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LAWRENCE LIVERMORE NATIONAL LABORATORY

Lawrence Livermore National Laboratory - 2022 Annual Site Environment Report (ASER)

E. D. Will

August 22, 2023

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Lawrence Livermore National Laboratory

2022 Annual Site Environmental Report

UCRL-TR-50027-22

Cover photography:

Top photo: Great horned owl (*Bubo virginianus*)
This species is protected by the Migratory Bird Treaty Act (MBTA) and is known to nest at the Livermore Site and Site 300. This fledgling left the nest near Building 111 before it was able to fly. While the fledgling owl was on the ground, or in this case perched on a catering cart, LLNL Crafts personnel barricaded the area to keep people at a safe distance. The fledgling's parents continued to feed it until it was able to fly away on its own.
Photo by Caleb Murphy

Middle photo: Cooper's hawk (*Accipiter cooperii*)
This species is protected by the MBTA and is known to nest at the Livermore Site. This immature female was photographed in the center of the Livermore Site near Building 361.
Photo by Caleb Murphy

Bottom photo: Burrowing owl (*Athene cunicularia*)
This species is protected by the MBTA and is a California Species of Special Concern. Burrowing owls are known to nest at Site 300 and in grasslands adjacent to the Livermore Site. Pictured here are two fledgling owls and an adult at a burrow entrance at Site 300.
Photo by Caleb Murphy

Cover page designed by Melissa Snider and Elyse Will

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Lawrence Livermore National Laboratory

Environmental Report 2022

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Preface

The purposes of the *Lawrence Livermore National Laboratory (LLNL) Environmental Report 2022* are to record LLNL's compliance with environmental standards and requirements, describe LLNL's environmental protection and remediation programs, and present environmental monitoring results for the two LLNL sites—the Livermore Site and Site 300. The report is prepared for the U.S. Department of Energy (DOE) by LLNL's Environmental Functional Area. Submittal of the report satisfies requirements under DOE Order 231.1B, "Environment, Safety and Health Reporting," and DOE Order 458.1, "Radiation Protection of the Public and Environment."

The report is distributed electronically and is available at https://aser.llnl.gov/. Previous LLNL annual environmental reports since 1994 are also on the website. Some references in the electronic report text are underlined, which indicates that they are clickable links. Clicking on one of these links will open the related document, data workbook, or website. Sampling location maps throughout this report were created using ArcGIS® software by Esri.

The report begins with an executive summary, which provides the purpose of the report and an overview of LLNL's compliance and monitoring results. The first three chapters provide background information: Chapter 1 is an overview of the location, meteorology, and hydrogeology of the two LLNL sites; Chapter 2 is a summary of LLNL's compliance with environmental regulations; and Chapter 3 is a description of LLNL's environmental programs with an emphasis on the Environmental Management System.

Most of the report covers LLNL's environmental monitoring programs and monitoring data for 2022:

- Chapter 4: Effluent and ambient air monitoring and dose assessment.
- Chapter 5: Waters, including wastewater, storm water runoff, surface water, rain, and groundwater.
- Chapter 6: Terrestrial, including soil, sediment, vegetation, foodstuff, ambient radiation, and special status wildlife and plants.
- Chapter 7: LLNL's groundwater remediation program.
- Chapter 8: Quality assurance for the environmental monitoring programs.
- Appendix A: Complete monitoring data, which are summarized in the body of the report.

The report uses Système International units, consistent with the federal Metric Conversion Act of 1975 and Executive Order 12770, "Metric Usage in Federal Government Programs" of 1991. For ease of comparison to environmental reports issued prior to 1991, dose values and many radiological measurements are given in both metric and U.S. customary units. A conversion table is provided in the glossary.

The report is the responsibility of LLNL's Environmental Functional Area. Monitoring data were obtained through the combined efforts of the Environmental Functional Area, Environmental Restoration Department, Physical and Life Sciences Environmental Monitoring Radiological Laboratory, and the Radiation Protection Functional Area.

