002	<0.002	<0.002	<0.002
	0.0025	0.0036	0.0030	0.0032
	<0.005	<0.005	<0.005	<0.005
	<0.002	<0.002	0.0025	0.0030
Silver	<0.0005	<0.0005	<0.0005	<0.0005
	<0.0005	<0.0005	<0.0005	<0.0005
	<0.001	<0.001	<0.001	<0.001
	<0.0005	<0.0005	<0.01	<0.01
Sodium	34	37	33	36
	33	39	34	40
	35	40	34	39
	35	42	35	40
Sulfate	43	74	45	61
	41	63	39	54
	35	57	35	49
	46	60	52	50
Total alkalinity (as $CaCO_3$)	150	150	150	150
	160	150	150	150
	200	200	200	210
	140	140	120	140

…continued

Table 7-5. Pit 1 well water analyses (*continued*).

	Well			
Parameter[a]	**K1-05**	**K1-07**	**K1-08**	**K1-09**
Lead (cont.)	<0.002	<0.002	<0.002	<0.002
	<0.005	<0.005	<0.005	<0.005
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
Magnesium	17	17	16	17
	16	16	15	15
	19	19	19	19
	17	17	16	15
Mercury	<0.0002	<0.0002	<0.0002	<0.0002
	<0.0002	<0.0002	<0.0002	<0.0002
	<0.0005	<0.0005	<0.0005	<0.0005
	<0.0002	<0.0002	<0.0002	<0.0002
Nitrate (as N)	5.1	3.8	5.2	5.2
Nitrate plus nitrite (as N)	8.3	7.5	8.1	8.1
	7.8	6.9	7.3	7.5
Potassium	<5	<5	<5	<5
	2.6	2.6	2.5	2.9
	3.2	3.4	3.7	3.6
	3.0	3.1	3.2	2.8
Selenium	<0.002	0.002	<0.002	<0.002
	0.0033	0.0021	0.0024	0.0020
	<0.005	<0.005	<0.005	<0.005
	<0.002	<0.002	<0.002	<0.002
Silver	<0.0005	<0.0005	<0.0005	0.0026
	<0.0005	0.00090	<0.0005	<0.0005
	<0.001	<0.001	<0.001	<0.001
	<0.01	<0.01	<0.01	<0.01
Sodium	38	40	40	41
	36	40	39	40
	41	42	42	40
	39	39	38	35
Sulfate	48	48	51	54
	44	45	45	48
	37	39	39	43
	55	43	53	52
Total alkalinity (as $CaCO_3$)	130	140	130	130
	130	140	140	140
	180	190	180	170
	120	130	120	120

…continued

Table 7-5. Pit 1 well water analyses (*continued*).

	Well			
Parameter[a]	**K1-01C**	**K1-02B**	**K1-03**	**K1-04**
Total dissolved solids	330	390	320	330
	360	420	350	350
	380	430	330	350
	250	470	380	400
	300	300	270	250
	370	430	350	350
	500	360	430	440
Total Kjeldahl nitrogen	<0.5	<0.5	<0.5	<0.5
	<1	<1	<1	<1
	0.11	0.16	<0.1	<0.1
Total suspended solids	9	<1	<1	<1
	2	<1	3	<1
	<1	<1	3	<1
Vanadium	<0.05	<0.05	<0.05	<0.05
	<0.2	<0.2	<0.2	<0.2
	0.063	0.047	0.043	0.031
	<0.05	<0.05	<0.05	<0.05
Zinc	<0.05	<0.05	<0.05	<0.05
	0.10	<0.05	<0.05	<0.05
	0.096	<0.05	<0.05	<0.05
	0.16	<0.07	<0.07	<0.07
General indicator parameters				
pH (units)	7.6	7.5	7.5	7.6
	7.1	7.2	7.3	7.4
	7.4	7.6	7.6	7.6
	7.5	7.5	7.5	7.6
	7.1	7.2	7.2	7.2
	7.5	7.2	7.9	7.3
	7.1	7.0	7.1	7.2
	7.0	7.0	7.2	7.2
	7.7	7.8	7.6	7.7
	7.6	7.5	7.8	7.8
	7.5	7.6	7.5	7.6
	7.7	7.5	7.9	7.7
	7.8	7.7	7.9	7.6
	8.1	8.0	7.9	8.2
	7.4	7.4	7.4	7.5
	7.6	7.5	7.5	7.6
	7.7	7.4	7.5	7.6
Specific conductance (µmhos/cm)	490	610	470	460
	520	600	510	540
	490	620	500	530
	540	590	510	400
	530	580	480	470

...continued

Table 7-5. Pit 1 well water analyses (*continued*).

	Well			
Parameter[a]	K1-05	K1-07	K1-08	K1-09
Total dissolved solids	320	330	320	330
	340	350	340	340
	340	370	290	350
	340	300	400	380
	260	220	250	200
	350	380	370	360
	430	440	390	410
Total Kjeldahl nitrogen	<0.5	<0.5	<0.5	<0.5
	<1	<1	<1	<1
	<0.1	<0.1	<0.1	<0.1
Total suspended solids	3	<1	<1	4
	<1	<1	<1	<1
	<1	3	<1	<1
Vanadium	0.063	0.055	0.063	<0.05
	<0.2	<0.2	<0.2	<0.2
	0.067	0.073	0.062	0.065
	0.073	0.099	0.061	0.069
Zinc	<0.05	<0.05	<0.05	<0.05
	<0.05	<0.05	<0.05	<0.05
	<0.05	<0.05	<0.05	<0.05
	<0.07	<0.07	<0.07	<0.07
General indicator parameters				
pH (units)	7.6	7.6	7.6	7.6
	7.5	7.5	7.5	7.5
	7.6	7.7	7.7	7.6
	7.6	7.6	7.6	7.5
	7.4	7.4	7.3	7.4
	7.4	7.3	7.4	7.3
	7.3	7.3	7.3	7.3
	7.6	7.5	7.5	7.5
	7.7	7.8	7.7	7.7
	7.8	7.7	7.7	7.6
	7.6	7.6	7.7	7.6
	8.0	7.8	7.7	7.7
	7.9	7.9	7.9	7.9
	7.9	8.0	8.0	7.9
	7.5	7.5	7.6	7.5
	7.7	7.6	7.7	7.7
	7.7	7.7	7.6	7.6
Specific conductance (µmhos/cm)	470	470	420	490
	460	510	500	520
	480	520	510	490
	520	420	510	490
	470	500	490	480

...continued

Table 7-5. Pit 1 well water analyses (*continued*).

	Well			
Parameter[a]	K1-01C	K1-02B	K1-03	K1-04
Specific conductance (μmhos/cm) (cont.)	480	620	460	540
	400	600	460	410
	520	630	460	560
	460	530	450	480
	490	560	470	490
	510	590	480	500
	510	570	490	510
	470	560	460	480
	460	560	450	450
	460	450	430	470
	480	560	460	480
	460	540	440	460
Total organic carbon (mg/L)	1.2	0.76	0.55	<0.5
	0.51	0.61	<0.5	<0.5
	0.54	0.73	0.52	<0.5
	0.78	0.73	0.50	<0.5
	1.6	1.3	1.0	0.84
	0.93	1.0	0.90	0.77
	0.75	0.86	0.67	0.58
	0.83	0.87	0.61	0.68
	2.1	6.1	4.5	3.5
	3.7	8.1	11.0	4.0
	3.6	4.2	3.6	9.4
	4.5	4.1	7.9	3.0
	3.7	4.7	4.5	4.9
Total organic halides, 1st replicate (mg/L)	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	0.010	0.014	0.011	0.012
	0.027	0.025	0.021	0.031
	0.018	0.026	0.022	0.021
	0.021	0.011	<0.01	<0.01
	<0.01	0.013	<1	0.016
Total organic halides, 2nd replicate (mg/L)	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02

…continued

Table 7-5. Pit 1 well water analyses (*continued*).

Parameter[a]	Well K1-05	K1-07	K1-08	K1-09
Specific conductance (μmhos/cm) (cont.)	510	520	520	520
	440	420	360	390
	530	140	530	480
	470	470	480	470
	480	490	480	470
	480	490	490	480
	490	500	500	490
	460	470	470	460
	440	450	450	450
	440	450	450	450
	460	460	460	460
	440	440	450	450
Total organic carbon (mg/L)	0.81	0.60	0.55	0.50
	<0.5	0.50	1.3	0.56
	0.54	<0.5	1.1	<0.5
	0.52	0.53	1.2	0.50
	0.84	0.97	1.4	0.81
	0.85	1.5	1.6	0.80
	0.78	0.66	3.5	0.93
	0.70	0.98	1.6	0.62
	4.5	4.5	6.2	6.5
	4.3	18	18	17
	2.9	3.1	3.7	3.1
	3.7	3.4	3.7	3.2
	2.2	3.6	3.1	2.9
Total organic halides, 1st replicate (mg/L)	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	0.021
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	0.013	0.011	0.018	0.041
	0.03	0.019	0.021	0.036
	0.024	0.034	0.024	0.035
	<0.01	0.019	0.025	0.015
	0.014	<0.01	0.029	0.040
Total organic halides, 2nd replicate (mg/L)	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	0.020

…continued

Table 7-5. Pit 1 well water analyses (*continued*).

	Well			
Parameter[a]	**K1-01C**	**K1-02B**	**K1-03**	**K1-04**
Total organic halides, 2nd replicate (mg/L) (cont.)	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	0.013	0.023	0.017	0.014
	0.027	0.027	0.021	0.030
	0.016	0.023	0.018	0.021
	0.012	<0.01	<0.01	0.010
EPA Method 601[c] (μg/L)				
Freon-113	<0.5	<0.5	<0.5	<0.5
		<1		
		<1		
	<1	<1	<1	<1
	<0.5	<0.5	<0.5	<0.5
EPA Method 624[d] (μg/L)				
Freon-113	<1	<1	<1	<1
	<1	<1	<1	<1
	<1	<1	<1	<1
	<1	<1	<1	<1
Radioactivity (Bq/L)[e]				
Gross alpha	0.21 ± 0.10	0.063 ± 0.085	0.065 ± 0.074	0.013 ± 0.083
	0.23 ± 0.078	0.071 ± 0.054	0.024 ± 0.029	0.023 ± 0.028
	0.29 ± 0.027	0.11 ± 0.021	0.061 ± 0.021	0.000 ± 0.019
	0.30 ± 0.021	0.078 ± 0.014	0.027 ± 0.021	0.036 ± 0.016
Gross beta	0.15 ± 0.055	0.11 ± 0.046	0.13 ± 0.050	0.13 ± 0.046
	0.18 ± 0.038	0.10 ± 0.039	0.086 ± 0.031	0.061 ± 0.029
	0.17 ± 0.013	0.12 ± 0.012	0.13 ± 0.012	0.13 ± 0.012
	0.19 ± 0.010	0.14 ± 0.009	0.13 ± 0.010	0.14 ± 0.0093
Radioisotopes (Bq/L)[e]				
Radium-226	0.015 ± 0.023	0.0067 ± 0.016	0.011 ± 0.018	0.0055 ± 0.021
	0.0047 ± 0.0035	0.00034 ± 0.0035	–0.00002 ± 0.0026	0.0026 ± 0.0032
	0.019 ± 0.0022	0.0093 ± 0.0019	0.018 ± 0.0022	0.017 ± 0.0022
	0.023 ± 0.0026	0.023 ± 0.0026	0.017 ± 0.0022	0.020 ± 0.0022
Thorium-228	0.0022 ± 0.0015	–0.00040 ± 0.0015	–0.00070 ± 0.0011	0.00074 ± 0.0015
	0.0078 ± 0.0026	0.0059 ± 0.0022	0.0033 ± 0.0026	0.0063 ± 0.0022
	–0.021 ± 0.0030	–0.0033 ± 0.0019	0.0067 ± 0.0022	–0.011 ± 0.0022
Thorium-230	0.019 ± 0.0026	0.036 ± 0.0041	0.016 ± 0.0037	0.018 ± 0.0022
	0.025 ± 0.0056	0.020 ± 0.0041	0.020 ± 0.0056	0.026 ± 0.0037
	0.063 ± 0.0048	0.010 ± 0.0033	0.023 ± 0.0030	0.0019 ± 0.0022
Thorium-232	–0.0004 ± 0.0011	–0.0011 ± 0.0011	–0.0067 ± 0.0026	0.0030 ± 0.0011
	–0.0048 ± 0.0037	0.00074 ± 0.0019	0.0022 ± 0.0019	0.00022 ± 0.00063
	0.00074 ± 0.00074	–0.0015 ± 0.0015	–0.00040 ± 0.00037	–0.0041 ± 0.0015

…continued

Table 7-5. Pit 1 well water analyses (*continued*).

Parameter[a]	Well K1-05	 K1-07	 K1-08	 K1-09
Total organic halides, 2nd replicate (mg/L) (contt)	<0.02	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02	<0.02
	<0.01	0.018	0.019	0.025
	0.034	0.026	0.024	0.039
	0.026	0.033	0.024	0.031
	0.019	0.011	0.016	0.015
EPA Method 601[c] (μg/L)				
Freon-113	4.1	<0.5	18	47
	3.1	<1	20	19
	3.4	<0.5	22	36
EPA Method 624[d] (μg/L)				
Freon-113	<1	<1	18	48
	3.7	<1	15	35
	4.0	<1	30	29
	7.0	<1	25	52
Radioactivity (Bq/L)[e]				
Gross alpha	0.068 ± 0.083	0.032 ± 0.070	0.038 ± 0.065	0.047 ± 0.081
	0.14 ± 0.091	0.053 ± 0.025	0.045 ± 0.039	0.031 ± 0.034
	0.065 ± 0.022	0.065 ± 0.019	0.069 ± 0.016	0.067 ± 0.019
	0.037 ± 0.012	0.061 ± 0.014	–0.0041 ± 0.014	0.038 ± 0.014
Gross beta	0.099 ± 0.045	0.10 ± 0.048	0.095 ± 0.044	0.096 ± 0.051
	0.11 ± 0.058	0.081 ± 0.030	0.078 ± 0.031	0.077 ± 0.030
	0.15 ± 0.014	0.13 ± 0.013	0.11 ± 0.012	0.12 ± 0.011
	0.12 ± 0.0085	0.11 ± 0.010	0.12 ± 0.010	0.10 ± 0.0085
Radioisotopes (Bq/L)[e]				
Radium-226	–0.0075 ± 0.021	0.0057 ± 0.021	–0.0062 ± 0.019	0.0071 ± 0.017
	0.0029 ± 0.0027	0.0027 ± 0.0036	0.0011 ± 0.0024	0.0021 ± 0.0023
	0.016 ± 0.0022	0.015 ± 0.0019	0.017 ± 0.0022	0.018 ± 0.0022
	0.018 ± 0.0022	0.014 ± 0.0019	0.012 ± 0.0019	0.016 ± 0.0022
Thorium-228	–0.0026 ± 0.0019	0.0044 ± 0.0015	–0.0096 ± 0.0026	0.0019 ± 0.0019
	0.0089 ± 0.0048	0.0048 ± 0.0059	–0.0030 ± 0.0044	–0.00074 ± 0.0037
	–0.011 ± 0.0030	0.0011 ± 0.0033	–0.0044 ± 0.0019	–0.0011 ± 0.0033
Thorium-230	0.021 ± 0.0030	0.016 ± 0.0022	0.074 ± 0.0056	0.046 ± 0.0041
	0.14 ± 0.010	0.047 ± 0.010	0.011 ± 0.0052	0.040 ± 0.0063
	0.0089 ± 0.0044	0.034 ± 0.0070	0.0011 ± 0.0056	0.0067 ± 0.0063
Thorium-232	0.0019 ± 0.0011	0.00000 ± 0.00037	0.0041 ± 0.0015	0.0056 ± 0.0015
	0.0070 ± 0.0022	0.0011 ± 0.0019	–0.0019 ± 0.0022	0.00026 ± 0.0023
	0.0059 ± 0.0026	0.0030 ± 0.0026	–0.024 ± 0.0041	–0.00074 ± 0.0026

…continued

Table 7-5. Pit 1 well water analyses (*continued*).

	Well			
Parameter[a]	**K1-01C**	**K1-02B**	**K1-03**	**K1-04**
Tritium	4.0 ± 3.1	74 ± 5.3	1.2 ± 2.9	0.29 ± 2.9
	6.5 ± 2.0	94 ± 3.9	5.0 ± 1.7	<1.5
	6.5 ± 2.0	65 ± 3.5	3.5 ± 1.9	<1.7
	8.0 ± 2.7	130 ± 4.5	5.5 ± 2.0	<1.8
Uranium-234	0.16 ± 0.018	0.050 ± 0.0079	0.035 ± 0.0072	0.038 ± 0.0074
	0.16 ± 0.021	0.047 ± 0.0092	0.034 ± 0.0074	0.040 ± 0.0080
	0.18 ± 0.024	0.063 ± 0.0044	0.041 ± 0.0037	0.075 ± 0.0059
	0.18 ± 0.021	0.076 ± 0.011	0.053 ± 0.0089	0.0059 ± 0.0026
	0.22 ± 0.013	0.077 ± 0.0070	0.035 ± 0.0056	0.055 ± 0.0067
	0.18 ± 0.0085	0.061 ± 0.0056	0.043 ± 0.0041	0.055 ± 0.0041
	0.19 ± 0.028	0.048 ± 0.012	0.036 ± 0.013	0.061 ± 0.014
Uranium-235	0.011 ± 0.0050	0.00035 ± 0.0014	0.0000 ± 0.0017	0.0011 ± 0.0014
	0.0037 ± 0.0022	0.0017 ± 0.0015	0.0021 ± 0.0017	–0.00032 ± 0.00023
	0.026 ± 0.0067	0.0019 ± 0.00074	0.0022 ± 0.0007	0.0063 ± 0.0019
	0.0059 ± 0.0022	0.0022 ± 0.0015	–0.00007 ± 0.0020	0.00007 ± 0.0012
	0.0089 ± 0.0026	0.0030 ± 0.0015	0.0022 ± 0.0015	0.0011 ± 0.0011
	0.019 ± 0.0030	0.0022 ± 0.0022	0.0037 ± 0.0011	0.0052 ± 0.0015
	0.0078 ± 0.0044	–0.00074 ± 0.0022	–0.0019 ± 0.0048	0.0033 ± 0.0033
Uranium-238	0.081 ± 0.012	0.028 ± 0.0059	0.020 ± 0.0056	0.016 ± 0.0043
	0.089 ± 0.014	0.028 ± 0.0066	0.014 ± 0.0044	0.024 ± 0.0060
	0.13 ± 0.018	0.034 ± 0.0033	0.024 ± 0.0030	0.043 ± 0.0044
	0.10 ± 0.013	0.046 ± 0.0078	0.027 ± 0.0059	0.0033 ± 0.0022
	0.13 ± 0.010	0.038 ± 0.0052	0.031 ± 0.0052	0.031 ± 0.0052
	0.11 ± 0.0067	0.026 ± 0.0048	0.018 ± 0.0030	0.032 ± 0.0033
	0.11 ± 0.019	0.027 ± 0.0089	0.014 ± 0.011	0.031 ± 0.010

[a] Other analyses requested include EPA Method 608, EPA Method 615, EPA Method 625, and explosive compounds. However, all values for those analyses were below detection limits. EPA Method 608 includes Aldrin; BHC, alpha isomer; BHC, beta isomer; BHC, delta isomer; BHC, gamma isomer (Lindane); chlordane; dieldrin; endosulfan I; endosulfan II; endosulfan sulfate; endrin; endrin aldehyde; heptachlor; heptachlor epoxide; methoxychlor; 4,4'-DDD; 4,4'-DDE; 4,4'-DDT; and toxaphene. EPA Method 615 includes 2,4,5-T; 2,4,5-TP (Silvex); 2,4-D; 2,4-dichlorophenoxy acetic acid; dalapon; dicamba; dichloroprop, dinoseb, MCPA, and MCPP. EPA Method 625 includes 1,2,4-trichlorobenzene; 1,2-dichlorobenzene; 1,2-diphenylhydrazine; 1,3-dichlorobenzene; 1,4 dichlorobenzene; 2,4,5-trichlorophenol; 2,4,6-trichlorophenol; 2,4-dichlorophenol; 2,4-dimethylphenol; 2,4-dinitrophenol; 2,4-dinitrotoluene; 2,6 dinitrotoluene; 2-chloronaphthalene; 2-chlorophenol; 2-methyl phenol; 2-methyl-4,6-dinitrophenol; 2-methylnaphthalene; 2 nitroaniline; 2-nitrophenol; 3,3'-dichlorobenzidine; 3-nitroaniline; 4-bromophenylphenylether; 4-chloro-3-methylphenol; 4-chloroaniline; 4-chlorophenylphenylether; 4-methyl phenol; 4-nitroaniline; 4-nitrophenol; acenaphthene; acenaphthylene; aniline; anthracene; benzidine; benzo(a)anthracene; benzo(a)pyrene; benzo(b)fluoranthene; benzo(g,h,i)perylene; benzo(k)fluoranthene; benzoic acid; benzyl alcohol; bis(2-chloroethoxy)methane; bis(2-chloroethyl)ether; bis(2-chloroisopropyl)ether; bis(2-ethylhexyl)phthalate; butylbenzylphthalate; chrysene; di-n-butylphthalate; di-n-octylphthalate; dibenzo(a,h)anthracene; dibenzofuran; dibutylphthalate; diethylphthalate; dimethylphthalate; fluoranthene; fluorene; hexachlorobenzene; hexachlorobutadiene; hexachlorocyclopentadiene; hexachloroethane; indeno(1,2,3-c,d)pyrene; isophorone; m- and p-cresol; N-nitrosodi-n-propylamine; N-nitrosodimethylamine; N-nitrosodiphenylamine; naphthalene; nitrobenzene; pentachlorophenol; phenanthrene; phenol; and pyrene. Explosive compounds analyses include HMX, RDX, and TNT.

Table 7-5. Pit 1 well water analyses (*concluded*).

	Well			
Parameter [a]	**K1-05**	**K1-07**	**K1-08**	**K1-09**
Tritium	3.6 ± 3.1	1.3 ± 2.9	0.90 ± 2.8	2.1 ± 3.0
	<1.5	<1.5	<1.6	1.6 ± 1.6
	<1.8	<1.8	<1.8	<1.7
	<1.8	2.8 ± 1.9	<1.8	<1.8
Uranium-234	0.036 ± 0.0072	0.040 ± 0.0081	0.032 ± 0.0073	0.043 ± 0.0063
	0.038 ± 0.0079	0.051 ± 0.0094	0.043 ± 0.0087	0.037 ± 0.0075
	0.063 ± 0.0048	0.079 ± 0.0052	0.053 ± 0.0044	0.048 ± 0.0033
	0.037 ± 0.011	0.051 ± 0.011	0.047 ± 0.0089	0.040 ± 0.0085
	0.047 ± 0.0026	0.057 ± 0.0030	0.043 ± 0.0063	0.050 ± 0.0030
	0.056 ± 0.0048	0.056 ± 0.010	0.057 ± 0.0081	0.048 ± 0.015
	0.050 ± 0.012	0.051 ± 0.0033	0.068 ± 0.0033	0.043 ± 0.0033
Uranium-235	0 ± 0.0015	0.00040 ± 0.0016	0.00048 ± 0.00094	0.0029 ± 0.0021
	0.0014 ± 0.0015	0.0015 ± 0.0014	0.00093 ± 0.0014	0.0011 ± 0.0013
	0.0030 ± 0.0011	0.0056 ± 0.0015	0.0063 ± 0.0015	0.0048 ± 0.0011
	0.0044 ± 0.0044	0.0015 ± 0.0022	0.0019 ± 0.0019	0.0033 ± 0.0022
	0.0015 ± 0.00074	0.00074 ± 0.00037	0.0037 ± 0.0022	0.0030 ± 0.00074
	0.00037 ± 0.00074	–0.0048 ± 0.0033	0.0089 ± 0.0037	0.0041 ± 0.0052
	0.0015 ± 0.0022	0.0041 ± 0.0011	0.0070 ± 0.0011	0.0026 ± 0.0015
Uranium-238	0.021 ± 0.0051	0.020 ± 0.0053	0.021 ± 0.0056	0.015 ± 0.0039
	0.021 ± 0.0056	0.020 ± 0.0052	0.023 ± 0.0059	0.017 ± 0.0047
	0.026 ± 0.0030	0.030 ± 0.0033	0.026 ± 0.0030	0.024 ± 0.0026
	0.016 ± 0.0081	0.023 ± 0.0070	0.020 ± 0.0056	0.017 ± 0.0052
	0.022 ± 0.0019	0.027 ± 0.0022	0.024 ± 0.0048	0.020 ± 0.0019
	0.024 ± 0.0033	0.014 ± 0.0067	0.029 ± 0.0063	0.023 ± 0.011
	0.023 ± 0.0078	0.023 ± 0.0022	0.030 ± 0.0022	0.023 ± 0.0026

[b] Other metals and minerals for which analyses were performed include aluminum, barium, beryllium, carbonate alkalinity (as $CaCO_3$), cobalt, copper, hydroxide alkalinity (as $CaCO_3$), iron, low level phenolics, manganese, nickel, nitrite (as N), nitrite (as NO_2), and surfactant. However, all values for those analyses were below detection limits.

[c] Other EPA Method 601 analytes include 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-chloroethylvinylether; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dichlorodifluoromethane; methylene chloride; tetrachloroethene; trans-1,2-dichloroethylene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; and vinyl chloride. However, all values for those analyses were below detection limits.

[d] Other EPA Method 624 analytes include 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-butanone; 2-chloroethylvinylether; 2-hexanone; 4-methyl-2-pentanone; acetone; acrolein; acrylonitrile; benzene; bromodichloromethane; bromoform; bromomethane; carbon disulfide; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dibromomethane; dichlorodifluoromethane; ethylbenzene; methyl ethyl ketone; methylene chloride; styrene; tetrachloroethene; toluene; total xylene isomers; trans-1,2-dichloroethylene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; vinyl acetate; and vinyl chloride. However, all values for those analyses were below detection limits.

[e] Negative radioactivity values can occur when natural background measurements are subtracted from very low level sample measurements near or at the limit of detection.

Table 7-6. Pit 7 well water analyses.

	Well				
Parameter[a]	**K7-01**	**K7-03**	**K7-06**	**K7-09**	**K7-10**
Metals and minerals[b] (mg/L)					
Arsenic	0.0088	0.0031	0.011	<0.002	<0.002
	0.013	0.0044	0.011	0.0027	0.0048
	0.0082	0.0021	0.01	<0.002	0.0027
Barium	0.18	0.073	0.057		<0.05
	0.16	0.068	0.063		0.037
	0.18	0.069	0.075		<0.05
	0.16	0.063	<0.05	<0.05	<0.05
Cadmium	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
	<0.0005	<0.0005	<0.0005	<0.0005	0.014
Copper	<0.01	0.046	<0.01	<0.01	<0.01
	<0.01	0.046	<0.01	<0.01	<0.01
	<0.01	0.076	<0.01	<0.01	<0.01
Lead	<0.002	<0.002	<0.002		<0.002
	0.0027	0.005	0.0026		<0.002
	<0.002	<0.002	<0.002		<0.002
	0.0051	<0.002	<0.002	<0.002	<0.002
	<0.002				
Nickel	0.0057	<0.005	<0.005	<0.005	<0.005
	0.014	<0.005	<0.005	<0.005	<0.005
	0.0054	<0.005	<0.005	<0.005	0.038
Total dissolved solids	480	460	260	540	690
	410	290	200	420	520
	450	410	280	520	710
	450	460	300	510	640
Vanadium	<0.05	<0.05	<0.05		<0.05
	0.013	<0.008	0.023		<0.008
	<0.02	<0.02	0.023		<0.02
	<0.02	<0.02	<0.05	<0.05	<0.05
Zinc	<0.02	0.023	<0.02	<0.02	<0.02
	0.054	0.029	<0.02	<0.02	<0.02
	<0.02	0.029	<0.02	<0.02	<0.02
General indicator parameters					
pH (units)	7.8	7.5	7.9	8.2	7.8
	7.9	8.1	7.7	8.2	7.5
	7.2	7.5	7.6	8.2	7.6
	7.1	7.4	7.5	7.9	7.5
	7.2	7.4	7.6	7.8	7.6
Specific conductance (µmhos/cm)	600	600	400	680	880
	580	600	380	650	780
	570	540	380	670	810
	570	580	380	660	840
	540	540	370	630	760

...continued

Table 7-6. Pit 7 well water analyses (*continued*).

Parameter[a]	Well			
	NC7-25	**NC7-26**	**NC7-47**	**NC7-48**
Metals and minerals[b] (mg/L)				
Arsenic	0.0048	<0.002	0.013	0.0078
	0.0055	0.0026	0.011	0.0071
	0.0068	0.0021	0.013	0.0062
Barium	0.05	<0.05	<0.05	0.14
	0.054	0.021	0.043	0.19
	0.055	<0.05	<0.05	0.17
	0.07	<0.05		0.14
Cadmium	<0.0005	<0.0005	<0.0005	<0.0005
	<0.0005	<0.0005	<0.0005	<0.0005
	0.060	<0.0005	0.0015	0.0015
Copper	0.011	<0.01	<0.01	<0.01
	0.01	<0.01	<0.01	0.026
	0.039	<0.01	<0.01	<0.01
Lead	<0.002	0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002	<0.002
Nickel	<0.005	0.02	<0.005	0.021
	<0.005	<0.005	<0.005	<0.005
	0.015	<0.005	0.0056	0.04
Total dissolved solids	490	440	300	580
	470	320	250	450
	560	430	380	570
	560	400	360	570
Vanadium	<0.05	<0.05	<0.05	<0.05
	0.016	<0.008	0.047	0.021
	<0.02	<0.02	0.039	0.028
	<0.05	<0.05	<0.05	<0.05
Zinc	<0.02	<0.02	<0.02	<0.02
	0.025	<0.02	<0.02	0.03
	0.036	<0.02	<0.02	<0.02
General indicator parameters				
pH (units)	7.4	7.7	7.9	7.7
	7.2	7.5	7.9	7.0
	7.3	7.5	7.9	7.0
	7.3	7.5	7.8	7.0
	7.5	7.6	8.0	7.0
Specific conductance (µmhos/cm)	790	560	530	750
	750	540	500	720
	740	530	490	710
	760	540	520	730
	720	500	480	710

…continued

Table 7-6. Pit 7 well water analyses (*continued*).

Parameter[a]	Well K7-01	 K7-03	 K7-06	 K7-09	 K7-10
EPA Method 601[c] (µg/L)					
1,1,1-Trichloroethane	<0.5	<0.5	<0.5		<0.5
	<0.5	<0.5	<0.5		<0.5
	<0.5	<0.5	<0.5		<0.5
	<0.5	<0.5	<0.5	<0.5	<0.5
1,1-Dichloroethene	0.68	<0.5	<0.5		<0.5
	0.53	<0.5	<0.5		<0.5
	0.8	<0.5	<0.5		<0.5
	0.5	<0.5	<0.5	<0.5	<0.5
Trichloroethene	5.6	2.8	<0.5		<0.5
	5.1	2.4	<0.5		<0.5
	4.9	3.3	<0.5		<0.5
	3.5	2.3	<0.5	<0.5	<0.5
Trichlorofluoromethane	<0.5	<0.5	<0.5		<0.5
	<0.5	<0.5	<0.5		<0.5
	<0.5	<0.5	<0.5		<0.5
	<0.5	<0.5	<0.5	<0.5	<0.5
EPA Method 624[d] (µg/L)					
1,1-Dichloroethene	1.6	0.7	<0.5		<0.5
	1.4	0.8	<0.5		<0.5
	<1	<1	<1		<1
1,2-Dichloroethene (total)	<0.5	<0.5	<0.5		<0.5
	<0.5	<0.5	<0.5		<0.5
	1	<1	<1		<1
Acetone	<5	<5	<5		<5
	<5	<5	<5		<5
	<10	<10	<10		<10
Toluene	<0.5	<0.5	<0.5		<0.5
	<0.5	<0.5	<0.5		<0.5
	<1	<1	<1		<1
Trichloroethene	5.5	2.9	<0.5		<0.5
	5.2	3.1	<0.5		<0.5
	6	4	<0.5		<0.5
Trichlorofluoromethane	<0.5	<0.5	<0.5		<0.5
	<0.5	<0.5	<0.5		<0.5
	<1	<1	<1		<1
Radioactivity (Bq/L)					
Gross alpha	0.34 ± 0.14	0.28 ± 0.14	0.13 ± 0.074		0.049 ± 0.19
	0.46 ± 0.13	0.20 ± 0.10	0.025 ± 0.027		0.058 ± 0.080
	0.42 ± 0.036	0.19 ± 0.020	0.10 ± 0.019		0.12 ± 0.023

...continued

Table 7-6. Pit 7 well water analyses (*continued*).

	Well			
Parameter[a]	**NC7-25**	**NC7-26**	**NC7-47**	**NC7-48**
EPA Method 601[c] (µg/L)				
1,1,1-Trichloroethane	<0.5	0.75	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
1,1-Dichloroethene	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
Trichloroethene	<0.5	0.55	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
Trichlorofluoromethane	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	0.83
	<0.5	<0.5	<0.5	1.7
	<0.5	<0.5	<0.5	<0.5
EPA Method 624[d] (µg/L)				
1,1-Dichloroethene	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
	<1	<1	<1	<1
1,2-Dichloroethene (total)	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
	<1	<1	<1	<1
Acetone	<5	<5	<5	<5
	<5	<5	23	<5
	<10	<10	<10	<10
Toluene	<0.5	<0.5	<0.5	<0.5
	0.8	<0.5	0.6	5.1
	<1	<1	<1	<1
Trichloroethene	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	<0.5
Trichlorofluoromethane	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	1.3
	<1	<1	<1	2
Radioactivity (Bq/L)				
Gross alpha	1.1 ± 0.32	–0.0050 ± 0.087	0.091 ± 0.12	5.6 ± 2.0
	1.1 ± 0.28	0.013 ± 0.034	0.13 ± 0.061	8.09 ± 0.15
	0.85 ± 0.038	0.045 ± 0.019	0.33 ± 0.028	0.94 ± 0.071

...continued

Table 7-6. Pit 7 well water analyses (*continued*).

	Well				
Parameter[a]	**K7-01**	**K7-03**	**K7-06**	**K7-09**	**K7-10**
Gross beta	0.19 ± 0.051	0.15 ± 0.048	0.23 ± 0.051		0.37 ± 0.13
	0.37 ± 0.070	0.22 ± 0.10	0.12 ± 0.036		0.38 ± 0.16
	0.33 ± 0.018	0.21 ± 0.012	0.11 ± 0.011		0.34 ± 0.016
Radioisotopes (Bq/L)					
Radium-226	0.023 ± 0.020	0.021 ± 0.022	0.030 ± 0.0037	0.014 ± 0.0022	0.025 ± 0.020
	0.038 ± 0.0087	0.017 ± 0.0052	0.021 ± 0.0022	0.012 ± 0.0019	0.012 ± 0.0056
	0.045 ± 0.0037	0.024 ± 0.0026	0.018 ± 0.0048	0.013 ± 0.0041	0.031 ± 0.0033
	0.056 ± 0.0044	0.021 ± 0.0022	—[e]	—[e]	0.020 ± 0.0030
	0.064 ± 0.0041	0.019 ± 0.0022	—[e]	—[e]	0.019 ± 0.0022
	0.052 ± 0.0089	0.014 ± 0.0048	—[e]	—[e]	0.016 ± 0.0044
Thorium-228	0.0078 ± 0.0026	0.0074 ± 0.0022	0.0030 ± 0.0011	0.0033 ± 0.0019	–0.0093 ± 0.0022
	0.0093 ± 0.0030	0.0044 ± 0.0026	0.0063 ± 0.0048	–0.0015 ± 0.0044	0.0093 ± 0.0022
	–0.00030 ± 0.0022	0.0026 ± 0.0044	–0.0081 ± 0.0048	0.0022 ± 0.0022	0.00037 ± 0.0048
Thorium-230	0.060 ± 0.0056	0.086 ± 0.0067	0.028 ± 0.0026	0.049 ± 0.0052	0.024 ± 0.0041
	0.021 ± 0.0041	0.021 ± 0.0044	0.0074 ± 0.0052	0.038 ± 0.0078	0.014 ± 0.0030
	0.0052 ± 0.0033	0.0015 ± 0.0048	0.021 ± 0.0067	0.0085 ± 0.0037	–0.0059 ± 0.0093
Thorium-232	0.0019 ± 0.0019	0.0056 ± 0.0019	0.0000 ± 0.00037	0.0015 ± 0.0015	0.0000 ± 0.0015
	0.00074 ± 0.0011	–0.00074 ± 0.0011	0.0026 ± 0.0033	0.0041 ± 0.0037	–0.00037 ± 0.0011
	–0.00007 ± 0.00037	–0.00074 ± 0.0026	0.0019 ± 0.0022	0.00074 ± 0.0015	–0.011 ± 0.0081
Tritium	1661 ± 83	7992 ± 392	<3.7	<1.7	<3.7
	1791 ± 14	7030 ± 28	<1.7	—[e]	<1.7
	1532 ± 14	5846 ± 29	1.9 ± 1.8	—[e]	<2.4
	1395 ± 14	6364 ± 32	<1.7	—[e]	<1.7
Uranium-234	0.23 ± 0.021	0.086 ± 0.011	0.024 ± 0.0058	0 .022 ± 0.0056	0.010 ± 0.0052
	0.23 ± 0.029	0.068 ± 0.011	0.023 ± 0.0062	0.012 ± 0.0030	0.022 ± 0.0058
	0.22 ± 0.011	0.065 ± 0.0056	0.020 ± 0.0033	0.0093 ± 0.0019	0.018 ± 0.0030
	—[e]	—[e]	—[e]	—[e]	—[e]
	0.25 ± 0.028	0.089 ± 0.014	0.050 ± 0.010	0.0078 ± 0.0022	0.046 ± 0.0081
	0.24 ± 0.0089	0.079 ± 0.0056	0.031 ± 0.0019	—[e]	0.0093 ± 0.0022
	0.15 ± 0.0078	0.089 ± 0.0056	0.030 ± 0.0033	—[e]	0.10 ± 0.0063
	0.26 ± 0.014	0.075 ± 0.0078	0.038 ± 0.0059	—[e]	0.020 ± 0.0044
Uranium-235	0.013 ± 0.0045	0.0050 ± 0.0026	0.0026 ± 0.0019	–0.0011 ± 0.0019	–0.00053 ± 0.0021
	0.011 ± 0.0038	0.0025 ± 0.0017	0.0010 ± 0.0013	0.0019 ± 0.0015	0.0023 ± 0.0017
	0.013 ± 0.0026	0.0044 ± 0.0019	0.0019 ± 0.0015	0.0011 ± 0.00074	0.0015 ± 0.00074
	—[e]	—[e]	—[e]	—[e]	—[e]
	0.012 ± 0.0033	0.0041 ± 0.0030	0.010 ± 0.0041	0.0011 ± 0.00074	0.0015 ± 0.0015
	0.016 ± 0.0022	0.010 ± 0.0022	0.0011 ± 0.00037	—[e]	0.00037 ± 0.00074
	0.11 ± 0.0067	0.011 ± 0.0022	0.020 ± 0.0026	—[e]	0.0074 ± 0.0019
	0.013 ± 0.0044	0.0033 ± 0.0019	0.0019 ± 0.0015	—[e]	<0.0022 ± 0.0015

…continued

Table 7-6. Pit 7 well water analyses (*continued*).

Parameter[a]	Well			
	NC7-25	**NC7-26**	**NC7-47**	**NC7-48**
Gross beta	0.69 ± 0.15	0.12 ± 0.046	0.27 ± 0.057	5.5 ± 0.97
	0.98 ± 0.12	0.14 ± 0.081	0.20 ± 0.051	2.64 ± 0.414
	0.76 ± 0.017	0.17 ± 0.013	0.28 ± 0.018	0.62 ± 0.031
Radioisotopes (Bq/L)				
Radium-226	0.046 ± 0.024	0.0061 ± 0.020	–0.0038 ± 0.021	0.36 ± 0.055
	0.027 ± 0.0068	0.024 ± 0.0026	0.015 ± 0.0019	0.67 ± 0.015
	0.035 ± 0.0030	0.027 ± 0.0026	0.018 ± 0.0022	0.023 ± 0.0022
	0.042 ± 0.0037	0.020 ± 0.0052	0.017 ± 0.0044	0.025 ± 0.0026
	0.033 ± 0.0030	—[e]	—[e]	0.033 ± 0.0070
	0.040 ± 0.0074	—[e]	—[e]	0.788 ± 0.135
Thorium-228	–0.0026 ± 0.0015	–0.0074 ± 0.0030	–0.0030 ± 0.0030	0 ± 0.0026
	–0.0059 ± 0.0037	0.0022 ± 0.0096	0.0033 ± 0.0037	–0.0022 ± 0.0030
	0.0011 ± 0.0026	0.0011 ± 0.0037	0 ± 0.0081	0.0011 ± 0.0033
Thorium-230	0.0037 ± 0.0019	0.12 ± 0.0096	0.078 ± 0.0078	0.033 ± 0.0041
	0.064 ± 0.0078	0.0011 ± 0.0070	0.043 ± 0.0059	0.14 ± 0.010
	0.0052 ± 0.0041	0.0011 ± 0.0030	0.012 ± 0.0081	0.010 ± 0.0056
Thorium-232	–0.0011 ± 0.0011	0.010 ± 0.0033	0.0033 ± 0.0026	0.0015 ± 0.0011
	0.0011 ± 0.0011	–0.00037 ± 0.0048	0.0011 ± 0.0011	0.0074 ± 0.0026
	0.0030 ± 0.0026	–0.00074 ± 0.0015	0.0015 ± 0.0033	0.00022 ± 0.0024
Tritium	8621 ± 422	29 ± 4.7	<3.8	<3.7
	11026 ± 33	39 ± 2.8	<1.7	11 ± 2.1
	10212 ± 41	50 ± 3.1	<1.8	8.3 ± 2.0
	10323 ± 41	52 ± 3.2	<1.7	4.8 ± 1.9
Uranium-234	0.45 ± 0.050	0.0043 ± 0.0028	0.057 ± 0.015	0.43 ± 0.033
	0.37 ± 0.044	0.0016 ± 0.0018	0.11 ± 0.030	0.54 ± 0.075
	0.58 ± 0.021	0.035 ± 0.0033	0.061 ± 0.0056	0.52 ± 0.033
	—[e]	—[e]	—[e]	0.28 ± 0.012
	0.42 ± 0.044	0.0089 ± 0.0033	0.060 ± 0.0096	0.081 ± 0.0059
	0.47 ± 0.015	0.0093 ± 0.0019	0.060 ± 0.0052	0.18 ± 0.0093
	0.43 ± 0.015	0.0037 ± 0.0011	0.053 ± 0.0056	0.18 ± 0.012
	0.37 ± 0.019	0.010 ± 0.0015	0.051 ± 0.0026	0.17 ± 0.0048
Uranium-235	0.032 ± 0.010	0 ± 0.0014	0.0010 ± 0.0019	0.037 ± 0.0071
	0.015 ± 0.0046	0.00055 ± 0.0010	0.045 ± 0.017	0.022 ± 0.0094
	0.027 ± 0.0044	0.0019 ± 0.0011	0.0030 ± 0.0011	0.033 ± 0.0096
	—[e]	—[e]	0.015 ± 0.0046	0.033 ± 0.0041
	0.017 ± 0.0037	0.00074 ± 0.0015	0.0030 ± 0.0019	0.076 ± 0.0056
	0.021 ± 0.0030	0.0015 ± 0.00074	0.0030 ± 0.0011	0.014 ± 0.0026
	0.023 ± 0.0030	–0.00037 ± 0.00074	0.0019 ± 0.0015	0.010 ± 0.0030
	0.011 ± 0.0033	–0.00033 ± 0.00056	0.0022 ± 0.00074	0.013 ± 0.0019

…continued

Table 7-6. Pit 7 well water analyses (*concluded*).

Parameter[a]	Well K7-01	K7-03	K7-06	K7-09	K7-10
Uranium-238	0.22 ± 0.020	0.078 ± 0.010	0.021 ± 0.0048	0.011 ± 0.0041	0.0078 ± 0.0043
	0.22 ± 0.029	0.058 ± 0.0097	0.019 ± 0.0056	0.0063 ± 0.0026	0.011 ± 0.0041
	0.21 ± 0.010	0.081 ± 0.0059	0.017 ± 0.0030	0.0052 ± 0.0015	0.017 ± 0.0030
	—[e]	—[e]	—[e]	—[e]	—[e]
	0.23 ± 0.026	0.084 ± 0.013	0.036 ± 0.0081	0.0056 ± 0.0019	0.025 ± 0.0056
	0.22 ± 0.0085	0.072 ± 0.0052	0.024 ± 0.0019	—[e]	0.0052 ± 0.0019
	0.016 ± 0.0044	0.074 ± 0.0052	0.0030 ± 0.0011	—[e]	0.30 ± 0.011
	0.23 ± 0.014	0.068 ± 0.0074	0.028 ± 0.0052	—[e]	0.0085 ± 0.0030

Parameters[a]	Well NC7-25	NC7-26	NC7-47	NC7-48
Uranium-238	0.37 ± 0.043	0.0028 ± 0.0022	0.025 ± 0.0084	1.2 ± 0.078
	0.32 ± 0.038	0.00090 ± 0.0015	0.071 ± 0.023	1.5 ± 0.19
	0.45 ± 0.019	0.030 ± 0.0030	0.038 ± 0.0044	1.3 ± 0.053
	0.322 ± 0.038	—[e]	—[e]	0.79 ± 0.020
	0.37 ± 0.039	0.0052 ± 0.0026	0.028 ± 0.0059	0.60 ± 0.067
	0.41 ± 0.011	0.0030 ± 0.0011	0.037 ± 0.0041	0.52 ± 0.015
	0.36 ± 0.012	0.00074 ± 0.00074	0.024 ± 0.0041	0.51 ± 0.019
	0.28 ± 0.016	0.0052 ± 0.0011	0.026 ± 0.0019	0.47 ± 0.0078

[a] Explosive compounds analysis, including HMX, RDX, and TNT, was also requested. However, all values for those analyses were below detection limits.

[b] Other metals for which analyses were performed include beryllium, cobalt, and mercury. However, all values for those analyses were below detection limits.

[c] Other EPA Method 601 parameters for which analyses were performed include 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-dichloroethylvinylether; dibromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dichlorodifluoromethane; Freon-113; methylene chloride; tetrachloroethene; trans-1,2-dichloroethylene; trans-1,3-dichloropropene; and vinyl chloride. However, all values for those analyses were below detection limits.

[d] Other EPA Method 624 parameters for which analyses were performed include 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4 dichlorobenzene; 2-butanone; 2-chloroethylvinylether; 2-hexanone; 4-methyl-2-pentanone; acrolein; acrylonitrile; benzene; bromodichloromethane; bromoform; bromomethane; carbon disulfide; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dibromomethane; dichlorodifluoromethane; ethylbenzene; Freon-113; methyl ethyl ketone; methylene chloride; styrene; tetrachloroethene; total xylene isomers; trans-1,2-dichloroethylene; trans-1,3-dichloropropene; and vinyl acetate; vinyl chloride. However, all values for those analyses were below detection limits.

[e] Additional measurements not required.

Table 7-7. HE Process Area well water analyses.

	Well				
Parameter	**W-817-01**	**W-817-02**	**W-817-03**	**W-817-04**	**W-817-03A**
Metals and minerals[a] (mg/L)					
Antimony	<0.2	<0.2	<0.2	<0.2	
	<0.2	<0.2	<0.2	<0.2	
	<0.5	<0.5	<0.5	<0.5	
	0.0092	<0.005	<0.005	<0.005	
Arsenic	0.042	0.051	0.047	0.051	
	0.036	0.053	0.051	0.052	
	0.041	0.048	0.041	0.043	
	0.040	0.051	0.040	0.043	
	0.038	0.049	0.041	0.046	
	0.046	0.048	0.049	0.05	
	0.045	0.05	0.047	0.039	
	0.038	0.047	0.041	0.052	
	0.045	0.053	0.05	0.053	
	0.045	0.054	0.053	0.055	
	0.04	0.043	0.041	0.046	
	0.044	0.055	0.041	0.043	
	0.045	0.053	0.05	0.048	
	0.055	0.065	0.064	0.063	
	0.047	0.052	0.05	0.054	
	0.058	0.067	0.063	0.066	
Beryllium	<0.0002	<0.0002	<0.0002	<0.0002	
	<0.0002	<0.0002	<0.0002	<0.0002	
	<0.0002	<0.0002	<0.0002	<0.0002	
	<0.0002	<0.0002	<0.0002	<0.0002	
	<0.0002	<0.0002	<0.0002	<0.0002	
	<0.0002	<0.0002	<0.0002	<0.0002	
	<0.0002	<0.0002	<0.0002	<0.0002	
	<0.0002	<0.0002	<0.0002	<0.0002	
	<0.01	<0.01	<0.01	<0.01	
	<0.001	<0.001	<0.001	0.0023	
	<0.001	<0.001	<0.001	<0.001	
	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	
Bicarbonate alkalinity (as $CaCO_3$)	260	240	260	250	
	260	240	260	250	
	350	240	250	250	
	350	327	350	350	

...continued

Table 7-7. HE Process Area well water analyses (*continued*).

Parameter	Well				
	W-817-01	W-817-02	W-817-03	W-817-04	W-817-03A
Calcium	21	35	20	20	
	13	35	19	19	
	14	35	20	21	
	14	34	20	20	
Chloride	150	300	220	240	
	160	300	230	240	
	140	260	200	210	
	150	270	200	210	
Chromium	<0.005	0.005	<0.005	0.0061	
	<0.005	<0.005	<0.005	0.019	
	<0.005	<0.005	<0.005	<0.005	
	<0.005	<0.005	<0.005	0.0058	
	<0.005	<0.005	<0.005	<0.005	
	<0.005	<0.005	<0.005	<0.005	
	<0.005	<0.005	<0.005	<0.005	
	<0.005	<0.005	<0.005	<0.005	
	<0.05	<0.05	<0.05	<0.05	
	0.0014	0.0012	0.0022	<0.001	
	0.0011	<0.001	0.0019	0.002	
	0.0018	0.0015	0.0023	0.0024	
	0.0025	0.0016	0.0036	0.0027	
	<0.001	<0.001	<0.001	<0.001	
	0.0031	0.0031	0.0039	0.0042	
	0.0037	0.005	0.0043	0.0045	
Fluoride	1.1	0.96	1.4	1.3	
Hardness, total (as $CaCO_3$)	<1	160	90	94	
	59	150	90	89	
	86	153	87	86	
Lead	<0.002	<0.002	<0.002	<0.002	
	<0.002	<0.002	<0.002	<0.002	
	<0.002	<0.002	<0.002	<0.002	
	<0.002	<0.002	<0.002	<0.002	
	<0.002	<0.002	<0.002	<0.002	
	<0.002	<0.002	<0.002	<0.002	
	<0.002	<0.002	<0.002	<0.002	
	<0.002	<0.002	<0.002	<0.002	
	<0.1	<0.1	<0.1	<0.1	
	<0.005	<0.005	<0.005	0.033	
	<0.005	<0.005	<0.005	<0.005	
	<0.002	<0.002	<0.005	<0.005	
	<0.002	<0.002	<0.002	<0.002	

...continued

Table 7-7. HE Process Area well water analyses (*continued*).

Parameter	Well				
	W-817-01	W-817-02	W-817-03	W-817-04	W-817-03A
Lead (cont.)	<0.002	<0.002	<0.002	<0.002	
	<0.002	<0.002	<0.002	<0.002	
	<0.002	<0.002	<0.002	<0.002	
Magnesium	8.2	16	9.1	8.8	
	5	17	8.8	9.1	
	5.6	17	9.8	10	
	5.9	17	9.8	9.6	
Molybdenum	<0.1	<0.1	<0.1	<0.1	
	<0.1	<0.1	<0.1	<0.1	
	<0.05	0.052	<0.05	<0.05	
	<0.05	<0.05	<0.05	<0.05	
Nickel	<0.005	0.0064	<0.005	<0.005	
	<0.005	<0.005	<0.005	<0.005	
	<0.1	<0.1	<0.1	<0.1	
	<0.1	<0.1	<0.1	<0.1	
Nitrate (as NO_3)	71	93	102	115	
	73	84	86	88	
	81	89	91	95	
Potassium	14	13	9.1	9.6	
	8.5	14	10	11	
	8.6	12	9.7	10	
	9.7	13	10	11	
Selenium	0.033	0.098	0.033	0.028	
	0.038	0.092	0.032	0.027	
	0.036	0.082	0.033	0.026	
	0.039	0.098	0.036	0.031	
	0.034	0.081	0.032	0.029	
	0.037	0.076	0.036	0.027	
	0.040	0.100	0.036	0.033	
	0.034	0.032	0.071	0.026	
	0.024	0.095	0.039	0.033	
	0.043	0.095	0.039	<0.005	
	0.044	0.099	0.039	0.032	
	0.045	0.095	0.038	0.032	
	0.043	0.100	0.039	0.033	
	0.040	0.085	0.031	0.028	
	0.045	0.095	0.039	0.033	
	0.036	0.078	0.034	0.027	
Silver	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	

…continued

Table 7-7. HE Process Area well water analyses (*continued*).

Parameter	Well W-817-01	W-817-02	W-817-03	W-817-04	W-817-03A
Silver (cont.)	<0.05	<0.0005	<0.05	<0.05	
	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	
	0.0006	0.0006	<0.0005	0.0024	
	<0.05	<0.05	<0.05	<0.05	
	<0.001	<0.001	<0.001	<0.001	
	<0.001	<0.001	<0.001	<0.001	
	<0.001	<0.001	<0.001	<0.001	
	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	
	<0.0005	<0.0005	<0.0005	<0.0005	
Sodium	370	370	300	330	
	260	450	320	360	
	270	430	350	380	
	270	410	340	360	
Sulfate	120	400	230	270	
	120	390	230	260	
	120	340	190	230	
	120	360	190	210	
Total alkalinity (as $CaCO_3$)	260	240	260	250	
	260	240	260	250	
	350	240	250	250	
	350	327	350	350	
Total dissolved solids	830	1400	1100	1200	
	850	1400	1100	1200	
	910	1400	1100	1200	
	900	1500	1100	1100	
Vanadium	0.1	0.1	0.12	0.086	
	<0.2	<0.2	<0.2	<0.2	
	0.13	0.13	0.11	0.11	
	0.12	0.1	0.11	0.11	
General indicator parameters					
pH (units)	8.0	7.8	7.9	8.0	
	8.2	8.0	8.0	8.1	
	8.0	7.8	7.9	8.1	
	7.7	7.7	7.6	7.8	
	7.9	7.7	7.8	7.9	
	7.8	7.6	7.0	7.8	
	7.8	7.6	7.6	7.8	

…continued

Table 7-7. HE Process Area well water analyses (*continued*).