Special recognition is given to the technologists who gathered the data – Karl Brunckhorst, Anton Fernandes, Richard Gonzalez, Ty Grace, Steven Hall, Kenya Hairston, Terrance Poole, and Emily Welk; and to the data management personnel – Lena Alkhatib, Katie Bailey, Nancy Bowers, Della Burruss, Suzanne Chamberlain, Bruce Curtis, Liz DaRosa, Lisa Graves, Tyler Jackson, Shenay Jorgenson, Ramona Murphy, Jimmy Nguyen, Beth Schad, Courtney Scialabba, and Kimberly Swanson. Special thanks to Sharon Cornelious of the Technical Information Department for editing support and to Mitzi Espinoza for distributing the report.

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Executive Summary

Lawrence Livermore National Laboratory (LLNL) is a premier research laboratory that is part of the National Nuclear Security Administration (NNSA) within the U.S. Department of Energy (DOE). As a national security laboratory, LLNL is responsible for ensuring that the nation's nuclear weapons remain safe, secure, and reliable. The Laboratory also meets other pressing national security needs including countering the proliferation of weapons of mass destruction, strengthening homeland security, and conducting major research in atmospheric, earth, and energy sciences, bioscience and biotechnology, and engineering, basic science, and advanced technology. The Laboratory is managed and operated by Lawrence Livermore National Security, LLC (LLNS) and serves as a scientific resource to the U.S. government and a partner to industry and academia.

LLNL operations have the potential to release a variety of constituents into the environment via atmospheric, surface water, and groundwater pathways. Some of the constituents, such as particles from diesel engines, are common at many types of facilities while others, such as radionuclides, are unique to research facilities like LLNL. All releases are highly regulated and carefully monitored. Engineering and administrative controls are applied to minimize releases.

LLNL strives to maintain a safe, secure, and efficient operational environment for its employees and neighboring communities. Experts in environment, safety, and health (ES&H) support all Laboratory activities. LLNL's radiological control program ensures that radiological exposures and releases are reduced to as low as reasonably achievable to protect the health and safety of its employees, contractors, the public, and the environment.

LLNL is committed to enhancing its environmental stewardship and managing potential operational impacts on the environment through a formal Environmental Management System (EMS). The Laboratory encourages public participation in matters related to LLNL's environmental impact on the community. LLNL also provides public access to information about ES&H activities through websites and public meetings.

LLNL consists of two sites – the Livermore Site and Site 300. The Livermore Site is an urban site in Livermore, California which occupies 1.3 square miles. Site 300 is a rural Experimental Test Site near Tracy, California which occupies 10.9 square miles. In 2022, the Laboratory had a staff of approximately 8,500.

Purpose and Scope of the Environmental Report

The purposes of the *Environmental Report 2022* are to record LLNL's compliance with environmental standards and requirements, describe LLNL's environmental protection and remediation programs, and present environmental monitoring results. Specifically, the report discusses LLNL's EMS; describes significant accomplishments in pollution prevention; presents the results of air, water, vegetation, and foodstuff monitoring; reports radiological doses from LLNL operations; summarizes LLNL's activities involving special status wildlife, plants, and habitats; and describes the progress LLNL has made in remediating groundwater contamination.

Environmental monitoring at LLNL, including analysis of samples and data, is conducted according to documented standard operating procedures. Duplicate samples are collected and analytical results are reviewed and compared to internal acceptance standards.

This report is prepared for DOE by LLNL's Environmental Functional Area (EFA). Submittal of the report satisfies requirements under DOE Order 231.1B, "Environment, Safety and Health Reporting" and DOE Order 458.1, "Radiation Protection of the Public and Environment." The report is distributed electronically and is available to the public at https://aser.llnl.gov. Previous LLNL annual environmental reports beginning with 1994 are also available on the website.