	Well				
Parameter	**W-817-01**	**W-817-02**	**W-817-03**	**W-817-04**	**W-817-03A**
pH (units) (cont.)	7.6	7.7	7.4	7.9	
	8.2	7.9	8.0	8.1	
	8.0	7.9	7.9	8.1	
	8.1	7.9	7.9	8.1	
	8.0	7.9	8.1	8.2	
	8.1	8.0	8.1	8.1	
	8.2	8.1	8.1	8.3	
	8.2	8.1	8.0	8.2	
	8.2	8.1	8.3	8.2	
Specific conductance (μmhos/cm)	1300	2080	1950	1950	
	1430	2140	1790	2050	
	1090	2180	1140	1570	
	1350	2050	1800	1570	
	1090	1920	1650	1550	
	1400	2300	1760	1880	
	1110	1910	1560	1650	
	1400	1850	2230	1280	
	1200	2000	1600	1700	
	1300	2100	1600	1700	
	1300	2200	1700	1700	
	1300	2100	1600	1700	
	1200	1900	1500	1600	
	1200	2000	1500	1600	
	1200	2000	1600	1600	
	1200	2000	1500	1600	
Total organic carbon (mg/L)	0.8	1.1	0.8	0.82	
	0.82	0.67	0.82	0.97	
	0.9	0.89	1.2	1.1	
	1.2	0.92	1	1	
	1.4	1.2	1.5	1.5	
	1.1	0.99	1.1	1.1	
	1	0.89	1	1	
	1.5	1.1	1	1.1	
	26	5.7	9	11	
	15	3.9	8.3	4.9	
	9	45	13	5.6	
	4.1	3.4	4.3	14	
	4.4	2.9	5.1	3.8	
	5.5	2.4	6.8	4.4	
	7.2	2.5	4.5	4.3	
	13	7	5	7.3	

…continued

Table 7-7. HE Process Area well water analyses (*continued*).

	Well				
Parameter	**W-817-01**	**W-817-02**	**W-817-03**	**W-817-04**	**W-817-03A**
Total organic halides, 1st replicate (mg/L)	0.026	<0.02	<0.02	<0.02	
	0.03	<0.02	<0.02	<0.02	
	0.026	<0.02	<0.02	<0.02	
	0.022	<0.02	<0.02	<0.02	
	0.024	0.02	0.029	0.029	
	0.027	<0.02	0.021	<0.02	
	<0.02	<0.02	<0.02	<0.02	
	0.023	0.027	<0.02	0.02	
	0.02	0.02	0.06	0.03	
	0.043	0.045	0.042	0.066	
	0.028	0.012	0.097	0.051	
	0.063	0.047	0.066	0.066	
	0.032	0.05	0.036	0.078	
	0.033	0.059	0.058	0.046	
	0.036	0.033	0.038	0.033	
	0.043	0.023	0.038	0.036	
Total organic halides, 2nd replicate (mg/L)	0.021	<0.02	<0.02	<0.02	
	0.027	<0.02	<0.02	<0.02	
	0.024	<0.02	<0.02	<0.02	
	0.023	<0.02	<0.02	<0.02	
	0.023	0.02	0.029	0.028	
	0.028	<0.02	0.02	<0.02	
	<0.02	<0.02	<0.02	<0.02	
	0.023	0.026	<0.02	0.021	
	0.02	0.04	0.02	0.04	
	0.05	0.061	0.049	0.044	
	0.026	<0.01	0.059	0.059	
	0.065	0.058	0.07	0.068	
EPA Method 601[b] (µg/L)					
1,2-Dichloroethene (total)	<0.5	<0.5	<0.5	<0.5	2.4
	<0.5	<0.5	<0.5	<0.5	3.3
	<0.5	<0.5	<0.5	<0.5	1.4
	<0.5	<0.5	<0.5	<0.5	1.7
Tetrachloroethene	<0.5	<0.5	<0.5	<0.5	<0.5
	<0.5	1.9	0.55	<0.5	<0.5
	<0.5	<0.5	<0.5	0.6	<0.5
	<0.5	<0.5	<0.5	<0.5	<0.5
Trichloroethene	<0.5	<0.5	20	13	46
	<0.5	2.2	22	9.2	63
	<0.5	0.8	13	11	39
	<0.5	<0.5	10	6.5	49

…continued

Table 7-7. HE Process Area well water analyses (*concluded*).

Parameter	Well W-817-01	W-817-02	W-817-03	W-817-04	W-817-03A
Explosive compounds[c] (µg/L)					
RDX	88	<30	<30	<30	<30
	64	<30	<30	<30	
	96	<30	<30	<30	
	96	<30	<30	<30	
	101	<30	<30	<30	<30
	91	<30	<30	<30	
	117	<30	<30	<30	
	91	<30	<30	<30	
	90	<30	<30	<30	<30
	110	<30	<30	<30	
	60	<30	<30	<30	
	110	<30	<30	<30	
	<30	<30	<30	<30	<30
	<30	<30	<30	<30	
	<30	<30	<30	<30	
	<30	<30	<30	<30	
Radioisotopes (Bq/L)					
Tritium	–0.83 ± 2.7	1.9 ± 3.0	1.7 ± 3.0	2.7 ± 3.1	1.4 ± 2.9
	<1.8	<1.5	<1.5	<1.8	<1.6
	<1.7	<1.7	<1.7	<1.7	<1.7
	<1.7	<1.6	<1.7	<1.7	<1.6

[a] Other metals and minerals for which analyses were performed include aluminum, barium, cadmium, carbonate alkalinity (as $CaCO_3$), cobalt, copper, hydroxide alkalinity (as $CaCO_3$), iron, manganese, mercury, nitrite (as N), nitrite (as NO_2), surfactant, thallium, and zinc. However, all values for those analyses were below detection limits.

[b] Other EPA Method 601 analytes for which analyses were performed include 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene;1,2-dichloroethane; 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-chloroethylvinylether; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,3-dichloropropene; dibromochloromethane; dichlorodifluoromethane; Freon -113; methylene chloride; trans-1,2-dichloroethylene; trans-1,3-dichloropropene; trichlorofluoromethane; vinyl chloride. However, all values for those analyses were below detection limits.

[c] Other explosive compounds for which analyses were performed include HMX and TNT. However, all values for those analyses were below detection limits.

Table 7-8. Pit 2 well water analyses.

	Well			
Parameter	**K1-01A**	**K1-01B**	**K1-02A**	**K2-01A**
Metals[a] (mg/L)				
Arsenic	0.0047	0.0098	0.012	<0.002
Barium	<0.05	<0.05	<0.05	<0.05
	<0.1	<0.1	<0.1	<0.1
		0.053	<0.05	<0.05
	<0.05	0.052	<0.05	<0.05
Iron	<0.1	0.11	<0.1	<0.1
Radioactivity (Bq/L)				
Gross alpha	0.068 ± 0.088	–0.0057 ± 0.064	0.070 ± 0.11	0.17 ± 0.12
	0.073 ± 0.069	–0.0056 ± 0.030	0.021 ± 0.040	–0.0023 ± 0.037
		–0.015 ± 0.017	0.030 ± 0.018	0.11 ± 0.020
	0.078 ± 0.026	0.013 ± 0.016		0.049 ± 0.023
Gross beta	0.21 ± 0.051	0.12 ± 0.046	0.10 ± 0.044	0.21 ± 0.052
	0.20 ± 0.052	0.11 ± 0.038	0.11 ± 0.043	0.14 ± 0.046
		0.13 ± 0.012	0.15 ± 0.014	0.22 ± 0.013
	0.27 ± 0.018	0.16 ± 0.015		0.23 ± 0.017
Radioisotopes (Bq/L)				
Radium-226	0.024 ± 0.021	0.0071 ± 0.019	0.0050 ± 0.011	0.0075 ± 0.021
	0.014 ± 0.0043	0.0015 ± 0.0033	0.0016 ± 0.0032	0.0065 ± 0.0038
		0.021 ± 0.0030	0.018 ± 0.0026	0.022 ± 0.0030
	0.037 ± 0.0074	0.016 ± 0.0044		0.023 ± 0.0059
Tritium	–3.3 ± 3.4	–3.7 ± 3.6	–2.0 ± 3.6	–3.4 ± 3.6
	<1.7	<1.8	<1.5	<1.7
		<1.6	<1.6	<1.6
	<1.8	<1.8	<1.8	<2.3
Uranium-234	0.019 ± 0.0048	0.0048 ± 0.0024	0.010 ± 0.0039	0.0049 ± 0.0030
	0.027 ± 0.0087	–0.0012 ± 0.0012	0.013 ± 0.0056	0.019 ± 0.0066
		0.0022 ± 0.00074	0.010 ± 0.0022	0.071 ± 0.0067
	0.026 ± 0.0022	0.00074 ± 0.0011		0.0033 ± 0.0011
Uranium-235	0.00000 ± 0.00071	0.0012 ± 0.0011	0.0016 ± 0.0016	0.00000 ± 0.00073
	0.0081 ± 0.0046	0.000056 ± 0.00085	0.0024 ± 0.0026	0.014 ± 0.0055
		0.00074 ± 0.00037	0.0011 ± 0.00074	0.0059 ± 0.0019
	0.00074 ± 0.00037	0.00026 ± 0.00074		0.00074 ± 0.00074
Uranium-238	0.010 ± 0.0036	0.0010 ± 0.0014	0.0082 ± 0.0033	0.0067 ± 0.0030
	0.0085 ± 0.0049	–0.00037 ± 0.0012	0.010 ± 0.0048	0.014 ± 0.0056
		0.00074 ± 0.00074	0.0063 ± 0.0019	0.021 ± 0.0037
	0.013 ± 0.0015	0.00026 ± 0.00093		0.0048 ± 0.0011

...continued

Table 7-8. Pit 2 well water analyses (*concluded*).

Parameter	Well		
	K2-01B	**K2-02A**	**K2-02B**
Metals[a] (mg/L)			
Arsenic	0.028	0.044	<0.002
Barium	<0.05	<0.05	<0.05
	<0.1	<0.1	<0.1
	<0.05	<0.05	<0.05
	<0.05	<0.05	<0.05
Iron	<0.1	<0.1	0.15
Radioactivity (Bq/L)			
Gross alpha	0.089 ± 0.094	0.12 ± 0.089	0.010 ± 0.073
	0.20 ± 0.10	0.077 ± 0.058	0.038 ± 0.055
	0.18 ± 0.024	0.15 ± 0.027	0.033 ± 0.030
	0.21 ± 0.028	0.26 ± 0.034	–0.058 ± 0.020
Gross beta	0.15 ± 0.047	0.10 ± 0.049	0.13 ± 0.053
	0.21 ± 0.050	0.18 ± 0.10	0.13 ± 0.046
	0.22 ± 0.013	0.18 ± 0.014	0.17 ± 0.013
	0.29 ± 0.017	0.27 ± 0.021	0.19 ± 0.015
Radioisotopes (Bq/L)			
Radium-226	0.011 ± 0.020	0.0055 ± 0.021	0.0000 ± 0.019
	0.0011 ± 0.0024	0.00093 ± 0.0031	0.0052 ± 0.0037
	0.019 ± 0.0026	0.017 ± 0.0026	0.024 ± 0.0030
	0.030 ± 0.0063	0.017 ± 0.0048	0.019 ± 0.0052
Tritium	3.0 ± 3.8	–2.0 ± 3.5	0.0000 ± 3.7
	4.4 ± 1.9	<1.6	<1.7
	5.4 ± 1.8	<1.7	<1.7
	5.5 ± 2.0	<1.8	<1.8
Uranium-234	0.090 ± 0.011	0.13 ± 0.014	0.0000 ± 0.0026
	0.085 ± 0.016	0.14 ± 0.033	–0.0010 ± 0.0015
	0.16 ± 0.011	0.13 ± 0.0085	0.014 ± 0.0030
	0.10 ± 0.0037	0.10 ± 0.0041	0.0026 ± 0.00074
Uranium-235	0.0023 ± 0.0026	0.0011 ± 0.0014	0.0000 ± 0.0010
	0.0026 ± 0.0024	0.017 ± 0.0094	–0.00012 ± 0.0015
	0.0081 ± 0.0030	0.0044 ± 0.0015	0.0015 ± 0.0015
	0.0041 ± 0.00074	0.0033 ± 0.0007	0.0011 ± 0.00074
Uranium-238	0.055 ± 0.0080	0.035 ± 0.0065	0.00044 ± 0.00086
	0.056 ± 0.012	0.041 ± 0.016	–0.00026 ± 0.0014
	0.077 ± 0.0081	0.029 ± 0.0041	0.021 ± 0.0037
	0.063 ± 0.0030	0.030 ± 0.0022	0.0044 ± 0.0011

[a] Other metals for which analysis was performed include beryllium, cadmium, chromium, lead, manganese, mercury, nickel, selenium, silver, and vanadium. However, all values for those analyses were below detection limits.

Table 7-9. Pit 9 well water analyses.

Parameter[a]	Well K9-01	K9-02	K9-03	K9-04
Metals and Minerals[b] (mg/L)				
Ammonia nitrogen (as N)	1.3	1.1	1.4	
Arsenic	0.0057	0.036	0.015	
Bicarbonate alkalinity (as $CaCO_3$)	210	260	140	
Calcium	77	65	79	
Chloride	130	160	140	
Chromium	0.0023	<0.01	0.0026	
Fluoride	0.35		0.36	
Hardness, total (as $CaCO_3$)	320	300	330	
Iron	<0.1		0.12	
	<0.1	<0.1	<0.1	
Magnesium	30	32	33	
Manganese	0.078		0.045	
	0.077	<0.03	<0.03	
Nitrate (as N)	<0.5	<0.5	1	
Nitrite (as N)	0.74	0.5	0.33	
Potassium	7	9	8.3	
Sodium	280		280	
	290	260	280	
Sulfate	600	480	610	
Total alkalinity (as $CaCO_3$)	210	260	140	
Total dissolved solids	1300	1200	1400	
Total Kjeldahl nitrogen	1	0.72	0.89	
Total suspended solids	<1		5	
General indicator parameters				
pH (units)	7.8	7.8	8.0	
Specific conductance (µmhos/cm)	1700	1600	1700	
Total organic carbon (mg/L)	13	11	11	
Total organic halides, 1st replicate (mg/L)	0.038	0.059	0.015	

...continued

Table 7-9. Pit 9 well water analyses (*concluded*).

Parameter[a]	Well K9-01	K9-02	K9-03	K9-04
Radioactivity (Bq/L)				
Gross alpha	0.051 ± 0.030	0.057 ± 0.015	0.037 ± 0.037	
Gross beta	0.35 ± 0.030	0.31 ± 0.026	0.36 ± 0.029	
Radioisotopes (Bq/L)				
Radium-226	0.013 ± 0.0019	0.012 ± 0.0019	0.014 ± 0.0019	—[c]
Tritium	<1.7	<1.7	<1.6	—[c]
Uranium-234	0.0022 ± 0.0011	0.033 ± 0.0033	0.030 ± 0.0030	0.032 ± 0.0026
Uranium-235	0.00037 ± 0.00074	0.0052 ± 0.0015	0.0026 ± 0.0015	0.0015 ± 0.00074
Uranium-238	0.00074 ± 0.00074	0.021 ± 0.0026	0.011 ± 0.0022	0.014 ± 0.0019

[a] Other analyses requested include EPA Method 524.2, EPA Method 624, EPA Method 608, EPA Method 615, and explosive compounds. However, all values for those analyses were below detection limits. EPA Method 524.2 includes 1,1,1,2-tetrachloroethane; 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,1-dichloropropene; 1,2,3-trichlorobenzene; 1,2,3-trichloropropane; 1,2,4-trichlorobenzene; 1,2,4 trimethylbenzene; 1,2-dibromo-3-chloropropane; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloropropane; 1,3,5-trimethylbenzene; 1,3-dichlorobenzene; 1,3-dichloropropane; 1,4-dichlorobenzene; 2-chlorotoluene; 4-chlorotoluene; benzene; bromobenzene; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dibromomethane; dichlorodifluoromethane; ethylbenzene; ethylene dibromide; Freon-113; hexachlorobutadiene; isopropylbenzene; m- and p-xylene isomers; methylene chloride; n-butylbenzene; n-propylbenzene; naphthalene; o-xylene; p-isopropyl toluene; sec-butylbenzene; styrene; tert-butylbenzene; tetrachloroethene; toluene; trans-1,2-dichloroethylene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; and vinyl chloride. EPA Method 624 includes 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-butanone; 2-chloroethylvinylether; 2-hexanone; 4-methyl-2-pentanone; acetone; benzene; bromodichloromethane; bromoform; bromomethane; carbon disulfide; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,3-dichloropropene; dibromochloromethane; dibromomethane; dichlorodifluoromethane; ethylbenzene; Freon-113; methylene chloride; styrene; tetrachloroethene; toluene; total xylene isomers; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; vinyl acetate; and vinyl chloride. EPA Method 608 includes Aldrin; BHC, alpha isomer; BHC, beta isomer; BHC, delta isomer; BHC, gamma isomer (Lindane); chlordane; dieldrin; endosulfan I; endosulfan II; endosulfan sulfate; endrin; endrin aldehyde; heptachlor; heptachlor epoxide; methoxychlor; p,p'-DDD; p,p'-DDE; p,p'-DDT; and toxaphene. EPA Method 615 includes 2,4,5-TP (Silvex) and 2,4-D. Explosive compounds include HMX, RDX, and TNT.

[b] Other metals and minerals for which analysis was performed include aluminum, barium, beryllium, cadmium, carbonate alkalinity (as CaCO3), copper, hydroxide alkalinity (as CaCO3), lead, mercury, nickel, phenolics, selenium, silver, surfactant, vanadium, and zinc.

[c] Not necessary to sampling plan.

Table 7-10. Elk Ravine drainage area well water analyses.

	Well				
Parameter	**K7-07**	**NC7-61**	**NC7-69**	**K2-04D**	**K2-04S**
Metals and minerals[a] (mg/L)					
Ammonia nitrogen (as N)				0.03	0.034
				<0.03	0.038
				<0.1	<0.1
				<0.1	<0.1
Barium	0.14				
	0.11				
Beryllium	<0.0002	0.0003	<0.0002	<0.0002	<0.0002
	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
		<0.001	<0.001	<0.0005	<0.0005
		<0.0005	<0.0005	<0.0005	<0.0005
Chromium		<0.005	<0.005		
		<0.005	<0.005		
		0.0044	<0.001		
		<0.01	<0.01		
Nitrate (as NO_3)				37	42
				32	37
Vanadium	<0.05				
	0.019				
EPA Method 601[b] (µg/L)					
Trichloroethene	<0.5	<0.5	<0.5	<0.5	<0.5
	0.86	<0.5	<0.5	<0.5	<0.5
		<0.5	<0.5	<0.5	<0.5
		<0.5	<0.5	<0.5	<0.5
EPA Method 624[c] (µg/L)					
Toluene	<0.5				
	0.9				
Radioactivity (Bq/L)					
Gross alpha	1.1 ± 0.30	0.033 ± 0.12	–0.019 ± 0.080	–0.016 ± 0.12	0.010 ± 0.091
	1.9 ± 0.41	0.27 ± 0.10	0.0044 ± 0.031	0.11 ± 0.072	0.16 ± 0.088
		0.33 ± 0.036	0.013 ± 0.014	0.098 ± 0.026	0.19 ± 0.031
		0.35 ± 0.046	0.015 ± 0.014	0.054 ± 0.050	0.32 ± 0.069
Gross beta	2.2 ± 0.15	0.13 ± 0.047	0.19 ± 0.055	5.2 ± 0.17	1.2 ± 0.088
	2.2 ± 0.24	0.27 ± 0.055	0.15 ± 0.046	0.11 ± 0.043	0.23 ± 0.096
		0.33 ± 0.020	0.18 ± 0.011	0.18 ± 0.015	0.23 ± 0.018
		0.35 ± 0.030	0.20 ± 0.012	0.19 ± 0.034	0.30 ± 0.043

…continued

Table 7-10. Elk Ravine drainage area well water analyses (*continued*).

	Well			
Parameter	**K2-01C**	**WELL01**	**NC2-11D**	**NC2-07**
Metals and Minerals[a] (mg/L)				
Ammonia nitrogen (as N)	0.06			
	0.039			
	<0.1			
	<0.1			
Barium				
Beryllium	<0.0002	<0.0002	<0.0002	
	<0.0002	<0.0002	<0.0002	
	<0.0005	<0.0005	<0.001	
	<0.0005	<0.0005	<0.0005	
Chromium		<0.005	<0.005	
		<0.005	<0.005	
		<0.01	<0.001	
		<0.01	<0.01	
Nitrate (as NO_3)	24			
	25			
Vanadium				
EPA Method 601[b] (µg/L)				
Trichloroethene	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	
	<0.5	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5	
EPA Method 624[c] (µg/L)				
Toluene				
Radioactivity (Bq/L)				
Gross alpha	0.51 ± 0.30	0.036 ± 0.081	0.097 ± 0.11	0.21 ± 0.12
	0.61 ± 0.23	0.089 ± 0.058	0.17 ± 0.075	
	0.95 ± 0.08	0.11 ± 0.018	0.18 ± 0.023	0.39 ± 0.048
	0.58 ± 0.12	0.18 ± 0.022	0.25 ± 0.030	
Gross beta	4.1 ± 0.22	0.060 ± 0.042	0.088 ± 0.051	0.27 ± 0.054
	0.59 ± 0.24	0.17 ± 0.047	0.21 ± 0.050	
	0.52 ± 0.029	0.15 ± 0.011	0.23 ± 0.013	0.40 ± 0.027
	0.47 ± 0.063	0.20 ± 0.012	0.19 ± 0.016	

...continued

Table 7-10. Elk Ravine drainage area well water analyses (*continued*).

	Well				
Parameter	**K7-07**	**NC7-61**	**NC7-69**	**K2-04D**	**K2-04S**
Radioisotopes (Bq/L)					
Radium-226					
Tritium	320 ± 17	9472 ± 463	0.21 ± 0.10	518 ± 27	707 ± 36
	714 ± 10	7844 ± 39	<1.6	825 ± 11	1425 ± 13
		7992 ± 32	<0.098	888 ± 12	1950 ± 16
		7770 ± 31	<0.083	477 ± 8.1	1199 ± 12
Uranium-234	0.11 ± 0.023	0.10 ± 0.011	0.0067 ± 0.0027	—[d]	—[d]
	0.096 ± 0.013	0.12 ± 0.017	0.0036 ± 0.0026		
		0.14 ± 0.0085	0.0015 ± 0.0015		
		0.16 ± 0.0048	0.0052 ± 0.0011		
Uranium-235	0.013 ± 0.0081	0.0021 ± 0.0015	0.00067 ± 0.0013	—[d]	—[d]
	0.0022 ± 0.0015	0.0046 ± 0.0025	0.0024 ± 0.0018		
		0.0067 ± 0.0019	0.0000 ± 0.00074		
		0.0052 ± 0.0011	0.0019 ± 0.00074		
Uranium-238	0.14 ± 0.026	0.079 ± 0.0089	0.00083 ± 0.0011	—[d]	—[d]
	0.11 ± 0.015	0.089 ± 0.014	0.0054 ± 0.0028		
		0.13 ± 0.0081	–0.00074 ± 0.00074		
		0.15 ± 0.0044	0.0011 ± 0.0011		

…continued

Table 7-10. Elk Ravine drainage basin well water analyses (*concluded*).

	Well			
Parameter	**K2-01C**	**WELL01**	**NC2-11D**	**NC2-07**
Radioisotopes (Bq/L)				
Radium-226	<0.037			
Tritium	148 ± 9.5	262 ± 15	74 ± 4.0	–1.8 ± 3.6
	103 ± 3.9	254 ± 5.8	76 ± 3.7	
	246 ± 6.1	256 ± 5.4	73 ± 3.6	<1.6
	349 ± 7.0	281 ± 6.5	80 ± 3.7	
Uranium-234	—[d]	—[d]	—[d]	—[d]
Uranium-235	—[d]	—[d]	—[d]	—[d]
Uranium-238	—[d]	—[d]	—[d]	—[d]

[a] Other metals and minerals for which analyses were performed include copper, lead, nitrite (as N), and total Kjeldahl nitrogen. However, all values for those analyses were below detection limits.

[b] Other EPA Method 601 analytes for which analyses were performed include 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-chloroethylvinylether; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dichlorodifluoromethane; Freon-113; methylene chloride; tetrachloroethene; trans-1,2-dichloroethene; trans-1,3-dichloropropene; trichlorofluoromethane; and vinyl chloride. However, all values for those analyses were below detection limits.

[c] Other EPA Method 624 analytes for which analyses were performed on K7-07 samples include 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene;1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-chloroethylvinylether; 2-hexanone; 4-methyl-2-pentanone; acetone; acrolein; acrylonitrile; benzene; bromodichloromethane; bromoform; bromomethane; carbon disulfide; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; ethylbenzene; Freon-113; methyl ethyl ketone; methylene chloride; styrene; tetrachloroethene; total xylene isomers; trans-1,2-dichloroethene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; vinyl acetate; and vinyl chloride. However, all values for those analyses were below detection limits.

[d] Measurement not deemed necessary for effective sampling plan.

Table 7-11. Pit 6 well water analyses.

		Well	
Parameter[a]	**K6-01**	**K6-03**	**K6-04**
Metals and minerals[b] (mg/L)			
Ammonia nitrogen (as N)	0.15	0.34	0.05
	0.13	0.27	0.05
	0.22	0.53	<0.1
Arsenic	0.011	0.018	0.015
	0.011	0.018	0.017
	0.016	0.021	0.017
Bicarbonate alkalinity (as $CaCO_3$)	190	180	170
	200	190	170
	250	250	230
Calcium	83	56	51
Chloride	91	89	84
	140	90	82
	140	82	73
Fluoride	0.47	0.57	0.49
	0.44	0.56	0.49
	0.42	0.56	0.53
Hardness, total (as $CaCO_3$)	350	260	230
Iron	0.24	<0.1	<0.1
	0.33	<0.1	<0.1
	<0.1	<0.1	<0.1
Lead	<0.002	<0.002	0.016
	<0.002	<0.002	<0.002
	<0.005	<0.005	<0.005
Magnesium	35	30	25
Manganese	<0.05	<0.05	<0.05
	0.052	0.052	<0.05
	0.086	0.082	<0.03
Nitrate (as N)	<5	<5	5
Nitrate plus nitrite (as N)	<0.1	<0.1	1.6
Potassium	8.1	8.1	8.1
Sodium	140	130	110
	140	100	100
	150	120	110
Sulfate	280	230	180
	300	240	200
	300	230	170
Surfactant	<0.5	<0.5	<0.5
Total alkalinity (as $CaCO_3$)	190	180	170
	200	190	170
	250	250	230

…continued

Table 7-11. Pit 6 well water analyses (*continued*).

Parameter[a]	Well EP6-07	 EP6-08	 EP6-09
Metals and minerals[b] (mg/L)			
Ammonia nitrogen (as N)	0.30	0.043	0.032
	0.26	0.036	<0.03
	0.44	<0.1	<0.1
Arsenic	0.022	0.017	0.015
	0.021	0.018	0.014
	0.02	0.018	0.015
Bicarbonate alkalinity (as $CaCO_3$)	180	190	190
	190	190	200
	250	260	260
Calcium	56	52	60
Chloride	90	96	120
	88	95	110
	81	93	100
Fluoride	0.49	0.44	0.44
	0.48	0.42	0.44
	0.52	0.44	0.48
Hardness, total (as $CaCO_3$)	260	240	260
Iron	<0.1	<0.1	<0.1
	<0.1	<0.1	<0.1
	<0.1	<0.1	<0.1
Lead	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002
	<0.005	<0.005	<0.005
Magnesium	30	26	28
Manganese	0.096	<0.05	<0.05
	0.12	<0.05	<0.05
	0.15	<0.03	<0.03
Nitrate (as N)	<5	<5	<5
Nitrate plus nitrite (as N)	<0.1	0.55	1.1
Potassium	7.7	8.7	8.5
Sodium	110	130	130
	110	120	120
	120	130	130
Sulfate	230	220	220
	250	240	240
	220	210	210
Surfactant	<0.5	<0.5	<0.5
Total alkalinity (as $CaCO_3$)	180	190	190
	190	190	200
	250	260	260

...continued

Table 7-11. Pit 6 well water analyses (*continued*).

Parameter[a]	Well K6-01	K6-03	K6-04
Metals and minerals[b] (mg/L)			
Total dissolved solids	750	680	600
	880	700	620
	960	740	670
Total suspended solids	2	<1	<1
	<1	<1	<1
	<1	1	<1
Selenium	<0.002	<0.002	<0.002
	<0.002	<0.002	<0.002
	<0.005	<0.005	<0.005
Silver	<0.0005	<0.0005	<0.0005
	<0.0005	<0.0005	<0.0005
	<0.001	<0.001	<0.001
Total Kjeldahl nitrogen	<0.5	<0.5	<0.5
	<1	<1	<1
	0.2	0.37	<0.1
General indicator parameters			
pH (units)	7.8	7.7	7.7
	7.2	7.3	7.3
	7.7	7.7	7.7
Specific conductance (µmhos/cm)	970	990	880
	1080	800	800
	1200	960	860
Total organic carbon (mg/L)	0.95	0.52	0.78
	1.2	0.86	0.81
	12	7.6	12
Total organic halides, 1st replicate (mg/L)	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02
	0.039	0.029	0.025
Total organic halides, 2nd replicate (mg/L)	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02
	0.052	0.031	0.027
EPA Method 601[c] (µg/L)			
1,2-Dichloroethane	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5
1,2-Dichloroethene (total)	<0.5	<0.5	<0.5
	1.2	<0.5	<0.5
	0.9	<0.5	<0.5
cis-1,2-Dichloroethene	<0.5	<0.5	<0.5
	1.2	<0.5	<0.5

...continued

Table 7-11. Pit 6 well water analyses (*continued*).

	Well		
Parameter[a]	**EP6-07**	**EP6-08**	**EP6-09**
Metals and minerals[b] (mg/L)			
Total dissolved solids	670	670	730
	690	690	730
	710	700	790
Total suspended solids	<1	<1	<1
	<1	<1	<1
	<1	<1	<1
Selenium	<0.002	0.003	0.0024
	<0.002	0.0029	<0.002
	<0.005	<0.005	<0.005
Silver	<0.0005	<0.0005	0.001
	<0.0005	<0.0005	<0.0005
	<0.001	<0.001	<0.001
Total Kjeldahl nitrogen	<0.5	<0.5	<0.5
	<1	<1	<1
	0.28	<0.1	<0.1
General indicator parameters			
pH (units)	7.6	7.6	7.6
	7.2	7.3	7.4
	7.7	7.7	7.8
Specific conductance (μmhos/cm)	830	980	1080
	920	980	920
	970	980	1100
Total organic carbon (mg/L)	<0.5	<0.5	<0.5
	0.6	0.59	0.75
	7	12	5.5
Total organic halides, 1st replicate (mg/L)	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02
	0.023	0.048	0.043
Total organic halides, 2nd replicate (mg/L)	<0.02	<0.02	<0.02
	<0.02	<0.02	<0.02
	0.025	0.044	0.037
EPA Method 601[c] (μg/L)			
1,2-Dichloroethane	<0.5	<0.5	1
	<0.5	<0.5	0.64
	<0.5	<0.5	<0.5
1,2-Dichloroethene (total)	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5
cis-1,2-Dichloroethene	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5

...continued

Table 7-11. Pit 6 well water analyses (*continued*).

	Well		
Parameter[a]	**K6-01**	**K6-03**	**K6-04**
Tetrachloroethene	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5
Trichloroethene	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5
	<0.5	<0.5	<0.5
Radioactivity (Bq/L)			
Gross alpha	–0.025 ± 0.090	–0.082 ± 0.084	–0.033 ± 0.099
	0.17 ± 0.12	0.034 ± 0.072	0.033 ± 0.055
	0.092 ± 0.029	0.041 ± 0.023	0.018 ± 0.019
Gross beta	0.25 ± 0.083	0.31 ± 0.075	0.34 ± 0.077
	0.27 ± 0.075	0.29 ± 0.065	0.30 ± 0.065
	0.36 ± 0.027	0.33 ± 0.018	0.33 ± 0.016
Radioisotopes (Bq/L)			
Tritium	0.88 ± 3.4	–0.25 ± 3.4	0.73 ± 3.4
	<1.6	<1.5	<1.5
	<1.8	<1.7	<1.8
Radium-226	0.013 ± 0.018	0.011 ± 0.018	0 ± 0.019
	–0.00089 ± 0.0029	0.0020 ± 0.0019	0.00054 ± 0.0017
	0.015 ± 0.0026	0.011 ± 0.0026	0.021 ± 0.0033
Uranium-234	0.016 ± 0.0054	0.0079 ± 0.0039	0.029 ± 0.0069
	0.021 ± 0.0065	0.0075 ± 0.0039	0.023 ± 0.0081
	0.016 ± 0.0019	0.011 ± 0.0019	0.023 ± 0.0030
Uranium-235	0.0000 ± 0.0021	0.00048 ± 0.00093	0.0020 ± 0.0024
	0.0095 ± 0.0042	0.00087 ± 0.0014	0.00036 ± 0.0017
	0.0030 ± 0.0011	0.0015 ± 0.00074	0.0015 ± 0.0015
Uranium-238	0.0067 ± 0.0036	0.0063 ± 0.0031	0.019 ± 0.0054
	0.0078 ± 0.0040	0.0060 ± 0.0034	0.019 ± 0.0073
	0.015 ± 0.0019	0.0067 ± 0.0015	0.023 ± 0.0030

[a] Other analyses requested include EPA Method 608, EPA Method 615, and explosive compounds. However, all values for those analyses were below detection limits. EPA Method 608 includes BHC, gamma isomer (Lindane); endrin; methoxychlor; and toxaphene. EPA Method 615 includes 2,4,5-TP (Silvex) and 2,4-D. Explosive compounds analysis includes HMX, RDX, and TNT.

[b] Other metals and minerals for which analyses were performed include aluminum, barium, beryllium, cadmium, carbonate alk (as $CaCO_3$), chromium, copper, hydroxide alk (as $CaCO_3$), low level phenolics, mercury, nickel, nitrite (as N), nitrite (as NO_2), vanadium, and zinc. However, all values for those analyses were below detection limits.

Table 7-11. Pit 6 well water analyses (*concluded*).

Parameter[a]	Well EP6-07	 EP6-08	 EP6-09
Tetrachloroethene	<0.5	0.78	<0.5
	<0.5	0.8	<0.5
	<0.5	<0.5	<0.5
Trichloroethene	<0.5	<0.5	18
	<0.5	<0.5	16
	<0.5	<0.5	14
Radioactivity (Bq/L)			
Gross alpha	0.0091 ± 0.12	0.085 ± 0.13	–0.0085 ± 0.15
	0.013 ± 0.060	–0.0028 ± 0.046	0.048 ± 0.067
	0.0000 ± 0.030	0.027 ± 0.031	0.14 ± 0.041
Gross beta	0.30 ± 0.075	0.33 ± 0.077	0.37 ± 0.078
	0.23 ± 0.062	0.30 ± 0.065	0.36 ± 0.074
	0.33 ± 0.024	0.35 ± 0.025	0.34 ± 0.026
Radioisotopes (Bq/L)			
Tritium	1.5 ± 3.4	–0.24 ± 3.4	–0.24 ± 3.3
	<1.6	2.2 ± 1.9	<1.6
	<1.6	<1.8	<1.6
Radium-226	–0.0075 ± 0.022	0.010 ± 0.016	–0.012 ± 0.014
	0.0025 ± 0.0031	0.0015 ± 0.0027	0.0068 ± 0.0039
	0.024 ± 0.0030	0.014 ± 0.0026	0.022 ± 0.0030
Uranium-234	0.0083 ± 0.0037	0.024 ± 0.0070	0.042 ± 0.0087
	0.0039 ± 0.0046	0.020 ± 0.0066	0.070 ± 0.016
	0.010 ± 0.0019	0.024 ± 0.0026	0.036 ± 0.0033
Uranium-235	0.00000 ± 0.00090	0.00000 ± 0.0010	0.0018 ± 0.0027
	–0.0010 ± 0.00074	0.0023 ± 0.0021	0.024 ± 0.0085
	0.0015 ± 0.00074	0.00037 ± 0.00074	0.010 ± 0.0019
Uranium-238	0.0046 ± 0.0030	0.016 ± 0.0052	0.032 ± 0.0070
	0.011 ± 0.0061	0.016 ± 0.0057	0.030 ± 0.0099
	0.0089 ± 0.0019	0.018 ± 0.0022	0.033 ± 0.0033

[c] EPA Method 601 analysis also includes 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene; 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4 dichlorobenzene; 2-chloroethylvinylether; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,3-dichloropropene; dibromochloromethane; dichlorodifluoromethane; Freon-113; methylene chloride; trans-1,2-dichloroethylene; trans-1,3-dichloropropene; trichlorofluoromethane; vinyl chloride. However, all values for those analyses were below detection limits.

Table 7-12. Well 20 water analyses.

Parameter[a]	Result	Parameter[a]	Result
EPA Method 502.2[b] (μg/L)		Methylene chloride	<0.2
1,2-Dichloroethane	0.6		<0.2
	<0.2		<0.2
EPA Method 524.2[c] (μg/L)			<0.2
1,2-Dichloroethane	<0.2		<0.5
	<0.2		<0.5
	<0.2		<1
	0.3		<1
	<0.5		<1
	<0.5		0.7
	<1	**Radioactivity (Bq/L)**	
	<1	Gross alpha	0.063 ± 0.17
	<1		–0.016 ± 0.061
	1		–0.021 ± 0.020
Chloromethane	<0.2		–0.014 ± 0.018
	<0.2	Gross beta	0.23 ± 0.082
	<0.2		0.30 ± 0.13
	<0.2		0.29 ± 0.018
	<0.5		0.30 ± 0.017
	<0.5	**Radioisotopes (Bq/L)**	
	<2	Tritium	0.37 ± 0.11
	<2		<0.026
	<2		<0.044
	2		<0.12

[a] Metals analyzed for include beryllium, chromium, copper, and lead. EPA Methods 601 and 602 were also performed on samples collected April 22. EPA Method 601 includes 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-chloroethylvinylether; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-cichloroethene; cis-1,3-cichloropropene; cibromochloromethane; cichlorodifluoromethane; Freon-113; methylene chloride; tetrachloroethene; trans-1,2-dichloroethene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; vinyl chloride. EPA Method 602 includes 1,2-dichlorobenzene; 1,3-dichlorobenzene; 1,4-dichlorobenzene; benzene; chlorobenzene; ethylbenzene; m- and p-xylene isomers; o-xylene; toluene; and total xylene isomers. All values for those analyses were below detection limits.

Table 7-12. Well 20 water analyses (*concluded*).

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[b] Other EPA Method 502.2 analytes for which analysis was performed include 1,1,1,2-tetrachloroethane; 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,1-dichloropropene; 1,2,3-trichlorobenzene; 1,2,3-trichloropropane; 1,2,4-trichlorobenzene; 1,2,4-trimethylbenzene; 1,2-dichlorobenzene; 1,2-dichloropropane; 1,3,5-trimethylbenzene; 1,3-dichlorobenzene; 1,3-dichloropropane; 1,4-dichlorobenzene; 2,2--dichloropropane; 2-chlorotoluene; 4-chlorotoluene; benzene; bromobenzene; bromochloromethane; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dibromomethane; dichlorodifluoromethane; ethylbenzene; Freon-113; hexachlorobutadiene; isopropylbenzene; m- and p-xylene isomers; methylene chloride; n-butylbenzene; n-propylbenzene; naphthalene; o-xylene; p-isopropyl toluene; sec-butylbenzene; styrene; tert-butylbenzene; tetrachloroethene; toluene; trans-1,2-dichloroethene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; and vinyl chloride. However, all values for those analyses were below detection limits.

[c] Other EPA Method 524.2 analytes for which analysis was performed include 1,1,1,2-tetrachloroethane; 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,1-dichloropropene; 1,2,3-trichlorobenzene; 1,2,3-trichloropropane; 1,2,4 trichlorobenzene; 1,2,4-trimethylbenzene; 1,2-dibromo-3-chloropropane; 1,2-dichlorobenzene; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3,5-trimethylbenzene; 1,3-dichlorobenzene; 1,3-dichloropropane; 1,4-dichlorobenzene; 2,2-dichloropropane; 2-chlorotoluene; 4-chlorotoluene; benzene; bromobenzene; bromochloromethane; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dibromomethane; dichlorodifluoromethane; ethylbenzene; ethylene dibromide; Freon-113; hexachlorobutadiene; isopropylbenzene; m- and p-xylene isomers; n-butylbenzene; n-propylbenzene; naphthalene; o-xylene; p-isopropyl toluene; sec-butylbenzene; styrene; tert-butylbenzene; tetrachloroethene; toluene; total xylene isomers; trans-1,2-dichloroethene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; and vinyl chloride. However, all values for those analyses were below detection limits.

Table 7-13. Off-site well water analyses.

	Well				
Parameter[a]	**STN**	**CARNRW2**	**CDF1**	**CON1**	**GALLO1**
Metals and minerals[b] (mg/L)					
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005
Bicarbonate alkalinity (as CaCO$_3$)	430	300	330	270	330
Calcium	110	26	85	43	5
Carbonate alkalinity (as CaCO$_3$)	<1	<1	<1	<1	4.9
Chloride	130	90	100	160	130
Chromium		<0.005	<0.005	<0.005	
		<0.005	<0.005	<0.005	<0.005
	<0.01	<0.001	<0.001	0.0017	<0.01
		<0.01	<0.01	<0.01	<0.01
Fluoride	0.48	0.34	0.39	0.47	1
Hardness, total (as CaCO$_3$)	520	88	350	130	16
Magnesium	59	5.5	35	6.7	0.81
Manganese	<0.03	0.032	<0.03	0.13	<0.03
Mercury	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Nitrate (as N)	1.2	<5	15	<5	<0.5
Potassium	5.7	10	6.5	8.1	3.8
Sodium	130	220	190	460	290
Sulfate	490	210	310	600	190
Total alkalinity (as CaCO$_3$)	430	300	330	270	330
Total dissolved solids	1200	740	870	1400	830
General indicator parameters					
Specific conductance (μmhos/cm)	1700	940	1300	2000	1100
pH (units)	7.5	8.1	7.8	8.2	8.6
EPA Method 524.2[c] (μg/L)					
Trichloroethene		<0.2	<0.2	<0.2	
			<0.2	<0.2	0.2
					<0.5
	<0.5	<0.5	<1	<0.5	<0.5
		<0.5	<0.5	<0.5	<0.5
EPA Method 601[d] (μg/L)					
Bromoform		1.6			

…continued

Table 7-13. Off-site well water analyses (*continued*).

Parameter[a]	Well MUL1	MUL2	VIE1	VIE2	W-35A-04
Metals and minerals[b] (mg/L)					
Arsenic	0.0056	<0.005	0.016	<0.005	<0.005
Bicarbonate alkalinity (as $CaCO_3$)	260	240	150	250	340
Calcium	72	150	41	160	100
Carbonate alkalinity (as $CaCO_3$)	<1	<1	<1	<1	<1
Chloride	53	69	84	75	110
Chromium					
	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoride	0.73	0.74	0.60	0.67	0.48
Hardness, total (as $CaCO_3$)	290	550	200	460	450
Magnesium	27	42	24	19	46
Manganese	<0.03	0.5	<0.03	<0.03	<0.03
Mercury	<0.0005	<0.0005	0.0008	<0.0005	<0.0005
Nitrate (as N)	0.58	2	4.7	2.2	5.5
Potassium	5.6	6.9	7.1	2.8	4.7
Sodium	71	100	120	73	150
Sulfate	210	440	110	180	350
Total alkalinity (as $CaCO_3$)	260	240	150	250	340
Total dissolved solids	610	1000	560	730	960
General indicator parameters					
Specific conductance (µmhos/cm)	790	1200	780	1000	1300
pH (units)	7.8	7.8	8	7.4	7.9
EPA Method 524.2[c] (µg/L)					
Trichloroethene	<0.5	<0.5	<0.5	<0.5	<0.5
EPA Method 601[d] (µg/L)					
Bromoform					

…continued

Table 7-13. Off-site well water analyses (*continued*).

	Well				
Parameter[a]	**STN**	**CARNRW2**	**CDF1**	**CON1**	**GALLO1**
Radioactivity (Bq/L)[e]					
Gross alpha		0.15 ± 0.16	0.031 ± 0.14	0.057 ± 0.20	
		0.032 ± 0.085	0.0066 ± 0.057	–0.067 ± 0.060	0.0084 ± 0.073
	0.21 ± 0.040	–0.022 ± 0.018	0.041 ± 0.023	-0.039 ± 0.045	0.068 ± 0.020
		0.085 ± 0.024	0.037 ± 0.034	0.019 ± 0.0081	0.034 ± 0.0085
Gross beta		0.35 ± 0.087	0.34 ± 0.085	0.33 ± 0.15	
		0.26 ± 0.063	0.25 ± 0.067	0.52 ± 0.16	0.12 ± 0.050
	0.21 ± 0.027	0.41 ± 0.020	0.26 ± 0.018	0.37 ± 0.033	0.090 ± 0.024
		0.37 ± 0.019	0.37 ± 0.026	0.57 ± 0.041	0.12 ± 0.020
Radioisotopes (Bq/L)					
Tritium		0.31 ± 0.084	0.59 ± 0.12	0.14 ± 0.070	
		0.14 ± 0.060	0.51 ± 0.088	0.19 ± 0.077	<0.16
	0.87 ± 0.16	<0.057	0.86 ± 0.14	<0.10	<0.12
		<0.089	0.16 ± 0.089	<0.12	<0.12

[a] Other analyses requested include EPA Method 608, EPA Method 615, and explosive compounds. EPA Method 608 includes Aldrin; BHC, alpha isomer; BHC, beta isomer; BHC, delta isomer; BHC, gamma isomer (Lindane); chlordane; dieldrin; endosulfan i; endosulfan ii; endosulfan sulfate; endrin; endrin aldehyde; heptachlor; heptachlor epoxide; methoxychlor; p,p'-DDD; p,p'-DDE; p,p'-DDT; and toxaphene. EPA Method 615 includes 2,4,5-T; 2,4,5-TP (Silvex); 2,4-D; 4-(2,4-dichlorophenoxy) butyric acid; dalapon; dicamba; dichloroprop; dinoseb; MCPA; and MCPP. Explosive compounds include HMX, RDX, and TNT.

[b] Other metals and minerals for which analyses were performed include aluminum, barium, beryllium, cadmium, copper, hydroxide alkalinity (as $CaCO_3$), iron, lead, nickel, phenolics, selenium, silver, surfactant, and zinc. However, all values for those analyses were below detection limits.

[c] Other EPA Method 524.2 analytes for which analyses were performed include 1,1,1,2-tetrachloroethane; 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,1-dichloropropene; 1,2,3-trichlorobenzene; 1,2,3-trichloropropane; 1,2,4-trichlorobenzene; 1,2,4-trimethylbenzene; 1,2-dibromo-3-chloropropane; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3,5-trimethylbenzene; 1,3-dichlorobenzene; 1,3-dichloropropane; 1,4-dichlorobenzene; 2,2-dichloropropane; 2-chlorotoluene; 4-chlorotoluene; benzene; bromobenzene; bromochloromethane; bromodichloromethane; bromoform; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dibromomethane; dichlorodifluoromethane; ethylbenzene; ethylene dibromide; Freon-113; hexachlorobutadiene; isopropylbenzene; m-and p-xylene isomers; methylene chloride; n-butylbenzene; n-propylbenzene; naphthalene; o-xylene; p-isopropyl toluene; sec-butylbenzene; styrene; tert-butylbenzene; tetrachloroethene; toluene; total xylene isomers; trans-1,2-dichloroethylene; trans-1,3-dichloropropene; trichlorofluoromethane; and vinyl chloride. However, all values for those analyses were below detection limits.

Table 7-13. Off-site well water analyses (*concluded*).

Parameter[a]	Well MUL1	 MUL2	 VIE1	 VIE2	 W-35A-04
Radioactivity (Bq/L)[e]					
Gross alpha	0.074 ± 0.027	–0.011 ± 0.030	0.078 ± 0.027	0.24 ± 0.034	0.19 ± 0.037
Gross beta	0.24 ± 0.015	0.15 ± 0.020	0.30 ± 0.017	0.095 ± 0.018	0.089 ± 0.025
Radioisotopes (Bq/L)					
Tritium	<0.17	<0.15	<0.22	0.76 ± 0.13	0.83 ± 0.13

[d] Other EPA Method 601 analytes for which analyses were performed (second quarter CARNRW2 samples only) include 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; 1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichlorobenzene; 1,2-dichloroethane; 1,2-dichloroethene (total); 1,2-dichloropropane; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 2-chloroethylvinylether; bromodichloromethane; bromomethane; carbon tetrachloride; chlorobenzene; chloroethane; chloroform; chloromethane; cis-1,2-dichloroethene; cis-1,3-dichloropropene; dibromochloromethane; dichlorodifluoromethane; Freon-113; methylene chloride; tetrachloroethene; trans-1,2-dichloroethylene; trans-1,3-dichloropropene; trichloroethene; trichlorofluoromethane; and vinyl chloride. EPA Method 602 was also performed for second quarter CARNRW2 samples. This method includes 1,2-dichlorobenzene; 1,3-dichlorobenzene; 1,4-dichlorobenzene; benzene; chlorobenzene; ethylbenzene; m- and p-xylene isomers; o-xylene; toluene; and total xylene isomers. However, all values for those analyses were below detection limits.

[e] Negative radioactivity values can occur when natural background measurements are subtracted from very low-level sample measurements near or at the limit of detection.

8. Ground Water Protection Management Program

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Introduction

LLNL's Ground Water Protection Management Program is a multifaceted effort to eliminate or minimize adverse impacts of Laboratory operations on ground water, determine the extent and understand the impact of past activities, remediate adversely affected areas, and monitor current operations. DOE Order 5400.1 requires all DOE facilities to prepare a plan 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.

Ground Water Regime

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 meters. The valley is approximately 25 kilometers long and averages 11kilometers in width. The valley floor is at its highest elevation of 220 meters along the eastern margin and gradually dips to 92 meters 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 only during the rainy season.

Livermore Valley Ground Water Basin. The Livermore Valley Ground Water Basin lies within the Diablo Range, which reaches a maximum elevation of 1160meters 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 meters and an area of approximately 250 square kilometers, 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 (California 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 (California 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 has been altered by construction activities 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 kilometers 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 1984). A constructed Central Drainage Basin for storm water diversion and flood control is present near Building 551 and collects surface water runoff from the Arroyo Las Positas drainage. This 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 meters 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 hydrostratigraphic 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 meters thick on the eastern part of the site to 120 meters thick on the west. Ground water flow is primarily in sand and gravel lenses and channels, bounded by the less permeable clay and silt.

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 40meters in the southeast corner of the site to 10 meters in the northwest and 12meters 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 a rise in 1986 and in 1993, and droughts caused a decline 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 Central Drainage Basin.

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

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. Ground water from the north half flows west and northwest and eventually discharges to Arroyo Las Positas near First Street in Livermore, about 2 kilometers 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 kilometers west of the Livermore site. The magnitude and direction of ground water flow in the area of the gap is uncertain; investigations are under way 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.

For the purposes of ground water surveillance (i.e., monitoring for potential releases from current operations), monitoring the ground water at any significant distance from the Livermore site is not required because of the slow ground water velocities. The 4meters/year horizontal ground water velocity results in a travel time that makes off-site ground water monitoring ineffective for early detection of releases.

Site 300

Geology. 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 elevation ranges from approximately 150meters above sea level at the southeast corner of the site to approximately 538meters in the northwestern portion.

The Altamont Hills in which Site 300 is located are part of the Coast Range Province and separate the Livermore Valley to the west from the San Joaquin Valley to the east. The southern boundary of the Altamont Hills is locally well defined by the abrupt rise in the terrain as the Franciscan Complex core of the Diablo Range emerges south of the Tesla Fault.

The Neroly Formation is the principal hydrologic unit within Site300 and has been the focus of the detailed geologic and hydrogeologic studies conducted during recent years (detailed in Webster-Scholten 1994). The total thickness of the Neroly Formation beneath Site300 appears to vary from about 140meters to more than 150meters. The lower portion of the section is thicker beneath the southerly part of Site300, whereas the upper portion is thickest beneath the northeastern portion of Site300.

The active flood plain of Corral Hollow Creek lies along the southern boundary of Site300, underlying portions of the western and eastern General Services Area. The floodplain also makes small incursions into Site300 in the vicinity of closed landfill Pit6. Floodplain alluvium consists dominantly of coarse cobble and boulder-bearing gravel derived from Franciscan sources, with lenses and local cappings of sandy silt and silty clay.

The bedrock sequence within Site300 has been slightly deformed into several gentle, low amplitude folds. The locations and characteristics of these folds, in combination with the regional fault and fracture patterns, may locally influence ground water flow within the site and have therefore been studied as part of LLNL's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) investigations.

Hydrogeology. Site300 is generally underlain by gently dipping sedimentary bedrock dissected by steep ravines. The bedrock is made up primarily of interbedded sandstone, siltstone, and claystone. Most ground water occurs in the Neroly Formation upper blue sandstone and lower blue sandstone aquifers. Significant ground water is also locally present in permeable Quaternary alluvium valley fill. Much less ground water is present in the Miocene Non-Marine unit, where it occurs as perched water-bearing zones beneath hilltops in the Building 833 and Building 834 areas, and more extensively in the High Explosives (HE) Process Area. The perched water-bearing zone at Building 833 is ephemeral. Fine-grained siltstone and claystone interbeds 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.

Recharge occurs predominantly in locations where saturated alluvium valley fill is in contact with underlying permeable bedrock, or where bedrock strata crop out because of structure or topography. Local recharge also occurs on hilltops, thus creating the perched water-bearing zones at Buildings833 and 834. Low rainfall, high evapotranspiration, steep topography, and intervening aquitards generally preclude direct vertical recharge of the bedrock aquifers.