Regulatory Permitting and Compliance

LLNL undertakes substantial activities to comply with many federal, state, and local environmental laws. The major permitting and regulatory activities that LLNL conducts are required by the Clean Air Act (CAA); the Clean Water Act (CWA) and related state programs; the Emergency Planning and Community Right-to-Know Act (EPCRA); the Resource Conservation and Recovery Act (RCRA) and state and local hazardous waste regulations; the National Environmental Policy Act (NEPA); the Endangered Species Act (ESA); the National Historic Preservation Act (NHPA); the Antiquities Act; and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

Integrated Safety Management System and Environmental Management System

LLNL established its EMS to meet the requirements of the International Organization for Standardization (ISO) 14001:1996 in June 2004 and has remained certified since that time, updating to revised standards in June 2006 (14001:2004) and May 2018 (14001:2015). LLNL identifies, documents, and updates environmental aspects of the EMS every three years and plans actions to address the most significant aspects annually. In FY2022, two ES&H Action Plans addressed environmental aspects including implementing measures to reduce greenhouse gas emissions and improve hazardous waste operations.

Pollution Prevention

A strong Pollution Prevention/Sustainability Program (P2S) is an essential supporting element of LLNL's EMS. LLNL operations have reduced the quantity and toxicity of waste generated, reduced or eliminated pollutant releases, and recycled common and unique materials. P2S Program efforts in 2022 included participation in workgroups to determine a recycling pathway for excess refrigerants, refining construction and demolition waste tracking, installing additional electric vehicle charging infrastructure, and expanding the recycling and composting program to additional buildings. The P2S program also supported the Green Hotline.

Air Monitoring

LLNL operations involving radioactive materials had minimal impact on ambient air during 2022. Estimated nonradioactive emissions are low compared to local air district emission criteria.

Releases of radioactivity to the environment from LLNL operations occur through stacks and from diffuse area sources. In 2022, radioactivity released to the atmosphere was monitored at five facilities at the Livermore Site and at one facility at Site 300. In 2022, 74.3 Ci (2,749 GBq) of tritium was released from the Tritium Facility and 8.0 Ci (296 GBq) of tritium was released from the National Ignition Facility (NIF). Additionally in 2022, the NIF released a total of 1.1×10^{-6} Ci (4.1×10^{-5} GBq) of Iodine-131 vapor and 4.0×10^{-7} Ci (1.5×10^{-5} GBq) of Bromine-82. The Contained Firing Facility (CFF) at Site 300 had measured stack emissions in 2022 for depleted uranium. A total of 3.2×10^{-8} Ci (1.2×10^{-6} GBq) of uranium-234, 4.4×10^{-9} Ci (1.6×10^{-7} GBq) of uranium-235, and 2.3×10^{-7} Ci (8.5×10^{-6} GBq) of uranium-238 was released in particulate form. The doses to the hypothetical, site-wide maximally exposed individual (SW-MEI) members at the Livermore Site and Site 300 are less than one percent of the annual National Emissions Standards for Hazardous Pollutants (NESHAPs), which is 100 µSv/y (10 mrem/y) total site effective dose equivalent. None of the other facilities monitored for gross alpha and gross beta radioactivity had emissions in 2022.

The magnitude of nonradiological releases (e.g., reactive organic gases/precursor organic compounds [ROGs/POCs], nitrogen oxides [NOx], carbon monoxide, particulate matter, sulfur oxides) is estimated based on specifications of equipment and hours of operation. Livermore Site air pollutant emissions were low in 2022 compared to the daily releases of air pollutants from all sources in the entire Bay Area. For example, the average daily emission of NOx in the Bay Area was approximately 2.70×10^5 kg/d, compared to the estimated daily release from the Livermore Site of 41.6 kg/d, or 0.015% of total Bay Area source emissions for NOx. The 2022 Bay Area Air Quality Management District (BAAQMD) estimate for ROGs/POCs daily emissions throughout the Bay Area was approximately 2.35×10^5 kg/d, while the daily emission estimate for 2022 from the Livermore Site was 14.2 kg/d, or 0.006% of the total Bay Area source emissions for ROGs/POCs. Nonradiological releases from LLNL continue to be a small fraction of releases from all sources in the Bay Area or San Joaquin County.