Ground water flow in most aquifers follows the attitude of the bedrock. In the northwest part of Site300 (north of the east-west trending Patterson anticline), bedrock ground water flows generally northeast, except where it is locally influenced by ground water in alluvium-filled ravines. In the southern half of the site, bedrock ground water flows roughly south-southeast, approximately coincident with the attitude of bedrock strata.

At Site300, some ground water bodies are regional in extent, such as the Neroly lower sandstone and Cierbo aquifers. Others occur as isolated, discontinuous, water-bearing zones underlying hilltops. Ground water is also locally present in alluvial terrace deposits and valley fill.

Ground water in the Neroly lower sandstone aquifer is unconfined in much of the northwestern part of Site300. In the southern HE Process Area, several flowing artesian wells are present. The elevation of the potentiometric surface in some flowing wells is about 5meters above ground level, or about 1meter higher than in the shallower Neroly upper sandstone aquifer.

The Cierbo Formation is saturated beneath Doall Ravine, the Building851 Area, and the southern part of the East Firing Area. This formation is unsaturated or does not otherwise yield water to wells in other parts of the East and West Firing Areas, and this may be the result of swelling clays in pore spaces.

Ground Water Monitoring

Several ground water monitoring programs are in place at the two Laboratory sites and in the surrounding area; their purposes constitute their primary differences. The Environmental Monitoring and Analysis Division and the Environmental Restoration Division are the main monitoring organizations. The former focuses its efforts on determining impacts from current and ongoing activities and the latter on contamination from past practices and its remediation.

Livermore-Site Ground Water Monitoring

Surveillance monitoring carried on in the Livermore Valley and on the Livermore site includes both surface and ground water monitoring (see Chapters6 and 7 of this report). Surface water monitoring is important for ground water protection because contaminants from surface water can reach ground water. The ground water monitoring network that supports the Livermore-site remediation effort was initially established to identify and delineate any ground water contamination that may have originated from the Livermore site. Over the years, monitoring has included a good spatial sampling of the entire site plus the off-site areas related to contaminant plumes that have migrated from the site. In every case, wells were drilled to establish a clean zone beyond the limits of measurable contaminants, both vertically and horizontally. Boreholes and monitoring wells were also placed to establish the sources of the contaminants. Over 400 wells are in the regularly monitored network (see **Figure 8-1**).

When a well is initially installed, a comprehensive suite of analyses is performed to establish the baseline conditions for ground water from that well. Follow-on analyses provide data on remedial activities, so sampling can be limited to analytes of concern. The primary ground water contaminants at both the Livermore site and Site 300 are volatile organic compounds (VOCs) and tritium. While these comprise the main analytes of concern, metals analyses (especially chromium, physical parameters, and indicator parameters such as pH) are also requested on many samples.

Ground water samples are collected quarterly for 18 months from newly installed monitoring wells and piezometers. This sampling schedule may be changed as the distribution of contaminants in ground water changes, according to the algorithm detailed in a recent letter to EPA (McConachie 1993). The sampling frequency is determined by evaluating the overall and recent (past 18months) histories of each well. Wells exhibiting little change (≤10 parts per billion per year) will be sampled annually, wells exhibiting moderate change (>10 parts per billion and ≤30 parts per billion per year) will be sampled semiannually, and wells showing large changes (>30 parts per billion per year) will be sampled quarterly.

Pump-and-treat remediation is under way at several locations on the Livermore site (Hoffman et al. 1993). Monitoring of the extracted ground water and the capture area surrounding the extraction wells is done by measuring ground water level drawdown in nearby monitoring wells and piezometers. This monitoring gives particular attention to the ground water cone of depression surrounding the pumping wells and the changes in contaminant concentrations resulting from the pump-and-treat efforts.

Site 300 Ground Water Monitoring Program

Water monitoring at Site 300 can be divided into three types—surveillance, compliance, and remedial action. As with the Livermore site, the purpose of the remedial monitoring is to support the investigations and restoration activities associated with CERCLA compliance and cleanup.

As with remedial monitoring at the Livermore site, when initially drilled, a general suite of analyses is performed on each new monitoring well. The results of these analyses, as well as historical information concerning suspected contaminants in the area, are used to determine the continuing monitoring program. Wells without measurable contaminants and located in areas with no history of contaminant usage are sampled a minimum of once a year. Wells in areas with known contaminants, but with generally stable conditions, are sampled at least twice per year. In regions where significant changes in contaminant concentrations are either observed or predicted (e.g., at the leading edge of the plume), quarterly sampling has been established. The depth to ground water is also measured quarterly, unless special circumstances make it impractical to measure a particular well.

The surveillance monitoring program supports 19 ground water wells—7 on site, including a drinking water supply well, and 12 off-site wells (**Figure 8-2**). The analytes are chosen in accordance with current understanding of the ground water quality in the area and to determine the impact, if any, of LLNL operations at the site. The wells are currently sampled primarily for metals, radioactivity, and organic compounds. Details of this network and data for 1993 can be found in Chapter 7 of this report.

The compliance monitoring program assures that LLNL meets its sampling, analysis, and reporting requirements, which are spelled out in our permits and state and federal regulations (other than the requirements under CERCLA). Currently, the monitoring program is designed to meet the requirements of the *Closure and Post-Closure Plans for Landfill Pits 1 and 7* (Rogers / Pacific Corporation 1990), Waste Discharge Requirements Order No. 85-188, and Waste Discharge Requirements OrderNo.93-100. Details of this network and results for 1993 can be found in Chapter 7 of this report.

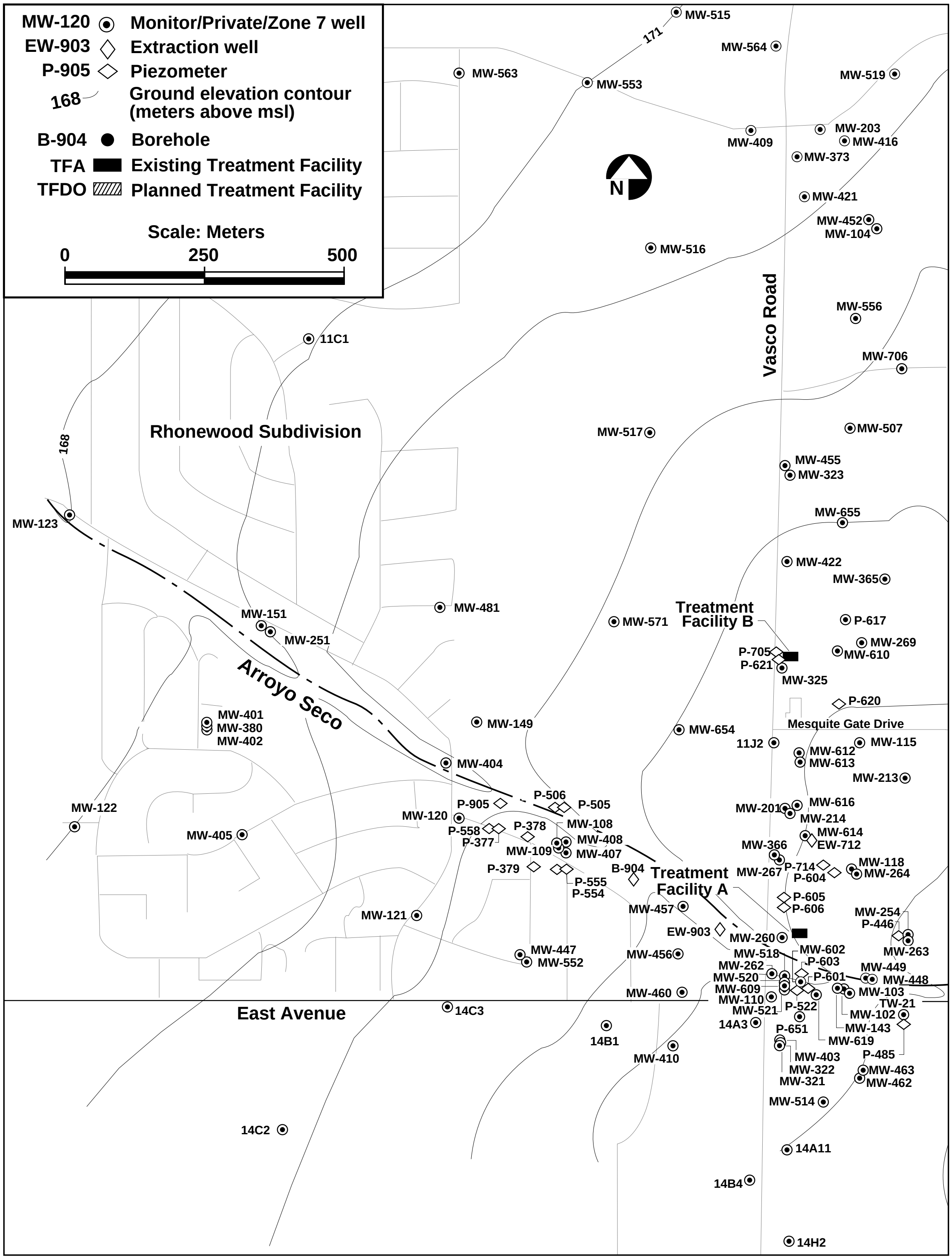
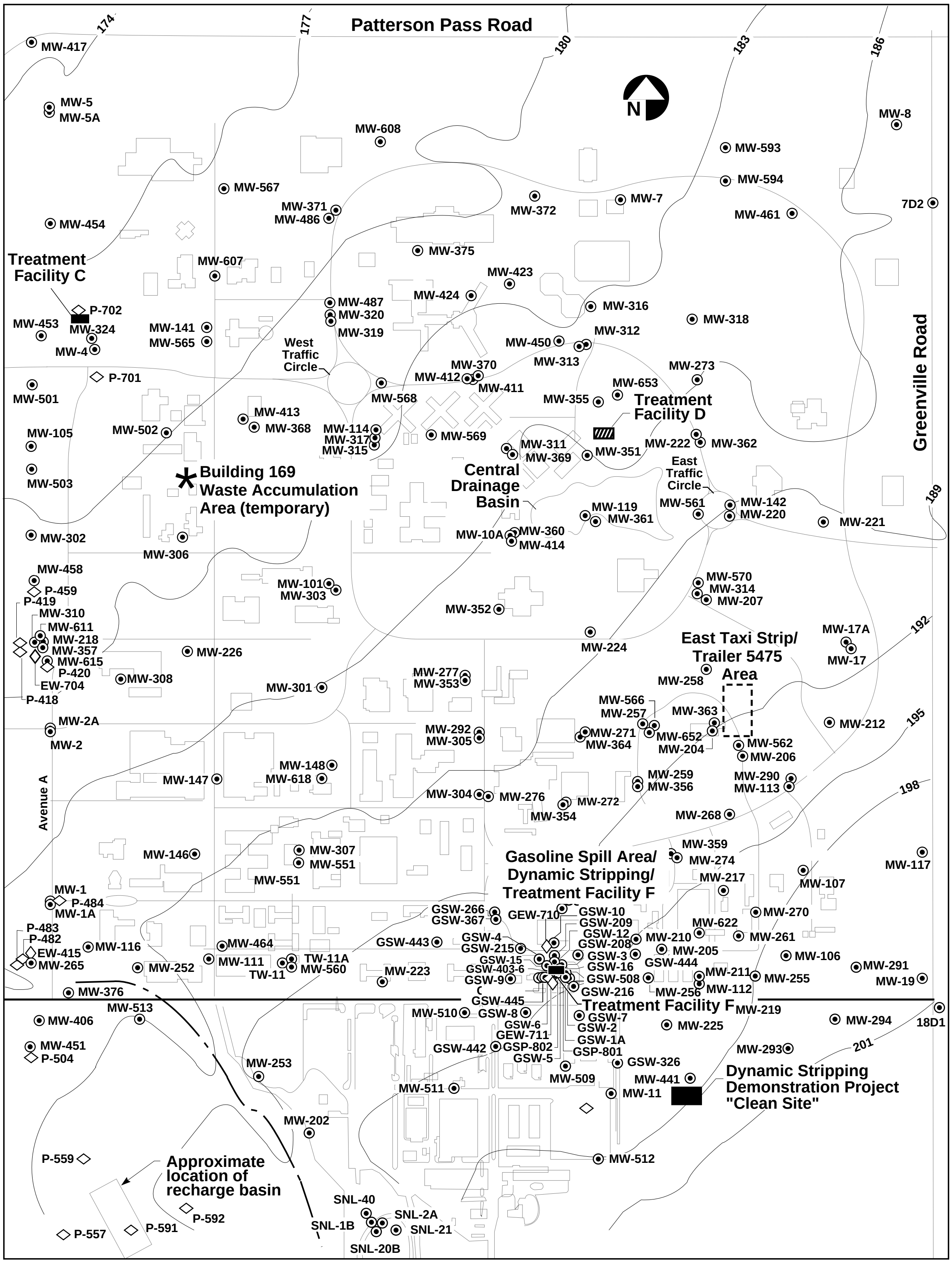


Figure 8-1. Livermore-site location map for monitor wells, piezometers, extraction wells, and treatment facilities.



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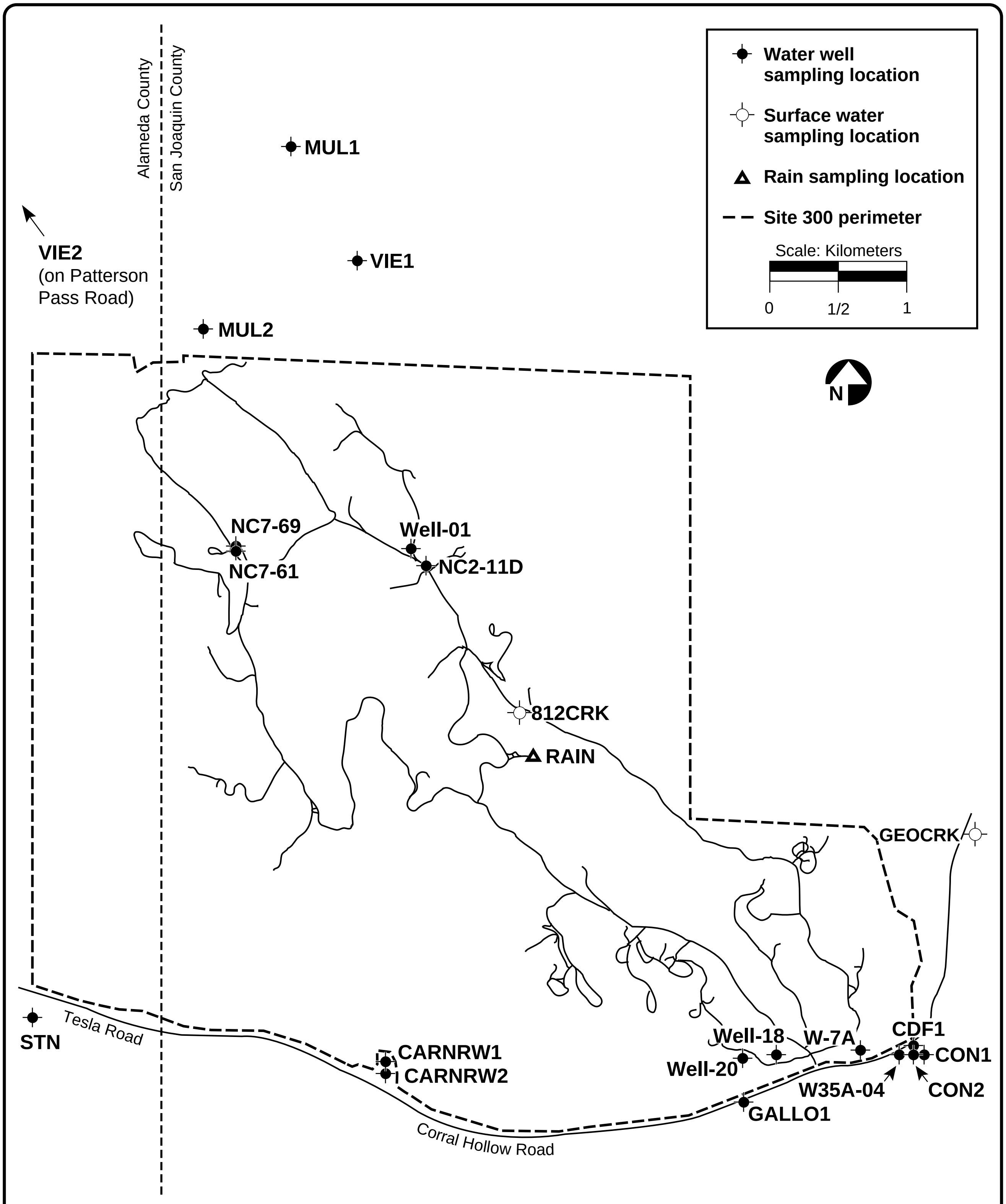

Figure 8-2. Water sampling locations and access roads, Site 300 and vicinity, 1993.

Areas of Contamination

Livermore Site

The Livermore site is on the National Priority List for sites requiring environmental restoration in accordance with CERCLA and the Superfund Amendments and Reauthorization Act. In light of this, extensive investigations have been performed to identify contamination from past practices that has affected or could affect the ground water underlying the Livermore site. Detailed descriptions of these findings are available in Thorpe et al. (1990) and Isherwood et al. (1990). In summary, VOCs, predominantly trichloroethene (TCE) and tetrachloroethene (PCE), exist in the ground water beneath about 85% of the Livermore site in relatively low concentrations (**Figure 8-3**). The contamination is believed to have started when the site was used as a naval maintenance base during World War II. The calculated total volume of undiluted VOCs is about

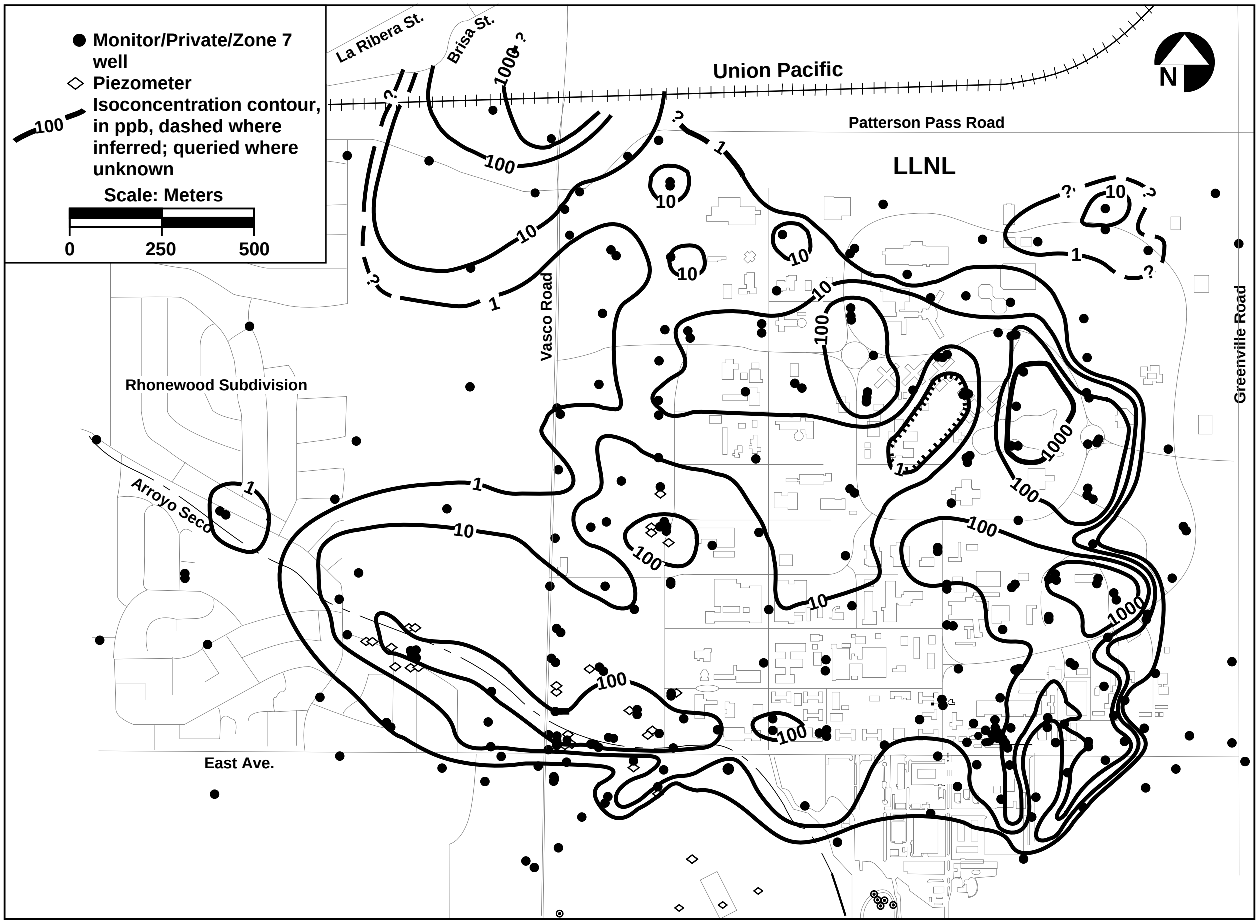

Figure 8-3. Isoconcentration contour map of total VOCs in ground water, in ppb.

800 liters. The VOCs are found in ground water plumes varying from 1 to 30meters thick, but seldom found at a depth of greater than 70meters. Concentrations are low, but localized areas of levels as high as 5 parts per million of TCE and 1 part per million of PCE are found in under 5% of the over 400wells. The contours of isoconcentration for total VOCs are shown in **Figure 8-3.**

In two specific areas, near Building 518 and Trailer 5475, the concentration of TCE in the unsaturated sediment is receiving special attention. Near Building518, the TCE concentration reached a maximum of about 6 parts per million at a depth of 7 meters. The source of this is believed to have originated from surface spills or leaking drums in the post-Navy operations era. The area surrounding Trailer 5475 was formerly used for landfills and surface impoundments (these areas were excavated and restored in the 1983–1985 time period). Total VOC concentrations of up to 5 parts per million are found in the unsaturated sediments in this area.

Fuel hydrocarbon contamination is isolated to the area affected by a 66,000-liter leaded gasoline spill that occurred during the U.S. Navy era and subsequent LLNL operation. The fuel tank was removed from service and subsequently abandoned in place in 1979. **Figure 8-4** shows the extent of the contamination prior to remediation efforts that are already under way (see section below for more information).

Tritium above the maximum contaminant level (MCL) of 740Bq/L, or 20,000pCi/L, is found in only one well (in the Trailer 5475 area). However, tritium is found at levels considered elevated in several locations (**Figure 8-5**). Two areas have unsaturated sediments with tritium concentrations that are also elevated. In the Trailer 5475 area, the tritium source is believed to be leakage of a lined solar evaporation pond. The source for the Building 292 contamination was a retention tank that leaked during the period that the facility housed the Rotating Neutron Target Source (more information about this is provided in Chapter 4 on Air Monitoring and Chapter12 on Radiological Dose Assessment).

In the past two years, LLNL has completed extensive investigations of the sanitary sewer system at the Livermore site and of the building drain systems at both sites. As might be expected at a site with most of its infrastructure over 30years old, closed-circuit television testing revealed cracks, breaks, and off-set joints in the sanitary sewer system. Exfiltration could have taken place at each of these locations. Repairs were prioritized based on an evaluation and ranking of the problems by an outside contractor. The worst portions of the system will be repaired and much of the system will be lined to reduce leakage from it. When repairs require excavation, soil samples are taken and analyzed to determine if exfiltration has released contaminants into the soil. When necessary, soil from the excavations has been removed and disposed of at a properly certified landfill. Further details of this effort are given in the last section of this chapter.

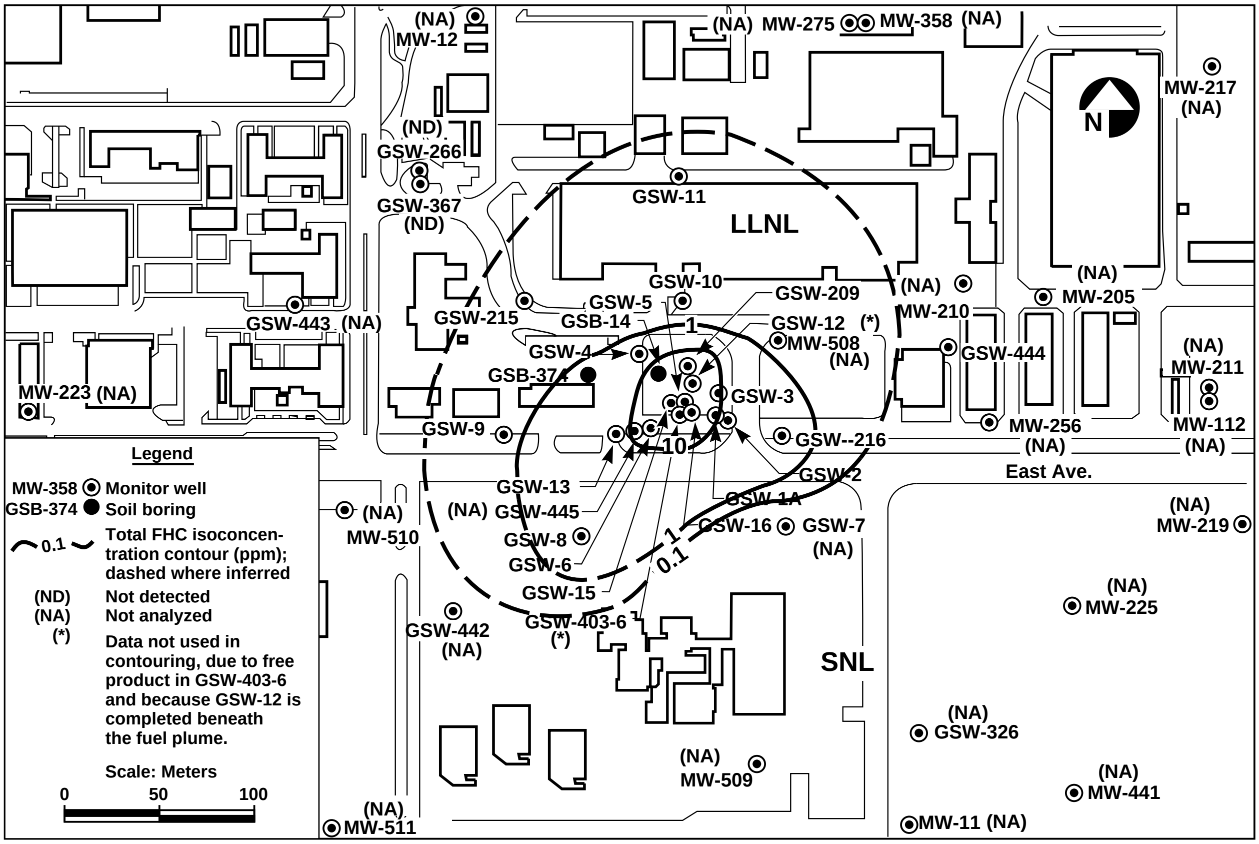

Figure 8-4. Isoconcentration contour map of total fuel hydrocarbons (FHCs) in ground water, Gasoline Spill Area, March 1989 (prior to dynamic stripping). All areas that exceed fuel hydrocarbon MCLs are encompassed by the 0.1-ppm contour.

In 1992–1993, LLNL tested thousands of drain discharges to determine the location of any non-storm water discharges to ground or storm sewer systems. The discharge points of the drains were identified through dye testing, smoke testing, and methods as simple as flushing popcorn down the line and watching for its re-appearance. Again, it was not surprising that deficiencies were found. Eleven discharges that could have affected human health or significantly affected the environment were stopped immediately upon detection. The remaining deficiencies were categorized and identified to facility management and DOE Oakland Operations Office staff. None of these deficiencies was believed to have created a situation that could lead to ground water contamination.

An area of concern in Livermore Valley ground water monitoring is the region west of the Livermore Water Reclamation Plant. Historical discharge from LLNL of sewerage containing low levels of tritium and an accidental release of plutonium in 1967 have resulted in measurable levels of tritium in the water and

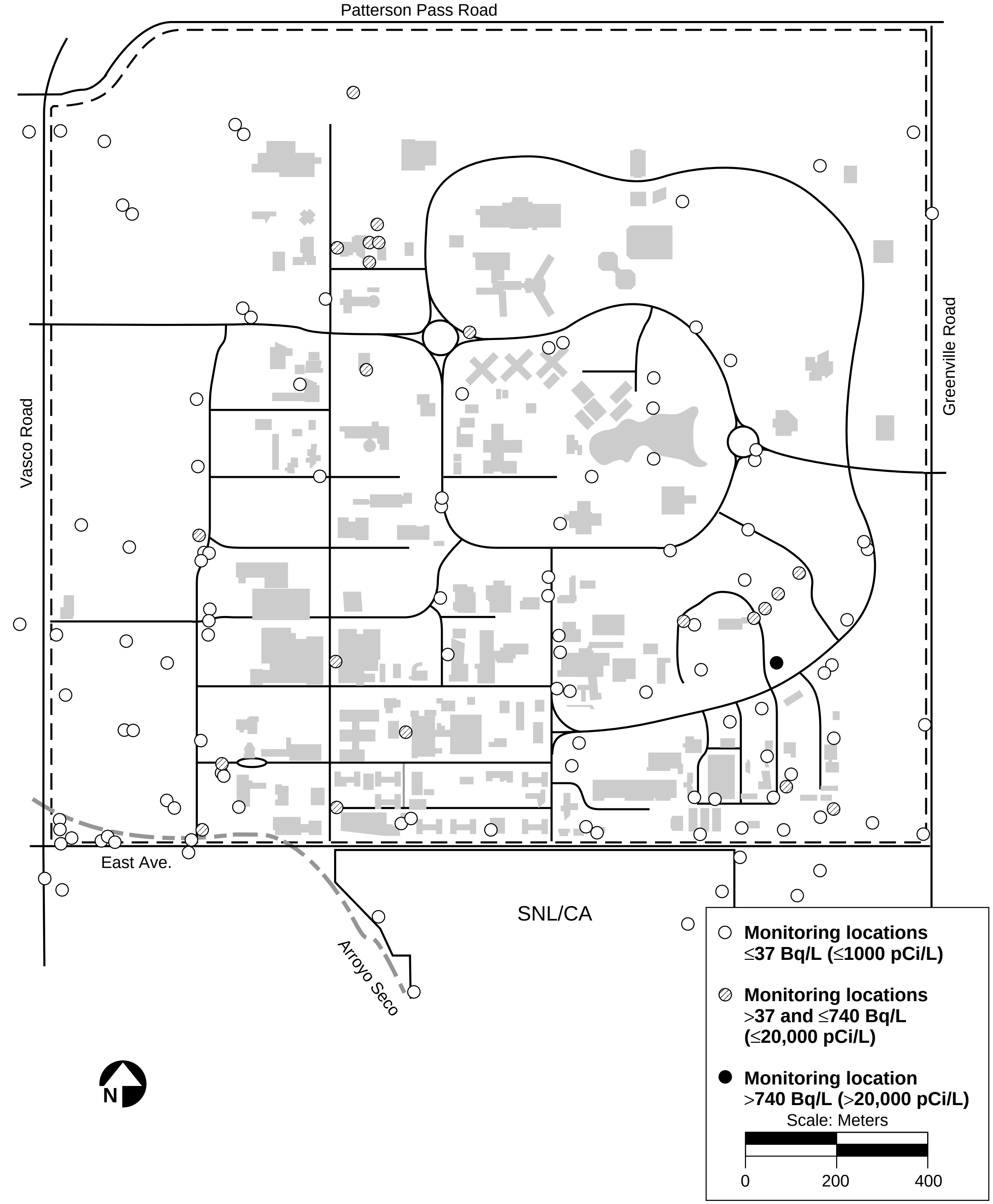

Figure 8-5. Ground water monitoring locations with tritium concentrations exceeding 37 Bq/L (1000 pCi/L) at LLNL.

plutonium in the soil near the reclamation plant. Monitoring efforts will continue to study the ground water in this region.

Site 300

Site 300 is also on the National Priority List for sites requiring environmental restoration in accordance with CERCLA. In light of this, extensive investigations have been performed to identify and delineate contamination from past practices that has affected or could affect the ground water underlying LLNL. Detailed descriptions of these findings are available in the *Final Site-Wide Remedial Investigation* report (Final SWRI; Webster-Scholten 1994). The remediation work at Site 300 has not reached the same stage as that at the Livermore site, so some areas of possible contamination are still under investigation.

Volatile organic compounds, primarily TCE, have been detected in the ground water and unsaturated sediments at Site 300 as well. The main areas of concern are predominantly in the southeast portion of the site (**Figure 8-6**). Contaminants in ground water have extended off site in the General Services Area, which houses the administrative buildings, crafts and mechanical shops, fuel and vehicle repair shops, cafeteria, and main parking. VOCs in excess of the MCL have been identified in the shallow ground water beneath the General Services Area in two locations: two small plumes occur in the central area; and one plume occurs in the eastern area and the gravels of Corral Hollow Creek, a seasonal arroyo running along the southern border of Site 300. TCE is also present in the Building 833 and Building834 areas, the HE Process Area, and downgradient of closed landfill Pit 6. Minor detections of TCE have been seen in the East and West Firing Areas and in wells downgradient from closed landfill Pit 7.

Freon-113 (1,1,2-trichloro-1,2,2-trifluoroethane) has been detected in wells downgradient from the closed Advanced Test Accelerator, which is considered to have been the source of the Freon. This is discussed further in Chapter 7 on Routine Ground Water Monitoring.

Discharges of rinse water from buildings within the HE Process Area were historically disposed of in unlined lagoons near the buildings. The use of the lagoons has terminated and they have been closed and capped. However, high-explosive compounds and metals have been detected in the unsaturated sediments beneath some of the lagoons. High-explosive compounds and TCE have been detected in two perched water-bearing zones within the HE Process Area.

Tritium has been identified in ground water in two areas in the northern portion of Site 300. These plumes are associated with closed landfill Pit 7 and Building 850, and Doall Road and Elk Ravine in the East and West Firing Areas.

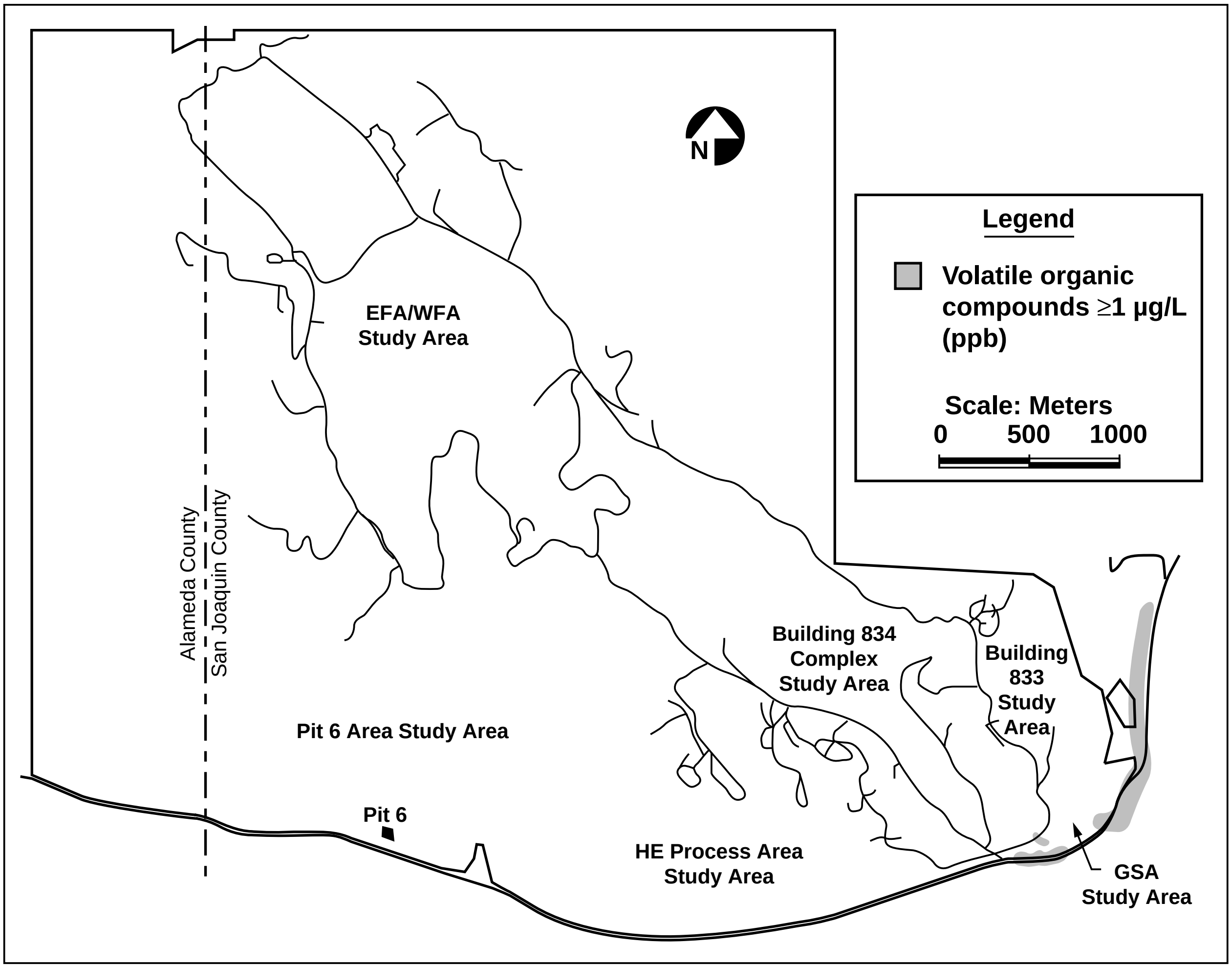

Figure 8-6. Distribution of VOCs in ground water at the General Services Area, Site 300.

The tritium is believed to have been released into the ground water when abnormally high water levels flooded landfills where tritiated waste had been placed.

The ratio of the isotopes ^{235}U to ^{238}U found in nature is 0.007. When uranium is enriched for various uses, such as in fission reactors and nuclear weapons, the level of ^{235}U becomes higher and the natural ratio changes to anywhere from 0.015 to 0.93. The by-product of this enrichment process is depleted uranium—uranium with a lower proportion of ^{235}U. Depleted uranium has been detected recently in a number of wells downgradient of Pit 7; studies are under way to determine its extent and magnitude.

Results from monitoring wells surrounding Pits 1 and 7 have shown "statistically significant evidence of release" of some constituents of concern and have indicated, through several monitoring parameters, changes in ground water quality. LLNL has reported data for ^{235}U and specific conductivity for Pit 1; and barium, tritium, ^{234}U, ^{235}U, ^{238}U, specific conductivity, pH, and lead for Pit 7. LLNL is required to report "statistically significant evidence of release" based on a comparison of upgradient and downgradient well results and historical monitoring data. LLNL will perform further investigations under CERCLA to determine if the results are due to releases from the pits. It is expected that the capping of the pits, completed in 1992, will eventually eliminate or reduce infiltration from the surface, thereby diminishing the rate of release of any material from the pits.

Remediation Activities

CERCLA Activities

Livermore Site. An extensive investigation of the remediation options for the contaminated areas discussed above is summarized in the *CERCLA Feasibility Study for the LLNL Livermore Site* (Isherwood et al. 1991). The *Record of Decision for the Lawrence Livermore National Laboratory Livermore Site* (ROD; Ziagos 1992) documents the remedial options selected for implementation. For ground water contamination, the selected remedies involve pumping the ground water for surface treatment by a combination of ultraviolet-light hydrogen peroxide, air stripping, and granulated activated carbon. For contaminants in the unsaturated zone, the selected remedies 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 1993 can be found in Chapter 2.

Site 300. The investigations and preparations for remediation at Site300 have not progressed as far as those at the Livermore site. As of May 1994, the Final SWRI report (Webster-Scholten 1994) has been accepted by the regulators and is in final printing. This report compiles all ground water and soil investigation information for the entire site and contains an assessment of the potential human health and ecological hazards or risks resulting from contamination of soil, sediment, and ground water. Feasibility Studies will be prepared for the individual study areas where an unacceptable risk or hazard exists. Current milestone dates for Final Feasibility Study Reports are: General Services Area on September 15, 1995; Building 834 Complex on June 15, 1994; HE Process Area on April 15, 1996; Building 850/Pits 3 and 5 on November 1, 1995; and Pit 6 on November 15, 1994. A description of the remediation efforts in 1993 can be found in Chapter 2.

Other Remedial Programs

The Tank Upgrade Project has included the closure and accompanying soil cleanup of 17 petroleum product underground storage tank (UST) systems with minor to moderate amounts of vadose zone contamination in their immediate vicinity. The suspected cause of contamination in the majority of these tank systems was overspill during filling operations. However, six of the tank systems (e.g., tanks 827-D1U1 and 490-D1U1) were found to have holes in their tank walls or piping at the time of removal. A total of 76 USTs and 44 aboveground or on-ground storage tanks (whose contents are hazardous product and hazardous/ nonhazardous waste) will be closed, replaced, or upgraded as part of this project. Approximately 47 pieces of oil-containing equipment will also be upgraded with secondary containment, accompanied by appropriate soil cleanup. Seventeen underground and one aboveground tank systems previously had been closed and cleaned up (as required) in an earlier Tank Systems Upgrade project.

The Sanitary Sewer Rehabilitation Project is an effort to investigate the condition of, and rehabilitate, the sanitary sewer system at the Livermore site. Over 9000meters of sewer line were examined to identify areas where lines were off-set, where joints were separated, or where a portion of a line was either punctured or had collapsed. The major line breaks and disruptions are being repaired by excavation and pipe replacement. Smaller problems (e.g., line off-sets and cracks) were identified in sufficient numbers to determine that in-situ lining of over 6000meters of piping in the system would be the most cost-effective repair. This lining is currently under way and is expected to be completed in 1994. This will reduce, to an acceptable level, exfiltration from the sewer pipes into the surrounding sediments. It will also reduce infiltration into the system that brings unwanted rain water into the sewerage system.

The Building Drain Investigation, completed in 1992, identified deficiencies in waste discharge systems that must be repaired or permitted. For those discharges deemed by the regulatory agencies to have no significant impact to the environment, LLNL may apply for a permit to continue the discharge. Examples of this type of discharge are water from testing of emergency showers and eye-washes, and condensate from air conditioners. When there may be an impact on the environment, LLNL will remove or re-route the discharge to the sanitary sewer or a retention tank. Improper discharges will be discontinued where hazardous materials may be handled, and related floor drains will be filled or covered. By the end of March 1995 for Site 300 and September 1995 for the Livermore site, LLNL will be required to certify that all discharges are in accordance with environmental regulations. The elimination of discharges that release industrial wastewater to ground will reduce the possibility that contaminants in the wastewater could reach the ground water.

At Site 300, dry wells and disposal lagoons have been primary points of wastewater release to the environment; they received wastewater and other liquids from various buildings and test cells by piping or lined trenches. Dry wells were typically filled with gravel and were generally not very deep (often less than 2meters). Disposal lagoons were often earthen depressions with no metal or concrete sides. In a few instances, drainage ditches appear to have been used as disposal lagoons. Most disposal lagoons were constructed in permeable soil and almost never had standing water. Some disposal lagoons were partially filled with gravel.

Forty-eight dry wells and disposal lagoons were identified in the initial remediation investigation in the 1980s. By 1989, the majority of these dry wells and disposal lagoons were permanently removed from service. Soil and rock samples have been collected and analyzed at most dry wells and disposal lagoons; some dry wells have been excavated. Details of the dry wells and disposal lagoons are presented in the Final SWRI report (Webster-Scholten 1994).

During the recent efforts to repair or permit deficiencies identified by the Building Drain Investigation, approximately 13 dry wells were identified as still being in use. We are working to determine if there are discharges to any of these wells and how to close them. Discontinuing their use assures that any constituents that are present in wastewater cannot reach the ground water. At this time, the only dry well that will continue to be used is located near Building815 and accepts blowdown from the cooling tower. When the percolation field for this cooling tower is operational, this dry well will also be closed.

In the past, landfills were in use at Site 300 to accept debris from high-explosive testing and other experiments. Except for Pits 1 and 7, all the landfills were closed prior to 1987. In 1988, LLNL also ceased operations of these landfills and began the closure process. Both were capped in 1992 and LLNL began post-closure activities under the submitted *Post-Closure Monitoring Plan* (Rogers/Pacific Corporation 1990). LLNL applied for and received a permit specifying Waste Discharge Requirements (WDR No. 93-100) and defining the monitoring and reporting requirements. Monitoring of wells surrounding Pits 1 and 7, under permit WDRNo. 93-100, has resulted in LLNL reporting “statistically significant evidence of release” of some constituents of concern and several monitoring parameters indicate changes in the ground water quality. Further investigations will be completed under CERCLA to determine if the results are due to releases from the pits. It is expected that the capping of the pits, completed in 1992, will eventually eliminate or reduce infiltration from the surface, thereby diminishing the rate of release of any material from the pits.

Twenty-three cooling towers are operated at Site 300 to cool buildings and equipment. Of these, six discharge wastewater to septic tanks. Seventeen towers discharge wastewater to on-site surface drainage courses. Most of the towers are of such low-volume flow and located in remote areas of Site 300 that the wastewaters never reach the major drainage channel, Corral Hollow Creek, except possibly during rain storms, and then the wastewater contribution to the total runoff discharges is negligible.

It has been determined by the Central Valley Regional Water Quality Control Board that alternate methods of discharge of the blowdown from all but three of these towers should be found. The alternate method must be such that the wastewater flow should not significantly exceed design volume, temperature should not alter the ambient temperature of the receiving water by more than 5°F, and pH should be within the range of 6.5–8.5 pH units.

Samples of the discharged wastewater indicate that the discharges routinely exceed the permit pH limitation. The noncomplying pH levels occur during normal operations. Water used in the cooling towers is supplied by on-site drinking water wells, and the pH of this water ranges from 8.1–8.7. The addition of corrosion-inhibiting chemicals further raises the pH.

LLNL will eliminate the surface discharge of 14 of the 17 cooling towers by engineering the wastewater discharges to percolation pits by December 1994. LLNL requested, in a permit renewal application submitted in December 1991, that the pH range for the three towers continuing to discharge to surface drainage courses be expanded to 6.5–10.0. Staff of the Regional Water Quality Control Board have supported the expansion of the pH range due to the low threat imposed by the cooling towers on the surface waters. The new permit will be issued in the spring of 1994.

Summary

It is the policy of LLNL to operate in a manner that does not adversely affect the environment. Past materials handling activities and practices have resulted in 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.

9. Soil and Sediment Monitoring

Gretchen M. Gallegos

Introduction

Soil, defined as the weathered materials near the surface of the earth that are suitable for growing plants, is an integrating medium that 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 “periodic sampling and analysis of indicator materials, such as soil …should be performed to determine if there is measurable long-term buildup of radionuclides in the terrestrial environment. … Soil sampling and analysis should be used to evaluate the long-term accumulation trends and to estimate environmental radionuclide inventories.” The guidance specifies that nuclides in use at the facility, as well as naturally occurring nuclides, should be monitored. In particular, the guidance states that “…it is desirable to assess, document, and periodically reassess the distribution and fate of radionuclides in the environment, especially plutonium in soil samples.” Particulate radionuclides are of major interest in the LLNL soil monitoring program because airborne particulate releases are the most likely potential 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. In a geologic sense, the top 1000 meters or more underlying the LLNL Livermore site is sediment. 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). The reader should note, however, that neither the Livermore site nor Site300 has habitats for aquatic species that are consumed by people, nor surface drainage that directly feeds drinking water supplies.

Since 1971, surface soil sampling in the vicinity of the Livermore site and Site300 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. 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.

Because high-explosive tests at Site300 occasionally involve the use of uranium depleted of ^{235}U, one purpose of the annual soil sampling is to determine if these tests increase the depleted uranium (^{238}U) content of the soil. The inclusion of the other 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. In 1991, LLNL began analyzing surface soil samples for beryllium, a potentially toxic metal used at both the Livermore site and Site300.

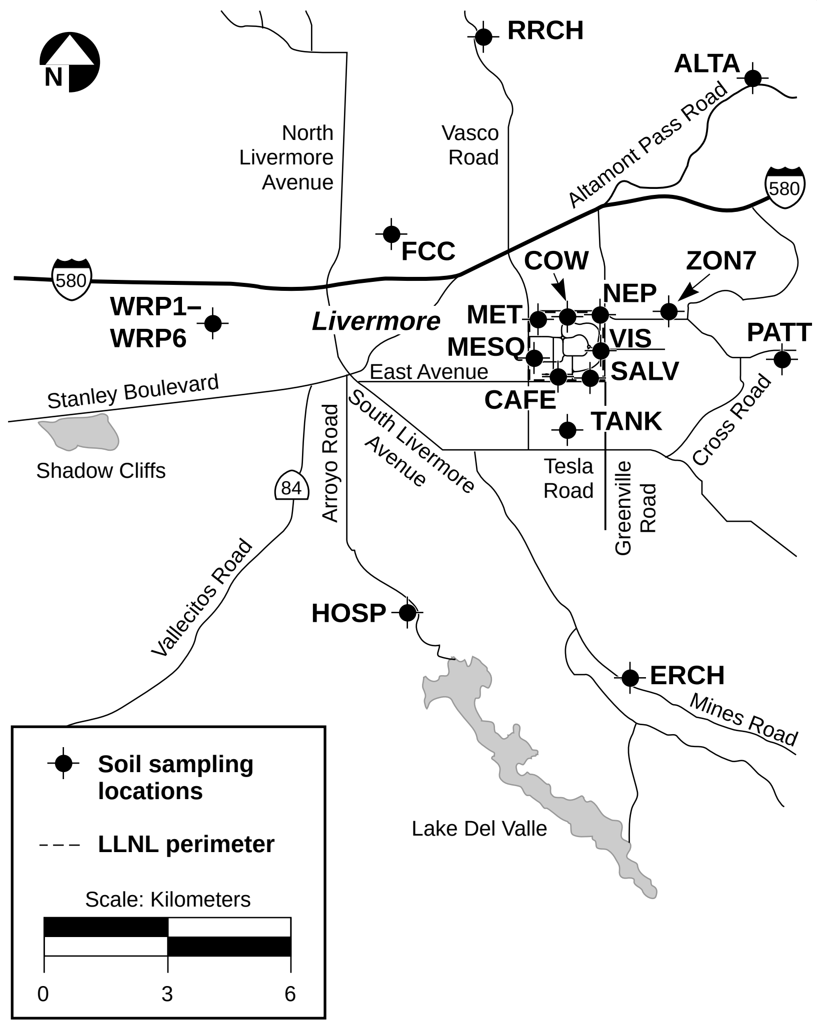

Figure 9-1. Soil sampling locations, Livermore Valley, 1993.

Location maps for soil and sediment sampling conducted during 1993 are provided in **Figures 9-1** through **9-3**. 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, Site300 soil sampling 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. Other locations can be selected and sampled using existing written procedures published with the *Environmental Monitoring Plan* (Gallegos etal. 1992b).

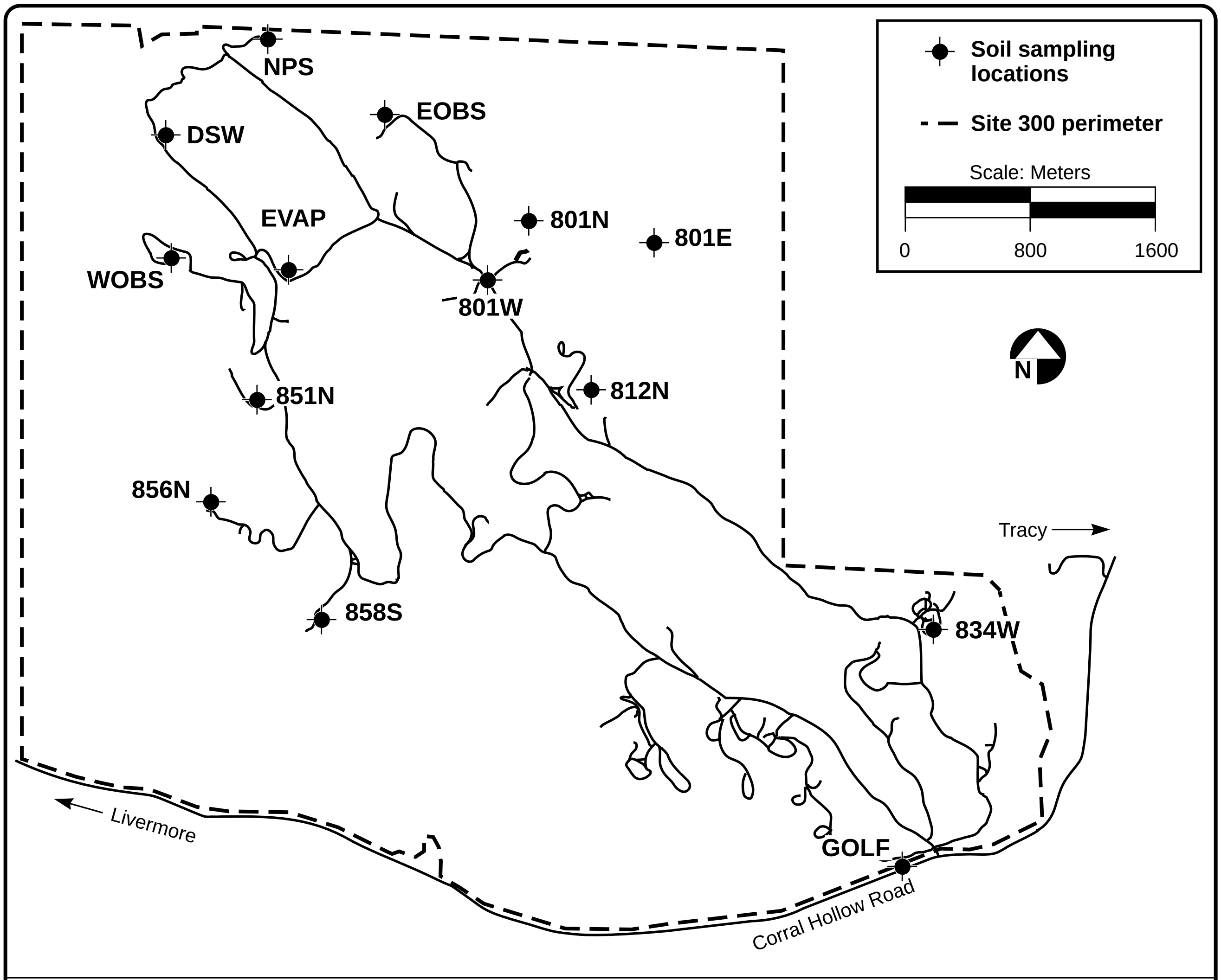

Figure 9-2. Site 300 soil sampling locations, 1993.

Methods

Soils

Prior to 1988, soil samples were collected at sites selected at random from Livermore Valley locations previously sampled for a 1971–1972 study. That earlier study was conducted to determine background concentrations of radionuclides in area soils. In 1988, Livermore Valley surveillance soil sampling locations were chosen to coincide with air sampling locations or to give coverage to areas with contaminants from past incidents or of other special concern. In 1991, five additional soil sampling locations associated with air sampling locations were established. The 1993 Livermore site soil samples were collected from the same locations as those in 1991 and 1992. The 1993 Site300 soil

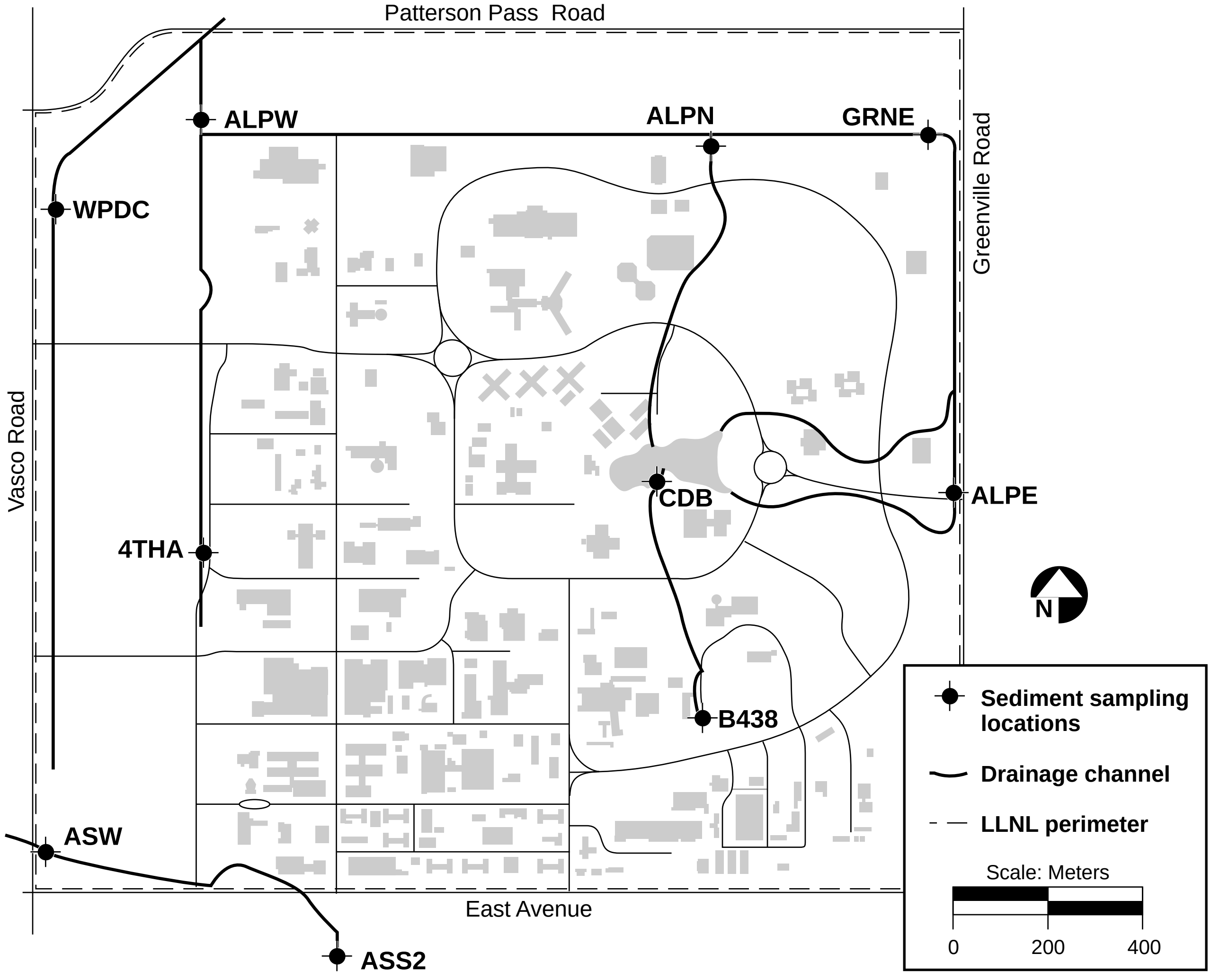

Figure 9-3. Arroyo and drainage basin sediment sampling locations, 1993.

samples were collected from the same fourteen sampling locations as in 1990 to 1992. The use of constant sampling locations from year to year allows more meaningful trending ofdata.

Sampling locations at areas with known or suspected contaminants were monitored to delimit the extent of the contaminants and to track the contaminants from year to year. For example, six soil sampling locations were located near LWRP to monitor soils that contain slightly elevated plutonium levels originating from a 1967 accidental release to the sewer.

Soil sampling is conducted according to written, standardized procedures contained in Gallegos etal. (1992b). Samples are collected from undisturbed areas in the proximity of the permanent sampling location marker. These areas generally are level, free of rocks, and are unsheltered by trees or buildings. The sampling technician chooses two 1-meter squares from which to collect the sample, and records how far away and in what direction from the permanent marker the sample is collected. Each sample is a composite consisting of ten subsamples that are collected, at a depth of 5 cm, with a 8.25-cm-diameter stainless steel core sampler, at the four corners and the center of each square. All subsamples are collected from the top 5cm of soil because surface deposition from the air is the primary pathway for potential contamination.

Quality assurance (QA) samples are submitted with each batch of soil samples. At locations chosen for duplicate sampling, two identical samples are collected. Adjacent cores are collected from the corners and center of the sampling squares. Separate composites of ten cores each are made, and the duplicate samples are identified with unique sample identifier codes.

Samples are delivered on the day of collection to LLNL’s Radiation Analytical Sciences (RAS) 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 (300grams) are analyzed for more than 150radionuclides by gamma spectroscopy, using a Ge (Li) detector (Hall and Edwards 1994). The 10-gram subsamples for beryllium analyses are sent to a contract analytical laboratory and are analyzed by graphite-furnace atomic absorption spectroscopy. Chain-of-custody procedures are followed throughout the sampling, delivery, and analytical processes.

Sediments

Samples of recent sediment are collected annually from drainages at and around the Livermore site after the cessation of spring runoff. For 1993, samples were analyzed for radionuclides and beryllium. Sediment samples were not analyzed for heavy metals and organic compounds because of an inadvertent failure to request these analyses from the new analytical laboratory before the holding time for these analyses had passed. This is of minor concern; for the five years 1988 to 1992, only one sample (near location ASS2) included an analytical result for any analyte, in this case lead, at a level of potential concern, and this result was not confirmed by subsequent analysis. The continued need for heavy metals and organic compounds analyses is currently being evaluated.

Sediment was sampled from ten major Livermore-site drainages, including four locations first sampled during 1991 (4THA, at Fourth and A Streets; B438, adjacent to Building 438; GRNE, at the northeast influent to Arroyo Las Positas just off Greenville Road; and WPDC, in the west-perimeter drainage channel). The sediment sampling locations coincided with storm water runoff sampling locations so it would be possible to compare the sampling results from these two media.

A culvert, bridge, or other permanent marker serves as a reference point for each sampling location. In 1993, the sediment sampling method was modified to one similar to the soils sampling. Ten subsamples, 5-cm deep, are collected at 1-meter intervals along a transect of the arroyo or drainage channel. The sample collection technicians record how far away and in what direction from the permanent marker the samples are actually collected. As for soils samples, QA samples are submitted with each batch of sediment samples.

Samples are delivered on the same day to LLNL's RAS laboratory for analysis. For samples collected for tritium analyses, RAS uses freeze-drying techniques to recover water from the samples, and determines the tritium content of the water by liquid-scintillation counting. The plutonium content of a sample aliquot is determined by alpha spectroscopy. Other sample aliquots are analyzed for more than 150radionuclides using gamma spectroscopy as described above for soil samples. The radioanalytical methods employed by the RAS laboratory enable detection of concentrations at levels far more sensitive than regulatory limits. Chain-of-custody procedures are followed throughout the sampling, delivery, and analytical processes.

Results

Livermore Site

Table 9-1 presents data on the concentrations of ^{239}Pu, ^{40}K, ^{60}Co, ^{137}Cs, ^{232}Th, ^{235}U, and ^{238}U, in surface soils from the Livermore Valley sampling locations. The concentrations and distributions of all observed radionuclides in soil for 1993 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%. As in 1991 and 1992, low levels of ^{60}Co were detected at the LWRP. While there is ^{60}Co 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 (0.1pCi/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/mL) 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 (25pCi/mL). The reader should note that LLNL is 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 operations.

Plutonium-239 was detected at a higher level than background, 3.0×10^{-3}Bq/g (8.1×10^{-2} pCi/g) at location ZON7. Since 1973, soil samples in this area have generally shown ^{239}Pu values that are higher than background, with the exception of the 1991 sample, which was within background. The slightly higher values have been attributed to historic operations at the Livermore site (Silver etal. 1974). Plutonium-239 is carried off site by resuspension of soil and other particles by wind. LLNL no longer operates the solar evaporators or any other open air treatment of plutonium-containing waste.

Elevated levels of ^{239}Pu, resulting from an estimated 32-mCi plutonium release to the sewer in 1967 and first observed in soils near LWRP during the early 1970s, again were detected in locations WRP1 to WRP6. The highest value of 0.055 Bq/g (1.5 pCi/g) measured at LWRP during 1993 represents 11% of the proposed EPA surface soil screening level of 7400Bq/m^2 (0.2 μCi/m^2), or 0.5Bq/g (13 pCi/g), assuming average Livermore Valley soil densities of 1.5g/cm^3 and a potential resuspension depth of 1.0 cm. (Areas that do not exceed the screening level are generally said to be in compliance and need no further investigation for possible remediation.) The proposed EPA screening level for surface soil contamination was derived from conservative assumptions and mathematical models that considered both the inhalation and ingestion pathways (42Federal Register230 1977; U.S. Environmental Protection Agency 1977, 1978).

Historical plots of average ^{239}Pu concentrations in soil in the Livermore Valley, at Site300, and at LWRP are shown in **Figure 9-4**. Livermore Valley and Site300 concentrations have remained relatively constant over the past ten years

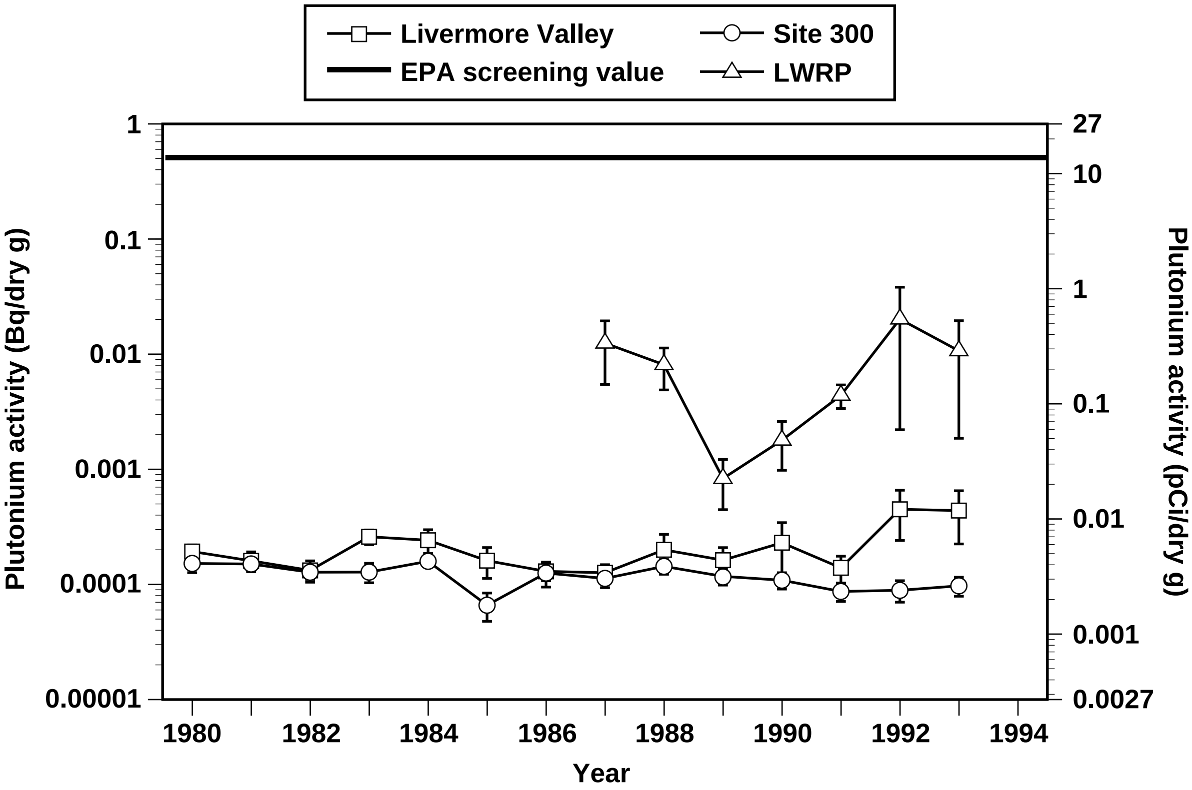

Figure 9-4. Mean plutonium activities in surface soils, 1980 to 1993 (error bars are ±1 standard error).

and generally are indicative of worldwide fallout (locations VIS and ZON7 at the Livermore site show activities greater than background). Greater variability in ^{239}Pu is seen at LWRP. The ^{239}Pu is likely to be present in discrete particles, so the presence or absence of the particles will dominate the measured ^{239}Pu in any given sample. Also, only six samples are being averaged to determine the mean, so any high or low value dominates the calculation of the mean. Further statistical analysis showed that all LWRP ^{239}Pu soils data are lognormally distributed and there is no general increase or decrease in ^{239}Pu values with time. Moreover, all measured concentrations, regardless of location and year, have been a small fraction of the proposed EPA screening level, which is also shown in **Figure 9-4** for comparison.

Table 9-1 also shows data on the concentrations of beryllium in surface soils from Livermore Valley sampling locations. Beryllium levels in soil samples from the Livermore Valley were comparable to the normal range of background concentrations (Wilber 1980).

Table 9-2 presents data on radionuclides detected in the sediment samples. The levels of ^{239}Pu were generally at background concentrations, reflective of worldwide fallout. The higher values at B438 and CDB 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 1991: ^{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. These results reflect decreased tritium emissions from LLNL operations.

Table 9-2 also presents data on concentrations of beryllium in sediment for 1993. Beryllium content of sediment samples were comparable to the normal range of background concentrations (Wilber 1980).

Site300

Table 9-3 presents data on the concentrations of ^{239}Pu, ^{40}K, ^{137}Cs, ^{232}Th, ^{235}U, and ^{238}U in soil from the Site300 sampling locations. The concentrations and distributions of all observed radionuclides in Site300 soil for 1993 remain similar to the levels measured from 1988 through 1992, lie within the ranges reported in all years since monitoring began, and generally reflect naturally occurring concentrations. The ratio of ^{235}U to ^{238}U reflects the natural ratio of0.7%.

Historical trends of ^{238}U concentrations from both the Livermore Valley and Site300 are shown in **Figure 9-5**. Mean values have remained relatively constant for both places; however, Site300 mean values are slightly greater than those

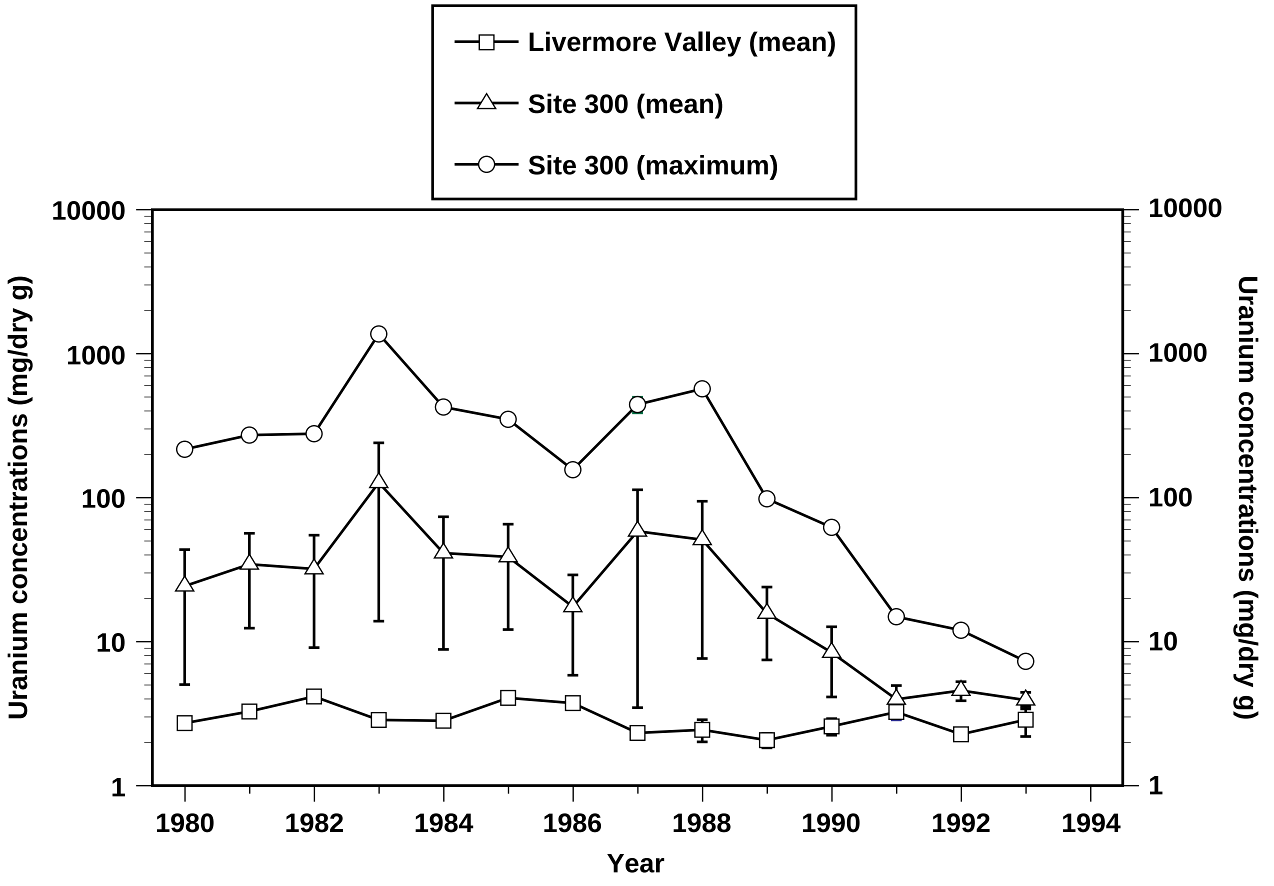

Figure 9-5. Mean uranium concentrations in surface soils, 1980-1993 (error bars are ± 1 standard error).

from the Livermore Valley because of naturally occurring uranium in Site300 soil. The highest values at Site300 are caused by the use of depleted uranium in high-explosive tests. Since 1988, these levels have been reduced by the cleanup activities around firing tables and landfills.

As in 1991 and 1992, no 1993 soil samples, including those from regions near the firing tables and disposal areas, had substantially higher than background concentrations of ^{238}U. The highest value of 7.3 µg/g (about two times greater than average background) was lower than the highest values reported for previous years (**Figure 9-5**). In 1989, a maximum value of 98.2 µg/g was detected in the vicinity of an inactive firing table (soil sampling location 812N), and in 1990, a maximum value of 62.2 µg/g was detected in the vicinity of an on-site landfill (soil sampling location DSW). In 1993, the soil samples from these locations contained ^{238}U at 7.1 µg/g and 7.3 µg/g.

Table 9-3 also presents 1993 data on concentrations of beryllium in soil from Site300 sampling locations. Beryllium content of these soil samples was comparable to the normal range of background concentrations (Wilber 1980).

However, it was approximately twice that from the Livermore Valley. It is unknown whether this difference is attributable to natural variability in background beryllium levels or to the use of beryllium at Site300 in high-explosive tests. But Shinn etal. (1989) states with regard to beryllium from high-explosive tests that "The maximum deposition of Be [beryllium] contributed a very small amount of Be to the soil compared to the natural background. The maximum observed deposition would amount to less than 3% of the natural background...."

Environmental Impact

Livermore Site

Routine soil and sediment sample analyses indicate that the impact of LLNL operations on these media in 1993 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. Sampling of soils will continue on an annual basis.

Site300

With the exception of slightly elevated concentrations of ^{238}U (below those reported for previous years), the concentrations of radionuclides and beryllium observed in soil samples collected at Site300 are representative of background or naturally occurring levels. In the past, ^{238}U-contaminated gravel from the firing tables was removed to on-site landfills. These landfills at Site300 have been inactive since 1988. The 1993 analyses did not detect significantly higher concentrations of ^{238}U in soil in areas adjacent to firing bunkers or near the landfills, in contrast to previous years (Gudiksen etal. 1973; Holland et al.1987; Holland and Brekke 1988; Sims et al. 1991). The level of ^{238}U has been reduced to near background levels, probably because of the bunker cleanup operations that removed contaminated gravel to the landfills.

Special Study

Plutonium in Soil, Southeast Quadrant of Livermore Site

Due to historic activities in the southeast quadrant of the Livermore site, higher values of plutonium in soils are found in this general area. In 1991, in response to a Tiger Team suggestion that LLNL further characterize the distribution of plutonium in the area, 195 surface soil samples were collected on a randomized grid and analyzed for plutonium. Although the highest result, 0.11Bq/g (3pCi/g), was below the proposed EPA surface soil screening level of 0.5Bq/g (13pCi/g), the EPA decided to resample locations with high values and to sample locations west of the 1991 sampling grid to assure that the boundary of the area of interest had been appropriately set. The sampling locations for the

EPA 1993 sampling effort are shown in **Figure 9-6**, and the results collected from the 1993 study, as well as data from the 1991 study for those locations, are presented in **Table 9-4**. For the purpose of comparison, some data from a similar LLNL study in 1974 are included as well. The 1993 samples were taken at two depths, 0.01 m and 0.05 m.

The highest value in the EPA 1993 study was found at location 64; the activity levels were 0.32 Bq/g (8.6 pCi/g) at a depth of 0.01 m and 0.45 Bq/g (12.2pCi/g) at a depth of 0.05 m. These peak values are a little higher than the highest value found in the 1991 study, which was 0.11 Bq/g (3 pCi/g) at location65, but they are still less than the proposed EPA guidance for surface soil. Moreover, comparison of the 1993 data with the data from 1974 and 1991 shows that plutonium activities have remained substantially the same; none of the data reveal levels of plutonium above the screening level. On the basis of these three studies, it is reasonable to conclude that plutonium levels are not changing and are not present at levels requiring further detailed study.

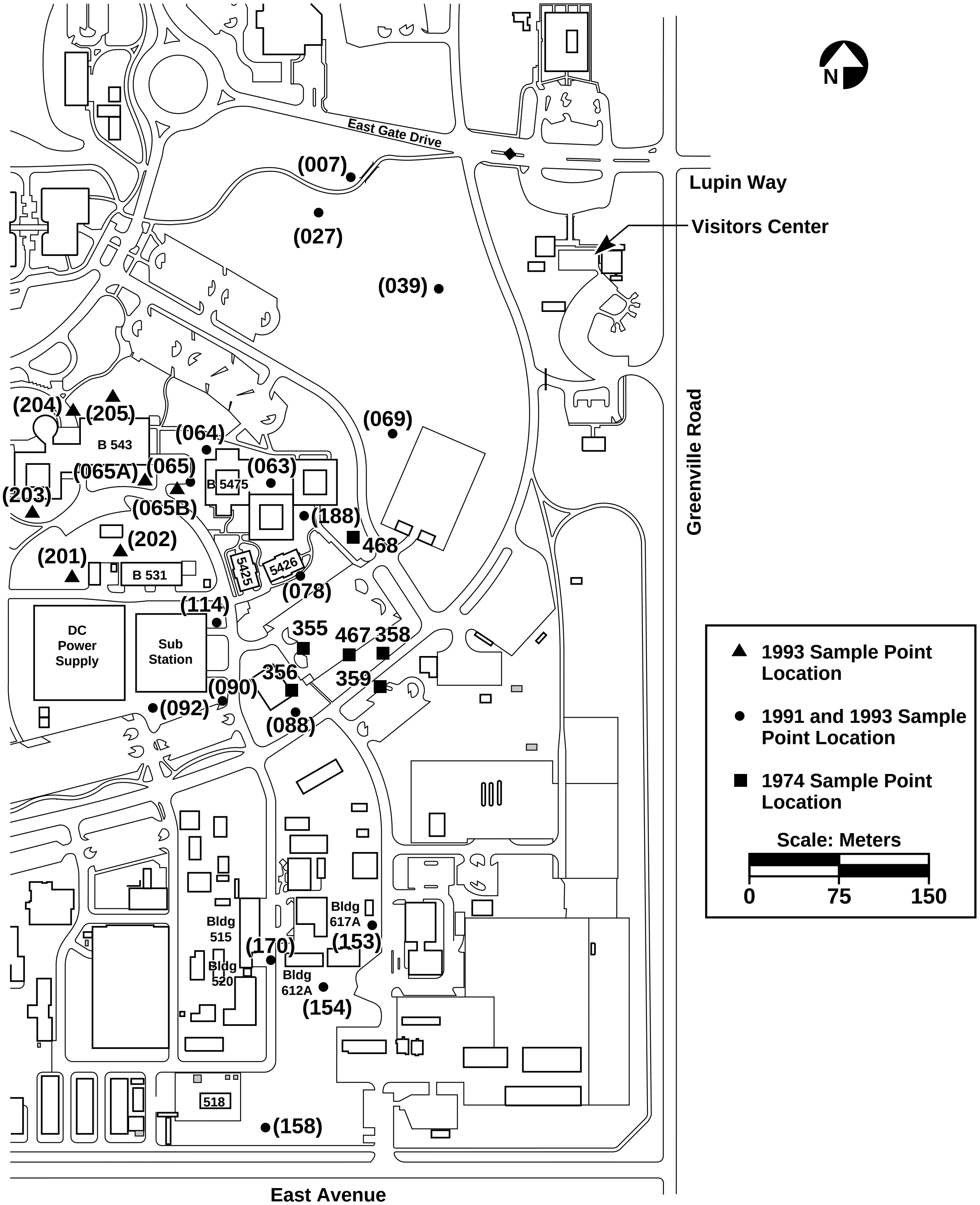

Figure 9-6. Approximate locations of surficial soil samples in the LLNL southeastern quadrant. The 1993 sampling was performed by the U.S. EPA.

Table 9-1. Radionuclides and beryllium in soil sampled at depths from 0 to 50 mm, Livermore Valley, 1993.

Location[a]	^{239}Pu	^{60}Co	^{137}Cs	^{40}K
	(10^{-3} Bq/dry g)			(Bq/dry g))
ALTA	0.28 ± 0.016	<0.086	12 ± 0.40	0.544 ± 0.0239
CAFE	0.86 ± 0.031	<0.070	2.6 ± 0.21	0.414 ± 0.0133
COW	0.08 ± 0.0064	<0.095	3.0 ± 0.33	0.562 ± 0.0169
ERCH	0.11 ± 0.0077	<0.076	3.7 ± 0.26	0.374 ± 0.0112
FCC	0.10 ± 0.0070	<0.064	4.1 ± 0.20	0.433 ± 0.0121
HOSP	0.12 ± 0.0085	<0.063	4.6 ± 0.17	0.511 ± 0.0123
MESQ	0.040 ± 0.0043	<0.099	1.5 ± 0.30	0.555 ± 0.0167
MET	0.046 ± 0.0045	<0.076	1.7 ± 0.25	0.566 ± 0.0113
NEP	0.042 ± 0.0042	<0.095	2.1 ± 0.28	0.551 ± 0.0143
PATT	0.030 ± 0.0037	<0.083	0.74 ± 0.20	0.585 ± 0.0187
RRCH	0.0015 ± 0.00080	<0.078	<0.080	0.511 ± 0.0163
SALV	0.29 ± 0.016	<0.098	1.4 ± 0.30	0.459 ± 0.0147
TANK	0.0055 ± 0.0016	<0.076	<0.081	0.448 ± 0.0161
VIS	1.55 ± 0.054	<0.12	6.1 ± 0.33	0.492 ± 0.0167
ZON7	3.0 ± 0.11	<0.088	8.8 ± 0.35	0.562 ± 0.0169
WRP1[b]	3.9 ± 0.13	0.22 ± 0.14	3.3 ± 0.23	0.444 ± 0.0142
WRP2[b]	3.4 ± 0.12	<0.10	3.7 ± 0.28	0.400 ± 0.0128
WRP3[b]	0.28 ± 0.014	<0.070	0.62 ± 0.16	0.367 ± 0.0132
WRP4[b]	55 ± 1.7	0.76 ± 0.13	6.4 ± 0.22	0.374 ± 0.0097
WRP5[b]	0.34 ± 0.015	<0.063	0.69 ± 0.15	0.351 ± 0.0126
WRP6[b]	1.5 ± 0.054	<0.077	0.96 ± 0.18	0.403 ± 0.0121
Mean	**0.44[c] 10.7[d]**	**<0.083[e]**	**2.60[e]**	**0.472**
Std dev	**0.83[c] 21.6[d]**	**—[f]**	**1.64[g]**	**0.078**
	(10^{-3} pCi/dry g)			**(pCi/dry g)**
Mean	**12[c] 289[d]**	**<2.23[e]**	**70.2[e]**	**12.8**
Std dev	**22[c] 585[d]**	**—[f]**	**44.2[g]**	**2.10**

...continued

Table 9-1. Radionuclides and beryllium in soil sampled at depths from 0 to 50 mm, Livermore Valley, 1993 *(concluded)*.

Location[a]	^{232}Th[h]	^{235}U[i]	^{238}U[j]	Be
	(µg/dry g)			(mg/kg)
ALTA	8.77 ± 0.228	0.022 ± 0.0059	2.2 ± 1.8	0.79
CAFE	4.58 ± 0.147	0.016 ± 0.0046	1.4 ± 1.3	0.32
COW	7.83 ± 0.251	0.022 ± 0.0070	<1.6	0.41
ERCH	6.32 ± 0.190	0.017 ± 0.0073	3.0 ± 2.0	0.5
FCC	5.33 ± 0.288	0.023 ± 0.0078	2.3 ± 1.3	0.95
HOSP	3.40 ± 0.218	0.018 ± 0.0051	1.4 ± 1.2	0.17
MESQ	7.80 ± 0.249	0.023 ± 0.0059	2.2 ± 2.1	0.67
MET	6.80 ± 0.245	0.019 ± 0.0077	3.1 ± 1.9	0.39
NEP	5.70 ± 0.148	0.015 ± 0.0049	2.1 ± 2.0	0.28
PATT	8.00 ± 0.272	0.025 ± 0.0068	12 ± 6.8	1.2
RRCH	7.68 ± 0.230	0.025 ± 0.0057	<2.3	0.65
SALV	7.88 ± 0.205	0.025 ± 0.0059	3.7 ± 3.4	0.51
TANK	4.62 ± 0.166	0.017 ± 0.0043	<1.1	0.51
VIS	7.21 ± 0.231	0.023 ± 0.0063	<2.3	0.36
ZON7	7.56 ± 0.197	0.024 ± 0.0060	<2.4	1.1
WRP1	7.34 ± 0.205	0.020 ± 0.0048	<1.3	0.45
WRP2	7.79 ± 0.249	0.024 ± 0.0072	3.3 ± 2.8	0.42
WRP3	6.27 ± 0.326	0.022 ± 0.0062	2.3 ± 1.4	0.35
WRP4	5.35 ± 0.257	0.030 ± 0.0050	3.1 ± 1.2	0.59
WRP5	6.38 ± 0.306	0.022 ± 0.0059	2.2 ± 1.2	0.42
WRP6	6.19 ± 0.272	0.020 ± 0.0037	1.5 ± 1.4	0.43
Mean	**6.61**	**0.022**	**2.25[e]**	**0.55**
Std dev	**1.38**	**0.004**	**0.69[g]**	**0.27**

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] See Fig. 9-1 for sampling locations.

[b] Samples from areas of known plutonium contamination.

[c] Summary statistics for samples only from uncontaminated areas.

[d] Summary statistics for samples only from areas of known contamination (i.e., Livermore Water Reclamation Plant).

[e] Median value; see Quality Assurance chapter.

[f] No measure of dispersion calculated; see Quality Assurance chapter.

[g] Median absolute deviation (MAD); see Quality Assurance chapter.

[h] Thorium-232 activities in Bq/dry g can be determined by dividing the weight in µg/g by 247.3 and pCi/dry g can be determined by dividing by 9.15.

[i] Uranium-235 activities in Bq/dry g can be determined by dividing the weight in µg/g by 12.5 and pCi/dry g can be determined by dividing by 0.463.

[j] Uranium-238 activities in Bq/dry g can be determined by dividing the weight in µg/g by 80.3 and pCi/dry g can be determined by dividing by 2.97.

Table 9-2. Radionuclides in arroyo sediments near the Livermore site, 1993.

	^{239}Pu	^{137}Cs	^{40}K	^{3}H
Location[a]	**(10^{-3} Bq/dry g)**		**(Bq/dry g)**	**(Bq/L)**
4THA	0.49 ± 0.022	9.7 ± 0.39	0.437 ± 0.0131	0.44 ± 0.14
ALPE	0.13 ± 0.0094	2.1 ± 0.23	0.448 ± 0.0134	1.0 ± 0.12
ALPN	0.016 ± 0.0028	0.33 ± 0.27	0.625 ± 0.0150	0.78 ± 0.27
ALPW	0.16 ± 0.0099	1.4 ± 0.28	0.544 ± 0.0141	0.40 ± 0.12
ASS2	0.0017 ± 0.0011	<0.078	0.496 ± 0.0188	0.69 ± 0.26
ASW	0.040 ± 0.0044	0.97 ± 0.14	0.518 ± 0.0197	1.7 ± 0.18
B438	6.2 ± 0.23	0.89 ± 0.17	0.477 ± 0.0172	0.53 ± 0.093
CDB	1.8 ± 0.064	0.92 ± 0.31	0.455 ± 0.0109	2.2 ± 0.18
GRNE	0.16 ± 0.0098	1.4 ± 0.18	0.548 ± 0.0164	0.74 ± 0.39
WPDC	0.0087 ± 0.0020	0.29 ± 0.23	0.544 ± 0.0141	0.48 ± 0.11
Mean	**0.90**	**0.95[b]**	**0.51**	**0.91**
Std dev	**1.93**	**0.55[c]**	**0.06**	**0.61**
	(10^{-3} pCi/dry g)		**(pCi/dry g)**	**pCi/L**
Mean	**24.2**	**25.6[b]**	**13.8**	**24.5**
Std dev	**52.3**	**14.7[c]**	**1.58**	**16.5**

...continued

Table 9-2. Radionuclides in arroyo sediments near the Livermore site, 1993 *(concluded).*

Location[a]	^{232}Th[d]	^{235}U[e]	^{238}U[f]	Be
		(µg/dry g)		mg/kg
4THA	6.3 ± 0.22	0.022 ± 0.0047	4.8 ± 2.8	0.72
ALPE	7.0 ± 0.22	0.019 ± 0.0063	1.8 ± 1.6	0.82
ALPN	5.9 ± 0.15	0.018 ± 0.0041	<1.1	0.58
ALPW	7.6 ± 0.20	0.018 ± 0.0047	2.8 ± 2.6	0.71
ASS2	7.2 ± 0.33	0.026 ± 0.0077	2.5 ± 1.8	0.99
ASW	6.5 ± 0.31	0.026 ± 0.0068	2.7 ± 1.3	0.79
B438	6.4 ± 0.21	0.019 ± 0.0052	1.9 ± 1.4	0.64
CDB	7.2 ± 0.21	0.021 ± 0.0060	<0.34	0.85
GRNE	6.7 ± 0.24	0.022 ± 0.0063	<0.84	0.7
WPDC	9.2 ± 0.20	0.022 ± 0.0050	2.8 ± 2.4	0.98
Mean	**7.01**	**0.02**	**2.23**[b]	**0.78**
Std dev	**0.93**	**0.003**	**0.59**[c]	**0.14**

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] See Fig. 9-2 for sampling locations.

[b] Median value; see Quality Assurance chapter.

[c] Median absolute deviation (MAD); see Quality Assurance chapter.

[d] Thorium-232 activities in Bq/dry g can be determined by dividing the weight in µg/g by 247.3 and pCi/dry g can be determined by dividing by 9.15.

[e] Uranium-235 activities in Bq/dry g can be determined by dividing the weight in µg/g by 12.5 and pCi/dry g can be determined by dividing by 0.463.

[f] Uranium-238 activities in Bq/dry g can be determined by dividing the weight in µg/g by 80.3 and pCi/dry g can be determined by dividing by 2.97.

Table 9-3. Radionuclides and beryllium in soil sampled at depths from 0 to 50 mm, Site 300, 1993.

	^{239}Pu	^{137}Cs	^{40}K	^{232}Th[d]	^{235}U[e]	^{238}U[f]	Be
Location[a]	**(10^{-3} Bq/dry g)**		**(Bq/dry g)**		**(µg/dry g)**		**(mg/kg)**
801E	0.036 ± 0.0058	1.3 ± 0.25	0.429 ± 0.0137	9.0 ± 0.25	0.022 ± 0.0058	2.9 ± 2.1	1.0
801N	0.084 ± 0.0066	3.7 ± 0.20	0.488 ± 0.0166	11 ± 0.47	0.032 ± 0.0087	5.8 ± 1.6	0.76
801W	0.073 ± 0.0061	2.5 ± 0.23	0.507 ± 0.0182	8.8 ± 0.35	0.032 ± 0.0069	5.6 ± 2.4	0.82
812N	0.019 ± 0.0028	0.5 ± 0.18	0.477 ± 0.0143	5.6 ± 0.16	0.029 ± 0.0068	7.1 ± 2.4	0.63
834W	0.17 ± 0.010	6.6 ± 0.28	0.511 ± 0.0112	11 ± 0.27	0.022 ± 0.0056	2.7 ± 2.6	2.4
851N	0.092 ± 0.0068	3.5 ± 0.29	0.503 ± 0.0131	14 ± 0.38	0.031 ± 0.0057	4.0 ± 2.1	2.1
856N	0.051 ± 0.0048	1.8 ± 0.32	0.403 ± 0.0161	10 ± 0.31	0.023 ± 0.0065	2.9 ± 2.4	2.1
858S	0.011 ± 0.0021	0.4 ± 0.24	0.673 ± 0.0215	11 ± 0.43	0.031 ± 0.0077	3.0 ± 1.8	1.4
DSW	0.16 ± 0.0099	6.9 ± 0.33	0.477 ± 0.0134	9.2 ± 0.26	0.041 ± 0.0067	7.3 ± 3.6	1.4
EOBS	0.027 ± 0.0036	1.1 ± 0.22	0.592 ± 0.0201	9.4 ± 0.41	0.027 ± 0.0080	2.0 ± 1.6	1.5
EVAP	0.099 ± 0.0070	4.0 ± 0.23	0.400 ± 0.0168	9.2 ± 0.29	0.030 ± 0.0073	5.0 ± 1.9	1.3
GOLF	0.20 ± 0.011	8.8 ± 0.41	0.544 ± 0.0163	8.9 ± 0.30	0.028 ± 0.0081	< 1.5	1.1
NPS	0.11 ± 0.0080	5.0 ± 0.28	0.622 ± 0.0174	7.2 ± 0.35	0.022 ± 0.0052	3.4 ± 2.7	1.0
WOBS	0.22 ± 0.015	8.7 ± 0.37	0.463 ± 0.0130	7.7 ± 0.20	0.020 ± 0.0054	< 1.8	1.5
Mean	**0.097**	**3.9**	**0.506**	**9.4**	**0.028**	**3.2**[b]	**1.4**
Std dev	**0.068**	**2.9**	**0.079**	**1.9**	**0.006**	**—**[c]	**0.54**
	(10^{-3} pCi/dry g)		**(pCi/dry g)**				
Mean	**2.6**	**106.1**	**13.7**				
Std dev	**1.8**	**78.4**	**2.1**				

Note: Radionuclide results are reported ±2σ; see Quality Assurance chapter.

[a] See Fig. 9-3 for sampling locations.

[b] Median value; see Quality Assurance chapter.

[c] No measure of dispersion calculated; see Quality Assurance chapter.

[d] Thorium-232 activities in Bq/dry g can be determined by dividing the weight in µg/g by 247.3 and pCi/dry g can be determined by dividing by 9.15.

[e] Uranium-235 activities in Bq/dry g can be determined by dividing the weight in µg/g by 12.5 and pCi/dry g can be determined by dividing by 0.463.

[f] Uranium-238 activities in Bq/dry g can be determined by dividing the weight in µg/g by 80.3 and pCi/dry g can be determined by dividing by 2.97.

Table 9-4. Plutonium results for southeast quadrant (10^{-3} Bq/dry g).

	U.S. EPA 1993 data[c]		1991	1974
Location [a]	**0.01-m deep**	**0.05-m deep**	**0.05-m deep**	**0.01-m deep**
7	0.52	0.37	0.16	—[b]
27	1.9	1.7	14	—[b]
39	0.15	0.81	0.11	—[b]
63	11	13	11	—[b]
64	130	430	28	—[b]
65	7.8	9.1	110	—[b]
65A	1.2	1.1	—[b]	—[b]
65B	11	9.4	—[b]	—[b]
69	4.5	1.6	18	—[b]
78	53	40	1.0	—[b]
88	0.70	1.1	1.3	—[b]
90	4.9	2.6	20	—[b]
92	1.2	0.89	0.81	—[b]
114	22	24	33	—[b]
153	2.2	12	64	—[b]
154	2.3	15	51	—[b]
158	0.37	0.48	1.0	—[b]
170	3.4	36	50	—[b]
188	3.2	6.8	29	—[b]
201	3.1	5.4	—[b]	—[b]
202	18	13	—[b]	—[b]
203	0.15	1.1	—[b]	—[b]
204	0.70	0.11	—[b]	—[b]
205	12	9.1	—[b]	—[b]
206	0.15	0.037	—[b]	—[b]
355	—[b]	—[b]	—[b]	340
356	—[b]	—[b]	—[b]	190
358	—[b]	—[b]	—[b]	6.7
359	—[b]	—[b]	—[b]	6.3
467	—[b]	—[b]	—[b]	14
468	—[b]	—[b]	—[b]	44

Note: Proposed EPA screening limit is 500×10^{-3} Bq/g (0.51 Bq/g).

[a] See Fig. 9-6 for sampling locations.

[b] Samples not taken at this location for this study.

[c] Data from *Draft Final Confirmatory Study of Plutonium in Soil from the Southeast Quadrant of the Lawrence Livermore National Laboratory* (U.S. Environmental Protection Agency 1994).

10. Vegetation and Foodstuff Monitoring

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Kris A. Surano

Introduction

Because vegetation can be a biological end point for pollutants originally released to the soil, to the air, or through liquid effluents, 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 ingesting the products from animals that have consumed it. DOE guidance states that "periodic sampling and analysis of indicator materials, such as soil or 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 Site300 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 items. During 1993, LLNL collected and analyzed samples of vegetation, milk, honey, and wine. Using the monitoring data and dose models presented in AppendixB, potential human doses from all of these substances are calculated.

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 has the propensity to move into the environment as tritiated water, and as such 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

Vegetation

LLNL surveillance vegetation samples, usually annual grasses, are collected quarterly from fixed locations in the Livermore Valley, San Joaquin Valley, San Ramon Valley, and Site 300 and then analyzed for tritium. Sampling locations in 1993 were the same as those sampled during 1992 and 1991; location maps are provided in **Figures 10-1** and **10-2**. These locations were originally selected so samples would represent vegetation (1)near LLNL with the potential for being affected by LLNL operations, (2)from background locations where vegetation was similar to that growing near LLNL, but was unlikely to be affected by LLNL operations, and (3) from areas of known or suspected LLNL-induced contamination.

10. Vegetation and Foodstuff Monitoring

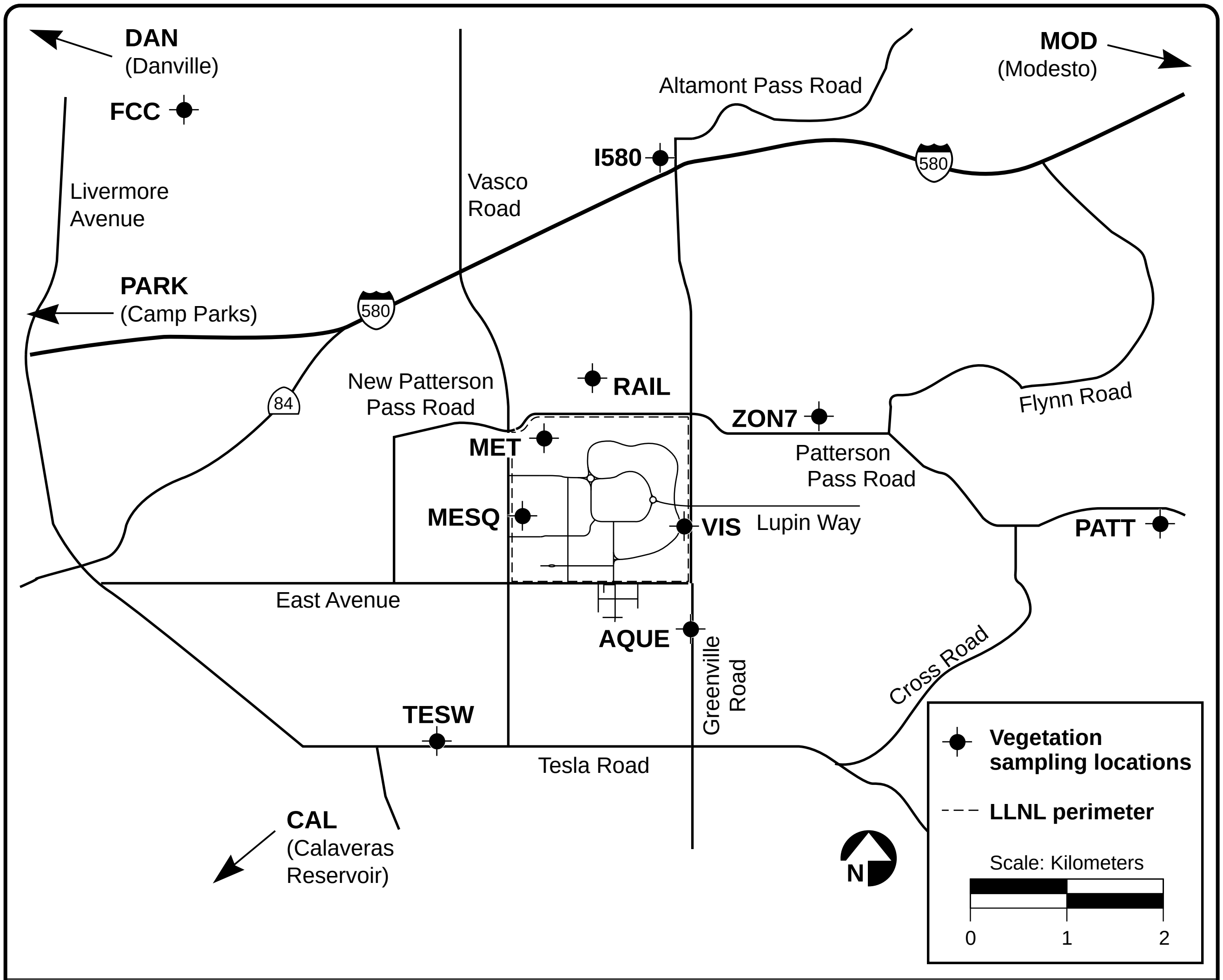

Figure 10-1. Livermore Valley vegetation sampling locations, 1993.

All vegetation sampling is conducted according to written and approved standardized procedures (Gallegos et al. 1992b). For all vegetation samples, frequently tilled or disturbed areas and locations near buildings or other obstructions are avoided. The selected areas are unshaded and exhibit native vegetation for much of the year. Areas with unusual wind or precipitation/irrigation influences also are avoided. Practical considerations also temper the location selections. These include access during inclement weather, personnel safety in vehicle operation, vehicle parking, or sample collection requirements.

The routine vegetation sampling locations are designated with permanent location markers. Consistent use of the same general sampling locations allows for more meaningful trending of data and closer monitoring of areas of concern. For example, at Site 300, vegetation from areas where tritium is known to be present in the subsurface soil is examined each year.

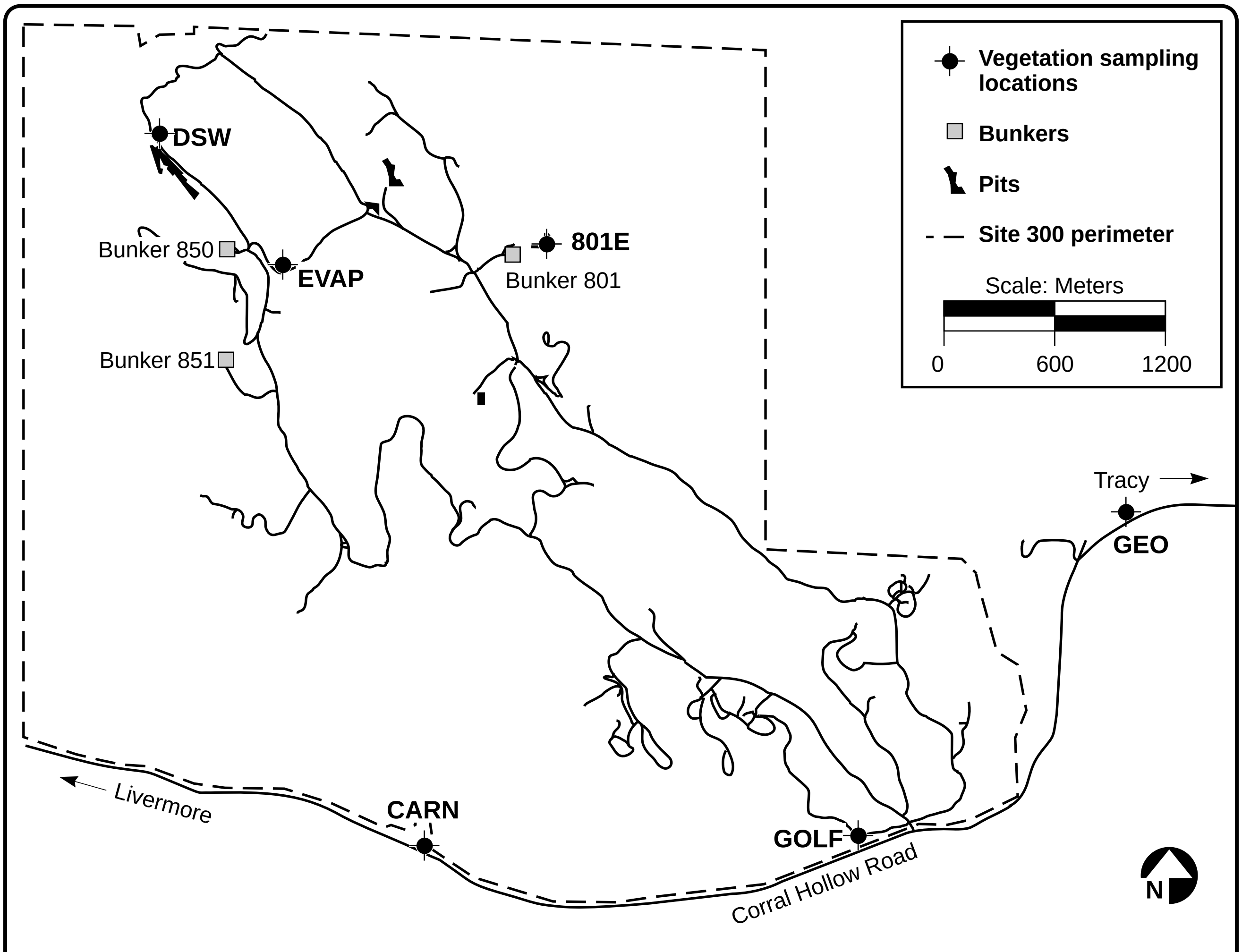

Figure 10-2. Site 300 vegetation sampling locations, 1993.

In 1993, vegetation samples usually consisted of the green leaves and green stems of annual grasses. Other herbaceous vegetation or even perennial vegetation was sampled if grasses were not available. Approximately 0.5 to 1 kilogram of vegetation was collected for analysis. Standard chain-of-custody procedures were followed (Gallegos et al. 1992b).

Samples are delivered on the day of collection to LLNL's Radiation Analytical Sciences laboratory and are kept frozen prior to processing. Water from the vegetation is collected using freeze-drying techniques (lyophilization) and the tritium content of the water is determined by liquid-scintillation counting.

Approximately 10% of the sites are sampled in duplicate to comply with quality assurance protocols (Garcia and Failor 1993). Duplicate samples are preserved, stored, processed, and analyzed with methods identical to those employed for all other samples.

Milk

Milk is widely consumed by all age groups and is one of the foods most frequently contributing radiation dose to people when dairy animals are pastured near a nuclear site (U.S. Department of Energy 1991). DOE guidance on milk sampling states that the number of sampling locations depends on the number of milk production facilities, but should include at a minimum one background location and one potentially affected location. Milk sampling locations around LLNL are limited by the lack of dairy animals kept near LLNL. As the Livermore Valley has become more suburban, there are fewer local milk producers. Since 1976, LLNL has been sampling milk from dairy goats, the only source of local milk production. By the end of 1993, there was only one local farm where goats are raised and those goats are not kept to produce milk. (Due to lack of goat milk production, goat milk will not be collected in 1994.) Nonetheless, LLNL obtained goat milk samples from the producers in the Livermore Valley for part or all of 1993 (from potentially affected locations, all within 5 kilometers of LLNL) and from producers in the Central Valley of California (to represent background locations for comparative purposes). Milk samples generally were collected where the goats were being raised (**Figure 10-3**). However, one set of samples was purchased from a grocery store, and another was purchased at a goat milk plant in the Central Valley.