In addition to air effluent monitoring, LLNL samples ambient air for tritium, radioactive particles, and beryllium. Some samplers are situated specifically to monitor areas of known contamination; some monitor potential exposure to the public; and others, distant from the two LLNL sites, monitor the natural background. In 2022, ambient air monitoring data was used to determine source terms for resuspended plutonium-contaminated soil, resuspended fallout from previous atmospheric testing, or resuspended fallout from the Fukushima nuclear accident; and tritium diffusing from area sources at the Livermore Site and resuspended uranium-contaminated soil at Site 300. In 2022, radionuclide particulate, tritium, and beryllium concentrations in air at the Livermore Site and in the Livermore Valley were well below the levels that would cause concern for the environment or public health.

Water Monitoring

Water monitoring is carried out to determine whether any radioactive or nonradioactive constituents released by LLNL have a negative impact on public health and the environment. According to monitoring data, discharges to the surface water and groundwater do not have any apparent environmental impact.

LLNL Wastewater Discharge Permit #1250 (2021 – 2026) regulates discharges of treated groundwater from the Livermore Site Ground Water Project (GWP) to the City of Livermore sanitary sewer system. During 2022, monitoring data complied with all discharge limits and most of the measured values were a small fraction of the allowable limits. There were no discharges to the sanitary sewer from GWP activities. Additionally, all discharges to the Site 300 sewage evaporation and percolation ponds regulated under Waste Discharge Requirements (WDR) Order No. R5-2008-0148 were within permitted limits and groundwater monitoring related to this area showed no measurable impacts.

Under the current storm water Industrial General Storm Water Permit (IGP) (2014-0057-DWQ), the only regulated industrial activities at the Livermore Site and Site 300 are those related to Treatment, Storage, and Disposal Facilities (TSDF). This includes the Decontamination and Waste Treatment Facility (DWTF) and Area 612 Facilities at the Livermore Site and B883, Explosive and Waste Treatment Facility (EWTF), and Explosives Waste Storage Facility (EWSF) at Site 300. LLNL has five storm water runoff sampling locations at the Livermore Site and two at Site 300. Storm water runoff samples were collected for three storm events at the Livermore Site and one storm event at Site 300 in 2022. Samples were collected from all five required storm water locations at the Livermore Site and Building 883 at Site 300. Based on annual sampling results, both the Livermore Site and Site 300 remain at Exceedance Response Action Level 2 for magnesium. LLNL has provided data and analysis that show the magnesium exceedance is due to aerial deposition from natural sources and not industrial activities at LLNL.

The annual storm water reports for the Livermore Site National Pollutant Discharge Elimination System (NPDES) General Permit 2014-0057-DWQ (Waste Discharge Identification Number [WDID] 2 01I025682) and Site 300 (NPDES General Permit 2014-0057-DWQ, WDID 5S39I021179) are available through the Stormwater Multiple Applications and Report Tracking System (SMARTS) managed by the California State Water Resources Control Board (SWRCB).

The Central Valley Regional Water Quality Control Board (CVRWQCB) issued a Water Code Section (WCO) 13267 Order for *Submittal of Technical and Monitoring Reports for the Active Building 851 Firing Table, Lawrence Livermore National Laboratory Site 300, San Joaquin County* (CVRWQCB 2020b) requesting a sediment and storm water runoff monitoring program during the Building 851 Firing Table operational period at Site 300. Only sediment samples were collected in 2022.

In addition to CERCLA-driven monitoring (i.e., for volatile organic compounds [VOCs]) conducted by LLNL's Environmental Restoration Department (ERD), extensive surveillance monitoring of groundwater occurs at and near the Livermore Site and Site 300. Groundwater from wells downgradient from the Livermore Site is analyzed for anions, hexavalent chromium, and radioactivity. To detect any off-site contamination quickly, the well water is sampled in the uppermost water-bearing layers. Near Site 300, monitored constituents in off-site groundwater include explosives residue, nitrate, perchlorate, metals, volatile and semivolatile organic compounds, tritium, uranium, and other radioactivity constituents (gross alpha and gross beta). No constituents attributable to LLNL operations at the Livermore Site or Site 300 were detected in the off-site groundwater supplies.