Milk samples were collected monthly except during the months of December and January, when the goat milk production was limited or nonexistent. All of the milk samples were obtained in precooled, one-gallon sample containers provided by LLNL and were kept refrigerated until analyzed.

The samples generally were delivered on the day of collection to LLNL's Radiation Analytical Sciences laboratory. If not delivered on the same day, samples were kept secure and refrigerated until they could be delivered. Chain-of-custody procedures were followed throughout the delivery and analytical process.

The laboratory analyzed the samples for tritium and gamma-emitting isotopes (todetermine background milk doses from fallout and naturally occurring radionuclides). A one-liter aliquot of each milk sample was preserved with formalin at the laboratory and was analyzed, in a Marinelli beaker with a Ge (Li) detector, for gamma-emitting isotopes. The remainder of each sample was freeze-dried (lyophilization) and the resultant water was analyzed for tritium by liquid-scintillation counting. At least one milk location was sampled in duplicate each month to comply with quality assurance protocols (Garcia and Failor 1993).

Honey

Honey is another local agricultural product that potentially could be affected by LLNL operations. Bees collecting pollen from contaminated vegetation may pass the contamination along in their honey. Human ingestion of contaminated honey can be a pathway contributing to total radiation dose. As was the case for milk, the honey sampling network design was limited by the number of the honey producers in the sampling area. During 1993, LLNL obtained two honey samples with a variety of flower sources from beekeepers in the Livermore Valley and four samples from background locations.

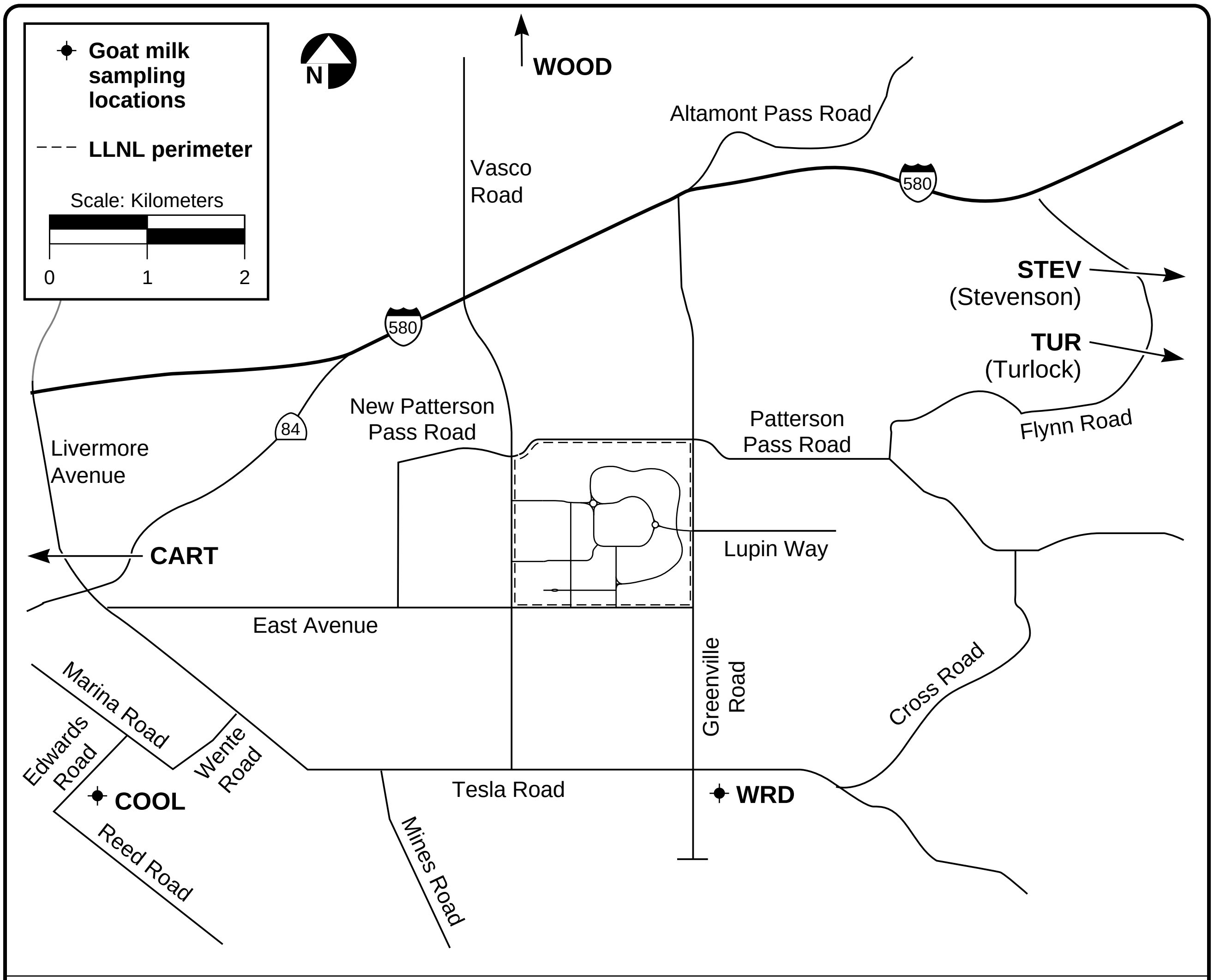

Figure 10-3. Goat and cow milk sampling locations, 1993.

Honey samples were collected during September and October. LLNL sampling technicians contacted the sample providers in advance to ensure that the honey collected was from 1993 and was from the desired general location. Each sample consisted of 0.5 to 1.5kilograms of honey. Because of the few sources of honey, the generally small tritium activities, and the low average levels of honey consumption (0.54 kilograms per year, USDA 1990), honey sampling will not be continued in 1994.

Chain-of-custody procedures were followed when delivering samples to the LLNL Nuclear Chemistry Noble Gas Mass Spectrometry Laboratory for analysis for tritium using ^{3}He mass spectrometry (Surano et al. 1991). Honey sample submittals complied with quality assurance protocols (Garcia and Failor 1993).

Wine

Wine is the most important agricultural product in the Livermore Valley, representing an approximately $30-million annual industry. Data since monitoring began have indicated that although tritium concentrations in all wines are low, Livermore Valley wines contain statistically more tritium than do their California counterparts.

Wine samples of three types 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 intoeight and thirteen wine-producing regions, respectively, and were used as comparative samples.

The wine samples were purchased from local retailers in a variety of vintages and thus reflect the body of wines locally available to the general public during 1993. The resulting analytical data can be used to estimate the potential tritium dose received by consumers during the year of purchase. The 1993 sampling data cannot, however, be used to indicate how the year’s operations at LLNL affected wines produced in 1993. 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 can be decay-corrected to its 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.

Wine samples were purchased in 750-milliliter to 1-liter bottles. One wine from six of the eight non-Livermore, California, wine growing regions and one wine from four of the thirteen European wine growing regions was purchased and submitted for tritium analyses. The selection of samples from all the wines available within a geographic area was random. Any estate wine from a designated area was considered representative of that area. The most recent vintages available were collected, with an equal mix of red and white wines. Approximately 10% of the total complement of wines were sampled in duplicate to comply with quality assurance protocols. Because of the importance of the wine sampling network, LLNL sampled and analyzed as many of the available Livermore Valley wines as possible. Twelve Livermore Valley estate wines not previously sampled were purchased and analyzed.

The wine samples were submitted for analysis unopened, to avoid airborne tritium contamination. Chain-of-custody procedures were followed when delivering samples and throughout the analytical process. Wines were analyzed for tritium using ^{3}He mass spectrometry in the LLNL Nuclear Chemistry Noble Gas Mass Spectrometry Laboratory (Surano et al. 1991). We used this highly sensitive method for our wine analysis so that we could determine differences in the tritium content of the samples. Had less sensitive methods been used, such as those employed by commercial analytical laboratories, the tritium content of all samples would be near or below detection limits and no differences would be apparent.

Results

Livermore

Vegetation. **Table 10-1** shows 1993 tritium data for vegetation collected in the Livermore-site vegetation monitoring program. In general, the tritium activities in vegetation were lower than found in previous years.

The vegetation locations were grouped into three groups for statistical evaluation. The first group, "Near," included locations at or within 1 kilometer of the Livermore-site perimeter (AQUE, RAIL, MESQ, MET, and VIS). The "Intermediate" group consisted of locations in the Livermore Valley, removed from the site (1 to 5kilometers 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. The third group, "Background," represented locations unlikely to be affected by LLNL operations. Three of the background locations (MOD, DAN, CAL) are more than 25 kilometers away; the other two (FCC, PARK) are in the Livermore Valley, but are greater than 5 kilometers from the Livermore site and are generally upwind so they are unlikely to be affected by LLNL operations. The tritium levels in the water of the vegetation from the "Near" and "Intermediate" groups were about three-fourths of those reported for 1992; background group concentrations remained essentially unchanged from 1991 and 1992.

Because the data for tritium in vegetation were lognormally distributed, the means of the logarithms were compared, using the Tukey-Kramer HSD (honestly significant difference) 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 10-4** 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 the Livermore site and historically have had higher values than other locations. The annual average for these locations are very close to the values for 1992 and are lower than values for previous years.

Wine. The results from the 1993 wine tritium analyses are shown in **Table10 -2**. The sample numbers shown in the table were assigned randomly to wine samples from each region and are not related to sample numbers used in previous years. 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 1993 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

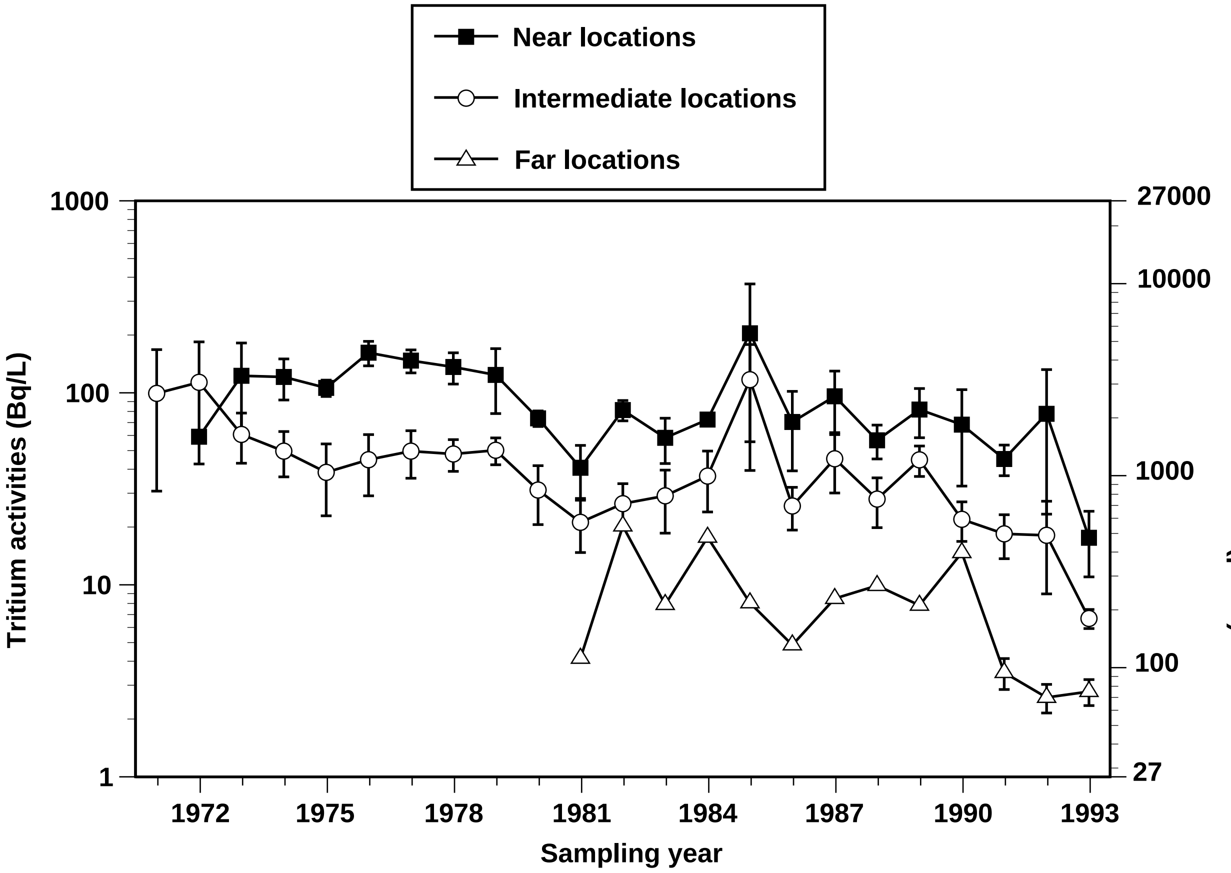

Figure 10-4. Mean tritium activities in Livermore Valley vegetation samples, 1971 to 1993 (error bars are ±1 standard error).

California (other than Livermore) wines and European wines sampled. The statistical analyses also indicated that there was no significant difference between the means of European and California wines sampled. Multiple comparison tests indicated that the mean levels of the 1993 sampling year data from all areas were not statistically different from those reported for the 1992 sampling year. **Figure10-5** , which shows the results of the wine analyses by sampling year since monitoring began, also shows that 1993 tritium concentrations are among the lowest for all Livermore wines since monitoring began.

Regression analyses and ANOVA of the wine data (when decay-corrected) grouped by vintage year showed tritium concentrations have statistically decreased for all areas since monitoring began, and since 1980.

Livermore wines, examined by vintage year, had statistically greater tritium concentrations since 1980 than both European and California wines. This is particularly apparent since 1986 (**Figure 10-6**). However, while vintage wines

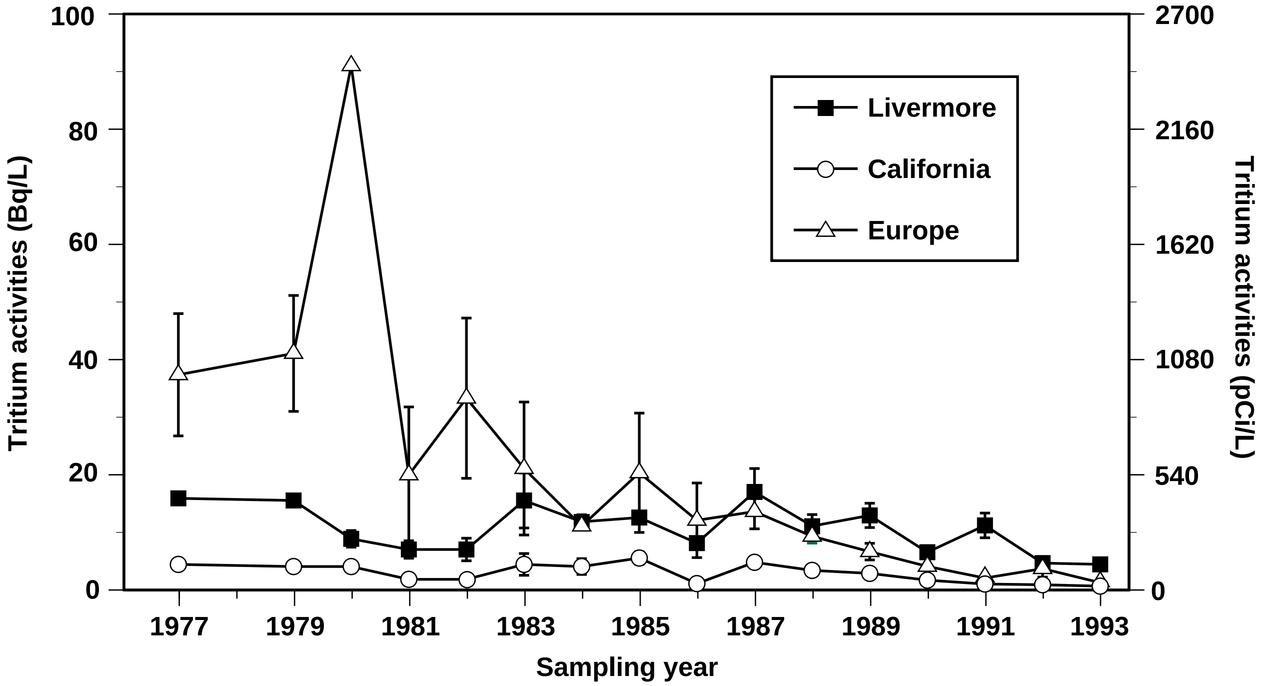

Figure 10-5. Mean tritium in retail wines, 1977 to 1993, plotted by sampling year (error bars are ± 1 standard error).

from Europe exhibited statistically higher tritium concentrations than vintage wines from California from 1980 to 1985, data from more recent vintage years are not statistically different. This indicates that the three distinct data sets discussed in previous annual reports no longer exist; Livermore wines, when decay-corrected and grouped by vintage year, contain higher tritium concentrations than either European or California wines similarly grouped, while European and California wines contain statistically identical concentrations.

Honey. **Table 10-3** shows tritium data for honey collected from producers in the Livermore Valley and from other producers in California during 1993. The mean tritium concentration of Livermore Valley honey is more than ten times that of honey from other areas of California. The difference, although large, is not statistically significant, as determined by the Wilcoxon rank sums test or the Van der Waerden test (normal quartiles), because of the small number of samples available. In any case, the dose from tritium for either California or Livermore honey is extremely low.

Analysis using the Tukey-Kramer HSD test indicated that tritium concentrations in Livermore Valley honey have not changed significantly during the past six years. **Figure 10-7** shows the mean values for Livermore Valley

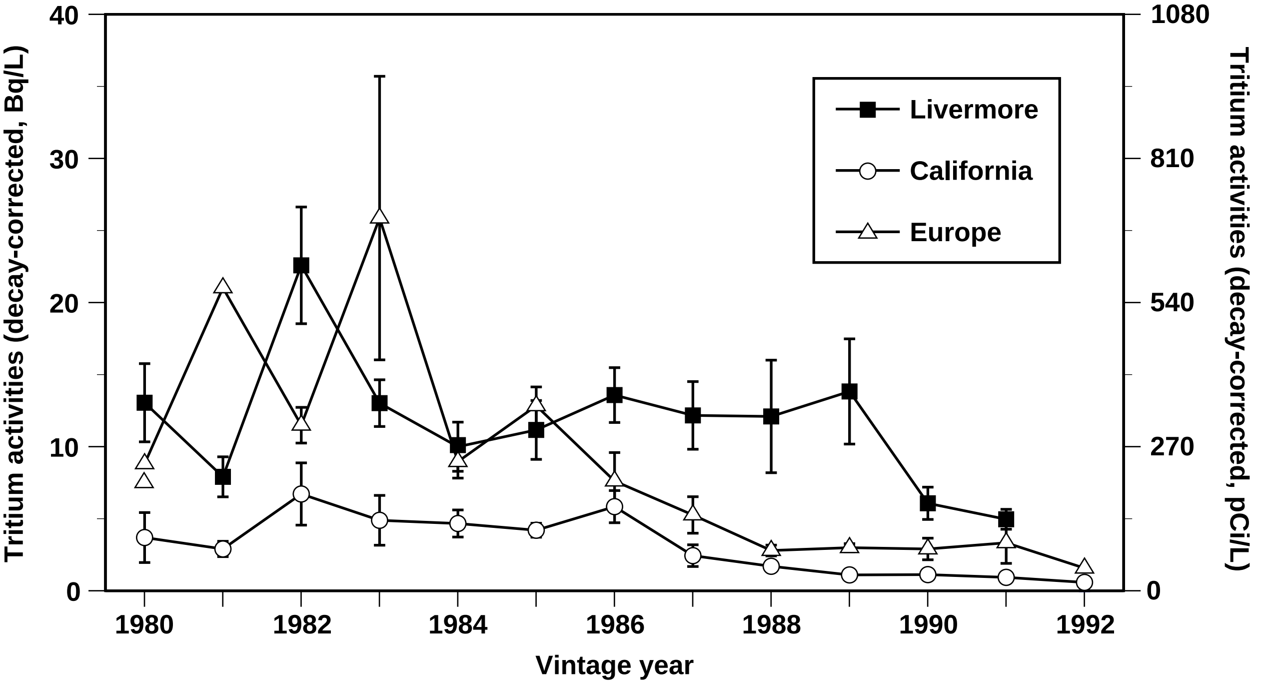

Figure 10-6. Mean tritium in retail wines, 1980 to 1992, decay-corrected and plotted by vintage year (error bars are ±1 standard error). No 1992 Livermore wines have as yet been analyzed.

honey collected from 1979 through 1993, and other California honey collected from 1980 through 1993. The graph shows that the tritium content of honey fluctuates from year to year, and although the mean Livermore Valley concentration is usually somewhat higher than that of other California honey, the differences are rarely statistically significant.

Goat Milk. The activities of tritium, ^{40}K (potassium-40, a naturally occurring radionuclide), and ^{137}Cs (cesium-137, a fallout product) in goat milk samples collected during 1993 are shown in **Tables 10-4** through **10-6**. No other radionuclides were present at detectable levels; ^{137}Cs and ^{40}K were detected at background levels.

Analysis using the Tukey-Kramer HSD test showed that tritium values for Livermore Valley goat milk is not significantly different (at 95% confidence) from the background concentrations. Dose calculations in **Table 10-4** are based on a goat milk intake of 310 liters per year, tritium dose factors provided by DOE (U.S. Department of Energy 1988), and on models described in Appendix B. Because ^{40}K and ^{137}Cs are not the result of operations at LLNL and because values from all goat milk samples were similar, individual doses from ^{40}K and ^{137}Cs were not calculated for each sampling location.

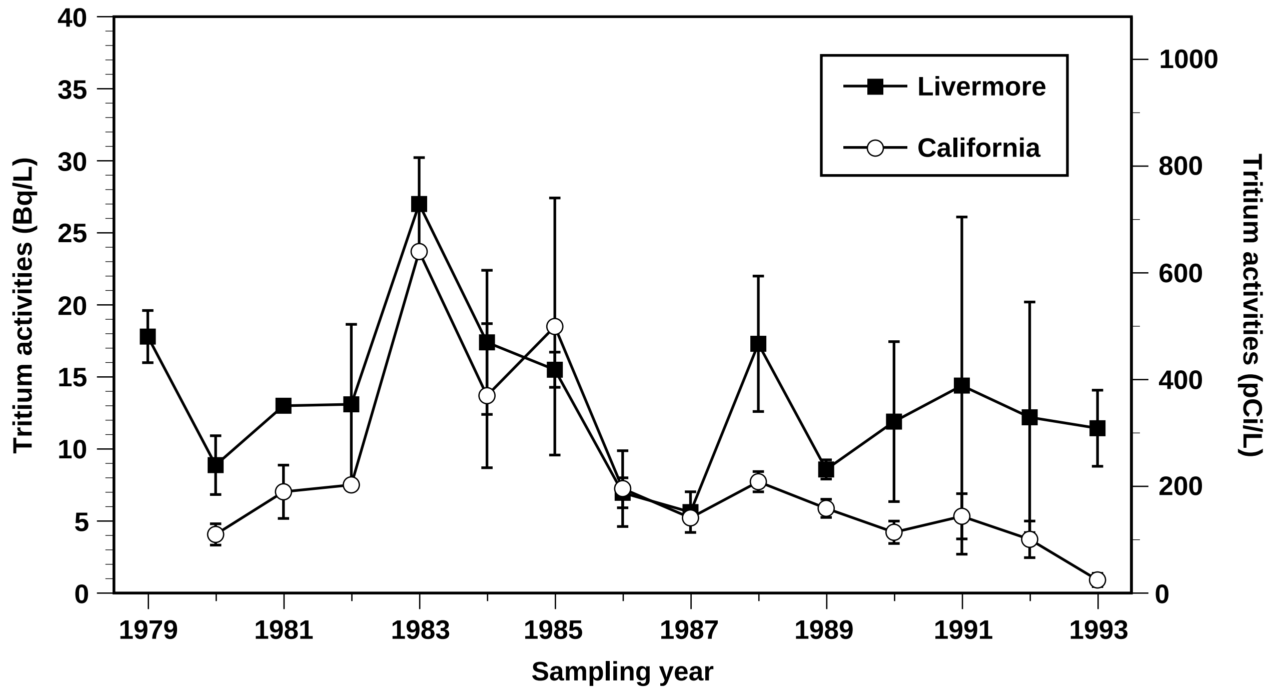

Figure 10-7. Mean tritium activities in honey, 1979 to 1993 (error bars are ±1 standard error).

Site 300

Vegetation. **Table 10-7** shows tritium data for vegetation collected at Site 300 during 1993. Historic values for tritium at Site300 sampling locations are shown in **Figure10 -8**. With the exception of a single location, most values are at or near detection limits and are similar to those reported from 1988 through 1992. Tritium activities in vegetation from an area previously of concern, EVAP, were not significantly elevated during 1993; the LLNL activities releasing tritium in this area were discontinued in 1991. As was the case in 1992, vegetation samples from location DSW contained the highest tritium values detected. As determined by the Tukey-Kramer HSD test on the logarithms of the data, location DSW exhibited tritium levels that were significantly greater than the other locations.

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 (tritium is no longer used at Site300). 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 (see, e.g.,

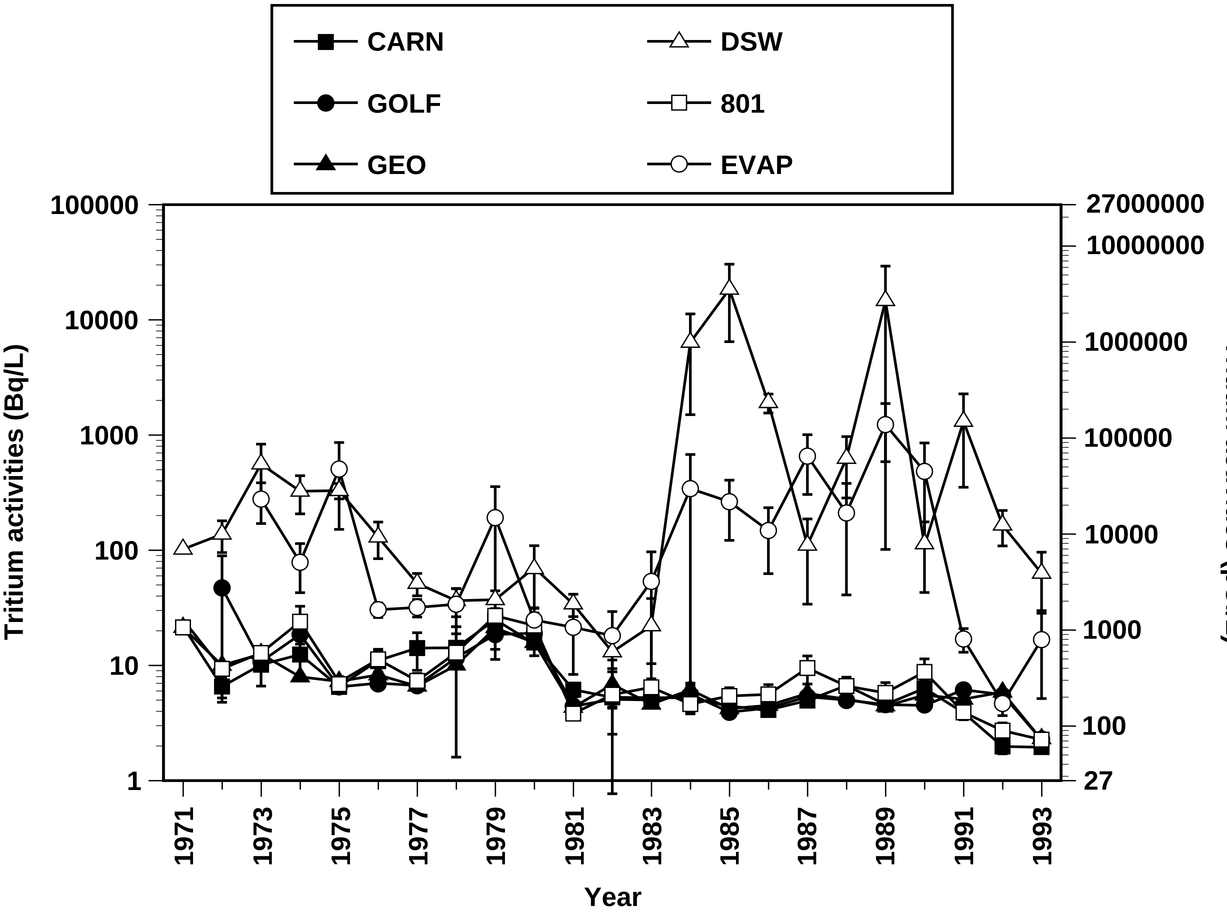

Figure 10-8. Mean tritium activities in vegetation at Site 300 sampling locations, 1971 to 1993 (error bars are ±1 standard error).

Lamarre 1989a–c; Taffet etal. 1989a, b; Taffet et al. 1991; Carlsen 1991a, b; and Webster-Scholten 1994). Purge water from the sampling of ground water monitoring wells at this location was recently discovered to have been released to the ground. This practice will be 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 effective dose equivalents shown in **Table 10-7** were derived using dose conversion factors provided by DOE (U.S. Department of Energy 1988) and a dose pathway model from NRC Regulatory Guide 1.109 (U.S. Nuclear Regulatory Commission 1977). Appendix B provides a detailed discussion of dose alculation methods.

Environmental Impact

Livermore Site

LLNL impacts on vegetation in the Livermore Valley remain minimal in 1993. Tritium levels were generally reduced from those observed in previous years and are probably the result of reduced tritium emissions from both LLNL and SNL/CA. The effective dose equivalents shown in **Table 10-1** 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). The dose from tritium in vegetation is based on the highly conservative assumptions that an adult's diet includes vegetables with the highest observed mean tritium concentration, and meat and milk derived from livestock fed on grasses with thesame concentration. These assumptions are conservative because most vegetables consumed directly by an adult will not contain tritium at the levels reported, nor will the livestock actually consume vegetation with the reported levels of tritium. Based on these conservative assumptions, the maximum potential dose for 1993 is 0.18 µSv (0.018mrem).

There are no health standards for radionuclides in wine. However, all the wine tritium levels were far below drinking water standards. In fact, even the highest detected Livermore Valley value (8.25 u/L [223 pCi/L]) represents only 1.1% of the California drinking water standard (740 Bq/L [20,000 pCi/L]). Doses from wine consumption can be calculated according to methods for water ingestion, which are detailed in Appendix B.

The corresponding annual dose of the highest detected Livermore Valley tritium value in wine (8.25 Bq/L [223 pCi/L]) is 0.00010mSv (0.010 mrem), based on the very conservative assumption that wine is consumed in the same quantities as water (730 liters per year or 2liters per day). Using a more realistic wine consumption factor (52liters per year or 1 liter per 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 0.0039 µSv (0.00039 mrem), from European wine would be 0.0011 µSv (0.00011 mrem), and from California wine would be 0.0008 µSv (0.00008 mrem). Compared with an annual background dose of approximately 3000 µSv (300mrem), which includes radon, and a 0.1-mSv (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.

The tritium concentrations in goat milk produced in the Livermore Valley were statistically the same as those of goat milk from other areas of California. Associated doses, like those for wine, were negligible. Doses were calculated based on the assumption that goat milk is consumed at the same rate as cow milk, i.e., 310 liters per year. The radiological dose from goat milk would be almost entirely from naturally occurring ^{40}K, which is the major ingestion pathway contributor to natural background dose. The annual ^{40}K dose for 1993 from goat milk consumption was estimated to be 0.1 mSv (10 mrem). In comparison, the maximum dose resulting from tritium (see **Table 10-4**) that could have been received from ingestion of Livermore Valley goat milk during 1993 was <0.0094 µSv (<0.00094 mrem). The same calculations indicate that the maximum dose resulting from tritium that could have been received from ingestion of other California goat milk during 1993 was <0.0099 µSv (<0.00099mrem). The highest dose estimated from ^{137}Cs, which is a fallout radionuclide, is as small as the dose from tritium; for 1993, it was 0.0034 µSv (0.00034 mrem) for a ^{137}Cs activity of 0.0187 Bq/L (0.50 pCi/L). Other radionuclides in goat milk could not be detected, or were present at background concentrations.

Honey produced in the Livermore Valley contained tritium in higher activities than honey produced in other areas of California, but the activities have not changed significantly over the past five years. There are no health or environmental standards for radionuclides in honey. At average honey consumption rates of 0.54kg/y, the dose from tritium for Livermore honey is7.8 $\times$ 10^{-5} µSv/y (7.8 $\times$ 10^{-6} mrem/y). The tritium values observed in the Livermore Valley would not be of health concern even if the honey were consumed in the same quantities as sugar generally used in the home, i.e., about 15 kilograms per year for each person (USDA 1990). At this consumption rate, the highest tritium concentration detected in Livermore Valley honey represents a dose for 1993 of 0.003 µSv (0.0003 mrem). Consequently, the environmental impact is considered minimal.

Site 300

In general, LLNL impacts on vegetation at Site 300 for 1993 were insignificant. With the exception of vegetation from the one known site of contamination, tritium levels found in the Site 300 vegetation were comparable to those observed in previous years: they were low, near the limits of detection. The areas where tritium is known to be present in the subsurface soil are well delineated and are very localized.

The calculated potential annual dose from vegetation at Location DSW, basedon the measured mean value of 63.1 Bq/L (1705 pCi/L), is 0.30 µSv (0.030mrem). This calculation uses conservative pathway modeling assump tions, in which an adult's diet is assumed to include vegetables with the highest observed mean tritium concentration, as well as meat and milk that come from livestock fed on grasses with the same high concentration. In actuality, this dose never would be received because vegetation at Site 300 is consumed neither by people nor by grazing livestock. In comparison, the calculated potential annual dose from vegetation at GEO, the off-site location that had a measured mean value of 2.26 Bq/L (61.0 pCi/L), is <0.011 μSv (<0.0011 mrem). Tritium levels in vegetation at Site 300 will continue to be monitored.

Table 10-1. Tritium in vegetation, 1993.

	Sampling location[a]						
Tritium (Bq/L)	**AQUE**	**VIS**	**RAIL**	**MET**	**MESQ**	**PATT**	**ZON7**
First Quarter	17.3 ± 2.56	5.88 ± 2.25	13.8 ± 2.44	5.29 ± 2.17	—[b]	<2.04	6.55 ± 2.21
Second Quarter	21.5 ± 2.24	19.8 ± 2.20	8.29 ± 1.84	8.95 ± 1.86	8.95 ± 1.86	<1.61	6.36 ± 2.45
Third Quarter	22.1 ± 2.43	48.1 ± 3.03	6.70 ± 1.99	6.07 ± 1.96	3.36 ± 1.70	2.42 ± 1.84	20.1 ± 2.25
Fourth Quarter	86.6 ± 3.90	46.3 ± 3.15	5.00 ± 2.17	4.85 ± 2.05	6.51 ± 2.11	15.7 ± 2.38	5.40 ± 2.06
Mean	**36.9**	**30.0**	**8.45**	**6.29**	**6.28**	**<2.23[c]**	**9.61**
Std dev	**33.2**	**20.6**	**3.82**	**1.85**	**2.80**	**—[d]**	**7.03**
Dose (µSv/y)[e]	**0.18**	**0.14**	**0.041**	**0.030**	**0.030**	**<0.011**	**0.046**
	pCi/L						
Mean	**997**	**811**	**228**	**170**	**170**	**<60.3[c]**	**260**
Std dev	**897**	**558**	**103**	**50**	**76**	**—[d]**	**190.0**
Dose (mrem/y)[e]	**0.018**	**0.014**	**0.0041**	**0.0030**	**0.0030**	**<0.0011**	**0.0046**

	Sampling location[a]						
Tritium (Bq/L)	**I580**	**TESW**	**FCC**	**DAN**	**PARK**	**MOD**	**CAL**
First Quarter	2.78 ± 2.07	11.8 ± 2.39	<1.97	9.73 ± 2.37	2.21 ± 2.10	10.1 ± 2.40	5.37 ± 2.22
Second Quarter	4.55 ± 1.72	3.15 ± 1.65	1.89 ± 1.60	<1.55	<1.57	<1.54	1.78 ± 1.60
Third Quarter	11.2 ± 2.12	7.33 ± 2.00	<1.80	<1.73	<1.77	<1.81	<1.78
Fourth Quarter	4.44 ± 2.06	<1.91	<1.84	<1.78	<1.74	<1.82	<1.83
Mean	**5.75**	**5.24[c]**	**<1.86[c]**	**<1.75[c]**	**<1.75[c]**	**<1.82[c]**	**<1.80[c]**
Std dev	**3.73**	**—[d]**	**—[d]**	**—[d]**	**—[d]**	**—[d]**	**—[d]**
Dose (µSv/y)[e]	**0.028**	**0.025**	**<0.009**	**<0.008**	**<0.008**	**<0.009**	**<0.009**
	pCi/L						
Mean	**155**	**142[c]**	**50.4[c]**	**47.4[c]**	**47.4[c]**	**49.1[c]**	**48.7[c]**
Std dev	**100.9**	**—[d]**	**—[d]**	**—[d]**	**—[d]**	**—[d]**	**—[d]**
Dose (mrem/y)[e]	**0.0028**	**0.0025**	**<0.0009**	**<0.0008**	**<0.0008**	**<0.0009**	**<0.0009**

Note: Radionuclide results are reported ±2σ, in Bq/L; see Quality Assurance chapter.

[a] See Fig. 10-1 for sampling locations.

[b] No sample obtained.

[c] Median value; see Quality Assurance chapter.

[d] No measure of dispersion calculated; see Quality Assurance chapter.

[e] This dose represents the total effective dose equivalent from the forage-cow-milk pathway; see Appendix B.

Table 10-2. Tritium in retail wine (in Bq/L), 1993.[a]

	Area of production		
Sample	**Livermore Valley**	**California**	**Europe**
1	7.03 ± 1.15	0.59 ± 0.22	0.96 ± 0.26
2	3.52 ± 0.59	0.44 ± 0.22	1.42 ± 0.26
3	6.73 ± 1.11	1.30 ± 0.44	1.42 ± 0.39
4	2.78 ± 0.48	0.30 ± 0.24	—[b]
5	1.33 ± 0.33	0.70 ± 0.22	
6	1.89 ± 0.37	—[b]	
7	4.55 ± 0.78		
8	6.25 ± 0.83		
9	2.81 ± 0.52		
10	8.25 ± 1.30		
11	3.03 ± 0.56		
12	5.20 ± 0.68		
Mean	**4.45**	**0.67**	**1.27**
Std dev	**2.23**	**0.38**	**0.27**
		(pCi/L)	
Mean	**120**	**18**	**34**
Std dev	**60**	**10**	**7**

Note: Radionuclide results are reported ±2σ, in Bq/L; see Quality Assurance chapter.

[a] Wines from a variety of vintages were purchased and analyzed in 1993. The concentrations shown are not decay-corrected to vintage year.

[b] Lost sample; see Quality Assurance chapter.

Table 10-3. Tritium in honey (Bq/L), 1993.

	Sampling locations	
Sample	**California**	**Livermore Valley**
1	0.82 ± 0.05	9.57 ± 1.32
2	1.11 ± 0.03	13.31 ± 2.63
3	1.40 ± 0.14	
4	0.32 ± 0.07	
Mean	**0.91**	**11.44**
Std dev	**0.46**	**2.64**
Dose (μSv/y)	**6.22×10^{-6}**	**7.79×10^{-5}**
	pCi/L	
Mean	**24.7**	**309**
Std dev	**12.5**	**71.4**
Dose (mrem/y)	**6.22×10^{-7}**	**7.79×10^{-6}**

Table 10-4. Tritium in goat milk (in Bq/L), 1993.

	Sampling location [a]					
	WRD	**COOL**	**STEV**	**TUR**	**WOOD**	**CART[b]**
Feb.	1.73 ± 1.49	—[c]	1.95 ± 1.49	<1.47	<1.48	<1.44
Mar.	<1.65	<1.52	<1.60	<1.62	<1.57	<1.54
Apr.	2.97 ± 1.72	<1.58	4.66 ± 1.78	<1.66	<1.61	<1.65
May	<1.47	<1.45	1.87 ± 1.51	2.44 ± 1.53	2.06 ± 1.51	<1.46
June	2.12 ± 1.73	<1.68	2.24 ± 1.74	<1.69	<1.68	<1.63
July	<1.69	2.32 ± 1.78	<1.76	1.98 ± 1.78	<1.75	2.92 ± 1.81
Aug.	<2.34	<1.64	2.12 ± 1.71	2.19 ± 1.72	1.76 ± 1.70	<1.65
Sept.	<1.68	—[d]	<1.72	<1.70	<1.67	<1.67
Oct.	<1.83	—[d]	<1.88	<1.81	<1.85	<1.84
Nov.	2.49 ± 1.85	—[d]	<1.81	<1.82	<1.79	2.45 ± 1.85
Median[e]	**<1.78**	**<1.61**	**<1.88**	**<1.75**	**<1.71**	**<1.65**
Dose (μSv/y)[f]	**<0.0094**	**<0.0085**	**<0.0099**	**<0.0092**	**<0.0090**	**<0.0087**
	pCi/L					
Median[e]	**<48.1**	**<43.5**	**<50.7**	**<47.4**	**<46.3**	**<44.7**
Dose (mrem/y)[f]	**<0.00094**	**<0.00085**	**<0.00099**	**<0.00092**	**<0.00090**	**<0.00087**

Note: Radionuclide results are report $\pm 2\sigma$, in Bq/L; see Quality Assurance chapter.

[a] See Fig. 10-3 for sampling locations.

[b] Sample from carton purchased in store.

[c] Sample unavailable (goats not producing milk).

[d] Goat milk provider moved goats from Livermore Valley.

[e] No measure of dispersion calculated; see Quality Assurance chapter.

[f] This dose is the effective dose equivalent; see Appendix B.

Table 10-5. Potassium-40 in milk (in Bq/L), 1993.

	Sampling location[a]					
Month	**WRD**	**COOL**	**STEV**	**TUR**	**WOOD**	**CART**
Feb.	—[b]	—[c]	51.0 ± 1.53	61.2 ± 1.83	59.5 ± 1.79	61.8 ± 3.09
Mar.	—[b]	48.4 ± 1.94	65.6 ± 1.97	62.5 ± 1.88	58.1 ± 1.74	62.0 ± 1.86
Apr.	28.5 ± 1.14	72.3 ± 1.45	61.6 ± 1.85	69.8 ± 2.09	63.3 ± 1.90	9.4 ± 0.66[d]
May	66.1 ± 1.98	54.8 ± 1.64	67.2 ± 2.02	66.7 ± 2.00	61.7 ± 1.85	63.2 ± 2.53
June	47.8 ± 1.43	66.5 ± 1.99	66.5 ± 1.99	66.5 ± 2.00	55.8 ± 1.67	65.7 ± 2.63
July	72.6 ± 2.18	59.8 ± 1.79	67.0 ± 2.01	67.2 ± 2.69	64.5 ± 1.29	65.3 ± 1.96
Aug.	63.3 ± 1.90	59.3 ± 1.78	66.3 ± 1.99	65.9 ± 1.32	67.2 ± 2.02	62.1 ± 1.24
Sept.	59.7 ± 1.79	—[e]	61.1 ± 1.83	67.7 ± 2.71	66.5 ± 1.33	61.8 ± 1.85
Oct.	55.4 ± 1.66	—[e]	58.3 ± 1.75	62.5 ± 1.88	62.5 ± 1.87	66.4 ± 1.99
Nov.	59.9 ± 1.80	—[e]	59.6 ± 1.79	60.3 ± 1.21	62.9 ± 1.26	61.1 ± 1.83
Mean	**56.7**	**60.2**	**62.4**	**65.0**	**62.2**	**57.9 (63.3)[f]**
Std dev	**13.5**	**8.4**	**5.2**	**3.2**	**3.6**	**17.1 (2.0)[f]**
			pCi/L			
Mean	**1530**	**1630**	**1690**	**1760**	**1680**	**1560**
Std dev	**366**	**227**	**141**	**86**	**97**	**463**

Note: Radionuclide results are reported ±2σ, in Bq/L; see Quality Assurance chapter.

[a] See Fig. 10-3 for sampling locations.

[b] Insufficient sample for gamma analysis.

[c] Sample unavailable (goats not producing milk).

[d] Outlier based on Rosner outlier test (Gilbert 1987).

[e] Goat milk provider moved goats from Livermore Valley.

[f] Statistics calculated without outlier.

Table 10-6. Cesium-137 in milk (in Bq/L), 1993.

	Sampling location[a]					
	WRD	**COOL**	**STEV**	**TUR**	**WOOD**	**CART**
Feb.	—[b]	—[c]	<0.0045	<0.0057	<0.0070	<0.0061
Mar.	—[b]	<0.0048	<0.0066	<0.0064	<0.012	<0.0057
Apr.	<0.020	<0.0069	<0.012	<0.0070	<0.028	<0.0023
May	<0.0058	<0.0060	<0.0070	<0.0069	<0.0058	<0.0062
June	<0.0082	<0.0063	<0.0052	0.018 ± 0.017	<0.0089	<0.0071
July	<0.0071	<0.0068	<0.0058	<0.0062	<0.0052	<0.0061
Aug.	<0.026	<0.0058	<0.022	<0.034	0.022 ± 0.018	<0.013
Sept.	0.061 ± 0.043	—[d]	<0.020	<0.015	<0.014	<0.020
Oct.	<0.022	—[d]	<0.014	<0.020	<0.023	<0.015
Nov.	<0.017	—[d]	<0.019	0.048 ± 0.034	<0.013	<0.018
Median[e]	**<0.019**	**<0.0061**	**<0.0097**	**<0.011**	**<0.013**	**<0.0066**
	pCi/L					
Median[e]	**<0.50**	**<0.17**	**<0.26**	**<0.30**	**<0.34**	**<0.18**

Note: Radionuclide results are reported ±2σ, in Bq/L; see Quality Assurance chapter.

[a] See Fig. 10-3 for sampling locations.

[b] Insufficient sample for gamma analysis.

[c] Sample unavailable (goats not producing milk).

[d] Goat milk provider moved goats from Livermore Valley.

[e] No measure of dispersion calculated; see Quality Assurance chapter.

Table 10-7. Tritium in vegetation, Site 300, 1993.

	Sampling location[a]					
	CARN	**GOLF**	**GEO**	**DSW**	**801E**	**EVAP**
First Quarter	1.93 ± 1.55	2.15 ± 1.57	2.26 ± 1.57	7.96 ± 1.77	2.36 ± 1.57	10.8 ± 1.86
Second Quarter	1.65 ± 1.62	<1.61	2.25 ± 1.61	122 ± 4.14	1.71 ± 1.62	51.1 ± 2.96
Third Quarter	2.52 ± 1.63	<1.56	2.87 ± 1.65	3.45 ± 1.67	—[b]	<1.58
Fourth Quarter	<1.71	3.74 ± 1.84	<1.71	119 ± 4.29	2.75 ± 1.81	3.61 ± 1.83
Mean	**1.82**[c]	**<1.88**	**2.26**	**63.07**	**2.27**	**7.21**[c]
St dev	**0.54**[d]	**—**[e]	**—**[e]	**66.27**	**0.52**	**—**[e]
Dose (μSv/y)[f]	**<0.009**	**<0.009**	**<0.011**	**0.303**	**0.011**	**<0.035**
	pCi/L					
Mean	**49.2**[c]	**50.8**	**61.0**	**1705**	**61**	**194.8**[c]
Std dev	**14.5**[d]	**—**[e]	**—**[e]	**1791**	**14**	**—**[e]
Dose (mrem/y)[f]	**<0.0009**	**<0.0009**	**<0.0011**	**0.0303**	**0.0011**	**<0.0035**

Note: Radionuclide results are reported ±2σ, in Bq/L; see Quality Assurance chapter.

[a] See Fig. 10-1 for sampling locations.

[b] Recent controlled burn consumed vegetation at this location.

[c] Median value; see Quality Assurance chapter

[d] Median absolute deviation; see Quality Assurance chapter.

[e] No measure of dispersion calculated; see Quality Assurance chapter.

[f] This dose represents the total effective dose equivalent from the forage-cow-milk pathway; see Appendix B.

11. Environmental Radiation Monitoring

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Introduction

Many types of radioisotopes are used at LLNL, including transuranics, biomedical tracers, tritium, and mixed fission products for general research and nuclear weapons research. In accordance with federal regulations, DOE Orders 5400.1 and 5400.5, and Title 17, California Code of Regulations, Section 30250, LLNL conducts direct gamma and neutron radiation monitoring to establish background radiation levels in its vicinity and to determine the environmental radiological impact of its 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. LLNL has measured both gamma and neutron radiation at the Livermore-site perimeter since 1973. A direct environmental radiation monitoring program was implemented at Site 300 in 1988.

Gamma radiation results from natural background sources of geologic/terrestrial or cosmic origin, or from man-made sources, such as fallout from past nuclear weapons testing and any contribution from LLNL operations. Gamma radiation is measured using thermoluminescent dosimeters (TLDs) that provide a measure of the total amount of gamma radiation at a particular location. Neutron radiation is measured with ^{235}U track-etch detectors.

Methods

External doses from gamma radiation are monitored at 16 Livermore-site perimeter locations (**Figure 11-1**), 48 Livermore Valley locations (**Figure 11-2**), 12 Site 300 perimeter locations, and 2 locations in the area surrounding Site 300 (**Figure 11-3**). Off-site TLDs are located in areas surrounding the Livermore site and in nearby residential areas. These are considered background locations and are used for comparison with perimeter measurements. Six locations, also shown in **Figure 11-3**, were added in 1991 in the area near Site 300 as part of a special study.

TLDs contain three components of thallium-activated calcium sulfate ($CaSO_4$) and one component of lithium borate ($Li_2B_4O_7$). Energy is stored when these compounds are exposed to gamma radiation. Impurities in the TLD crystal form low-temperature trapping sites for electrons that have been excited to higher energy states by gamma radiation at normal ambient temperatures. When the TLDs are heated in the analytical laboratory, the electrons return to lower energy states and light (photons) is emitted. The light intensity is proportional to the original absorbed energy and is measured with a photomultiplier tube. After the TLD is read, it is heated again and reread. This second reading should be near zero, indicating that all the stored energy in the traps has been released and measured. This process, called annealing, also verifies that the TLD is again ready for field deployment.

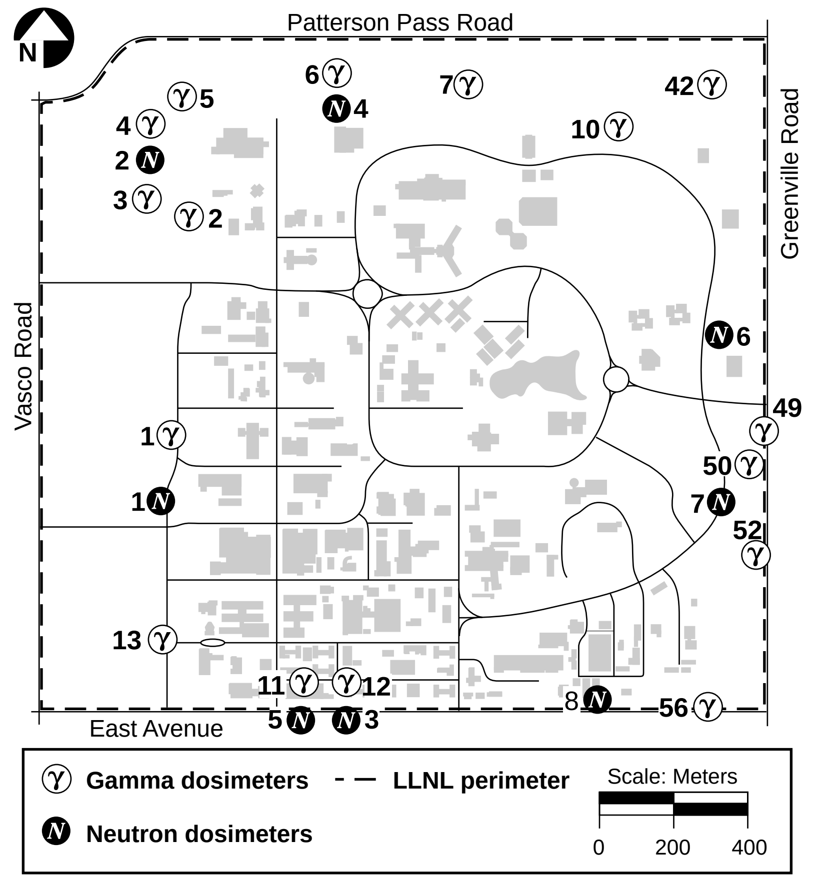

Figure 11-1. Gamma and neutron dosimeter locations, Livermore site, 1993.

Direct gamma radiation exposures are measured in milliroentgens (mR). The measured exposure is converted to dose by calibrating the dosimeters against sources that deliver a known absorbed dose and then applying a quality factor for a beta/gamma radiation field. The resultant dose equivalents, in millisieverts (mSv) or millirem (mrem), are compared to the DOE Order 5400.5 radiation protection standards. The doses at the site boundaries are also compared to background measurements to determine the contribution, if any, from LLNL operations.

To ensure accuracy in TLD measurements, some TLDs are irradiated each quarter to specific exposures for calibration purposes and others are irradiated to specific exposures to serve as quality control accuracy checks. Duplicate TLDs are co-located in the field at several locations each quarter to assess TLD measurement precision.

When a TLD is missing or damaged, its annual dose value is calculated from its mean quarterly dose, as determined from available data, multiplied by four. Data TLDs found on the ground open or damaged are not used to calculate the quarterly or annual totals. These TLDs trap moisture and the readings can yield erroneous data.

Direct gamma radiation doses are measured with reusable TLDs mounted in the field on existing structures (such as fences) at approximately 1meter above ground level. Each TLD is heat-sealed in a 8.9 cm × 5.7 cm, 4.5-mm-thick foil pouch for protection against

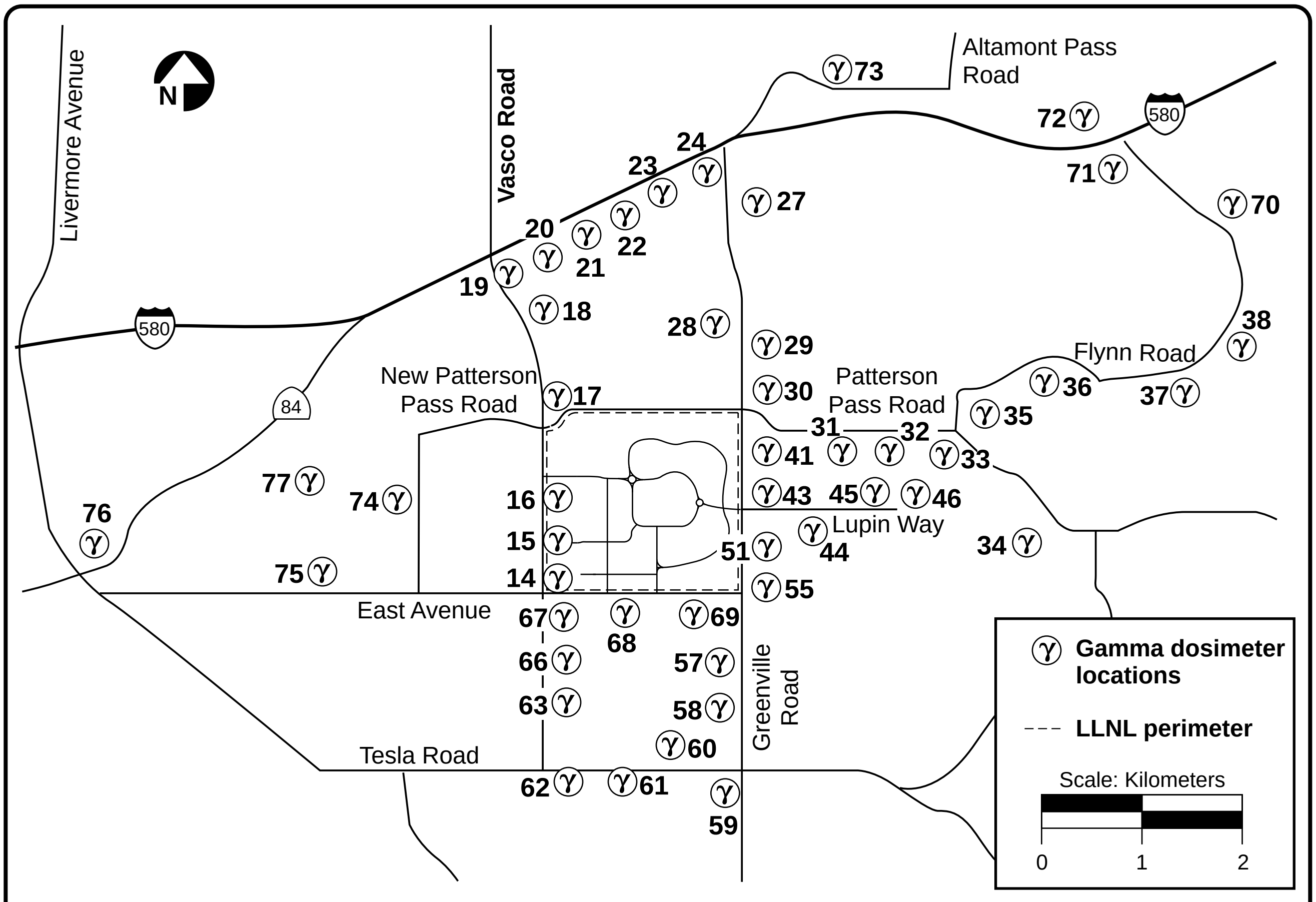

Figure 11-2. Gamma dosimeter locations, Livermore Valley, 1993.

light and moisture. Each quarter, the TLDs are exchanged and read, data are analyzed, and the dose rates are subsequently calculated.

Environmental neutron dose measurements are made using ^{235}U track-etch detectors (modified neutron rem-meters) at eight Livermore-site perimeter locations (**Figure 11-1**). A detailed description of the detector and spark-count procedure may be found in Fisher (1976). The neutron rem-meters are exchanged and analyzed each quarter. To ensure accuracy of measurements, quality control checks are conducted on two rem-meters selected at random eachquarter.

Results

Livermore Site

Table 11-1 shows the quarterly and annual TLD gamma radiation dose equivalent for the Livermore-site perimeter locations, and **Table 11-2** presents data for Livermore Valley off-site locations. The mean 1993 dose equivalent from external direct radiation exposure at the Livermore-site perimeter, 0.65 mSv (65mrem), is the same, within statistical uncertainty, as the background external dose measured in the Livermore Valley (0.65mSv; 65mrem). **Figure 11-4** presents the external radiation dose distribution as a percent of the total measured at 49Livermore Valley locations. This annual total dose equivalent is typical when compared to that of previous years, i.e., 1987, 0.64mSv (64mrem); 1988, 0.63mSv (63mrem); 1989, 0.63mSv (63mrem); 1990, 0.65mSv (65mrem); 1991, 0.65mSv (65mrem); 1992, 0.66mSv (66mrem); and 1993, 0.65mSv (65mrem).

Table 11-3 presents the data for neutron monitoring at the Livermore-site perimeter. The annual average neutron radiation dose at theLivermore-site perimeter for 1993 was 0.058mSv (5.8mrem), similar to val ues in 1987, 0.050mSv (5.0mrem); 1988, 0.042mSv (4.2mrem); 1989, 0.053mSv (5.3mrem); 1990, 0.046mSv (4.6mrem); 1991, 0.047mSv (4.7mrem), and 1992, 0.058 mSv (5.8mrem). The neutron doses measured at the site boundary are consistent with those expected from natural background radiation (NCRP [National Council on Radiation Protection and Measurements] 1976a, b). An absorbed dose rate of 0.047mSv (4.7mrem) per year due to cosmic rays was estimated for LLNL from a plot in *Natural Background Radiation in the United States* (NCRP 1976b). This is based upon an energy deposition rate of 0.043 µrad/h and a quality factor of 10. The dose rate was also derived from information in NCRP Report No. 50 (NCRP 1976a) as 0.087mSv (8.7mrem), which is based on an energy deposition rate of 0.1 µrad/h. These dose rates are consistent with the 1993 monitored neutron dose at the LLNL perimeter.

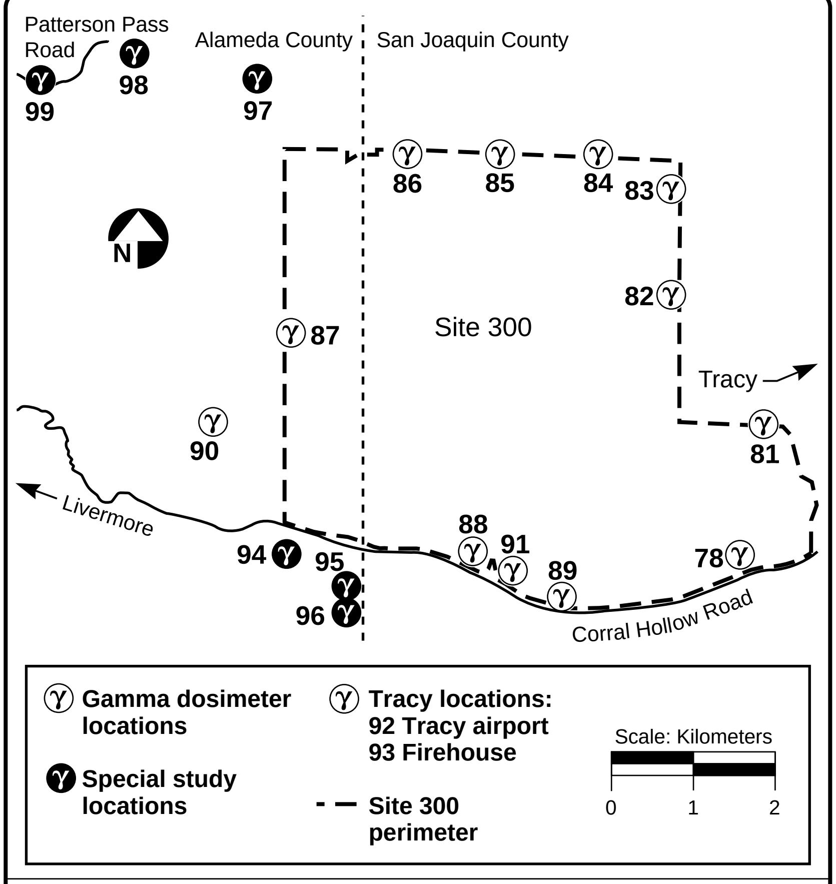

Figure 11-3. Gamma dosimeter locations, Site 300, 1993.

Site 300

Table 11-4 presents the TLD data for routine monitoring at Site 300 during 1993, expressed as dose equivalent. Based on past measurements (Lindeken et

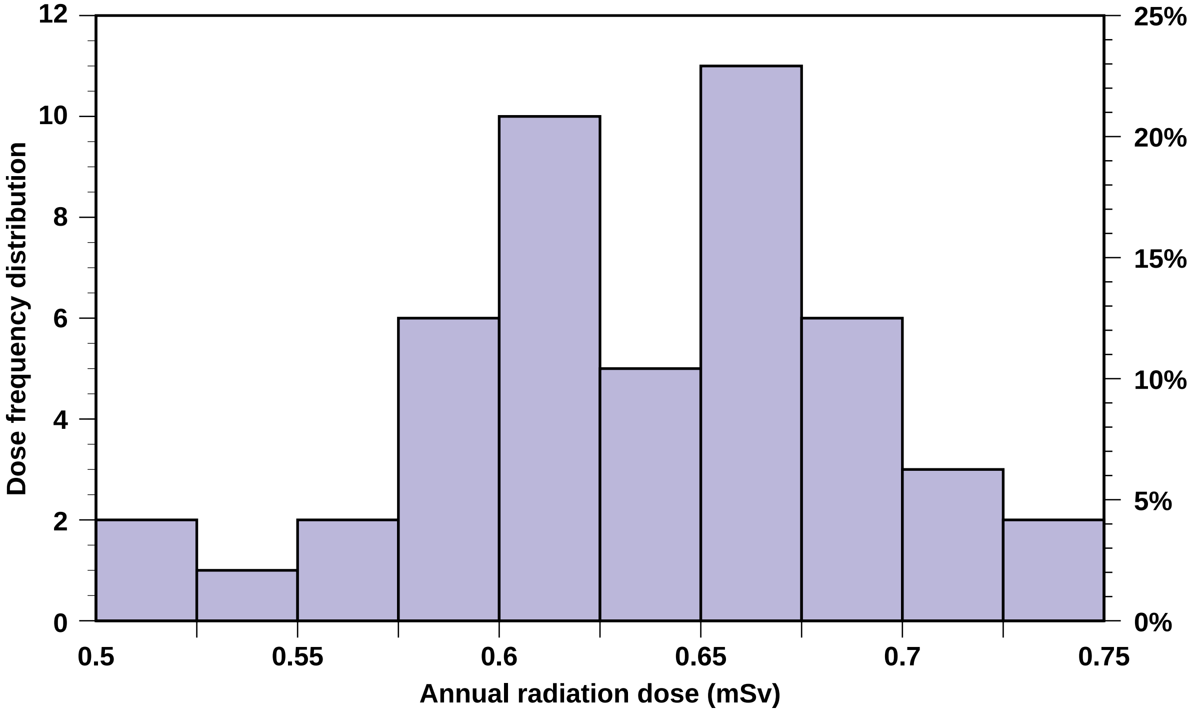

Figure 11-4. Annual radiation dose, Livermore Valley, 1993.

al. 1973), environmental terrestrial doses in this area vary from 0.30mSv/y (30mrem) to 0.60 mSv/y (60 mrem/y). Cosmic radiation yields adose of about 0.35 mSv/y (35mrem/y), calculated from local elevation and geomagnetic latitude according to the data of Lowder and Beck (1966). The average measured dose at the locations in and near Tracy and at the Site 300 perimeter ranged from 0.67 mSv (67 mrem) to 0.77 mSv (77mrem) in 1989; 0.68mSv (68mrem) to 0.78 mSv to (78mrem) in 1990; 0.64mSv (64 mrem) to 0.78mSv (78mrem) in 1991; 0.64 mSv (64 mrem) to 0.78 mSv (78mrem) in 1992; and 0.65mSv (65 mrem) to 0.76 mSv (76 mrem) in 1993. Total annual doses for Site 300 off-site locations (not in Tracy) in 1992 was 0.81 mSv (81 mrem) and 0.828mSv (82.8mrem) in 1993.

Environmental Impact

Livermore Site

Based on past measurements (Lindeken et al. 1973), environmental terrestrial (geologic) radiation doses in the Livermore Valley vary from 0.30 to 0.60 mSv/y (30 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 0.65 to 0.95 mSv/y (65 to 95 mrem/y). Direct radiation doses measured at the LLNL perimeter in 1993 fall within these predicted values and are statistically equivalent to the off-site doses, which are considered natural background levels. This indicates that there is no measurable contribution from LLNL operations to the direct radiation dose at or beyond the Livermore-site perimeter. See Chapter 12 for further information on radiation exposure.

Site 300

The initial TLD network design limited monitoring to the Site 300 perimeter and two locations in and near the city of Tracy. These off-site locations were chosen to provide exposure information about nearby population centers as well as background radiation levels. However, the Tracy region has different terrain and geological composition from that at Site 300. The region around Site 300 haselevated levels of naturally occurring uranium, which is present in the Neroly Formation. The Tracy area, on the other hand, is at a lower elevation and the geological constituents are composed of alluvium deposits of clays, sands andsilts overlying the bedrock. The 1993 average measured dose at the Site300perimeter was 0.76 mSv (76 mrem), and the average measured doses at and near the city of Tracy were 0.59 and 0.70 mSv (59and 70 mrem), respectively, and the average dose at Site300 off-site locations was 0.828 mSv (82.8 mrem). These doses fall within the expected range for background locations (Lindeken etal. 1973) .

Table 11-1. TLD environmental radiation measurements (in mSv), Livermore-site perimeter, 1993.

Location[a]	Jan.–Mar.	Apr.–June	July–Sept.	Oct.–Dec.	Annual total
1	0.156	0.172	0.182	0.169	0.679
2	0.148	0.159	0.170	0.154	0.631
3	0.160	0.180	0.186	0.177	0.703
4	0.166	0.177	0.194	0.200	0.737
5	0.167	0.176	0.186	0.179	0.708
6	0.163	0.173	0.187	—[b]	0.697[c]
7	0.154	0.192	0.193	0.170	0.709
10	0.147	0.167	0.168	0.158	0.640
11	0.132	0.136	0.140	0.132	0.540
12	0.132	0.142	0.150	0.142	0.566
13	0.134	0.161	0.170	0.167	0.632
42	0.149	0.174	0.169	0.166	0.658
47	0.146	—[b]	0.174	0.161	0.641[c]
48	0.164	—[b]	—[b]	—[b]	0.656[c]
49	—[b]	0.160	—[b]	—[b]	0.640[c]
50	0.133	0.154	0.161	0.158	0.606
52	0.145	0.149	0.159	0.161	0.614
56	0.149	0.164	0.169	0.158	0.640
Mean	**0.150**	**0.165**	**0.172**	**0.163**	**0.650**
Std dev	**0.012**	**0.015**	**0.015**	**0.016**	**0.051**
			[mrem]		
Mean	**15.0**	**16.5**	**17.2**	**16.3**	**65.0**
Std dev	**1.2**	**1.5**	**1.5**	**1.6**	**5.1**

[a] See Fig. 11-1 for sampling locations.

[b] No data available for these samples.

[c] When a TLD is missing, the annual dose is calculated as four times the mean quarterly dose, as determined from available data.

Table 11-2. TLD environmental radiation measurements (in mSv), Livermore Valley, 1993.

Location[a]	Jan.–Mar.	Apr.–June	July–Sept.	Oct.–Dec.	Annual total
14	0.146	0.153	0.217	0.156	0.672
15	0.139	0.160	0.163	0.142	0.604
16	0.146	—[b]	0.158	0.164	0.624[c]
17	0.145	0.161	0.178	0.162	0.646
18	0.134	0.123	0.132	0.130	0.519
19	0.145	—[b]	0.152	0.141	0.584[c]
20	—[b]	—[b]	0.157	0.151	0.616
21	0.135	0.149	0.156	0.149	0.589
22	0.153	0.168	0.188	0.170	0.679
23	0.160	0.166	0.191	0.167	0.684
24	0.150	0.167	—[b]	0.161	0.637[c]
27	0.156	—[b]	0.201	0.176	0.711[c]
28	0.168	0.179	0.204	0.179	0.730
29	0.162	0.172	0.185	0.169	0.688
30	—[b]	0.170	0.182	—[d]	0.704[c]
31	0.144	0.154	0.159	0.154	0.611
32	0.150	0.150	0.172	0.158	0.630
33	0.158	0.166	0.182	—[d]	0.683
34	0.162	0.174	0.189	0.173	0.698
35	—[b]	0.168	0.174	0.167	0.679[c]
36	0.174	0.169	0.193	0.167	0.703
37	0.145	0.155	0.167	0.151	0.618
38	0.148	0.161	0.184	—[d]	0.658
41	0.145	0.156	0.165	0.156	0.622
43[d]	—[e]	0.300[d]	0.182	0.165	0.656
44	0.153	0.174	0.188	0.172	0.687
45	0.142	0.116	0.160	0.145	0.563
46	0.146	0.154	0.165	0.154	0.619
51	—[b]	0.160	0.173	0.163	0.661[c]
55	0.173	0.160	0.164	0.156	0.653
57	0.159	0.168	0.184	0.161	0.672
58	0.145	0.156	0.169	0.155	0.625
59	0.139	0.144	0.156	0.152	0.591

...continued

Table 11-2. TLD environmental radiation measurements (in mSv), Livermore Valley, 1993 (*concluded*).

Location[a]	**Jan.–Mar.**	**Apr.–June**	**July–Sept.**	**Oct.–Dec.**	**Annual total**
60	0.155	0.164	0.173	0.164	0.656
61	0.131	0.141	0.153	0.140	0.565
62	0.131	0.154	0.159	0.153	0.597
63	0.151	0.179	0.172	—[b]	0.669[c]
66	0.151	0.167	0.173	0.165	0.656
67	0.143	0.151	0.163	0.152	0.609
68	0.148	0.158	0.171	0.160	0.637
69	0.144	0.148	0.153	0.153	0.598
70	0.149	0.153	0.166	0.159	0.627
71	—[d]	—[b]	—[d]	—[d]	—[d]
72	0.165	0.179	0.202	0.183	0.729
73	0.149	0.163	0.174	0.169	0.655
74	0.137	0.147	0.157	0.148	0.589
75	0.127	0.129	0.134	0.133	0.523
76	0.126	0.136	0.134	0.133	0.529
77	0.140	—[b]	0.161	0.154	0.607[c]
Mean	**0.145**	**0.161**	**0.171**	**0.158**	**0.637**
Std dev	**0.024**	**0.026**	**0.018**	**0.012**	**0.051**
			[mrem]		
Mean	**14.5**	**16.1**	**17.1**	**15.8**	**63.7**
Std dev	**2.4**	**2.6**	**1.8**	**1.2**	**5.1**

[a] See Fig. 11-2 for sampling locations.

[b] No data available for these samples.

[c] When a TLD is missing, the annual dose is calculated as four times the mean quarterly dose, as determined from available data.

[d] TLDs found on the ground or damaged or wet are not used to calculate the quarterly or annual totals.

[e] No sample was taken at this location in the first quarter of 1993 and the second quarter represents the sum total of the first and second quarter.

Table 11-3. Neutron environmental radiation measurements (in mSv), Livermore-site perimeter, 1993.

Location[a]	**Jan.–Mar.**	**Apr.–June**	**July–Sept.**	**Oct.–Dec.**	**Annual total**
1	0.009	0.014	0.012	0.008	0.043
2	0.011	0.009	0.011	0.006	0.037
3	0.011	0.009	0.013	0.004	0.037
4	0.010	0.008	0.019	0.005	0.042
5	0.011	0.029	0.010	0.016	0.066
6	0.008	0.011	0.010	0.007	0.036
7	0.006	0.019	0.013	0.007	0.045
8	0.012	0.015	0.011	0.008	0.046
Mean	**0.010**	**0.014**	**0.012**	**0.008**	**0.044**
Std dev	**0.002**	**0.007**	**0.003**	**0.004**	**0.010**
			mrem		
Mean	**1.0**	**1.4**	**1.2**	**0.8**	**4.4**
Std dev	**0.2**	**0.7**	**0.3**	**0.4**	**1.0**

[a] See Fig. 11-1 for sampling locations.

Table 11-4. TLD environmental radiation measurements (in mSv), Site 300 perimeter locations, 1993.

Location[a]	Jan.–Mar.	Apr.–June	July–Sept.	Oct.–Dec.	Annual total
Site perimeter					
78	0.147	0.160	0.175	0.164	0.646
81	0.191	0.216	0.232	0.217	0.856
82	0.164	—[b]	0.201	0.184	0.732[c]
83	0.175	0.201	0.218	—[b]	0.792[c]
84	0.155	0.179	0.203	—[b]	0.716[c]
85	—[d]	0.186	0.196	—[d]	0.672
86	0.162	0.199	0.204	—[c]	0.753[b]
87	0.180	0.207	0.227	0.238	0.852
88	0.170	0.192	0.193	0.192	0.747
89	0.172	0.196	0.206	0.202	0.776
90	0.177	0.200	0.221	0.200	0.798
91	0.164	0.184	0.205	0.193	0.746
Mean	**0.162**	**0.193**	**0.207**	**0.199**	**0.757**
Std dev	**0.025**	**0.015**	**0.016**	**0.021**	**0.063**
			[mrem]		
Mean	**16.2**	**19.3**	**20.7**	**19.9**	**75.7**
Std dev	**2.5**	**1.5**	**1.6**	**2.1**	**6.3**

[a] See Fig. 11-3 for sampling locations.

[b] No data available for these samples.

[c] When a TLD is missing, the annual dose is calculated as four times the mean quarterly dose, as determined from available data.

[d] TLDs found on the ground damaged or opened are not used to calculate the quarterly annual total.

Table 11-5. TLD environmental radiation measurements (in mSv), Site 300 vicinity, 1993.

Location[a]	Jan.–Mar.	Apr.–June	July–Sept.	Oct.–Dec.	Annual total
Tracy					
92	0.162	0.171	0.191	0.180	0.704
93	0.140	0.149	0.151	0.148	0.588
Mean	**0.151**	**0.160**	**0.171**	**0.164**	**0.646**
Std dev	**0.016**	**0.016**	**0.028**	**0.023**	**0.082**
			[mrem]		
Mean	**15.1**	**16.0**	**17.1**	**16.4**	**64.6**
Std dev	**1.6**	**16**	**2.8**	**2.3**	**8.2**
Off site					
94	0.211	0.243	0.271	—[b]	0.967[c]
95	0.187	0.215	0.235	—[b]	0.821[c]
96	0.191	0.215	0.240	—[b]	0.861[c]
97	—[d]	—[b]	0.203	—[b]	0.812[c]
98	—[d]	0.188	0.198	—[b]	0.772[c]
99	0.166	—[d]	0.204	0.179	0.732[c]
Mean	**0.189**	**0.215**	**0.225**	**0.179**	**0.828**
Std dev	**0.018**	**0.021**	**0.029**	**0.029**	**0.074**
			[mrem]		
Mean	**18.9**	**21.1**	**22.5**	**21.6**	**82.8**
Std dev	**1.8**	**2.1**	**2.9**	**2.9**	**0.74**

[a] See Fig. 11-3 for sampling locations.

[b] TLDs found on the ground damaged or opened are not used to calculate the quarterly or annual totals.

[c] When a TLD is missing, the annual dose is calculated as four times the mean quarterly dose, as determined from available data.

[d] No data available for these samples.

12. Radiological Dose Assessment

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Introduction

Radiological doses to the public result from both natural and man-made radiation. The total dose to different populations is estimated by extensive 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 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 the reader is referred to *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 the radioactive elements, such as radon, that arise following 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 due 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–1960s spread radioactivity across the surface of the globe, and the nuclear reactor accident at Chernobyl affected a large area. At present, medical treatment is the largest common source of public exposure to man-made radiation. Individual medical doses vary enormously—someone who has never had an x-ray examination may receive zero medical dose while patients undergoing treatment for cancer may receive many thousands of times the annual average dose 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 are naturally occurring but 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 light) by nuclei.

Radioisotopes decay at quite different rates; their “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 undergo a decay chain, forming radioisotopes that decay into other radioisotopes until a stable state is achieved. As an 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. It 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 chemical 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 with the ability 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 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 deposited 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 insult 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 that a nucleus decays is expressed in units of becquerels, abbreviated Bq, where one becquerel is one decay per second, or alternatively in curies, Ci, where one 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 100rads. 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 sievert (Sv); 1 Sv equals 100rem. Also commonly used are millirem (mrem) and millisievert (mSv), which are one-thousandth of a rem and sievert, respectively.

Just as one type of radiation can be more damaging than others, some parts of the body are potentially more vulnerable to radiation damage than 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 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.

Sources of Natural Radioactivity

The average radiation dose from natural sources in the United States, according to the National Council on Radiation Protection (1987), is 3.0mSv/y (300mrem/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 (30mrem/y) of the average natural dose. Another significant part ofthe dose comes from radionuclides we ingest through food and drink, resulting in approximately 0.4m Sv/y (40 mrem/y). Potassium-40 and carbon-14 are common radionuclides in food.

The remaining 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 the short-lived decay products of radon. The dose varies with geographic location, but the average U.S. citizen receives approximately 2 mSv/y (200 mrem/y) of natural exposure from radon. **Figure12 -1** shows the distribution of annual radiation doses from natural and other common sources.

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. 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

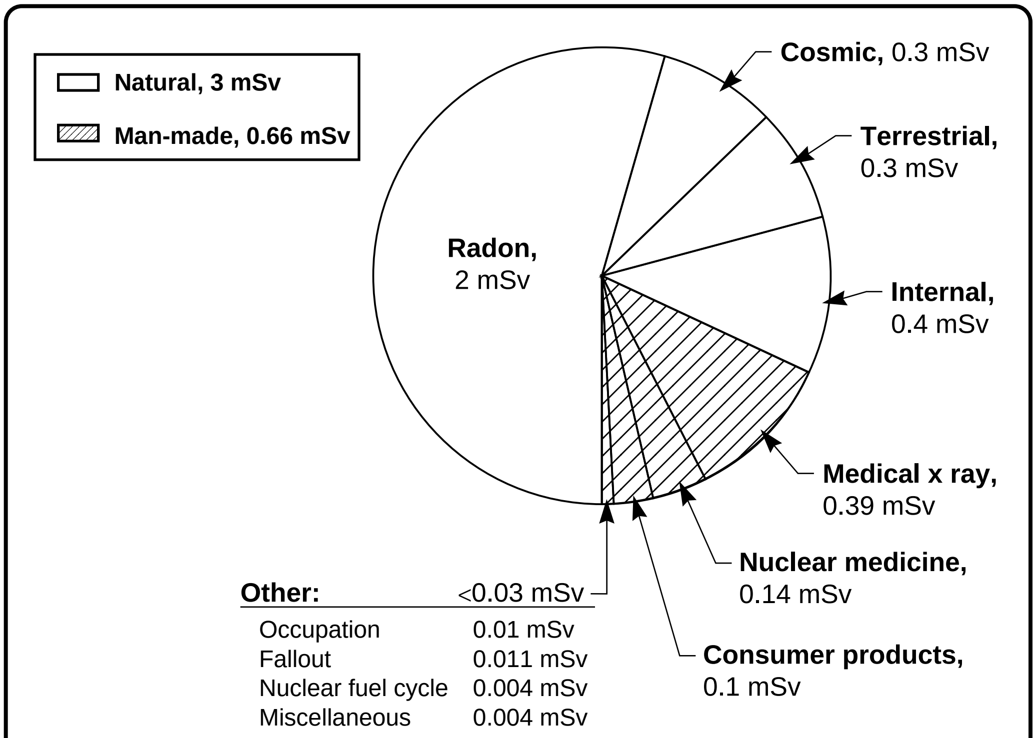

Figure 12-1. Typical annual radiation doses from various sources (NCRP 1987).

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 (63mrem/y). The average dose from other man-made sources, including fallout from nuclear testing, is about 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 12-1**.

Radiation Sources, Control Measures, and Standards

Radionuclides at LLNL

A wide variety of radioisotopes is used at LLNL, including transuranics, biomedical tracers, tritium, mixed fission products, and others for general research and nuclear weapons research. To minimize both worker and off-site exposures, 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. Exhaust paths to the atmosphere range from triple-filtered stacks and direct small-hood roof vents at the Livermore site, to direct dispersal of depleted uranium during nonnuclear explosives testing at Site300.

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 of 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 engineering controls are specified to minimize exposure and release of dangerous quantities of radioactivity. These controls might include, but are not limited to, physical access control, 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.

The other stages of the radiation control program come into play when a facility is occupied for use. The second part of the program takes place when, 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 last stage of the radiation control program involves direct monitoring of the work environment and physical sampling of air and surfaces in facilities where radioactive materials are handled. Additionally, personal dosimetry and bioassay programs monitor for potential worker exposure to direct radiation and exposure to radioactive isotopes. This monitoring program measures the effectiveness of a facility's radiation control program, as well as providing information on worker exposures.

Radiation Protection Standards

DOE environmental radiation protection standards are provided in DOE Order 5400.5, *Radiation Protection of the Public and the Environment*, which incorporates 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 1976 a, b). The primary DOE radiation standards for protection of the public are 1 mSv/y

(100mrem / 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. 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 the National Emission Standards for Hazardous Air Pollutants (NESHAPs) under 40CFR 61. It limits to 0.1mSv / y (10mrem / y) the whole-body effective dose equivalent to members of the public from DOE activities. Before December 15, 1989, the standard was 0.25mSv / y (25mrem / 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 compared to natural exposures to radioactivity, it would be difficult to prove compliance with the standard by measuring the effects of the dispersal of radioactivity in the atmosphere. EPA has 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 either the EPA's AIRDOS-PC or CAP88-PC code. The latter is a recently developed, improved, and expanded computer code, described below in the section on Calculations of Radiological Dose. 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.

Radiological Doses from Air Emissions

In accordance with DOE environmental protection orders and other federal and state requirements, LLNL assessed the radiological impact from operations at the Livermore site and Site300 during 1993. Small amounts of radioactive materials from LLNL operations were discharged to the environment with air and sewer effluents (see Chapter 4 on Air Monitoring and Chapter 5 on Sewage Monitoring). Because sewer effluents are not consumed, they do not represent an ingestion or inhalation pathway for radiation exposure. Therefore, dose calculations are based only on material that enters the environment via air releases.

Potential radiological doses to the public are determined either from measurements of radionuclides in the environment or calculations using EPA-approved computer codes and procedures. The calculations use theoretical models for transport of radionuclides through the environment, including dispersion in air, into water and food, and finally into human beings through inhalation or ingestion. Although LLNL seeks to obtain sufficient samples of the local environment to assure that its impacts are well understood, sampling for radioactivity cannot occur at all locations. The theoretical calculations are important because they set an upper bound on the potential radiological impacts of LLNL operations. The radionuclide source terms used in the codes are based on measured emissions and/or potential emissions based upon facility inventories.

The results of the measurements and calculations reported in this chapter are an important indicator of the success of LLNL's discharge control program. Development of the Livermore Valley and the San Joaquin Valley has decreased the distance between sources of emissions and the residents that 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 impact of LLNL operations.

Monitored Releases of Radioactive Materials

General surveillance air monitoring for tritium and for radioactive particulates has been in place since the 1970s and will continue. The data from this monitoring network provide continuous measures of the concentrations of radionuclides present in the air at the Livermore site, Site300, and in the surrounding areas. This network allows for direct measurements of the overall impact of LLNL operations, as discussed in detail in Chapter 4 on Air Monitoring. Beyond the general 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 monitoring networks measure the concentrations of radionuclides present in the air near these sources and allow a direct determination of their environmental impact. This practice will continue at these locations and will be instituted for any newly identified significant diffuse sources.

Radionuclide concentrations measured in environmental media are presented in the chapters in this report covering each specific medium. In particular, measurements of external direct radiation reported in Chapter 11, Environmental Radiation Monitoring, show no difference (within the fairly large measurement uncertainty) between doses measured in the immediate environs of LLNL's Livermore site and Site300, as compared to measurements made at remote locations. While the Livermore-site boundary measurements of external gamma doses averaged 0.65 mSv (65mrem), Livermore Valley locations averaged 0.64 mSv (64 mrem). Site300 boundary locations averaged 0.76 mSv (76mrem), while off-site samples from different areas showed 0.65 to 0.81mSv

(65 to 81 mrem). Because the measurement uncertainty is about ±5%, or nearly ±3mrem, these results cannot distinguish between on-site and off-site doses.

Routine LLNL operations during 1993 released a total of 8.99×10^{12} Bq (243Ci) of tritium to the atmosphere; of that, 4.4×10^{12} Bq (119 Ci) was in the form of tritiated water. An additional 6.9×10^{12} Bq (187 Ci) was released by Sandia National Laboratories, California (SNL/CA), with approximately 4.9×10^{12}Bq (132 Ci) in the form of tritiated water. LLNL's electron-positron linear accelerator was reactivated in 1993, resulting in releases of 2.7×10^{11} Bq (7.2 Ci) of the short half-life radioisotopes nitrogen-13 (half-life of ten minutes) and oxygen-15(half-life of two minutes), similar to those we reported in previous years. The amount of radioactivity released from LLNL during 1993 was slightly more than in 1992 and was below the range of previous years (see **Table 4-14** in Chapter 4).

There was one unplanned atmospheric radionuclide release at the Livermore site in 1993 and none from Site 300. In September 1993, an analysis of gross alpha data from a continuous particulate sampler, located in a stack on the unhardened portion of Building 251, revealed a release to the atmosphere of radon-220 (radon daughters were detected). Subsequent investigation revealed that the release commenced in early June 1993, gradually rising to the level at which it was discovered some three months later. The source of the release was a thorium-228 experiment occurring in a glove box releasing to the atmosphere through a stack with a high efficiency particulate air (HEPA) filter. Data and calculations evaluated the total release during the entire period to be 5.9×10^{11}Bq (16 Ci), witharesultant maximum dose to a member of the public of 3×10^{-3} μSv/y (3×10^{-4} mrem/y), well below levels of health concern.

Air Emissions

The annual releases of radionuclides to the atmosphere that we report are calculated potential releases. For unmonitored and noncontinuously monitored sources, the calculations are based on inventory data using unabated EPA potential release fractions (discussed below); for continuously monitored facilities, the calculations are based on actual emission measurements. The continuously monitored facilities at LLNL are Buildings 175, 231-Vault, 251, 331, 332, 419, 490, and 491. Many of the monitored facilities show zero emissions. These data are based on limit-of-sensitivity (LOS) results from the analysis of air filter samples. Use of zero values for LOS data in this case can be justified based on facility knowledge; the use of tested, multiple-stage HEPA filters (see next paragraph) in all significant release pathways; and isotopic analyses of selected filters, by alpha spectroscopy, which demonstrate that measured activity on filters comes from naturally occurring radionuclides such as radon daughters, e.g., polonium. In any case, given the level of HEPA filtration, it is likely that actual concentrations are closer to zero than they are to the LOS. Furthermore, even if the LOS values are substituted in screening dose calculations (a very conservative assumption), the total dose attributable to LLNL activities is not significantly affected.

HEPA filters are used in many LLNL facilities to control particulate emissions. For some discharge points, scrubbers and electrostatic precipitators aid the control of emissions. The operational performance of all HEPA filtration systems is tested on a routine basis. 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.

LLNL Areas and Buildings with Radionuclide Release Potential

We have evaluated all LLNL buildings that contain Radioactive Materials Management Areas (RMMAs), i.e., locations in which radionuclides are used or activation products potentially occur, and we have analyzed areas (generally exterior to buildings) at the two sites where diffuse emissions occur. There are 56buildings containing RMMAs—48 on the Livermore site and 8 at Site300. **Table12-1** lists these buildings, gives the number of potential radionuclide discharge points associated with each of them, and identifies the types of operations occurring in each facility. **Table 12-1** also includes information for three Site300 explosive testing facilities associated with Buildings 801, 850, and 851. Diffuse area sources listed in the table include five at the Livermore site and six at Site 300. Some details about these point and diffuse sources, and an explanation of the dose information given in **Table 12-1**, is provided in the Calculated Results Summary section below. A more complete description appears in the *LLNL NESHAPs 1993 Annual Report* (Harrach et al. 1994).

Calculations of Radiological Dose

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 kilometers 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 input. 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 one in ten to one in ten 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).

Because CAP88-PC and AIRDOS-PC do 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 nuclides than AIRDOS-PC. By rerunning calculations in 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.

We report separate determinations of doses for the Livermore site and Site300. Three potential doses are emphasized: (1) The dose to the "site-wide 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 "fenceline" dose) due to each emission point on the site, and (3) the collective dose to the populations residing within 80 kilometers of the two LLNL sites, adding the products of individual doses received times the number of people receiving them. Dose (1) is used to evaluate LLNL under the 100-µSv/y (10-mrem/y) EPA standard on total radionuclide emissions to air from DOE facilities (NESHAPs, 40 CFR Part 61.92, Subpart H). Dose (2), which is calculated without regard for any emission abatement devices (such as filters) that may be present, 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 Part61.93).

The SW-MEI is defined as the hypothetical member of the public (individual receptor) 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 10meters outside the controlled eastern perimeter of the site. This location lies 948 meters from LLNL's principal radionuclide source, the Tritium Facility (Building 331), in an east-northeast direction. At Site300, the SW-MEI is located in an experimental area termed "Bunker 2" operated by Physics International. Bunker 2 lies about 300 meters outside the east-central boundary of Site300. This bunker is 2.4 kilometers southeast of the principal firing table at Building 801. Some of our calculations preceded the choice of SW-MEI and may report the maximum fenceline dose value, which is at least as large as the dose to the SW-MEI. Thus, the EDE values we quote in this document are either those at the location of the SW-MEI or the maximum to any member of the public, in any direction.

Appendix B of this document gives an expanded discussion of the doses of major interest and presents examples of explicit dose calculations for different exposure pathways.

Specification of Source Terms in the Model Runs; Point and Diffuse Sources

The source term for each emission point in the calculations was arrived at by one of two methods: for continuously monitored sources, the data on curies released per unit time for each radionuclide were used directly as input variables into the modeling codes. 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 the 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, no credit was taken for radionuclide emission control devices when calculating total dose; emission inputs into the models were assumed to be unabated. Hence, when control devices were in use, actual emissions and exposures were much lower than those calculated and reported. The use of actual monitoring data is much more direct and more accurate than using assumptions based on inventory and release fractions.

For this year’s report, covering activities in 1993, we updated the radionuclide inventories for our key Livermore-site facilities, defined as those that accounted for 90% of the 1992 Livermore-site radiological dose to members of the public. Inventory forms, accompanied by detailed guidance for completing them, were sent to these facilities, filled out by experimenters, certified by facility managers, and returned. We also updated our inventories for all Site 300 explosive experiments (which in 1992 was the major source of off-site dose at Site 300) and our assessments of source terms for identified diffuse sources at both sites. Inventories from 1992, and in some cases 1991, were used for the relatively insignificant Livermore site sources, to avoid having to update every facility in the first year of implementing our new inventory process.

Modeling releases to the atmosphere from explosive tests using depleted uranium at Site 300 requires special attention compared to conventional stack or area sources. During experiments, the explosive device containing depleted uranium is placed on an open-air firing table and detonated. We have limited data to characterize the initial state of the cloud of explosive decomposition products created by the detonation, because properties of the cloud are not typically measured in the experiments. However, well known empirical scaling laws can define the cloud through the use of radionuclide and explosive inventories. 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. We assume all of the depleted uranium is dispersed into the cloud, and the median particle size is assumed to be the CAP88-PC default value of 1micrometer. This assumption that all uranium is aerosolized and dispersed as a vapor is highly conservative regarding the off-site dose. We believe a more realistic release-to-air fraction for the uranium is no greater than 0.2, but we lack sufficient justification to use a value other than 1.0.CAP88-PC simulates each shot as a low-level, steady-state, stack-type emission occurring over one year. An alternative modeling methodology for treating these short-duration explosive events was submitted for approval in 1992, but LLNL was directed by EPA to use the CAP88-PC code for these calculations despite the recognized difficulties.

Another category of sources requiring special attention is diffuse emissions, including fugitive emissions. Diffuse, or nonpoint, sources often are difficult to quantify. Presently, dose calculations associated with them are left to the discretion of the DOE facility, although proposed guidance for estimating diffuse emissions of radionuclides at DOE facilities was sent out by EPA in 1993 forreview.

Four different modeling approaches were used for diffuse sources at LLNL’s Livermore site in 1993. Elevated tritium levels in soil moisture near Building 292 required a calculation of the source term and the use of CAP88-PC; tritium-contaminated equipment outside Building 331 and radioactive wastes stored in the Building 612 Yard required facility personnel knowledge and environmental surveillance data to estimate emissions; for Building 514, which houses the Hazardous Waste Management tank farm for waste processing and storage, inventories were used with standard CAP88-PC modeling techniques; and elevated levels of plutonium in the southeast quadrant of the Livermore site used direct ambient air monitoring to get data on which to base dose calculations.

Diffuse sources at Site 300 were evaluated based on data provided in the *Final Site-Wide Remedial Investigation* report (Webster-Scholten 1994). 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, the well 8 spring, and ground areas associated with Buildings 802, 850, and 851) were characterized, and diffuse sources of uranium were treated collectively in a resuspension calculation tied to air-particulate sampling data. A description of each source at the two sites and the assumptions made regarding their emissions are given in our 1993 NESHAPs annual report (Harrach et al. 1994).

Calculated Results Summary—Livermore Site and Site300, 1993

Table12-1 summarizes the sources of the radiation dose from airborne radionuclides emitted by LLNL operations in 1993. Each of 56 buildings containing a Radioactive Materials Management Area is listed and its principal operations summarized. 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 the two sites.

Table 12-2 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 98% 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 almost 93% of the Livermore-site dose, and uranium (principally uranium-238) for 5%. At Site 300, practically the entire dose was due to the isotopes uranium-238, uranium-235, and uranium-234 in depleted uranium.

The relative significance of inhalation and ingestion is different for these nuclides and depends on the assumptions made about consumption of food in the assessment area. We adopted the “local agriculture” option in CAP88-PC, where all food consumed is assumed to be locally grown and therefore maximally affected by the emissions we are evaluating. We then find that ingestion is most important in the case of tritium, contributing 86% of the dose, versus 14% for inhalation. For uranium these numbers are nearly reversed: inhalation accounts for 82% of the dose, versus 18% for ingestion. For both radionuclides, external doses from air immersion and ground irradiation were negligible.

Maximum Dose to an Individual Member of the Public. For the Livermore site, the contribution from point source emissions to the dose calculated for the SW-MEI was 0.40 µSv (0.040 mrem) and from diffuse emissions was 0.26 µSv (0.026 mrem). Summing the contributions from both point and diffuse sources yields a total dose of 0.66 µSv (0.066 mrem) for the Livermore site in 1993. The leading contributors to this total were 0.35 µSv (0.035 mrem) due to emissions from the two 30-meter stacks at the LLNL Tritium Facility (Building 331), and 0.20 µSv (0.020 mrem) from the Building 612 Yard diffuse source.

Compared to data of previous years, the total of 0.66 µSv (0.066 mrem) for 1993 is slightly below the 1992 value of 0.79 µSv (0.079 mrem), and is well below the dose values reported for 1991 and 1990, which were 2.34 µSv (0.234 mrem) and 2.40 µSv (0.240 mrem), respectively. We note that differences in annually averaged wind speeds and directions tended to reduce the EDE at the location of the SW-MEI in 1993 relative to 1992. In particular, the dose to the SW-MEI resulting from the Building 331 stack emissions in 1993 was about 6% less than in 1992, even though the tritium (HTO) emissions were about 14% higher.

The total dose to the SW-MEI at Site300 during 1993 was calculated to be 0.37 µSv (0.037 mrem). Explosive tests at the Building 801 firing table accounted for nearly all of the point source dose of 0.11 µSv (0.011 mrem), while a source representing resuspension of uranium in surface soils throughout the site accounted for nearly all of the diffuse sources total of 0.26 µSv (0.026 mrem). In comparison, the total dose values for 1992, 1991, and 1990 resulting from firing table experiments or tests were 0.21 µSv (0.021 mrem), 0.44 µSv (0.044 mrem), and 0.57 µSv (0.057 mrem), respectively. The dose from firing table operations shows a monotonic decline from one year to the next, reflecting reduced use of depleted uranium in the tests. Comparison of the diffuse source contribution in 1993 with previous years cannot be made because we did not evaluate Site 300's diffuse emissions prior to 1993.

Table 12-3 compares the 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 three thousand times lower than doses from background radiation. **Table 12-3** shows that radon emissions rank highest among the sources of natural radioactivity, contributing an average dose of 2.0 mSv/y (200 mrem/y). Emissions of radon caused by LLNL operations in 1993 were estimated to be 5.9×10^{11} Bq (16 Ci) from a single unplanned release of radon-220 occurring over a period of several months, and 2.2×10^6 Bq (59 µCi) from radon-222 emissions in research experiments. The resultant EDEs to the SW-MEI were 3×10^{-3} µSv/y (3×10^{-4} mrem/y) and 2×10^{-6} µSv (2×10^{-7} mrem), respectively—far below the natural background level.

Collective Doses to Exposed Populations. Population doses, or collective EDEs, for both LLNL sites were calculated out to a distance of 80 kilometers in all directions from the centers of the sites using CAP88-PC with 1990 census data. 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.

The collective EDE due to 1993 Livermore-site operations was 0.0098person-Sv (0.98 person-rem), of which 0.0078 person-Sv (0.78 person-rem) was contributed by point source emissions and the remaining 0.0020 person-Sv (0.20person-rem) by diffuse sources. This value is down from 0.017 person-Sv (1.7 person-rem) caused by Livermore-site operations in 1992.

The corresponding collective EDE from operations at Site 300 in 1993 was 0.069 person-Sv (6.9 person-rem), composed of 0.046 person-Sv (4.6 person-rem) from point source emissions and 0.023 person-Sv (2.3 person-rem) from diffuse source emissions. This total is slightly reduced from 0.071 person-Sv (7.1 person-rem) in 1992, despite the fact that diffuse emissions at Site 300 were not evaluated for 1992 and earlier years.

The large value for Site 300 relative to the Livermore site in both years is traceable primarily to our highly conservative, health protective assumptions about the explosive experiments, especially regarding the fraction of radioactive material that is aerosolized, and the height and trajectory of the explosive debris cloud. This conservative modeling methodology overpredicts the long-range dispersal of material in these experiments.

We note that the diffuse sources contribute relatively more to the individual dose to the SW-MEI than to the collective population dose. The reason is their less dynamic nature, originating low to the ground at low initial velocity. Stacks forcefully expel the effluent at considerable speed high above the ground, and the explosive experiments throw decomposition products high into the air, allowing contaminants to more readily reach population centers downwind.

Summary and Conclusion

Calculations of effective dose equivalents for all Livermore-site and Site300 facilities having the potential to release radionuclides to the atmosphere have been completed. The annual dose from emissions of all facilities (taking into account emission control devices) 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). Among the eight continuously monitored facilities at the Livermore site—Buildings 175, 231-Vault, 251, 331, 332, 419, 490, and 491—only Building 331, Building 332, and the hardened portion of Building 251 are required to maintain continuous monitoring systems based on a potential for their emissions to exceed 1 µSv/y (0.1 mrem/y) in the absence of emission control devices. Nonetheless, continuous monitoring will be maintained at all eight of these facilities. No additional facilities at either the Livermore site or Site300 were found to require continuous monitoring systems under the EPA standard.

Using EPA-mandated computer models and actual LLNL meteorology, the 1993 calculated EDE to the individual site-wide maximally exposed member of the public from Livermore-site radionuclide air emissions was 0.66 µSv (0.066mrem). The corresponding EDE to the individual site-wide maximally exposed member of the public at Site300 was calculated to be 0.37 µSv

(0.037mrem). These levels represent less than 0.7% and 0.4%, respectively, of the EPA's federal standard.

The collective effective dose equivalent or population dose for LLNL 1993 operations was 0.0098 person-Sv (0.98 person-rem) from the Livermore site and 0.069 person-Sv (6.9 person-rem) from Site300. These doses were calculated out to a distance of 80 kilometers from each site in all directions using 1990 population data comprising 6.3 million people for the Livermore site and 5.4million for Site300.

We conclude that the potential radiological doses from LLNL operations were approximately three thousand times less than the doses normally received by this population from natural background radiation sources, even though highly conservative assumptions were used in the calculations. Thus, the maximum credible doses show that LLNL's use of radionuclides had no significant impact on public health during 1993.

Table 12-1. Sources of radiation dose from LLNL releases to air (stacks on buildings containing radioactive materials management areas and area releases from diffuse sources)**.**

Bldg	Facility	Potential discharge points	Max EDE[a] (μSv/y)	Quarter reported[b]	Operations
131	Engineering	2	4.0×10^{-3}	Dec. 91	Handling, storing, machining, characterizing, assembling, sorting, and transferring materials, repackaging of waste
151	Nuclear Chemistry	23	1.5×10^{-5}	94 Annual	Chemical separation, crushing/dissolving, aliquot preparation and storage, gas analysis, radiochemical separations, preparation of radioactive counting standards
171	Lasers	1	3.1×10^{-8}	Sept. 92	Melting of uranium under vacuum
175	MARS[c]	6	0.0	94 Annual	Cleaning/disassembly of uranium parts
177	Lasers	6	2.2×10^{-4}	94 Annual	Vaporization and coating of uranium
179	Lasers	2	1.3×10^{-3}	Sept. 92	Melting of uranium under vacuum
190	Physics	1	0.0	Mar. 92	Accelerator
194	Physics	2	4.0×10^{-4}	94 Annual	Accelerator
212	Physics	2	1.8×10^{-9}	Sept. 92	Environmental, safety, and health surveillance for shutdown of accelerator
222	Chemistry	16	9.4×10^{-6}	94 Annual	Radioanalytical analyses and tracer use
226	Chemistry	1	8.1×10^{-8}	Mar. 92	Radioactive and mixed waste chemical analyses
227	Chemistry	3	8.2×10^{-5}	Sept. 91	Uranium bonding and testing
231	Mechanical Engineering	5	2.3×10^{-3}	Mar. 92	Materials research and testing, plastics shop work, electron beam welding
	Mechanical Engineering Vault	1	0.0[c]	Sept. 92	Storage, handling, and shipping of radionuclides
235	WMRDF	8	2.7×10^{-6}	Dec. 91	Welding, actinide and uranium catalyst research
241	Physics	2	2.1×10^{-5}	Sept. 92	Materials development, measurement, and testing
243	Energy Research	1	0.0	Mar. 92	Earth sciences and geological studies
251	Heavy Elements				Heavy-element research
	Hardened area	4	0.0[c]	94 Annual	
	Unhardened areas	44	0.0[c,g]	94 Annual	
253	Hazards Control	1	6.3×10^{-14}	Sept. 92	Radiochemical analyses
254	Hazards Control	1	0.0	Sept. 92	Radiochemical analyses of bioassays
255	Hazards Control	1	4.1×10^{-6}	Sept. 92	Instrument calibration
2581	Test Program	1	1.0×10^{-7}	Sept. 92	Foil testing
281	Nuclear Chemistry	4	5.1×10^{-3}	Sept. 91	Preparation and storage of radiochemical stock solutions
282	Nuclear Chemistry	1	1.0×10^{-2}	Sept. 91 Mar. 92	Use of tritium gas in spectrometer experiment

...continued

Table 12-1. Sources of radiation dose from LLNL releases to air (stacks on buildings containing radioactive materials management areas and area releases from diffuse sources) *(continued).*

Bldg	Facility	Potential discharge points	Max EDE[a] (μSv/y)	Quarter reported[b]	Operations
292	Physics	3	7.8×10^{-7}	Sept. 92	Tritium contamination from prior operations
298	Laser Fusion	2	1.8×10^{-3}	Sept. 92	Handling and assembly of tritium-filled targets; sputtering uranium
321	Materials Fabrication	5	4.0×10^{-3}	Dec. 91	Machining
331	Tritium	2	2.2×10^{-1}[c]	94 Annual	Cryogenic tritium experiments and cryogenic experiments on deuterium-tritium
332	Plutonium	11	0.0[c]	Dec. 92	Machining and metallurgy
341	Physics	1	4.2×10^{-6}	Mar. 92	High-energy research
361	Biomedical Research	16	1.1×10^{-5}	Sept. 91 Dec. 92	Radiolabeling and use of tracers for biomedical research
363	Biomedical Research	—[d]	0.0	Sept. 91	Biomedical research
365	Biomedical Research	4	0.0	Sept. 91	Radiolabeling and use of tracers for biomedical research
366	Biomedical Research	—[d]	0.0	Sept. 91	Biomedical research
377	Environmental Research	3	8.8×10^{-5}	Mar. 92	Radiolabeling and use of tracers for environmental research
378	Environmental Research	2	1.6×10^{-8}	Mar. 92	Radiolabeling and use of tracers for environmental research
381	Laser Research	2	1.9×10^{-4}	Sept. 92	Neutron generation
391	NOVA	3	2.0×10^{-3}	Sept. 92	Vaporization of targets
412	Environmental Research	—[d]	0.0	Mar. 92 Dec. 92	Environmental monitoring of soils and other media
419	Decontamination	2	0.0[c]	94 Annual	Decontamination of equipment (in process of being closed)
490	Laser Isotope Separation	4	0.0[c]	94 Annual	Melting and vaporization of uranium, isotope separation
491	Laser Isotope Separation	1	0.0[c]	94 Annual	Refurbishment of separator components
493	Support Facility	—[d]	0.0	Dec. 92	Isotope storage
513	Hazardous Waste Management	3	6.3×10^{-4}	Sept. 91	Storage, solidification, and shredding of waste
514	Hazardous Waste Management	1[e]	8.2×10^{-3}	94 Annual	Waste treatment
594	Environmental Research	—[d]	0.0	Dec. 92	Tracer experiments for atmospheric pollution

...continued

Table 12-1. Sources of radiation dose from LLNL releases to air (stacks on buildings containing radioactive materials management areas and area releases from diffuse sources) *(concluded).*

Bldg	Facility	Potential discharge points	Max EDE[a] (μSv/y)	Quarter reported[b]	Operations
612	Hazardous Waste Management	5	0.0	94 Annual	Lab packing, bulking, compacting, baling, and handling of waste; drum crushing
614	Hazardous Waste Management	—[d]	0.0	Dec. 92	Storage of waste
625	Hazardous Waste Management	—[d]	0.0	Dec. 92	Container storage
801	Site 300	—[d]	0.0	Mar. 93	Electron beam accelerator/ machining/firing table
	Site 300 Firing Table at 801	—[f]	1.1×10^{-1}	94 Annual	Detonation of explosives
804	Site 300	—[d]	0.0	Mar. 93	Low-level-waste storage area
810A	Site 300	—[d]	0.0	Mar. 93	Storage of parts
810B	Site 300	—[d]	0.0	Mar. 93	Storage of parts
822B	Site 300	—[d]	0.0	Mar. 93	Storage of parts
850	Site 300	—[d]	0.0	Mar. 93	Firing table bunker
	Site 300 Firing Table at 850	—[f]	0.0	94 Annual	Detonation of explosives
851	Site 300	—[d]	0.0	Mar. 93	Electron beam accelerator/firing table
	Site 300 Firing Table at 851	—[f]	1.5×10^{-2}	94 Annual	Detonation of explosives
854F	Site 300	—[d]	0.0	Mar. 93	Storage of mixed fission products
	Livermore site diffuse sources[e]	5	2.0×10^{-1}	94 Annual	Storage areas and contaminated ground
	Site 300 diffuse sources[e]	6	2.6×10^{-1}	94 Annual	Contaminated ground

[a] The maximum effective dose equivalent occurring at or beyond the site boundary from a single discharge point, among all discharge points modeled for the indicated facility or building.