Surface waters and drinking water are analyzed for tritium and gross alpha and gross beta radioactivity. In the Livermore Valley, the maximum tritium measurement was less than 1% of the drinking water standard and the maximum gross alpha and gross beta measurements were less than 17% and 8% of their respective drinking water standards. At Site 300, operation and maintenance of the drinking water system did not have an adverse impact on surrounding waters.

Terrestrial Radiological Monitoring

The impact of LLNL operations on surface soil in 2022 was insignificant. Surface soils at the Livermore Site and in the surrounding Livermore Valley are analyzed for plutonium, alpha-, beta- and gamma-emitting radionuclides, and tritium. Surface soils at Site 300 are analyzed for alpha-, beta- and gamma-emitting radionuclides and beryllium. Plutonium concentrations in soil at the Livermore Water Reclamation Plant continued to be elevated compared to other sampled locations, but even this concentration was only 1.5% of the screening level for cleanup recommended by the National Council on Radiation Protection (NCRP). At Site 300, uranium-235 and uranium-238 concentrations in soils were below NCRP-recommended screening levels.

Vegetation and Livermore Valley wine were sampled for tritium. In 2022, the median of concentrations in all off-site far vegetation samples was below the analytical method's lower limit of detection (approximately 2.0 Bq/L). In 2022, median concentrations at the near and intermediate locations were 3.4 Bq/L and 2.5 Bq/L, respectively. For Livermore Valley wines purchased in 2022, the highest tritium concentration of 3.5 Bq/L was just 0.47% of the Environmental Protection Agency's (EPA's) standard for maximal permissible level of tritium in drinking water.

LLNL's extensive network of thermoluminescent dosimeters measures the natural terrestrial and cosmogenic background. In 2020, the method for calculating the quarterly doses was updated to better reflect recommendations in American National Standards Institute/Health Physics Society (ANSI/HPS) N13.37-2014 (R2019), resulting in higher annual averages. If these were calculated using previous methods, the results for 2020 – 2022 would be consistent with those of previous years.

Biota

Through monitoring and compliance activities in 2022, LLNL avoided known impacts to special status species and enhanced habitats. LLNL studies, preserves, and improves the habitat of five species at Site 300 that are covered by the federal or California Endangered Species Acts – California tiger salamander (*Ambystoma californiense*), California red-legged frog (*Rana draytonii*), Alameda whipsnake (*Masticophus lateralis euryxanthus*), valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*), and the large-flowered fiddleneck (*Amsinckia grandiflora*) – as well as species that are rare and otherwise of special interest. At Site 300, LLNL monitors populations of rare plant species and continues restoration activities for the four rare plant species known to occur at Site 300 – large-flowered fiddleneck, big tarplant (*Blepharizonia plumosa*), diamond-petaled California poppy (*Eschscholzia rhombipetala*), and shining navarretia (*Navarretia nigelliformis* ssp. *radians)*.

LLNL took several actions to control invasive species in 2022. Measures taken at the Livermore Site to control bullfrogs, which are a significant threat to California red-legged frogs, included surveying and dispatching any bullfrogs observed in Lake Haussmann and Arroyo Las Positas. To reduce populations of bullfrog tadpoles and invasive fish, the LLNL reach of Arroyo Las Positas was allowed to dry out in September 2022 by temporarily halting groundwater discharges to the arroyo.

The 2022 radiological doses calculated for biota at the Livermore Site and Site 300 were far below screening limits set by DOE, even though highly conservative assumptions maximized the potential effect of LLNL operations on biota.