[b] Date of quarterly or annual NESHAPs report submission to EPA.

[c] The effluents from the facility are and will continue to be monitored.

[d] Radionuclides are not in use, are encapsulated or sealed, or the quantities fall below the screening levels for modeling.

[e] Diffuse sources are described briefly on p. 12-14, and more fully in the 1993 NESHAPs Annual Report (Harrach et al. 1994).

[f] Open air dispersal in 1993.

[g] Table entries refer to routine operations. Building 251 had an unplanned release, described in the section on Monitored Releases of Radioactive Materials (see p. 12-9).

Table 12-2. Major contributors to LLNL's radiation dose via airborne emissions, 1993.

Facility or operation[a]	Dominant radionuclide(s)	EDE at SW-MEI[b]	
		μSv/y	mrem/y
Livermore site			
B331/Tritium Facility	^{3}H	0.35	0.035
B612 Yard Area[c]	^{3}H	0.20	0.020
B331 Exterior[c]	^{3}H	0.038	0.0038
B321	^{238}U	0.017	0.0017
B282	^{3}H	0.016	0.0016
SE Quadrant[c]	^{239}Pu	0.015	0.0015
B514[c]	^{238}U,^{235}U, ^{241}Am	0.0082	0.00082
Sum of other sources	Various	0.013	0.0013
		Total = 0.66[d,e]	0.066[d,e]
Site 300			
B801/firing table	^{238}U,^{234}U,^{235}U	0.11	0.011
Soil resuspension[c]	^{238}U,^{234}U,^{235}U	0.26	0.026
		Total = 0.37[d]	0.037[d]

[a] The facilities cited here are discussed in the text of this report, and in more detail in the NESHAPs quarterly and 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 12-1, which represent the dose from the single largest emission point on each facility. The site-wide maximally exposed individual member of the public (SW-MEI) is defined on p. 12-12.

[c] Diffuse sources (see text).

[d] These Livermore site and Site 300 totals represent 0.7% and 0.4%, respectively, of the federal standard.

[e] Directly measured emissions (mainly those from Buillding 331 stacks and SE quadrant diffuse emissions) comprise 56% of this total; the remainder is estimated by CAP88-PC calculations assuming unabated emissions
(see text).

Table 12-3. Comparison of background and LLNL radiation doses, 1993.

	Individual dose[a]		Population dose[b]	
Location/source	**(mSv)**	**(mrem)**	**(person-Sv)**	**(person-rem)**
Livermore-site sources				
Atmospheric emissions	0.00066	0.066	0.0098	0.98
Site 300 sources				
Atmospheric emissions	0.00037	0.037	0.069	6.9
Other sources[c]				
Natural radioactivity[d,e]				
Cosmic radiation	0.3	30	1,900	190,000
Terrestrial radiation	0.3	30	1,900	190,000
Internal (food consumption)	0.4	40	2,500	250,000
Radon	2.0	200	12,500	1,250,000
Medical radiation (diagnostic procedures)[e]	0.53	53	3,300	330,000
Weapons test fallout[e]	0.011	1.1	68	6,800
Nuclear fuel cycle[e]	0.004	0.4	25	2,500

[a] This dose represents that experienced by the site-wide maximally exposed individual member of the public.

[b] The population dose is the collective (combined) dose for all individuals residing with an 80-kilometer 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.

13. Compliance Self-Monitoring

Allen R. Grayson

Introduction

The environmental monitoring program at LLNL focuses on the evaluation of possible impacts of potential pollutant releases on the local community and environment. For this purpose, sampling and analysis of media at the site boundary are most effective. Previous sections of this report describe these efforts. In addition, LLNL samples specific waste streams prior to or during discharge or emission from the site. Often this monitoring is required by regulatory agencies. Generally, these waste streams are emitted from processes that, either due to the nature of the materials used or the large quantities produced, are considered to be potential sources of pollutants. The methods range from actual sampling of the waste stream as it is generated, to visual inspection of operational conditions, depending on the waste stream and the requirements of the regulatory agency.

LLNL implements process controls to prevent the release of significant quantities of pollutants, and the volumes of the waste streams are usually modest. However, the monitoring requirements frequently are developed under federal or state pollution control programs that are designed to detect pollutant releases from industrial facilities, whose characteristic waste streams differ from that of a multidisciplinary research and development facility.

Discharges of Treated Ground Water

Past hazardous materials handling and disposal practices, and leaks and spills that have occurred at the Livermore site and Site 300, both prior to and during LLNL operations, have resulted in concentrations of environmental contaminants that are unacceptable by current standards. The Environmental Restoration Division at LLNL addresses Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) compliance issues, assesses the impact of such releases on the environment, and determines the restoration activities needed to reduce contamination concentrations to protect human health and the environment. Restoration activities include soil removal, ground water and surface water treatment, and closure of inactive facilities in a manner designed to prevent environmental contamination. Self-monitoring is required at the point of discharge from the treatment facility to verify performance and effectiveness. The self-monitoring activities and results which

LLNL performs for compliance with environmental discharge parameters are described below.

Treatment Facility A

Ground water containing volatile organic compounds (VOCs) is treated at Treatment Facility A (TFA). Waste Discharge Order (WDR) No. 88-075 requires a monthly grab sampling program for this facility (see **Table13-1** for discharge limits). In 1993, TFA successfully treated over 87million liters of ground water containing VOCs. Self-monitoring analytical results of TFA effluent samples indicate that the VOC discharge limit of 5 ppb was not exceeded during 1993.

Treatment Facility B

WDR Order No. 91-091 governs the operation of Treatment Facility B (TFB) and imposes monthly grab sampling requirements (see **Table13 -2** for discharge limits). This facility is used to treat ground water contaminated with VOCs and chromium. In 1993, TFB successfully treated nearly 55million liters of ground water. Self-monitoring analytical results of TFB effluent samples indicate that the VOC discharge limit, which is 5 ppb, was not exceeded. LLNL exceeded the 10-ppb detection limit for hexavalent chromium, which is very close to the discharge limit of 11 ppb, and has taken measures to reduce and control the levels of hexavalent chromium.

Treatment Facility C

LLNL also conducted monthly grab sampling at the newly constructed Treatment Facility C (TFC), designed to treat ground water contaminated with VOCs and chromium. The facility was constructed in 1993 and began operation for ground water treatment on October 30 under WDR Order No.91 -091. The monthly self-monitoring analytical results of TFC effluent samples indicate that the VOC discharge limit of 5 ppb was not exceeded during 1993.

Treatment Facility F

Treatment Facility F (TFF) is used in support of the DOE-sponsored Dynamic Stripping research project (located at the Building 403/406 Gas Pad) as well as soil and ground water remediation. The discharge of ground water remediated at TFF to the sanitary sewer (which in 1993 amounted to 42.7 million liters) is governed by the provisions of the Livermore Water Reclamation Plant (LWRP) permit for LLNL. 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 13-3 shows the BETX sampling results; no result was above the detection limit. Annual sample results for total toxic organics, sampled on December 14, 1993, showed nondetects for all reportable organic compounds (detection limit is 0.01 mg/L). Two compounds not regulated under the total toxic organic compound standard were detected: acetone at 0.017mg/L, and 1,1,2-trichloro-1,2,2-trifluoroethane at 0.065 mg/L. These values for the nonregulated compounds are well below the LWRP permit limit of 1.0 mg/L for total toxic organic compounds.

Annual metals sample results for NPDES metals (EPA Method 200) are shown in **Table13-3** . No results were found above discharge limits. Annual total cyanide sample results (EPA Method 335.2) for the year, sampled on December 14, 1993, showed nondetects at the reporting limit of 0.020mg/L. The LWRP permit limit for cyanide is 0.04 mg/L.

Also during 1993, a short-term experimental operation to evaluate the use of steam for contaminant removal was permitted. The experimental operations ran in two phases and ended on June 30, 1993. The steam was provided by a steam boiler, whose process streams were also regulated. Discharge limits for these process streams were the same as for remediated ground water. Self-monitoring results for the semiannual monitoring period at TFF, including both experimental runs, demonstrated compliance with BETX self-monitoring provisions of the permit.

Monitoring Well-566 Discharge of Ground Water to Sanitary Sewer

Under Treatability Permit No. 1510G (93–94), LLNL discharged untreated ground water to test well drawdown and determine extraction influences around Monitoring Well-566. Data from the April 1, 1993, and May 17, 1993, sampling events reported VOCs at 275µg/L and 291µg/L, respectively. The drawdown test was performed over a 48-hour period between September 31 and October 2, 1993. During the test duration, a total of 245,700 liters of ground water was extracted. Compliance sampling at the end of the 48-hour test period on October 2, 1993, confirmed that all discharges were below the LWRP discharge limits.

Site 300 Central General Services Area Treatment Facility

A ground water and soil vapor extraction and treatment system was constructed in 1993 to respond to a CERCLA mandate to remove VOCs from the central General Services Area. During 1993, some 433,000 liters of ground water containing 187 grams of VOCs were extracted and treated. Pilot extraction and treatment of VOCs in soil vapor has started, and regular soil vapor extraction and treatment is scheduled to commence in mid-1994. Monthly grab sample self-monitoring requirements are listed in **Table 13-4**, which also shows the regulatory restrictions, none of which were exceeded.

Site 300 Building 834 Treatment Facility

During 1993, the pilot ground water and soil vapor extraction system at Building 834 was upgraded in preparation for a CERCLA Removal Action, set to begin in early 1994. Ground water will be treated by air-sparging. Vapor-phase TCE will be treated by carbon adsorption. The substantive requirements for this removal action are listed in **Table 13-4**.

Storm Water Runoff

Storm water contacts a large number of potential pollution sources and can disperse contaminants across broad areas. For this reason, comprehensive sampling and analysis of storm water discharges is not a practicable means of isolating and controlling pollutant releases. To evaluate the overall impact of LLNL 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 6, assess the effectiveness of LLNL's pollution control program. To prevent releases of pollutants, LLNL implements Best Management Practices at construction sites and at facilities that use significant materials (as defined by the storm water regulations) that might contact storm water. The permits under which storm water is discharged require that LLNL inspect these locations to assure that the necessary management measures are being implemented.

Under the California General Construction Activity Storm Water Permit, three construction sites were inspected during 1993. These included the Closure of Landfill Pits 1 and 7 Project, the Site 300 Main Gate Road Improvement Project, and the construction of Building 132. Monitoring included visual observation of sites both before and after storms to assess the effectiveness of implemented Best Management Practices and, if necessary, to modify these practices to accomplish better storm water runoff protection. LLNL made no changes to the Best Management Practices implemented at each of these large construction sites. However, minor changes were made to smaller projects located in environmentally sensitive areas. These changes included the addition of staked haybales to minimize sediment in runoff and modifying storage of materials to prevent the introduction of these materials into storm water runoff.

Under the California General Industrial Activity Storm Water Permit, visual inspections of the storm drainage system are required monthly during the wet season when significant storm events occur, and twice annually during the dry season to identify any dry weather flows. Wet weather observations found floatables that were evidence of debris (mostly leaf litter) washing from the site, and cloudy water from heavy sediment load carried in the storm water. Dry weather observations indicated three specific areas where ponding and growth of vegetation was evidence of dry weather flow. These are located in Arroyo Las Positas, but the observations are believed to be associated with landscape irrigation overflows.

Each LLNL directorate must inspect its facilities once each year to verify that Best Management Practices are being followed. Pending finalization of LLNL's

Storm Water Pollution Prevention Plans, which define Best Management Practices, the facility inspections were not performed during 1993.

Livermore-Site Central Drainage Basin

The Central Drainage Basin (CDB; see **Figure 13-1**) was lined as part of the Livermore-site remedial activities and has a capacity of approximately 53 million liters (43 acre-feet). Remedial action studies had indicated that infiltration of storm water from the basin was a cause of increased dispersal of ground water contaminants. Basin lining was completed in March 1992 and LLNL adopted the *Drainage Retention Basin Management Plan*.

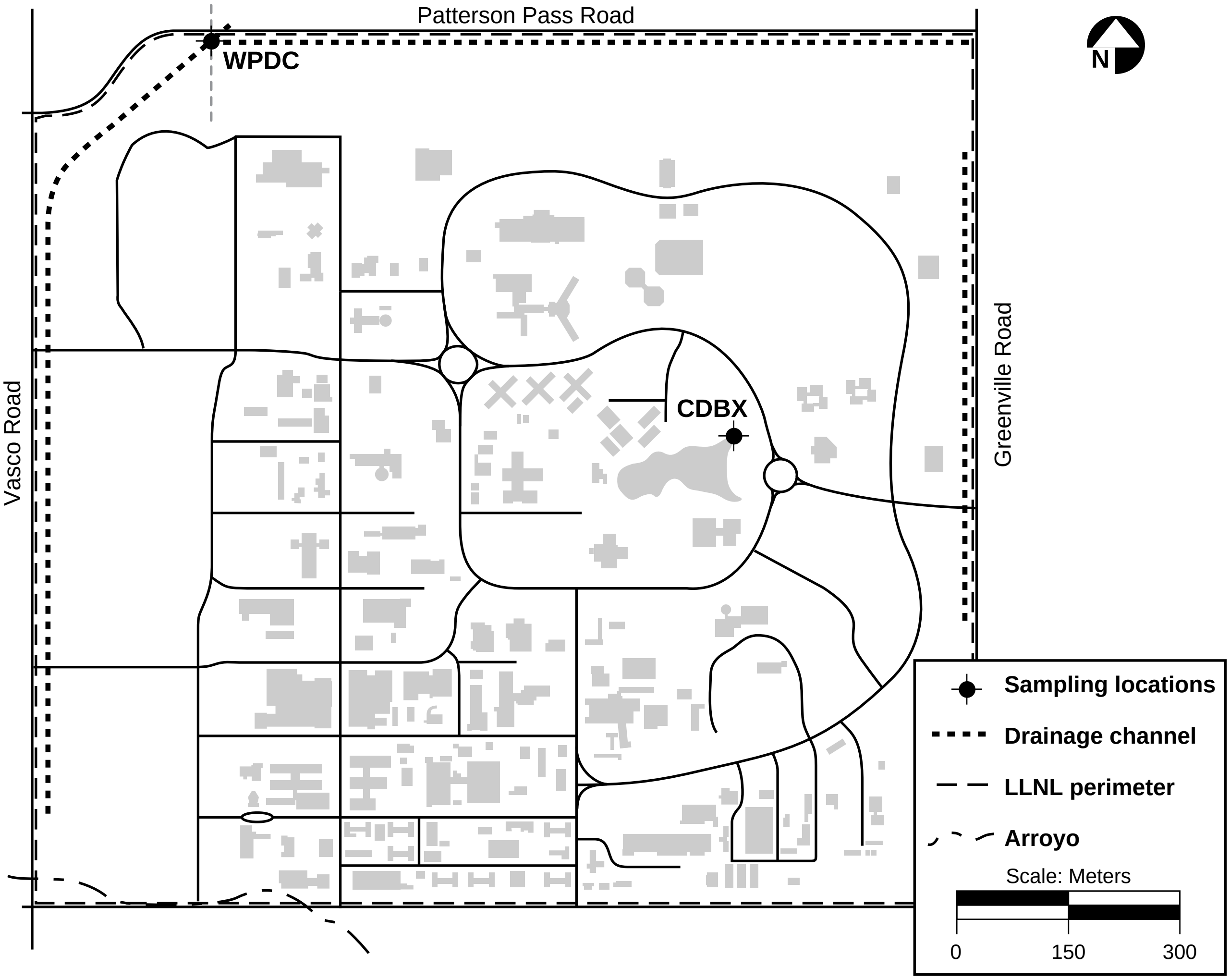

Figure 13-1. Sampling locations to monitor compliance with waste discharge permit.

The focus of the Management Plan was to implement a long-term biological monitoring and maintenance program and to address water quality problems through reduction of nutrient loading and bioremediation. Water quality management objectives are maintained through sediment removal in sediment basins located at the influent points to the CDB; management of upstream watershed activities; use of submersed plants and, in the shallow portions of the basin, rooted aquatic plants to remove urban runoff pollutants and control erosion of the basin lining cover; and addition of oxygen by means of recirculating pumps.

The Management Plan identifies two sources of water to fill and maintain the level of the CDB. The primary water source it identified in the Management Plan 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 CDB. The secondary water source identified in the Management Plan was storm water runoff. During 1993, storm water runoff was the only source of water to the CDB.

The San Francisco Regional Water Quality Control Board (SFBRWQCB) regulates discharges from the basin under WDR NO. 91-091, NPDES Permit No.CA0029289, and the Livermore-site CERCLA Record of Decision. WDR No.91-091 and the CERCLA Record of Decision establish discharge limits for all remedial activities at the Livermore site through the storm water collection system, directly to arroyos, to infiltration trenches, to injection wells, and discharges from the CDB to the Livermore storm water collection system. Discharge limits are found in **Table 13-2**. Exceeding any of these limits constitutes noncompliance with the NPDES permit and the CERCLA Record of Decision.

In 1992, LLNL developed a sampling program for the CDB which was approved by the SFRWQCB. The sampling program consists of sampling discharges from the CDB and the site storm water outfall (location WPDC; **Figure13 -1**) every month during the first year (1992) and in subsequent years during the first release from the CDB and two additional storms (chosen in conjunction with storm water runoff monitoring). In addition, LLNL agreed to conduct and report to the SFBRWQCB routine monitoring of the basin as specified in the Management Plan for water quality management objectives. Water quality management objectives are found in **Table13-5** ; they are used as a tool to optimally operate the CDB. While operation outside these parameters does not constitute noncompliance with limits established in the NPDES permit and CERCLA Record of Decision, it indicates that an action should be taken to properly maintain water quality within the CDB.

Since September 1993, results of routine water quality monitoring for management parameters and discharges monitoring have been reported to regulatory agencies in the monthly, quarterly, and annual ground water project progress reports.

Sampling is performed to provide information necessary to establish compliance with WDR No. 91-091 and the Applicable, Relevant, and Appropriate Requirements identified in the CERCLA Record of Decision; to provide information necessary for CDB maintenance; and to document the effectiveness of nutrient removal.

Sampling to determine compliance with WDR No. 91-091 occurs at the CDB outfall (CDBX) and at the site storm water outfall monitoring location at Arroyo Las Positas (WPDC). These sampling locations are identified in **Figure 13-1**. During the 1992–93 wet season, site outfall monitoring was conducted at a point upstream of WPDC (at location ALPX). However, ALPX was eliminated at the beginning of the 1993–94 wet season and replaced with WPDC. Discharge monitoring parameters are identified in **Table 13-5**.

Sampling to determine whether water quality maintenance objectives are met is conducted at several points within the CDB. Sampling for dissolved oxygen and temperature occurs at eight locations identified in **Figure 13-2**. Sampling during the 1992–93 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, all sampling locations except CDBE located at the middle depth of the CDB were eliminated starting March 31, 1993, for all parameters except dissolved oxygen and temperature. The routine maintenance parameters are identified in **Table13 -2**.

During 1993, only diesel and nickel exceeded NPDES discharge limits. A new analytical laboratory contractor reported sample detection limits that in several cases were well above required discharge limits. By November 1993, analytical test methodologies had been revised to have the capacity to acquire sample results below discharge limits.

Diesel exceeding discharge limitations was seen once in January 1994. This level of hydrocarbons is consistent with normal storm water runoff and was also seen in storm water runoff sampling discussed in Chapter 6. Nickel was seen for the first time in December 1993 but has continued to show up in samples collected in early 1994. Nickel from the CDB is higher than the nickel found in storm water discharges at the site, but is not inconsistent with these discharges.

During 1993, turbidity, pH, nitrate, ammonia nitrogen, phosphorous, total phosphate, silver, and zinc levels exceeded acceptable management objectives and/or management action levels (**Table 13-6**). However, no constituent from CBD discharges was found in excess of NPDES permit discharge limitations. Dissolved oxygen concentrations rarely were maintained at the management objective of at least 80% saturation of oxygen in the water. On only two monitoring events, in April and July 1993, did concentrations drop below the critical management action level of 5 mg/L.

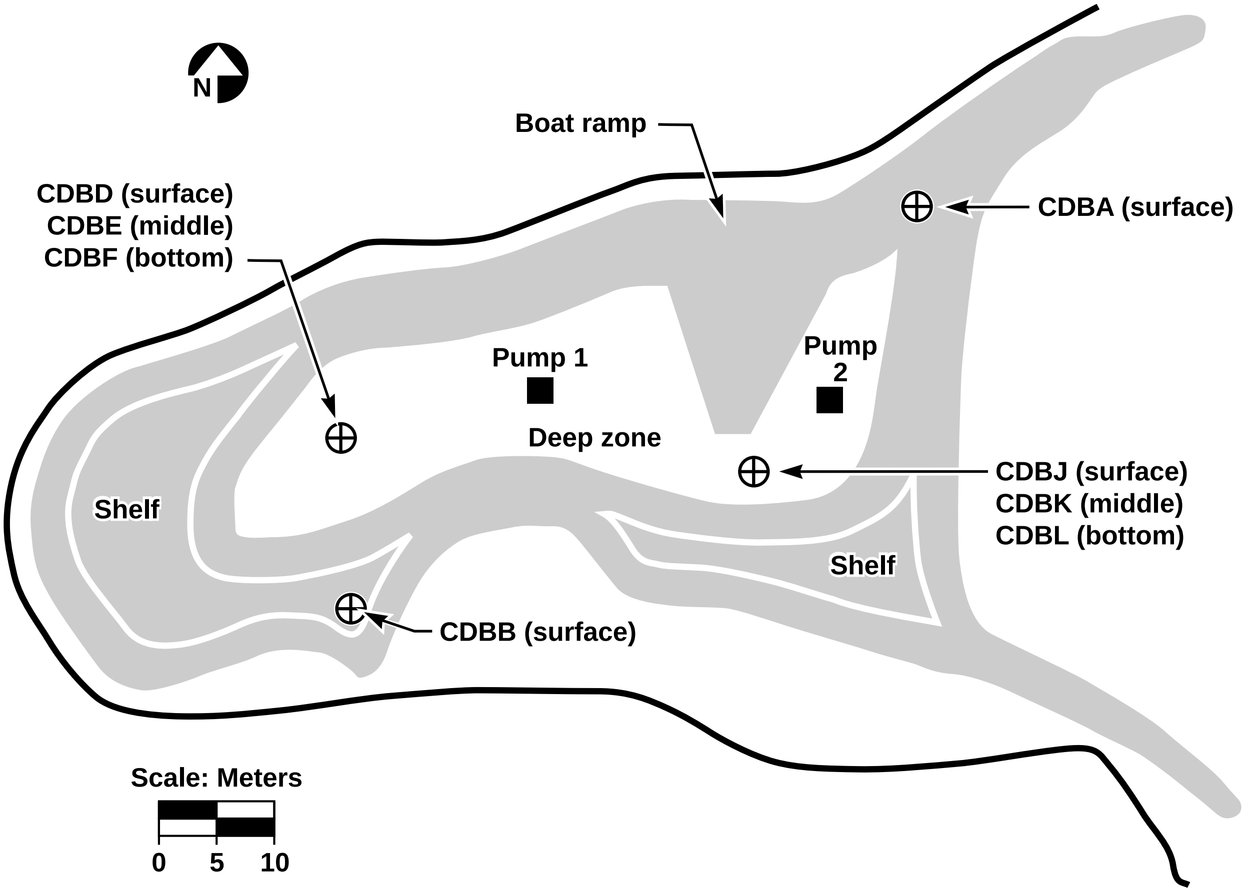

Figure 13-2. Sampling locations within Central Drainage Basin to determine maintenance of water quality objectives.

Dissolved oxygen levels were controlled manually with aeration pumps temporarily installed in the CDB. Permanent pumps were purchased and received in 1993 but installation was not completed until March 1994. The aeration pumps are started whenever oxygen levels at any level of the CDB drop close to or below the management action level of 5 mg/L. Maintaining adequate dissolved oxygen levels prevents nutrient release back into the CDB water column by decaying organic matter in the bottom sediments.

Elevated turbidity above acceptable management levels occurred during the 1993–94 wet season and is probably a result of sediments discharging into the CDB that were not captured by the sediment traps. The sediment traps were not cleaned after the 1992–93 wet season and, therefore, may have not been functioning properly. Maintenance will be scheduled prior to the 1994–95 wet season to avoid similar turbidity problems. In addition, a management contract was implemented with a landscaping company in December 1993 to assure that the plants contained within the nutri-pods (suspended nylon sacks that house the plants) are maintained within the proper photic zone to allow optimal growth.

Nutrient levels for nitrate/nitrites, total ammonia, and phosphate/phosphorous had higher than acceptable management levels from the beginning of 1993 through November 1993. December results showed nutrient levels to be below management levels. The nutrients are introduced from storm water discharges, from introduction of fecal matter to the lake resulting from migrating water fowl and the mosquito fish population, and from decaying organic matter. The plants introduced to the lake to reduce nutrient loading had died off in late 1992, most likely as a result of inadequate light supply because the plant pods had sunk below the photic zone.

Repair of the pods, replacement of plants, and planting of the shallow shelf areas occurred in September 1993. By November 1993, ammonia nitrogen was the only nutrient elevated above CDB management levels. By December 1993, all nutrients were below management levels. The restocking of the plants and the beginning of the wet season, which resulted in flushing the lake with new storm water runoff flows, was probably responsible for the decrease in nutrient levels.

Silver and zinc above acceptable management levels were seen only once in third-quarter monitoring results. The source of these elevated metals is unknown. Subsequent monitoring in 1994 did not show these metals above detection limits.

Site 300 Cooling Tower Discharges

The Self-Monitoring Program of NPDES Permit No.CA0081396 (WDR Order No. 82-105) requires LLNL to submit quarterly results of biweekly monitoring of the flow, temperature, and pH of cooling tower wastewater discharges. The cooling towers used to cool buildings and equipment at Site 300 discharge non-contact cooling water to man-made and natural surface drainage courses that drain into Corral Hollow Creek. Corral Hollow Creek is a tributary of the San Joaquin River, a water of the United States, and hence is governed by an NDPES permit.

Currently, 17 towers discharge wastewater to on-site surface drainage courses. Most of the towers are of such low-volume flow and located in remote areas of Site 300 that the wastewaters never reach Corral Hollow Creek, except possibly during rain storms, and then the wastewater contribution to the total runoff discharges is negligible.

Specific limitations imposed by the NPDES permit include: flow not to significantly exceed design volume; temperature not to alter the ambient temperature of the receiving water by more than 5°F; and pH must be within the range of 6.5–8.5 pH units. **Table 13-7** presents a summation of the 1993 monitoring data for flow, pH, and temperature, respectively.

Samples of the discharged wastewater indicate that the discharges routinely exceed the permit pH limitation. The noncomplying pH levels occur during normal operations. Water used in the cooling towers is supplied by on-site drinking water wells, and the pH of this water ranges from 8.1–8.7. The addition of corrosion-inhibiting chemicals further raises the pH.

LLNL originally notified the Regional Water Quality Control Board about exceeding the pH limitation in 1991 and submitted a compliance plan and time schedule to bring the towers into compliance. LLNL will eliminate the surface discharge from 14 of the 17 cooling towers by engineering the wastewater discharges to percolation pits by December 1994. In a permit renewal application submitted in December 1991, LLNL requested that the pH range for the three towers continuing to discharge to surface drainage courses be expanded to 6.5–10.0. RWQCB staff have supported the expansion of the pH range due to the low threat imposed by the cooling towers upon the surface waters. The new permit was issued on May 20, 1994, with the expanded permit range.

Discharges from Categorical Processes

Self-monitoring pretreatment programs are required at both the Livermore site and Site 300 by the LWRP under the authority of San Francisco Bay Regional Water Quality Control Board. The sampling and monitoring from nondomestic, industrial sources covered by pretreatment standards defined in 40 CFR 403 is required in the 1993–94 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 general and specific discharge standards 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 industrial categories. The LWRP has identified specific LLNL processes that fall under the regulation of two categorical standards: electrical and electronic components and metal finishing.

Fifteen electrical, electronic component, and metal finishing processes operated at LLNL are regulated as “categorical processes” under the Clean Water Act and regulations. Five processes discharge directly to sanitary sewer, another five processes are discharged indirectly through dedicated retention tank systems. The remaining five processes are either treated prior to discharge to sanitary sewer or are shipped off site for disposal. **Tables 13-8** and **13-9** provide LLNL’s internal discharge limits for these wastewaters. 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 Livermore Water Reclamation Plant (LWRP). Quarterly and semiannual sampling results, as well as the current status of all identified processes, are reported in semiannual wastewater reports submitted to the LWRP. In 1993, no exceptions to the pollutant limitations of the discharge permit were observed.

Table 13-1. Treated ground water discharge limits identified in WDR Order No. 88-075 for TFA.

Constituent	Discharge limit[a]	Units
Metals		
Antimony	1.46	mg/L
Arsenic	500	µg/L
Beryllium	0.68	µg/L
Boron	7	mg/L
Cadmium	100	µg/L
Chromium (+3)	1700	mg/L
Chromium (+6)	500	µg/L
Copper	2	mg/L
Iron	3	mg/L
Lead	500	µg/L
Manganese	500	µg/L
Mercury	20	µg/L
Nickel	134	µg/L
Selenium	100	µg/L
Silver	500	µg/L
Thallium	130	µg/L
Zinc	20	mg/L
Volatile organic compounds		
Total volatile organic compounds	5	µg/L
Acid extractable organic compounds		
2,4-Dimethylphenol	400	µg/L
Phenol	5	µg/L
2,4,6-Trichlorophenol	5	µg/L
Base/neutral extractable organic compounds		
1,4-Dichlorobenzene	5	µg/L
Naphthalene	620	µg/L
Phenanthrene	5	µg/L
Pyrene	5	µg/L

[a] These limits are instantaneous maximum values.

Table 13-2. Treated ground water and Central Drainage Basin discharge limits identified in WDR Order No. 91-091 for outfalls at locations CDBX, WPDC, TFB, and TFC.[a]

Parameter	Discharge limit[b]
Metals (μg/L)	
Antimony	1460
Arsenic	20
Beryllium	0.7
Boron	7000
Cadmium	5
Chromium (total)	50
Chromium (hexavalent)	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 (units)	6.5–8.5
Toxicity	
Aquatic survival bioassay (96 hours)	90% survival median, 90 percentile value of not less than 70% survival

[a] Monitoring occurs at first discharge from the CDB and at two additional discharges associated with storm water runoff monitoring. Toxicity testing using the aquatic survival bioassay occurs only once per year.

[b] Discharge limits do not apply to samples collected at the storm water runoff location WPDC.

Table 13-3. Self-monitoring sampling results, Treatment Facility F.

Parameter	Sample date	Concentration (mg/L)	Effluent limitations[a] (mg/L)
BETX (total)	February 3, 1993	<0.01	0.25 (LWRP permit)
	June 3, 1993	0.027	
	September 22, 1993	<0.01	
	December 14, 1993	<0.01	
Metals[a]	December 14, 1993		
Arsenic		0.005	0.06
Cadmium		<0.0005	0.14
Copper		0.014	1.00
Chromium (total)		<0.010	0.62
Lead		<0.0020	0.20
Mercury		<0.0002	0.01
Nickel		<0.0050	0.61
Silver		<0.0005	0.20
Zinc		<0.020	3.00
Cyanide	December 14, 1993	<0.02	0.04
Toxic organics (total)	December 14, 1993	<0.01	1.00

[a] From Section 13.32.100 of the Livermore Municipal Code.

Table 13-4. Site 300 ground water treatment effluent limitations.

	Treatment facility	
Parameter	**General Services Area**	**Building 834**
VOCs[a]		
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	—[b]
pH	Between 6.5 and 8.5 and no receiving water alteration greater than ±0.5 units	Between 6.5 and 8.5
Temperature	No alteration of ambient conditions more than 5°F	—[b]
Place of discharge	To surface water drainage course	Treated effluent to ground will be accomplished by misting
Total petroleum hydrocarbons		
Daily MCL	—[b]	100 µg/L
Monthly median	—[b]	50 µg/L
Flow rate (30-day average daily dry weather maximum discharge limit)	272,520 L	7570 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 and TPHs	Discharge limit ≤0.3 µg/L	Method EPA 601/602, modified EPA Method 8015, discharge limit ≤0.5 µg/L

[a] The sum of concentrations in a single sample shall not exceed 5 µg/L.

[b] No effluent limitation for this parameter at the treatment facility.

Table 13-5. Routine water quality management levels for the Central Drainage Basin.

Parameter	Location	Frequency	Management action levels
Physical			
Dissolved oxygen (mg/L)	CDBA, CDBC, CDBD, CDBE, CDBF, CDFJ, CDBK, CDBL	Weekly	Not less than 5, 80% saturation
Temperature (°F)	CDBA, CDBC, CDBD, CDBE, CDBF, CDFJ, CDBK, CDBL	Weekly	<60 and >80
Total alkalinity (mg/L)	CDBE	Monthly	<50
Chlorophyll A (mg/L)	CDBE	Monthly	>10
pH (units)	CDBA, CDBC, CDBD, CDBE, CDBF, CDFJ, CDBK, CDBL	Weekly	<6.0 and >9.0
Total suspended solids (mg/L)	CDBE	Monthly	
Total dissolved solids (mg/L)	CDBE	Monthly	>350
Turbidity (meters)	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/0.1L)	CDBE	Quarterly	>5000
Fecal coliform (MPN/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
Chromium, hexavalent	CDBE	Semiannually	>11
Copper	CDBE	Semiannually	>20
Iron	CDBE	Semiannually	>3000

...continued

Table 13-5. Routine water quality management levels for the Central Drainage Basin (*concluded)*.

Parameter	Location	Frequency	Management action levels
Metals (µg/L) (con't)			
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 (%/96-hour survival)			
Fish bioassay	CDBE	Annually	90% survival median, 90 percentile value of not less than 70% survival

Table 13-6. 1993 Central Drainage Basin monitoring events showing exceeded management action levels.

	Analyte						
	Nitrate/ nitrite (N)	**Ammonia nitrogen**	**Phosphorus total (as P)**	**pH**	**Turbidity secchi disk**	**Silver**	**Zinc**
Units	mg/L	mg/L	mg/L	units	meters	µg/L	µg/L
Action level	>0.2	>0.1	>0.2	>9.0 <6.0	<.914	>2.3	>58
Feb. 01		0.11	0.3				
Mar. 01		0.22	0.29				
Mar. 31	0.49		0.35				
May 21			0.26				
June 09			0.3				
July 07							
Aug. 31		0.26	0.17				92
Sept. 30			0.16	9.1		11	
Oct. 15	0.51	0.12	0.11				
Nov. 19		0.27					
Dec. 28					0.5		
Number of samples	11	11	11	11	11	11	11

Table 13-7. Cooling tower monitoring summary, 1993.

Tower	Number of samples	Minimum	Maximum	Average	Standard deviation
Flow (liters)	**Not to exceed design flow**				
851 (#1)	25	1276	6132	4294	1249
851 (#2)	21	87	1706	611	1283
854	24	169	4939	2321	1334
865	24	0	42,256	15,009	12,923
801	24	0	21,739	7388	5797
812	12	338	1619	1187	1470
805	21	87	1363	392	1300
807	14	169	1363	748	1427
809	20	87	1276	612	1293
810	23	169	2044	1029	1166
815	20	125	4633	1249	1529
817	17	169	1450	671	1380
826	15	169	1706	813	1472
827 (#1)	23	507	6132	1927	1715
827 (#2)	20	850	5789	2923	1373
828	16	256	5282	993	1765
836A	25	0	6160	1523	1929
836D	25	55	1483	548	1179
pH	**Not less than 6.5 nor greater than 8.5**				
851 (#1)	25	8.58	9.08	8.83	0.123
851 (#2)	24	7.63	9.86	8.75	0.659
854	22	8.56	9.45	8.87	0.223
865	0[a]				
801	0[a]				
812	12	8.52	9.22	8.91	0.225
805	21	8.09	9.60	8.80	0.334
807	14	8.39	9.46	8.83	0.328
809	20	8.43	9.20	8.82	0.214
810	23	8.63	9.79	8.90	0.297
815	20	8.31	9.41	8.78	0.248
816	17	8.39	9.19	8.80	0.248
826	15	8.28	9.32	8.92	0.272
827 (#1)	23	8.52	9.58	8.93	0.221
827 (#2)	20	8.62	9.10	8.89	0.145
828	16	8.50	9.40	9.04	0.305
836A	2	8.81	9.01	8.91	0.141
836D	1	8.79	8.79	8.79	

...continued

Table 13-7. Cooling tower monitoring summary, 1993 (*concluded*).

Tower	Number of samples	Minimum	Maximum	Average	Standard deviation
Temperature (°C) Not to alter receiving water by more than 2.8°C					
851 (#1)	25	40	45	42	1
851 (#2)	24	23	38	33	5
854	24	29	42	37	4
865	0[a]				
801	0[a]				
812	12	34	46	41	3
805	21	31	40	37	2
807	14	28	53	39	7
809	20	32	46	40	3
810	23	34	62	42	5
815	20	28	41	35	3
817	17	32	46	39	4
826	15	37	53	44	6
827 (#1)	23	29	49	39	5
827 (#2)	20	31	48	41	4
828	16	32	44	40	3
836A	2	35	39	37	3
836D	1	33	33	33	5

[a] Flow and pH not reported because samples collected from tank and, therefore, not representative of discharge effluent.

Table 13-8. LLNL's internal discharge limits for nonradioactive parameters in wastewaters from noncategorical and categorical processes, mg/L.

		Discharge limits[a]	
Parameter	Noncategorical[b]	Metal finishing	Electronic components
Metals			
Beryllium	0.74		
Cadmium	0.9	0.26	
Chromium (total)	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 (units)	5–10	5–10	5–10
Other			
Oil and grease	500		
Total dissolved solids	375 above background		

[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 13-9. LLNL's internal discharge limits for radioisotopes in wastewaters.

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)
Gamma	—[a]		—[a]	

[a] There is no gross gamma limit; isotope-specific limits apply.

14. Quality Assurance

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Introduction

Quality assurance (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 5700.6B 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 ofEnergy 1991) requires the preparation of an Environmental Monitoring Plan containing a QA section discussing the applicable elements of the American NationalStandards Institute/American Society of Mechanical Engineers (ANSI/ASME)NQA-1, *Quality Assurance Program Requirements for Nuclear Facilities* (ASME1989).

During the first nine months of 1993, LLNL conducted QA activities at the Livermore site and Site300 in accordance with a plan based on DOE Order 5700.6B and ANSI/ASME NQA-1 (Holland 1987). A revised QA plan, based on the new DOE Order 5700.6C, was developed and implemented in October (Garcia and Failor 1993). Sampling was conducted according to procedures published in an appendix to the LLNL *Environmental Monitoring Plan* (Gallegos etal. 1992b).

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 each laboratory's procedures. 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 quality assurance programs and documentation of methods.

In July 1993, three new laboratories were contracted to perform analyses of LLNL environmental monitoring samples after existing contracts for analytical services expired. These laboratories were chosen based on a lengthy selection process that included the development and specification of performance criteria, review of laboratory proposals, and audits of each candidate laboratory by a team of LLNL technical and QA personnel. Several minor problems related to definition of detection limits, data formatting, sample volume requirements, and subcontracting of analyses occurred during the transitional period but these issues are being resolved and a good working relationship is being established with the new laboratories.

Deviations and Changes to the Sampling Program

The sections below describe changes to the environmental sampling effort made during 1993, deviations from planned environmental sampling, and regularly scheduled samples for which data are not reported because they could not be collected or were lost during analysis.

Sampling Location Designators

Tables14-1 and **14-2** decode sampling location designators and provide a cross-reference for current designators and those used in previous years. Changes made in 1993 are noted on those tables.

Air Sampling Program

No changes were made to either the air tritium or the air particulate network during 1993. During the year, 1598 of 1664 possible air particulate samples and 472 of 494 possible air tritium samples were collected as part of the routine monitoring program. These represent sample recovery rates of 95% for air tritium and 96% for air particulates. (The Quality Assurance Plan [Holland 1987] sets a minimum sample recovery rate of 85%.) Air tritium sample loss was caused by sampler malfunction, loss of electric power, or breakage of sample flasks. Loss of air particulate samples was usually caused by sampler malfunction, weather (soaked or iced filters), or loss of electric power. In three cases, two or more of the weekly samples that are composited to give a monthly result were lost and the composite result could not be reported.

Sewage Monitoring Program

The sewage monitoring program was unchanged until the last month of 1993, when budgetary considerations led to some decrease in sampling activities, and health and safety concerns led to sampling protocol changes for monthly sampling of physical and chemical parameters.

During the October planning process, review of the sewage sampling protocols identified two locations that could be sampled and analyzed less frequently without affecting the goals of the monitoring program. Daily sampling of effluent discharge to LLNL by Sandia National Laboratories, California, is still conducted, but samples are not analyzed on a routine basis unless analysis of LLNL effluent indicates that a significant release has occurred.

Daily sampling of the treated wastewater discharged at the Livermore Water Reclamation Plant (LWRP) was also discontinued; past experience has shown that analytical results of LLNL samples allows adequate characterization of the immediate impacts of contaminant discharges. At this time, daily LWRP effluent samples are composited and analyzed once each week.

Sample and data capture in the compliance sampling program was excellent: 922 of 940 samples were acquired and analyzed, yielding a data capture rate of 98%. Missed samples resulted from failed sampling equipment, improper execution of the sampling procedure, and improper preparation and analysis of samples for biological oxygen demand.

Water Sampling Program

Routine water sampling networks in and around the Livermore site include Livermore Valley wells, Livermore Valley surface and tap water, Livermore-site storm water runoff, and Livermore Valley rain. Routine water sampling in and around Site 300 includes on-site monitoring wells, on-site production wells, on-site surface water, off-site domestic supplies, and rain. Ground water monitoring at Site 300 includes surface impoundments and landfills.

Valley wells are sampled annually. Twenty-two planned samples, including duplicate quality control samples, were taken and analyzed, giving 100% sample recovery for that network. Livermore Valley waters are sampled quarterly at 11 locations and monthly at the LLNL swimming pool. A total of 168 samples was planned for 1993; 166 were collected and analyzed, resulting in a 99% recovery rate. One planned pool sample was overlooked and another could not be taken because the pool was empty.

Livermore-site storm water runoff was sampled for nine different storms during 1993. For quality control purposes, duplicate samples were taken at one location for each storm. Eleven of 491 planned samples were lost, resulting in a sample recovery of 98% for that network.

Livermore Valley rain was sampled at 19 locations during the spring and 11 locations during the fall of 1993. Duplicate quality control samples were taken at two locations during each storm. (This network was reduced in size during the fall as described in Chapter 6 on Surface Water Monitoring.) Rain from thirteen storm events was collected during 1993, but due to budget constraints, only five of the sample sets, one per month of the rainy season, were submitted for analysis. For those five events, 237 of 265 planned samples were successfully analyzed, giving a sample recovery of 84%. Samples were considered lost when there was insufficient rainfall for analysis or when sample buckets were missing at the time of collection. Locking the sample buckets to the sampling locations has resulted in fewer samples being lost due to missing buckets.

All forty of the planned samples from Site 300 production wells were successfully collected and analyzed. One domestic well near Site 300 is sampled monthly, six are sampled quarterly, and 10 are sampled annually. For these wells, 141 samples were planned and 140 were obtained and analyzed, giving a recovery rate of 99%. The missed sample occurred when sampling technologists were unable to gain access to a well owner's property. Six Site 300 rain samples were planned and analyzed, giving 100% recovery.

Changes to the routine water sampling networks are described in Chapter 6.

Site 300 ground water monitoring includes 38 wells representing six landfill pits, the High Explosives (HE) Process Area, and four wells of general interest. Only 5 of 2645 planned ground water samples could not be taken in 1993; this was due to a hose leak in one of the Barcad samplers. The sample recovery rate was greater than 99% for that network. Changes to the ground water monitoring network made in 1993 are described in Chapter 7 on Routine Ground Water Monitoring.

Vegetation and Foodstuff Sampling Program

No changes were made to the vegetation sampling program in 1993. Of 80 planned samples, 78 were collected and analyzed, giving a 98% recovery rate. The honey network was also unchanged in 1993. All seven planned samples were collected and analyzed, giving a 100% recovery rate for honey.

The distribution of wine samples was changed from six European and four California wines in 1992 to four European and six California wines in 1993 because the comparison of Livermore wines to California wines is of greater interest than the comparison with European wines. Planned wine sampling also included twelve Livermore Valley wines and three QA duplicates. Of the 25 planned samples, 23 were successfully collected and analyzed, resulting in a sample recovery rate of 92%.

No cow milk samples were taken in 1993. One of the six goat milk sample providers moved during the year, reducing the total number of available locations to five. One duplicate sample was also taken for QA purposes. As occurs every year, goat milk was not available from any providers in January and December because goats do not produce milk during these months. Out of 60 planned milk samples, 56 were collected and analyzed, giving a recovery rate of 93%.

Environmental Radiation Monitoring Program

No major changes were made to the environmental radiation monitoring program in 1993. Of 316 planned thermoluminescent dosimeter (TLD) measurements, 20 could not be analyzed, leading to a 94% recovery for this network. All planned neutron measurements were completed successfully.

Missing TLDs usually result from consumption or other interference by cows, or from vandalism.

Meteorology Monitoring Program

Meteorological instruments at both the Livermore site and Site 300 take readings every 2 to 3 seconds throughout the year. These readings are combined to a 15-minute average which is archived. The industry- and EPA-approved interval for model input and wind rose calculation is an hourly average; these are computed from the 15-minute results. All equipment at both meteorological towers was operational for the entire year. Calibrated sensors (traceable to National Institute for Standards and Technology) for air temperature, wind speed, wind direction, and relative humidity were routinely replaced with newly calibrated instruments twice during the year. Data recovery at the Livermore site was 99.8% and recovery at Site 300 was 93%. Data loss was caused by downtime for calibration and equipment problems at Site 300.

Soils/Sediments Monitoring Program

Soils were sampled at 21 locations at the Livermore site and in Livermore Valley and at 14 locations at Site 300. All planned samples were obtained and successfully analyzed for radionuclides and beryllium. No changes to soil sampling locations were made during 1993.

All ten planned sediment samples at the Livermore site were collected and analyzed for radionuclides, giving a recovery rate of 100% for those analytes. Sediment samples were not analyzed for metals or organic compounds because of an inadvertent failure to properly request those analyses from the new analytical laboratory. This is of minor concern, however, as historically only those contaminants that are typical of suburban storm water runoff, such as copper and zinc, have been found in sediment samples.

Quality Assurance Activities

Major accomplishments in the area of Quality Assurance during 1993 include the publication of a new QA plan based on DOE Order 5700.6C, continued work on sampling and analysis procedures, the development of an on-the-job (OJT) training program for sampling technologists based on those procedures, the creation of a computerized document retention center, and qualification and development of relationships with new analytical laboratories. The new QA plan is tailored to meet the needs of the Environmental Monitoring Section and was created after a thorough evaluation of the Section’s activities. The plan uses a risk-based approach that takes resource requirements into consideration while developing QA controls for quality-affecting activities. Two staff members completed a DOE-sponsored course for OJT instructors and subsequently created a formal performance-based OJT program used to train three new sampling technologists during 1993. Development of the Document Retention Center is complete; however, resource limitations have precluded its implementation.

During 1993, 166 Nonconformance Reports (NCRs) were written. The major sources of NCRs were difficulties with air monitoring equipment, followed by analytical laboratory issues. Problems with air monitoring equipment are related to weather and to the effects of constant use with environmental exposure. Significant improvements cannot be made in this area without expensive equipment upgrades; at this time, the number of samples lost does not justify the expense of these improvements. Issues with analytical laboratories are expected to decrease as the relationship with new contract laboratories continues to improve.

Participation in Laboratory Intercomparison Studies

During 1993, LLNL's Radiation Analytical Sciences (RAS) laboratory and the Hazards Control Department Analytical Laboratory (HCAL) both participated in the EPA's Environmental Monitoring Systems Laboratory (EMSL) Intercomparison Studies Program. **Table 14-3** shows the comparison of analyses by these laboratories with known values. The ratio of the measured value to the known value is considered acceptable if it falls between 0.7 and 1.3. However, normalized deviations that fall between 0.7 and 0.8 and those that fall between 1.2 and 1.3 are considered suspect and could indicate a potential problem with laboratory accuracy. RAS achieved 15 of 15 results, or 100%, within the acceptable range.

Only 50% of the HCAL results were within the acceptable range. The HCAL results for tritium analysis fell outside of specified control limits in June 1993 and within the questionable range in November 1993. The June value was reported incorrectly (an exponent was inadvertently omitted). Both the June and the November values were affected by a faulty lot of scintillation cocktail. Apparently, the lot was not stable with age and affected the quench characteristics such that the quench-curve-determined efficiency was 28% too high. This could mean that tritium analyses in water performed during that period were up to 28% too low. This laboratory only performs analyses for tritium in sewage and the tritium levels are far enough below reporting levels in that medium that the discrepancy is not of serious concern. The laboratory has initiated procedures to ensure that the problem does not recur. The HCAL results for gross alpha in January (10.33 pCi/L) fell far below the known value of 34.0pCi/L. However, the grand average for that analysis, shown next to the known value, was only 17.09 pCi/L. The grand average is the average value reported by all laboratories participating in the study with outliers eliminated. The fact that the grand average was only 50% of the known value might suggest that either the EMSL initial known value was wrong, or that the alpha detection mounting used by participant laboratories was incorrect. Because the HCAL result was within 3σ of the grand average, HCAL's performance was comparable to that of the other participants.

The HCAL participated in four California Department of Health Services Environmental Laboratory Accreditation Program (ELAP) Water Pollution Studies for metals during 1993 as shown in **Table 14-4**. The HCAL measures aluminum, arsenic, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, silver, and zinc in sewage effluent for the LLNL environmental monitoring program. All ELAP intercomparison values for these metals were found to be acceptable.

RAS also participated in the 1993 intercomparison studies by the DOE Environmental Measurements Laboratory for various radionuclides on air filters and in soil, vegetation, and water. The HCAL participated in these studies as well, but only analyzed tritium in water. The data from this study are presented in **Table 14-5**. All results for the HCAL (three of three) and all RAS values but the January 1994 value for ^{239}Pu in soil (51 of 52, or 98%) were acceptable. The unacceptable value is currently under investigation by the laboratory. Contract laboratories are also required to participate in laboratory intercomparison programs; however, permission to publish their results for comparison purposes has not been granted.

Duplicate Analyses

Tables 14-6 through 14-8 present data generated by duplicate samples submitted to the same analytical laboratory, grouped by sample matrix and analyte. Samples from both the Livermore site and Site 300 are included. **Tables14-6** and **14-7** contain data pairs with both values above the detection limit, and all radiological results for which a reported value was available. They exclude radiological values for which only a minimum detectable activity was reported. In addition, **Table 14-7** excludes radiological results for which the reported value was negative. **Table 14-8** contains data pairs with either or both values below the detection limit.

If there are more than eight data pairs with both results above the detection limit, precision and regression analyses are performed; the results are presented in T**able14-6** . Precision is measured by the percent relative standard deviation (%RSD; see the EPA *Data Quality Objectives for Remedial Response Activities*, 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 **Table14-6** are the 75th percentile of the distribution of individual precision values. Regression analysis consists of fitting a straight line to the duplicate-routine pairs, as illustrated in **Figure14 -1**. Good agreement between the duplicate and routine samples is

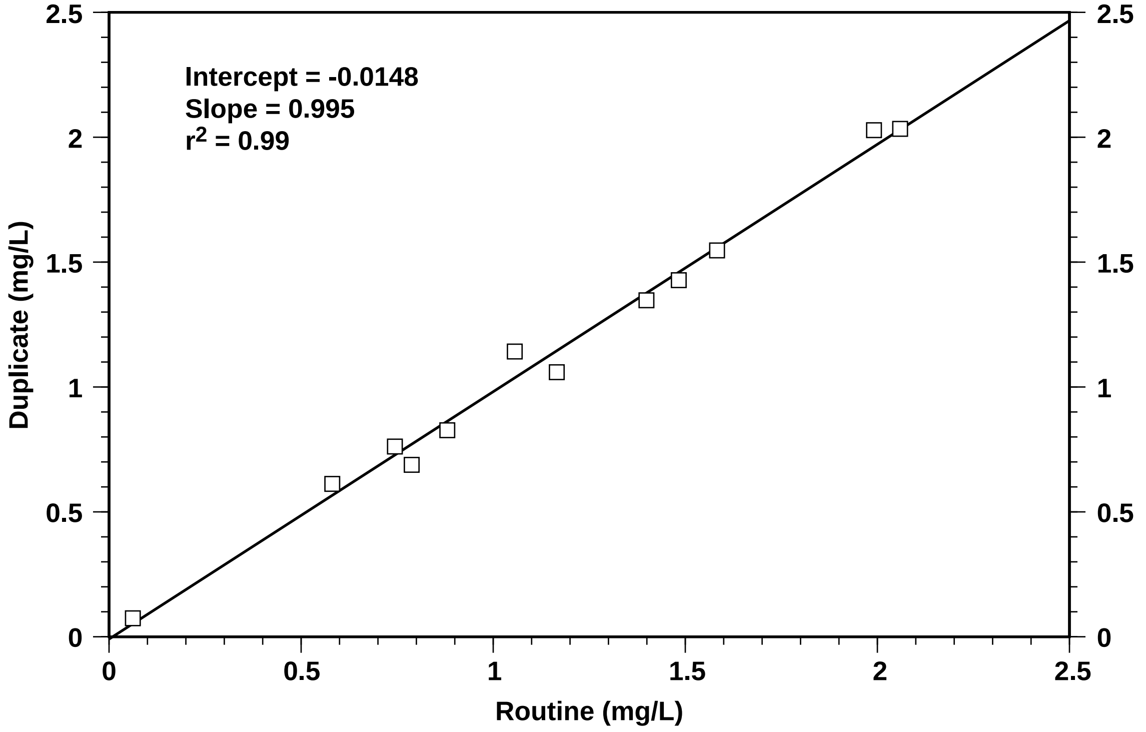

Figure 14-1. Quality assurance duplicate sampling; regression analysis of chromium in sewage.

indicated when the data lie close to a line with slope equal to one and intercept equal to zero. Allowing for normal analytical variation, the slope of the line should be between 0.7 and 1.3, and the interceptshould be within ±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 **Table14 -7**. The average 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 14-8** 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.

These analyses show generally good agreement between routine samples and quality assurance duplicates: approximately 75% of the pairs have a precision better than 30%. Data pairs that do not fall into this area of precision generally fall into one of two categories. Outliers can occur due to data transcription or data errors, or measurement errors. Of 45 datasets reported in **Table 14-6**, ten did not meet the criterion for acceptability due to outliers. 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 a problem for measurements at extremely low concentrations in general. Low concentrations of particulates in air highlight this effect even more because one or two particles on an air filter can significantly impact results. Another cause of high variability is sampling methodology. Analyses of total organic carbon and total organic halides are particularly difficult to control. Of the 45 data sets in **Table 14-6**, nine show sufficient variability in results to make them fall outside of the acceptable range.

Quality assurance duplicates may also be used to identify errors—for example, mis-labeled samples and data entry errors. Less than one percent of the samples involved in the duplicate sampling regime appear to have errors of this kind. This indicates that we have maintained a high standard of sample handling and data management.

Statistical Methods

Statistical methods used in this report have been implemented pursuant to the *Environmental Monitoring Plan* (Gallegos et al. 1992b). 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* (Gallegos et al. 1992b) 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 data tables as 2σ counting errors. 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 inthe 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 (regression, t-test, and analysis of variance, or ANOVA) 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 Environmental Monitoring Section’s Data Analysis Procedure. For data sets not containing values below the detection criterion, measures of central tendency are reported as the arithmetic or geometric mean and the arithmetic or geometric standard deviation.

For data sets with one or more, but fewer than one half, values below the detection criterion, measures of central tendency are reported as 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 median absolute deviation from the median. 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 containing greater-than or equal-to one half 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 1993 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, as these were the reporting units used in previous environmental reports, and will be useful for making data comparisons.

Table 14-1. Livermore site and Livermore Valley sampling location designators.

Medium/location	Current designator	Previous designator(s)	Notes
Air particulate			
Altamont Pass	L-ALTA	90-07	
Near Building 531	L-B531	—	
East Ave. “South” Cafeteria	L-CAFE	90-12	
Northeast of Building 592	L-COW	90-15	
UNCLE Credit Union, Greenville Road	L-CRED	—	
Residence (Livermore)	L-ERCH	90-11	
FCC station	L-FCC	90-08	
East Ave. firehouse	L-FIRE	90-17	
Livermore VA hospital	L-HOSP	90-10	
Livermore City Corp. Yard	L-LCCY	90-09	
LWRP	L-LWRP	90-16	
Mesquite Way	L-MESQ	90-02	
Northwest perimeter (Met Tower)	L-MET	90-13	
Patterson Pass	L-PATT	90-05	
Residence (Livermore)	L-RRCH	90-06	
East & Greenville Aves. (Salvage)	L-SALV	90-01	
Sandia tanks	L-TANK	90-03	
East perimeter (Visitors Center)	L-VIS	90-14	
Zone 7	L-ZON7	90-04	
Air tritium			
Altamont Pass	L-ALTA	93-07	
Building 292 Area	L-B292	—	
Building 331 Yard	L-B331	—	
Building 514 Yard	L-B514	—	
Building 624 (612 Yard)	L-B624	—	
East Ave. “South” Cafeteria	L-CAFE	93-12	
Northeast of B592	L-COW	93-15	
East Ave. firehouse	L-FIRE	93-17	
Livermore City Corp. Yard	L-LCCY	93-09	
West parking lot (Mesquite Way)	L-MESQ	93-02	
Northwest perimeter (Met Tower)	L-MET	93-13	
LLNL pool	L-POOL	—	
East & Greenville Aves. (Salvage)	L-SALV	93-01	
West of Sandia (veterinarian)	L-VET	93-S2	
East perimeter (Visitors Center)	L-VIS	93-14	
East of Sandia (crossroad)	L-XRDS	93-S1	
Zone 7	L-ZON7	93-04	

...continued

Table 14-1. Livermore site and Livermore Valley sampling location designators *(continued).*

Medium/location	Current designator	Previous designator(s)	Notes
Cow milk			
Residence (Livermore)	L-WRD	—	abandoned in 1993
Goat milk			
Cartoned milk	C-CART	91-97	
Residence (Modesto)	C-MOD	91-12	abandoned
Residence (Modesto)	C-MOD2	—	replaced
Residence (Ripon)	C-RIP	—	replaced
Residence (Stevenson)	C-STEV	—	replaced C-MOD2
Pre-pasteurized (Turlock)	C-TUR	—	
Residence (Brentwood)	C-WOOD	—	replaced L-LUP
Residence (Livermore)	L-COOL	—	abandoned in 1993
Residence (Livermore)	L-LUP	91-13	replaced
Residence (Livermore)	L-MZF	91-07	abandoned
Residence (Livermore)	L-WRD	91-05	
Vegetation			
Residence (Modesto)	C-MOD	—	
Aqueduct	L-AQUE	95-23	
Calaveras Reservoir	L-CAL	—	
Residence (Danville)	L-DAN	—	
FCC station	L-FCC	95-33	
I-580 & Greenville Rd.	L-I580	95-20	
Mesquite Way	L-MESQ	—	replaced L-VASW
Met Tower	L-MET	—	replaced L-VASW
Camp Parks	L-PARK	—	
Patterson Pass	L-PATT	95-04	
North of LLNL (railroad tracks)	L-RAIL	95-29	
Tesla Rd. (west)	L-TESW	95-32	
Vasco Rd. (west of LLNL)	L-VASW	95-31	replaced
Visitors Center	L-VIS	—	
Zone 7	L-ZON7	95-15	
Arroyo sediment			
East of Building 438	L-438E	—	
4th and A Streets	L-4THA	—	

...continued

Table 14-1. Livermore site and Livermore Valley sampling location designators *(continued).*

Medium/location	Current designator	Previous designator(s)	Notes
Arroyo sediment			
Arroyo Las Positas East	L-ALPE	ALPE	
Arroyo Las Positas North	L-ALPN	—	
Arroyo Las Positas West	L-ALPW	ALPW	
Arroyo Seco East	L-ASE	ASE	abandoned
Arroyo Seco South	L-ASS	ASS	replaced
Arroyo Seco South #2	L-ASS2	—	replaced L-ASS
Arroyo Seco West	L-ASW	L-ASN	renamed
Central Drainage Basin	L-CDB	CDB	
Central Drainage Basin 2	L-CDB2	—	
Greenville Rd., northeast perimeter	L-GRNE	—	
West perimeter drainage channel	L-WPDC	—	
Soil			
Altamont	L-ALTA	—	
East Ave. “South” cafeteria	L-CAFE	—	
Cowbarn	L-COW	L-15	
Residence (Livermore)	L-ERCH	—	
FCC station	L-FCC	L-08	
Livermore VA hospital	L-HOSP	L-10	
Mesquite Way	L-MESQ	L-02	
Northwest perimeter (Met Tower)	L-MET	L-13	
Northeast corner perimeter fence	L-NEP	L-18	
Patterson Pass	L-PATT	L-05	
Residence (Livermore)	L-RRCH	—	
Salvage	L-SALV	—	
Sandia tanks	L-TANK	L-03	
East perimeter (Visitors Center)	L-VIS	L-14	
LWRP (1/3 North)	L-WRP1	L-19	
LWRP (2/3 North)	L-WRP2	L-20	
LWRP (Northwest)	L-WRP3	L-21	
LWRP (1/3 West)	L-WRP4	L-22	
LWRP (2/3 West)	L-WRP5	L-23	
LWRP (Southwest)	L-WRP6	L-24	
Zone 7	L-ZON7	L-04	

...continued

Table 14-1. Livermore site and Livermore Valley sampling location designators *(continued).*

Medium/location	Current designator	Previous designator(s)	Notes
Sewage			
Manhole 163A (Sandia)	L-163A	—	
Building 196 (daily composite)	L-B196	LLNL	
Building 196 (weekly composite)	L-C196	—	
LWRP	L-LWRP	LWRP	replaced
Manhole 125C	L-M125	—	
Manhole 177E	L-M177	—	
Manhole 185F	L-M185	—	
Manhole 231A	L-M231	—	
Manhole 238C	L-M238	—	
Manhole 40B	L-M40	—	
Manhole 51A	L-M51	—	
Manhole 53A	L-M53	—	
Manhole 69A	L-M69	—	
Manhole 86B	L-M86	—	
LWRP (digestor)	L-WRD1	—	
LWRP (digestor)	L-WRD2	—	
LWRP (digestor)	L-WRD3	—	added in 1993
LWRP (effluent)	L-WRPE	—	replaced L-LWRP
Runoff			
4th and A Streets	L-4THA	—	abandoned
Arroyo Las Positas (east of LLNL)	L-ALPE	01	
Greenville Road (south of L-GRNE)	L-ALPO		added in 1993
Arroyo Las Positas (north at cowbarn)	L-ALPN	—	abandoned
Arroyo Las Positas (northwest boundary)	L-ALPW	03	abandoned
Arroyo Seco East (influent to Sandia)	L-ASE	04	abandoned
Arroyo Seco South (west parking lot)	L-ASS	05	replaced
Arroyo Seco South #2	L-ASS2	—	replaced L-ASS
Arroyo Seco West (Vasco/East Ave.)	L-ASW	L-ASN;06	renamed
East of Building 438	L-B438	—	abandoned
Central Drainage Basin	L-CDB	02	
Greenville Road (northeast perimeter)	L-GRNE	—	
West perimeter drainage channel	L-WPDC	—	

...continued

Table 14-1. Livermore site and Livermore Valley sampling location designators *(concluded).*

Medium/location	Current designator	Previous designator(s)	Notes
Rain			
Altamont	L-ALTA	—	abandoned in 1993
Aqueduct	L-AQUE	—	
Building 291	L-B291	—	
Building 343	L-B343	—	
Residence (Livermore)	L-BVA	—	abandoned in 1993
Central Drainage Basin	L-CDB	—	
Cowbarn	L-COW	—	
Del Valle/Zone 7	L-DEL7	—	abandoned in 1993
East of Sandia	L-ESAN	—	
FCC station	L-FCC	—	abandoned in 1993
Greenville and Tesla Rds.	L-GTES	—	abandoned in 1993
Northwest perimeter (Met Tower)	L-MET	—	
Camp Parks	L-PARK	—	abandoned in 1993
Patterson Pass	L-PATT	—	abandoned in 1993
East & Greenville Aves. (Salvage)	L-SALV	—	
Residence (Livermore)	L-SLST	—	
Vineyard	L-VINE	—	abandoned in 1993
Visitors Center	L-VIS	—	
Zone 7	L-ZON7	—	
Water			
Arroyo de Laguna (Sunol)	L-ALAG	92-24	
Residence (Livermore)	L-BELL	92-37	
Calaveras Reservoir	L-CAL	92-29	
Central Drainage Basin	L-CDB	—	
Del Valle Lake	L-DEL	92-11	
Springtown duck pond	L-DUCK	92-16	
Gas station tap water	L-GAS	92-19	
Private well	L-ORCH	92-34	
Residence (Livermore)	L-PALM	92-31	
LLNL pool	L-POOL	92-43	
Shadow Cliffs	L-SHAD	92-26	
Building 151 tap water	L-TAP	92-30	
Zone 7	L-ZON7	92-15	

Table 14-2. Site 300 sampling location designators.

Medium/location	Current designator	Previous designator(s)	Notes
Air particulate			
East of Building 801	3-801E	40-10	
East control post	3-ECP	40-02	
East observation point	3-EOBS	40-01	
West of main gate	3-GOLF	40-05	
Linac Rd.	3-LIN	40-04	
North power station	3-NPS	40-08	
Tracy firehouse	3-TFIR	40-06	
West control post	3-WCP	40-03	
West observation point	3-WOBS	40-09	
Soil			
East of Building 801	3-801E	3NXXH01 or 1114	
North of Building 801	3-801N	1117	
West of Building 801	3-801W	3NNWG01 or 1113	
Behind Building 812	3-812N	3NXXC01 or 1115	
West of Building 834	3-834W	3ESEI01 or 1103	
North of road to Building 851	3-851N	3WNWI01 or 1107	
North of Building 856	3-856N	3WXXK01 or 1106	
Near Building 858	3-858S	3WSWI01 or 1104	
West landfill (Disposal Site West)	3-DSW	3NWXP02 or 1111	
North of east observation point	3-EOBS	3NNWL01 or 1112	
North of Well #8	3-EVAP	3WNWK01 or 1109	
West of main gate	3-GOLF	3SEXL01 or 1116	
North power station	3-NPS	3NWXP01 or 1110	
West observation point	3-WOBS	3WNWN01 or 1108	
Vegetation			
East of Building 801	3-801E	45-12	
Carnegie	3-CARN	45-01	
Near well K7-03	3-DSW	45-06	
Near well #8	3-EVAP	45-13	
Geodetic	3-GEO	45-03	
West of main gate	3-GOLF	45-02	

...continued

Table 14-2. Site 300 sampling location designators *(concluded).*

Medium/location	Current designator	Previous designator(s)	Notes
Water			
Monitoring well	3-W35A04		replaced GALLO2 in 1993
Well 1	3-WELL01	42-01	
Private well	3-CON1	42-07	
Private well	3-CON2	—	
Well 18	3-WELL18	42-22	
Geodetic creek	3-GEOCRK	42-14	
Rain	3-RAIN	42-20	
812 creek	3-812CRK	42-21	
Carnegie retention well 1	3-CARNRW1	42-23	
Carnegie retention well 2	3-CARNRW2	42-24	
Well 20	3-WELL20	42-31	
Private well	3-GALLO1	42-28	
Private well	3-GALLO2	—	abandoned
CDF well	3-CDF1	42-27	
Private well	3-MUL1	—	
Private well	3-MUL2	—	
Private well	3-VIE1	—	
Private well	3-VIE2	—	
Private well	3-STN	—	

Table 14-3. Results from the EPA Environmental Monitoring Systems Laboratory (EMSL) Intercomparison Program, 1993.

Analysis	Date	Medium	Units	LLNL	Known	Grand avg.	Ratio (LLNL/ known)	Ratio (LLNL/ grand avg.)
^{137}Cs	Sept.	milk	pCi/L	46.00[a]	49.0	50.02	0.94	0.92
^{131}I				107[a]	120.0	120.12	0.89	0.89
^{40}K				1601.67[a]	1679.0	1674.07	0.95	0.96
^{133}Ba	Nov.	water	pCi/L	78.2[a]	79.0	76.45	0.99	1.02
^{60}Co	Nov.			30.8[a]	30.0	29.72	1.03	1.04
^{134}Cs	Nov.			55.6[a]	59.0	54.42	0.94	1.02
^{137}Cs	Nov.			38.9[a]	40.0	42.14	0.97	0.92
Gross alpha	Jan.			10.33[b]	34.0	17.09	0.30[c,d]	0.60
	July			14.67[b]	15.0	12.06	0.98	1.22
	Oct.			11.67[b]	20.0	14.08	0.58[c,d]	0.83[e]
Gross beta	Jan.			42.67[b]	44.0	41.99	0.97	1.02
	July			36.33[b]	43.0	37.65	0.84	0.96
	Oct.			12.67[b]	15.0	17.01	0.84	0.74
^{239}Pu	Jan.			19.9[a]	20.0	18.5	1.00	1.08
^{106}Ru	Nov.			203.4[a]	201.0	175.18	1.01	1.16
^{3}H	June			9796.7[a]	9844.0	9591.82	1.00	1.02
				10881.3[a]	9844.0	9591.82	1.11	1.13
				65.33[b]	9844.0	9591.82	0.01[c,d]	0.01
	Nov.			7436.67[a]	7398.0	7215.65	1.01	1.03
				5317.67[b]	7398.0	7215.65	0.72[c]	0.74
^{65}Zn	Nov.			147.6[a]	150.0	156.07	0.98	0.95

[a] Data were provided by LLNL’s Radiation Analytical Sciences laboratory.

[b] Data were provided by LLNL’s Hazards Control Department Analytical Laboratory.

[c] Ratios are acceptable if they are between 0.7 and 1.3; however, deviations between 0.7 and 0.8 or between 1.2 and 1.3 are indicative of potential problems with laboratory accuracy.

[d] Outside of acceptable range.

[e] Outside of acceptable range when compared to known, but inside of acceptable range when compared to grand average. May be indicative of problem with EMSL samples.

Table 14-4. Hazards Control Department Analytical Laboratory results from the California Department of Health Services Environmental Laboratory Accreditation Program (ELAP) Water Pollution Studies.[a]

Analysis	Date	Sample	LLNL value[a]	True value[a]	Acceptable limits[b]	Warning limits[b]
Aluminum	2/3/93	1	77.6	76.3	62.6–93.2	N/A
	6/22/93	1	1110	1100	898–1300	949–1250
		2	3940	4000	3370–4570	3520–4410
	8/13/93	1	310	309	274–335	N/A
	12/27/93	1	688	681	550–784	579–755
		2	146	140	107–182	117–173
Arsenic	2/3/93	1	69.4	70.2	58.2–80.2	N/A
	6/22/93	1	278	280	225–334	238–320
	8/13/93	1	89.6	91.4	76.5–103	N/A
	12/27/93	1	518	492	408–587	430–565
		2	79.8	74.3	56.7–92.9	61.2–88.4
Beryllium	2/3/93	1	3.10	3.27	2.78–3.76	N/A
	6/22/93	1	58.6	63.0	51.1–74.5	54.1–71.5
	8/13/93	1	1.030	0.933	0.699–1.17	N/A
	12/27/93	1	448	461	382–533	401–514
		2	234	240	198–278	208–268
Cadmium	2/3/93	1	13.7	12.8	10.2–15.4	N/A
	6/22/93	1	8.10	8.12	6.30–10.3	6.80–9.79
		2	92.2	93.9	78.3–110	82.2–106
	8/13/93	1	4.95	4.80	3.84–5.76	N/A
	12/27/93	1	162	165	138–194	145–187
		2	59.4	61.0	50.8–72.0	53.5–69.4
Chromium	2/3/93	1	81.1	81.6	69.4–93.8	N/A
	6/22/93	1	56.9	62.0	49.2–73.7	52.3–70.6
		2	427	460	378–533	397–514
	8/13/93	1	63.8	68.1	57.9–78.3	N/A
	12/27/93	1	688	730	604–843	634–813
		2	22.4	23.4	17.4–29.0	18.9–27.6

...continued

Table 14-4. Hazards Control Department Analytical Laboratory results from the California Department of Health Services Environmental Laboratory Accreditation Program (ELAP) Water Pollution Studies *(continued)*.

Analysis	Date	Sample	LLNL value[a]	True value[a]	Acceptable limits[b]	Warning limits[b]
Copper	2/3/93	1	111	110	99.0–121	N/A
	6/22/93	1	61.6	62.0	53.5–69.8	55.6–67.8
		2	406	410	365–462	377–450
	8/13/93	1	817	820	738–902	N/A
	12/27/93	1	598	601	524–657	541–640
		2	18.7	18.7	13.6–24.1	14.9–22.8
Iron	6/22/93	1	3840	3800	3350–4230	3460–4120
		2	853	860	755–963	781–937
	12/27/93	1	55.3	58.0	43.5–72.5	47.2–68.8
		2	1060	1100	950–1270	991–1230
Lead	2/3/93	1	12.1	12.4	8.68–16.1	N/A
	6/22/93	1	79.9	79.2	62.7–97.1	67.0–92.8
		2	449	450	393–513	408–498
	8/13/93	1	5.20	5.16	3.61–6.71	N/A
	12/27/93	1	1180	1200	1060–1350	1100–1310
		2	733	738	636–833	661–809
Mercury	2/3/93	1	0.940	0.908	0.636–1.18	N/A
	6/22/93	1	1.000	0.983	0.620–1.42	0.719–1.32
		2	2.12	2.10	1.57–2.75	1.72–2.61
	8/13/93	1	6.04	6.23	4.36–8.10	N/A
	12/27/93	1	8.90	9.38	7.31–11.9	7.89–11.3
		2	6.40	6.67	5.00–8.48	5.44–8.04
Nickel	2/3/93	1	66.7	68.0	57.8–78.2	N/A
	6/22/93	1	128	130	111–150	116–145
		2	1290	1300	1160–1450	1200–1420
	8/13/93	1	95.0	95.2	80.9–109	N/A
	12/27/93	1	827	860	766–952	789–928
		2	332	340	296–383	307–372
Silver	6/22/93	3	2.30	2.39	1.80–2.96	1.95–2.82
		4	10.00	9.75	7.8–11.5	8.25–11.0
	8/13/93	2	24.2	25.1	21.2–29.4	N/A
	12/27/93	3	73.9	73.9	60.6–86.8	63.9–83.5
		4	25.9	25.8	21.1–30.4	22.2–29.2

...continued

Table 14-4. Hazards Control Department Analytical Laboratory results from the California Department of Health Services Environmental Laboratory Accreditation Program (ELAP) Water Pollution Studies *(concluded)*.

Analysis	Date	Sample	LLNL value[a]	True value[a]	Acceptable limits[b]	Warning limits[b]
Zinc	2/3/93	1	167	179	161–190	N/A
	6/22/93	1	1070	1100	961–1220	993–1190
		2	235	240	209–271	216–263
	8/13/93	1	82.9	83.8	73.7–91.1	N/A
	12/27/93	1	828	842	737–947	763–921
		2	47.5	46.3	37.5–56.1	39.8–53.7

[a] All results reported in micrograms per liter. Based upon theoretical calculations, or a reference value when necessary.

[b] Acceptance limits are a 99% confidence interval calculated from available performance evaluation data of EPA and state laboratories. Warning limits are a 95% confidence interval produced in the same way as the acceptable limits. Results should fall within acceptable limits 99 times out of 100. Results outside warning limits but inside acceptable limits should be reviewed for possible problems, but not necessarily considered unacceptable.

Table 14-5. Results from the DOE Environmental Measurements Laboratory (EML) Quality Assurance Program, 1993.

Analysis	Date	Medium	LLNL value	EML value	Ratio (LLNL/ EML)
^{7}Be	Mar. 93	air filter	29.4[a]	27.4	1.07
^{144}Ce	Mar. 93		17.1[a]	19.3	0.89
	Jan. 94		36.20[a]	40.3	0.90
^{57}Co	Mar. 93		2.50[a]	2.71	0.92
	Jan. 94		16.60[a]	17.30	0.96
^{60}Co	Mar. 93		1.81[a]	1.70	1.06
	Jan. 94		20.60[a]	20.50	1.00
^{134}Cs	Mar. 93		2.27[a]	1.96	1.16
	Jan. 94		13.60[a]	12.20	1.11
^{137}Cs	Mar. 93		3.30[a]	3.07	1.07
	Jan. 94		19.80[a]	18.80	1.05
^{54}Mn	Mar. 93		12.2[a]	11.7	1.04
	Jan. 94		15.6[a]	15.4	1.01
^{238}Pu	Mar. 93		0.035[a]	0.036	0.97
	Jan. 94		0.128[a]	0.129	0.99
^{239}Pu	Mar. 93		0.024[a]	0.023	1.04
	Jan. 94		0.0788[a]	0.0800	0.99
^{125}Sb	Jan. 94		19.10[a]	17.40	1.10
U	Mar. 93		2.08[a]	1.80	1.16
	Jan. 94		5.59[a]	5.41	1.03
^{137}Cs	Mar. 93	soil	1040[a]	923	1.13
	Jan. 94		13.3[a]	11.4	1.17
^{40}K	Mar. 93		296[a]	321	0.92
	Jan. 94		29.8[a]	28.6	1.04
^{239}Pu	Mar. 93		11.4[a]	11.6	0.98
	Jan. 94		2.10[a]	1.52	1.38[b,c]
^{60}Co	Jan. 94	vegetation	6.05[a]	6.45	0.94
^{137}Cs	Mar. 93		26.4[a]	24.6	1.07
	Jan. 94		97.3[a]	89.2	1.09
^{40}K	Mar. 93		372[a]	383	0.97
	Jan. 94		913[a]	842	1.08
^{238}Pu	Mar. 93		1.20[a]	1.14	1.05
	Jan. 94		0.429[a]	0.463	0.93

...continued

Table 14-5. Results from the DOE Environmental Measurements Laboratory (EML) Quality Assurance Program, 1993 (*concluded*).

Analysis	Date	Medium	LLNL value	EML value	Ratio (LLNL/ EML)
^{239}Pu	Mar. 93		0.34[a]	0.32	1.06
	Jan. 94		0.818[a]	0.965	0.85
^{144}Ce	Mar. 93	water	84.4[a]	83.6	1.01
	Jan. 94		173[a]	173	1.00
^{60}Co	Mar. 93		43.9[a]	45.3	0.97
	Jan. 94		103[a]	99.6	1.03
^{134}Cs	Mar. 93		43.6[a]	42.4	1.03
	Jan. 94		62.7[a]	56.1	1.12
^{137}Cs	Mar. 93		53.7[a]	50.8	1.06
	Jan. 94		81.6[a]	75.5	1.08
^{54}Mn	Mar. 93		103.0[a]	105.0	0.98
	Jan. 94		111[a]	109	1.02
^{238}Pu	Mar. 93		52.7[a]	49.4	1.07
	Jan. 94		1.15[a]	1.14	1.01
^{239}Pu	Mar. 93		91.7[a]	82.8	1.11
	Jan. 94		0.326[a]	0.338	0.96
^{3}H	Mar. 93		101.85[a]	97.0	1.05
	July 93		97.0[d]	97.0	1.00
	July 93		94.4[d]	97.0	0.97
	Jan. 94		280[a]	270	1.04
	Jan. 94		185[d]	170	1.09
U	Jan. 94		0.0810[a]	0.0842	0.96

[a] Data were provided by LLNL’s Radiation Analytical Sciences Section.

[b] Ratios are acceptable if they are between 0.7 and 1.3; however, deviations between 0.7 and 0.8 or between 1.2 and 1.3 are indicative of potential problems with laboratory accuracy.

[c] Outside of acceptable range.

[d] Data were provided by LLNL’s Hazards Control Department Analytical Laboratory.

Table 14-6. Quality assurance duplicate sampling. Summary statistics for analytes with more than eight pairs in which both results were above the detection limit.

Matrix	Analyte	Units	N[a]	% RSD[b]	Intercept	Slope	r^2
Air	Beryllium	pg/m^3	12	17.2	–44.9	4.87	0.0988[c]
	Gross alpha	Bq/L	76	86.0	5.44×10^{-9}	1.01	0.232[d]
	Gross beta	Bq/L	90	38.8	-5.93×10^{-8}	1.19	0.639[d]
	Lead	pg/m^3	9	10.4	2040	0.249	0.274[c]
	Plutonium^{239}	Bq/L	11	40.3	1.92×10^{-11}	0.264	0.122[d]
	Tritium	10^{-7} Bq/mL	49	26.8	–0.028	1.06	0.891
Radiation dose	Radiation dose, average	mrem	52	2.64	–0.279	1.01	0.863
Ground water	Arsenic	mg/L	30	9.43	–0.000691	1.04	0.967
	Bicarbonate alkalinity (as $CaCO_3$)	mg/L	13	2.05	20.5	0.928	0.908
	Calcium	mg/L	13	3.63	–1.85	1.01	0.983
	Chloride	mg/L	13	3.14	–0.54	0.995	0.995
	Gross alpha	Bq/L	18	37.5	0.0103	1.05	0.910
	Gross beta	Bq/L	19	15.0	–0.0975	1.5	0.157[c]
	Magnesium	mg/L	13	4.04	–0.938	1.02	0.981
	Potassium	mg/L	12	10.1	0.23	0.936	0.836
	Radium^{226}	Bq/L	15	35.7	–0.00303	1.03	0.915
	Selenium	mg/L	16	5.90	0.0142	0.588	0.328[c]
	Sodium	mg/L	16	4.61	3.9	0.926	0.936
	Specific conductance	µmhos/cm	43	5.94	48.9	0.916	0.958
	Sulfate	mg/L	13	5.44	–8.67	1.05	0.998
	TDS	mg/L	20	5.28	–5.70	1.01	0.979
	TOC	mg/L	31	27.2	0.944	0.617	0.358[d]
	TOX	mg/L	18	15.7	0.00373	0.82	0.719[d]
	Total alkalinity (as $CaCO_3$)	mg/L	13	2.05	20.5	0.928	0.908
	Tritium	Bq/L	26	8.02	11.9	0.968	0.999
	Uranium^{233,234}	Bq/L	24	44.4	–0.0123	0.981	0.666[c]
	Uranium^{235,236}	Bq/L	21	92.7	0.00131	0.38	0.336[d]
	Uranium^{238}	Bq/L	25	37.2	0.00425	0.701	0.413[c]
	pH	Units	43	1.0	1.15	0.856	0.658[d]
Milk	Tritium	Bq/L	9	3.45	–0.205	1.09	0.480[c]

...continued

Table 14-6. Quality assurance duplicate sampling. Summary statistics for analytes with more than eight pairs in which both results were above the detection limit (*concluded*).

Matrix	Analyte	Units	N[a]	% RSD[b]	Intercept	Slope	r^2
Sewage	Aluminum	mg/L	11	1.10	–8.64	1.02	0.996
	Cadmium	mg/L	12	7.40	–0.0014	1.00	0.903
	Chromium	mg/L	12	6.10	–0.0148	0.995	0.990
	Copper	mg/L	11	1.40	–0.0449	0.995	0.971
	Gross alpha	Bq/L	80	82.2	0.00279	1.24	0.640[c,d]
	Gross beta	Bq/L	93	24.7	–0.0296	1.08	0.805
	Iron	mg/L	12	1.44	–0.419	1	0.999
	Lead	mg/L	12	9.48	0.0746	0.87	0.918
	Mercury	mg/L	13	6.47	–0.0304	1.34	0.679[c]
	Nickel	mg/L	11	19.4	0.509	0.67	0.519[d]
	Silver	mg/L	12	13.7	–0.0625	1.04	0.923
	Tritium	Bq/L	80	102	2.33	0.838	0.990
	Zinc	mg/L	12	9.85	–11.2	1.73	0.790[c]
Vegetation	Tritium	Bq/L	10	24.8	–0.107	1.07	0.998
	Tritium, per gram dry weight	pCi/g	10	44.5	–0.412	1.56	0.678[c,d]

[a] Number of duplicate pairs included in 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] Outside acceptable range of >0.8 due to one or two outliers.

[d] Outside acceptable range of >0.8 due to variability.

Table 14-7. Quality assurance duplicate sampling. Summary statistics for selected analytes with eight or fewer pairs in which both results were above the detection limit.

Matrix	Analyte	N[a]	Mean ratio	Minimum ratio	Maximum ratio
Rain	Tritium	8	1.0	0.52	2.0
Runoff	Tritium	7	1.2	0.65	2.2
Soil	Beryllium	4	1.0	0.93	1.1
	Plutonium^{239}	4	0.69[b]	0.1	1.0
	Tritium	1	0.83	0.83	0.83
Surface water	Tritium	8	1.6[b]	0.68	6.0
Sewage	Beryllium	2	1.1	1.0	1.1
	Plutonium^{239}	3	5.4[b]	1.1	13

[a] Number of data pairs.

[b] Outside acceptable range of 0.7–1.3.

Table 14-8. Quality assurance duplicate sampling. Summary statistics for analytes with at least four pairs in which one or both results were below the detection limit.

Matrix	Analyte	Number of inconsistent pairs	Number of pairs	Percent of inconsistent pairs
Air	Gross beta	1	12	8.3
Ground water	Lead	2	43	4.7
	Nickel	1	18	5.6
	Selenium	1	7	14
	Silver	1	23	4.3
	Trichloroethene	1	17	5.9
Sewage	Beryllium	1	10	10
All other samples		2	2474	0.08

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Appendix B. Methods of Dose Calculations

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Introduction

The effective dose equivalents (EDEs) presented in this report have been calculated using EPA-approved computer models, as described in Chapter 12. In particular, the techniques used to calculate environmental transport and to estimate dose and risk in the CAP88-PC model are detailed in Chapter 8 of the EPA's *Users Guide for CAP88-PC, Version 1.0* (Parks 1992).

Insight into these code results is provided by the explicit dose calculation methods described here. The methods 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 byWorkers* (International Commission on Radiological Protection 1980). Examples of these calculations are presented below, following a review of the doses of major interest that amplifies the description in Chapter 12.

Principal Doses

1. Dose to the Site-Wide Maximally Exposed Individual (SW-MEI). This dose represents the maximum credible dose to a "hypothetical" member of the public in a fixed, publicly accessible facility, such as a place of business, a school, or a residence. The location is chosen to maximize the integrated effects of all emission points at a site, i.e., summing the doses at this location due to each emission point. The locations of this SW-MEI for the Livermore site and Site 300 are specified in the section on Calculations of Radiological Dose in Chapter 12. This hypothetical person is assumed to continuously reside at the facility for 24hours per day, 365 days per year. We further assume that during this occupancy period, the air the person breathes contains the highest ground-level radionuclide concentration, and a portion of the person's diet consists of locally produced foodstuff and drinking water containing the highest radionuclide concentrations. Thus, this is not a dose actually received by any individual and should be viewed as a conservative estimate (i.e., overestimate) of the highest possible dose to any member of the public. The dose to the SW-MEI is used to determine LLNL's compliance with the National Emissions Standards for Hazardous Air Pollutants (NESHAPs), which is 100 μSv / y (10 mrem / y).

2. Maximum Dose to a Member of the Public from a Particular Emission Point. If we consider the maximum dose to a member of the public from a particular emission point, rather than the sum of doses from all emission points, then the location of the public individual is generally different for each emission point. This maximum dose rate at a point of unrestricted public access typically occurs at a point on the site perimeter. Therefore, it is often referred to loosely as the maximum "fenceline" dose, although the off-site maximum dose could occur some distance beyond the perimeter (e.g., when the perimeter is close enough to a stack that the peak ground-level concentration of radionuclides occurs further away). The requirement for continuous monitoring of a particular emission point under the NESHAPs 1-µSv/y (0.1-mrem/y) standard is based on calculations of this maximum dose at or beyond the site boundary in any direction from the source. These calculations assume unabated emissions, i.e., take no credit for emission abatement devices (such as filters) that may be present.

3. Doses Calculated from Measured Activities. The potential 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 6, 9, and 10. The data on radionuclide concentrations or activities in the various media are necessary inputs to the dose-rate equations described here. As shown in the examples below, the dose assessments concern each of the significant agricultural products of the Livermore Valley, including milk, wine, honey, and general vegetation, and in particular the forage-cow-milk pathway for tritium in vegetation. Doses also can be calculated for water at each of the eight Livermore Valley and thirteen Site 300 water sampling locations. (None of these locations is a primary source of drinking water.) Similarly, data needed to evaluate potential doses from the inhalation and immersion pathways are provided by air surveillance monitoring (see Chapter 4).

4. Population Dose. The population dose is the collective effective dose equivalent (collective EDE) for the population residing within 80 kilometers of a site. Data for the populations within this range of the Livermore site and Site 300 have been obtained from the Alameda County Planning Department. As explained in Chapter 12, this dose is calculated by summing over all local areas the products of average individual dose and number of individuals receiving that dose.

Dose Calculation Methods

The following dose calculation methods for the ingestion, inhalation, and immersion pathways are outlined in conventional activity units of picocuries (pCi) and dose units of millirem (mrem). Below are the conversion constants that apply when converting to Systéme International (SI) activity units of becquerels (Bq) and dose units of sieverts (Sv):

$$1\ \text{pCi} = (3.7 \times 10^{-2})\ \text{Bq}$$
$$1\ \text{mrem} = (1 \times 10^{-5})\ \text{Sv} = 10\ \mu\text{Sv} = 1 \times 10^{-2}\ \text{mSv}$$

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. 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 0.51kg / y per person, or about 0.36 L / y, in the U.S. Department of Agriculture food consumption survey of 1977–78 (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:

$$D_{\text{whole body}}(\text{mrem / y}) = C_w \times U_w \times D_w \qquad \text{(B-1)}$$

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 730L 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:

$$D_{\text{whole body}}(\text{mrem / y}) = D_{\text{veg}} + D_{\text{meat}} + D_{\text{milk}} \qquad \text{(B-2)}$$

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:

$$D_{\text{veg(leafy)}} = U_{\text{veg}} \times C_{\text{veg}} \times D_{\text{HTO}} \qquad \text{(B-2a)}$$

where

U_{veg} = intake rate (kg / y): 64 kg / y for maximally exposed individual

C_{veg} = concentration (pCi / kg): $10^9 \dfrac{\text{pCi / kg}}{\mu\text{Ci / mL}} \times (C_{\text{veg}}\ [\mu\text{Ci / mL measured}])$

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:

$$D_{\text{meat}}(\text{mrem / y}) = U_{\text{meat}} \times C_{\text{meat}} \times D_{\text{HTO}} \qquad \text{(B-2b)}$$

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

$C_{\text{meat}} = (F_f) \times (Q_f) \times (C_{\text{veg}}) \times (e^{[-\lambda_i t_s]})$

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 kg 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:

$$D_{milk}(\text{mrem/y}) = U_{milk} \times C_{milk} \times D_{HTO} \quad \text{(B-2c)}$$

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 ^{3}H 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} = 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_f = time from milking to milk consumption (d): 2 d

$$
\begin{aligned}
C_{\text{milk}} = {} & (1.0 \times 10^{-2}\ \text{d}/\text{L}) \times (50\ \text{kg}/\text{d}) \times (C_{\text{veg}}\ [\mu\text{Ci}/\text{mL}]) \\
& \times (10^{9}\ \frac{\text{pCi}/\text{kg}}{\mu\text{Ci}/\text{mL}}) \times (\exp[\{-1.5 \times 10^{-4}\} \times \{2\}]) \\
= {} & (0.5 \times 10^{9}\ \frac{\text{pCi}/\text{kg}}{\mu\text{Ci}/\text{mL}}) \times (C_{\text{veg}}\ [\mu\text{Ci}/\text{mL measured}]).
\end{aligned}
$$

The tritium dose rate from directly consumed milk is then

$$
\begin{aligned}
D_{\text{milk}}\,(\text{mrem}/\text{y}) = {} & (310\ \text{L}/\text{y}) \times ([0.5 \times 10^{9}\ \frac{\text{pCi}/\text{kg}}{\mu\text{Ci}/\text{mL}}] \times [C_{\text{veg}}\ \{\mu\text{Ci}/\text{mL measured}\}]) \times \\
& (6.3 \times 10^{-8}\ \text{mrem}/\text{pCi}) \\
= {} & (0.97 \times 10^{4}) \times (C_{\text{veg}}\ [\mu\text{Ci}/\text{mL measured}]).
\end{aligned}
$$

Whole Body:

$$
\begin{aligned}
D_{\text{whole body}}\,(\text{mrem}/\text{y}) = {} & ([0.40 \times 10^{4}] \times [C_{\text{veg}}\ \{\mu\text{Ci}/\text{mL measured}\}]) \\
+ {} & ([0.41 \times 10^{4}] \times [C_{\text{veg}}\ \{\mu\text{Ci}/\text{mL measured}\}]) \\
+ {} & ([0.97 \times 10^{4}] \times [C_{\text{veg}}\ \{\mu\text{Ci}/\text{mL measured}\}]).
\end{aligned}
$$

The total annual dose rate from the forage-cow-milk pathway for tritium in vegetation is then

$$
D_{\text{whole body}}\,(\text{mrem}/\text{y}) = ([1.78 \times 10^{4}] \times [C_{\text{veg}}\ \{\mu Ci/\text{mL measured}\}]).
$$

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, $\chi(\text{Ci}/\text{m}^3)$ 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 $\chi(\text{Ci}/\text{m}^3)$ at all locations of interest and the source release rate $\text{Q}(\text{Ci}/\text{s})$.

For inhalation dose, once χ or the product $(\chi/\text{Q}) \times (\text{Q})$ 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

$$
D_{\text{whole body}}(\text{mrem}/\text{y}) = U_{\text{inhalation}} \times C_{\text{radionuclide}} \times D_{\text{radionuclide}} \qquad \text{(B-3)}
$$

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 ingestion pathway, where the factor 1.5 accounts for absorption through the skin; for other radionuclides, see Table 2.1 in Eckerman et al. [1988])

$C_{\text{radionuclide}}$ = $(F) \times (\chi / \text{Q}) \times (\text{Q})$ = radionuclide concentration at the receptor (pCi/m^3)

$F = \dfrac{1 \times 10^{12}\ \text{pCi}/\text{Ci}}{3.15 \times 10^{7}\ \text{s}/\text{y}} = 3.17 \times 10^4\ (\text{pCi}/\text{Ci})/(\text{s}/\text{y})$

Q = radionuclide release rate (Ci / y)

χ / Q = diffusion parameter (s/m^3); calculated.

The wholebody inhalation dose rate is then

$$
\begin{aligned}
D_{\text{whole body}}(\text{mrem}/\text{y}) &= (3.17 \times 10^4\,[\text{pCi}/\text{Ci}]/[\text{s}/\text{y}]) \times (\chi / \text{Q})(\text{s}/\text{m}^3) \times (\text{Q}[\text{Ci}/\text{y}]) \\
&\quad \times (8.4 \times 10^3\ \text{m}^3/\text{y}) \times D_{\text{radionuclide}}\,(\text{mrem}/\text{pCi}).
\end{aligned}
$$

The immersion dose is similarly expressible as

$$D_{\text{whole body}}(\text{mrem}/\text{y}) = C_{\text{radionuclide}} \times (DRF) \tag{B-4}$$

where

$C_{\text{radionuclide}}$ = $(F) \times (\chi / \text{Q}) \times (\text{Q})$ = radionuclide concentration at the receptor (pCi/m^3)

$F,$ = $\dfrac{1 \times 10^{12}\ \text{pCi}/\text{Ci}}{3.15 \times 10^{7}\ \text{s}/\text{y}} = 3.17 \times 10^4\ (\text{pCi}/\text{Ci})/(\text{s}/\text{y})$

Q = radionuclide release rate (Ci / y)

χ / Q = diffusion parameter (s/m^3); calculated, and

DRF = the external dose-equivalent rate factor per unit radionuclide concentration $(\text{mrem}/\text{y})/(\text{pCi}/\text{m}^3)$ (for elemental ^{3}H this factor DRF is 3.9×10^{-8} $(\text{mrem}/\text{y})/(\text{pCi}/\text{m}^3)$; for the short-lived isotopes ^{13}N and ^{15}O it equals 5.1×10^{-3} $(\text{mrem}/\text{y})/(\text{pCi}/\text{m}^3)$; for other radionuclides see Table 2.3 in Eckerman et al. [1988])

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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.
	ACEHS	Alameda County Environmental Health Services.
	ACG	Ambient concentration guide.
	Action Level	Defined by regulatory agencies, it is the level of pollutants which, if exceeded, requires regulatory action.
	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.
	ANOVA	Analysis of variance. A test of whether two or more sample means could have been obtained from the same statistical population.
	ANSI	American National Standards Institute.
	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.
	ASME	American Society of Mechanical Engineers.
	ATA	Advanced Test Accelerator.
	Atom	The smallest particle of an element capable of entering into a chemical reaction.

	Atomic absorption spectroscopy	Chemical analysis performed by vaporizing a sample and measuring the absorbance of light by the vapor. Abbreviated AA.
	AVLIS	Atomic Vapor Laser Isotope Separation.
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 (economically achievable).
	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.
	BMP	Best management practice.
	BOD	Biochemical (biological) oxygen demand. A measure of the amount of oxygen in biological processes that break down organic matter in water; a measure of the organic pollutant load. It is used as an indicator of water quality.
	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	CAP88	Computer code required by the EPA for modeling air emissions.
	CCR	California Code of Regulations.
	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. CEQA also requires that adverse environmental impacts be mitigated through mitigation measures or project alternatives.

CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980. Administered by EPA, this program, also known as Superfund, requires private parties to notify the EPA after the release of hazardous substances and undertake short-term removal and long-term remediation. If conditions exist that could create the threat of hazardous substances being released, the Act also requires the remediation of those conditions. 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 $8.5billion.
CFR	Code of Federal Regulations. A codification of all regulations promulgated by federal government agencies.
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.
Ci	Curie. A unit of measurement of radioactivity, defined as the amount of radionuclide in which the decay rate is 2.22×10^{12} disintegrations per minute (3.7×10^{10} disintegrations per second), which 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, and 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, and 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.
	CRWQCB	California Regional Water Quality Control Board.
D	Daughter nuclide	A nuclide formed by the radioactive decay of another nuclide, which is called the parent.
	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).
	DCL	Discharge Concentration Limit (City of Livermore Ordinance 13.32).
	DOE	U.S. Department of Energy. The federal agency that is responsible for conducting energy research and regulating nuclear materials used for weapons production.
	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 theuse of various types of radiation measurement instruments.

	DTSC	California Environmental Protection Agency, Department of Toxic Substances Control.
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. 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.
	EDO	Environmental Duty Officer.
	EFA	East Firing Area (LLNL Site 300).
	Effluent	A liquid or gaseous waste discharged to the environment.
	EIR	Environmental Impact Report. A detailed report, required by the California Environmental Quality Act, 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.
	EMAD	Environmental Monitoring and Analysis Division (LLNL).
	EML	U.S. Department of Energy Environmental Measurements Laboratory.

	EMS	Environmental Monitoring Section in the Environmental Monitoring and Analysis Division of the Environmental Protection Department (at LLNL).
	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.
	EPD	Environmental Protection Department (LLNL).
	ERD	Environmental Restoration Division of the Environmental Protection Department at LLNL.
	ES&H	Environmental, Safety, and Health.
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.
	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.
	FONSI	Finding of No Significant Impact.
	FS	Feasibility Study. A study based on a Remedial Investigation to evaluate and develop remedial action alternatives to prevent, or mitigate, the migration or the release of hazardous substances or contaminants.
G	g	Gram. The standard metric measure of weight approximately equal to 0.035 ounce.

	G	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 one joule per kilogram.
	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. Gamma rays are identical to x rays except for the source of the emission.
H	Half-life (radiological)	The time required for one-half the radioactive atoms in a given amount of material to decay. After one half-life, 50 out of 100 atoms will have changed; during thenext 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.
	HE	High explosives. Materials that release large amounts of energy when detonated.
	HMX	Cyclotetramethyltetramine, a high-explosive compound.
	HT	Tritiated hydrogen gas. Tritium is the hydrogen isotope with one proton and two neutrons in the nucleus. It emitsa low-energy beta particle and has a half-life of 12.3years.
	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 (LLNL).
	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	ICRP	International Commission on Radiological Protection. An international organization that studies radiation, including its measurement and effects.
	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 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.
	Isotopes	Forms of an element having the same number of protons in their nuclei but differing numbers of neutrons.
L	L	Liter. The SI measure of capacity approximately equal to 1.057 quart.
	Land Ban	A regulatory program that identifies hazardous wastes that are restricted from land disposal. The regulations incorporate a phasing-in of restrictions in three stages.
	LEDO	Laboratory Emergency Duty Officer. A senior LLNL management official with authority to commit LLNL resources on the behalf of the Director during an emergency.
	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.
	LLNL	Lawrence Livermore National Laboratory.

	LLW	Low-level waste.
	Lower limit of detection.	The smallest concentration or amount of analyte that can be detected in a sample at a 95% confidence level.
	LWRP	Livermore Water Reclamation Plant. The City of Livermore’s municipal wastewater treatment plant, which accepts discharges from the LLNL Livermore site.
M	MAD	Median absolute deviation. The median of the differences of all data values from the median.
	MCL	Maximum contaminant level in drinking water established by EPA or DTSC.
	mR	Milliroentgen. A unit of measurement used to express radiation exposure.
	mrem	Millirem. A unit of measurement used to express radiation dose to a person—equal to 0.00001sievert.
	msl	Mean Sea Level. The average sea surface level for all stages of the tide over a 19-year period. This is usually determined by hourly height readings from a fixed reference level.
N	NAAQS	National Ambient Air Quality Standards. Air standards established pursuant to the Clean Air Act to protect human health and the environment.
	NCRP	National Council on Radiation Protection.
	NEPA	National Environmental Policy Act. This federal legislation, enacted in 1969, requires all federal agencies to document and consider environmental impacts from federally funded or approved projects. DOE is responsible for NEPA compliance at LLNL.
	NESHAPs	National Emission Standards for Hazardous Air Pollutants. These standards are found in the Clean Air Act and set limits for arsenic, asbestos, beryllium, mercury, radionuclides, vinyl chloride, and benzene.
	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.
	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).
	NOV	Notice of Violation.
	NPDES	National Pollutant Discharge Elimination System. This federal regulation, under the Clean Water Act, requires permits for discharges into surface waterways.
	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.
	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.
	ORAD	Operations and Regulatory Affairs Division (LLNL).
	OSHA	Occupational Safety and Health Act.
	OSP	Operational Safety Procedure.

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.
	Performance standards	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.
	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).
	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.
	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.
	Public comment period	A specified amount of time allowed for members of the public to express their views and concerns regarding an action by a public agency.

	Public hearing	A formal gathering of officials and the public where the views and concerns of members of the public are verbally expressed regarding a public agency's action; public comments may be written or oral. The agency is required to consider the comments in its evaluation of the action beingtaken.
	Public notice	Notification by an agency informing the public of agency actions (e.g., the issuance of a draft permit).
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.
	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.
R	R	Roentgen. A unit of exposure dose of x- or gamma-radiation such that the electrons and positrons liberated by this radiation produce, in air, when stopped completely, ions carrying positive and negative charges of 2.58×10^{-4} coulomb per kilogram of air.
	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.
	RAIP	Remedial Action Implementation Plan.
	RCRA	Resource Conservation and Recovery Act of 1976. RCRA is a program of federal laws and regulations that govern the management of hazardous wastes. RCRA is applicable to all entities that manage hazardous wastes.

	RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine, a high-explosive compound.
	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).
	Response to comments	A document that addresses all significant public comments received by EPA during the public comment period on a proposed permit or action. The document includes a summary of each comment, as well as EPA's response to each comment.
	RI	Remedial Investigation. An investigation conducted to fully assess the nature and extent of the release, or threat of release, of hazardous substances, pollutants, or contaminants and to gather necessary data to support the corresponding feasibility study.
	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.
	RMMA	Radioactive materials management areas.
	ROD	Record of Decision.
	ROV	Report of Violation.
	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.

Sampling and Analysis Plan	A detailed document describing the procedures used to collect, handle, and analyze groundwater samples for detection or assessment-monitoring parameters. The plan details quality control measures that will be implemented to ensure that sample-collection, analysis, and data-presentation activities meet the prescribed requirements.
SARA	Superfund Amendments and Reauthorization Act of 1986. This act modifies and reauthorizes CERCLA. TitleIII of this act is also known as the Emergency Planning and Community Right-to-Know Act of 1986.
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.
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 high-explosives test facility, located approximately 24 kilometers east of the Livermore site.
SDM	Standard deviation of the mean. (See standard deviation.)
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.
SNL/CA	Sandia National Laboratories, California.

	Std dev	Standard deviation. An indication of the dispersion of a set of results around their average (mean).
	STLC	Soluble Threshold Limit Concentration. A value that can be used to determine if a waste is hazardous.
	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.
	Sv	Sievert. The SI unit of dose equivalent. This is the product of the absorbed dose (gray), quality factor (Q), distribution factor, and other necessary modifying factors. The unit Sv describes the effectiveness of various radiations to produce biological effects; 1 Sv = Gy × Q × N = 100 rem.
	SWPPP	Storm Water Pollution Prevention Plan.
T	TDS	Total Dissolved Solids. The portion of solid material in a waste stream that is dissolved and passed through a filter.
	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.

	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.
	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.
	TRU	Transuranic waste.
	TSCA	Toxic Substances Control Act. The law governing the manufacture, processing, and use of chemical substances.
	TTO	Total toxic organic compounds. A list of organic compounds for which EPA has established discharge limits for specific processes or industries.
	TTU	Transportable Treatment Unit.
U	UC	University of California.
	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.
	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	Vadose zone	The partially saturated or unsaturated region above the water table that does not yield water to wells.
	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.

	VSI	Visual Site Inspection. An inspection required by EPA as part of the RCRA permit process to identify solid waste management units that could have had, or continue to have, releases of hazardous constituents to the environment.
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.
	WFA	West Firing Area (LLNL Site 300).
	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.
	WDR	Waste Discharge Requirements. Issued by the California Regional Water Quality Control Board.
	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.
	WMP	Waste Minimization Project.
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 groundwater basin.

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Environmental Report
Reader Survey

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Each annual Environmental Report publishes the results of environmental monitoring at the Lawrence Livermore National Laboratory and documents our compliance with environmental regulations. In providing this information, our goal is to give our readership—whether they be regulators, scientists, or the public—a clear accounting of the range of environmental activities we undertake, the methods we employ, and the degree of accuracy of our results.

It is important that the information we provide is easily understood, is of interest, and communicates LLNL's effort to protect human health and the environment. We would like to know from you, our readers, whether we are successful in these goals. Your comments are welcome.

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A business reply envelope has been attached for returning these surveys to the Laboratory. Laboratory staff may simply send their survey forms through Lab mail to Bob Harrach, L-629.

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