Radiological Dose

Annual radiological doses at the Livermore Site and Site 300 in 2022 were found to be well below the applicable standards for radiation protection of the public. Doses calculated to the SW-MEI for 2022 were 2.9×10^{-2} µSv (2.9×10^{-3} mrem) at the Livermore Site and 2.8×10^{-3} µSv (2.8×10^{-4} mrem) at Site 300. These doses are well below the federal NESHAPs Site-Wide standard of 100 µSv (10 mrem) and are significantly less than the doses from natural background radiation.

Groundwater Remediation

Groundwater at both the Livermore Site and Site 300 is contaminated from historical operations; the contamination is mostly confined to each site. Groundwater at both sites is undergoing cleanup under the CERCLA. Remediation activities removed contaminants from groundwater and soil vapor at both sites and investigations continue to meet regulatory milestones.

At the Livermore Site, contaminants include VOCs, fuel hydrocarbons, metals, and tritium, but only the VOCs in groundwater and saturated and unsaturated soils need remediation. Combinations of VOCs, nitrate, perchlorate, tritium, high explosives, depleted uranium, organosilicate oil, polychlorinated biphenyls, dioxins, furans, and metals have been identified for remediation at one or more of the nine Operable Units (OUs) at Site 300.

In 2022, concentrations continued to decrease in most of the Livermore Site VOC plumes due to active remediation and the removal of more than 42 kg of VOCs from both groundwater and soil vapor. Groundwater concentration and hydraulic data indicate subtle but consistent declines in the VOC concentrations and areal extent of the contaminant plumes in 2022.

In 2022 at Site 300, perchlorate, nitrate, the high explosive RDX, and organosilicate oil were removed from groundwater in addition to about 5.2 kg of VOCs. Each Site 300 OU has a different profile of contaminants, but overall, groundwater and soil vapor extraction and natural attenuation continue to reduce the mass of contaminants in the subsurface. Cleanup remedies have been fully implemented and are operational at eight of the nine OUs at Site 300. The CERCLA pathway for the last OU, Building 812, was negotiated with the regulatory agencies in 2011 and characterization activities continued in 2022. All milestones were met or renegotiated with the regulatory agencies (see **Chapter 2**).

Conclusion

LLNL's EMS provides a framework that integrates environmental protection into all work planning processes. The success of EMS is evidenced by LLNL's certification to the ISO 14001:2015 standard, coupled with a consistent record of environmental stewardship and compliance. The combination of surveillance and effluent monitoring, source characterization, and dose assessment showed that the radiological dose to the hypothetical, maximally-exposed individual member of the public caused by LLNL operations in 2022 was substantially less than the dose from natural background. Potential dose to biota was well below DOE screening limits. LLNL demonstrated compliance with permit conditions for releases to air and to water. Air and water monitoring results showed minimal contributions from LLNL operations. Remediation efforts at both the Livermore Site and Site 300 further reduced concentrations of contaminants of concern in groundwater and soil vapor.

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1. Introduction

Mark Buscheck • Anthony Wegrecki • Elyse Will

Lawrence Livermore National Laboratory (LLNL) is a premier research laboratory that is part of the National Nuclear Security Administration (NNSA) within the U.S. Department of Energy (DOE). LLNL is managed and operated by Lawrence Livermore National Security, LLC (LLNS); the LLNS management team includes Bechtel National, University of California, BWX Technologies, and Amentum. LLNS manages LLNL under NNSA Contract Number DE-AC52-07NA27344.

As a national security laboratory, LLNL is responsible for ensuring that the nation's nuclear weapons remain safe, secure, and reliable. The Laboratory also meets other pressing national security needs, including countering the proliferation of weapons of mass destruction and strengthening homeland security and conducting major research in atmospheric, earth, and energy sciences, bioscience and biotechnology, and engineering, basic science, and advanced technology. The Laboratory staff of approximately 8,500 serve as a scientific resource to the U.S. government and a partner to industry and academia.

1.1 Location

LLNL consists of two sites – an urban site in Livermore, California, referred to as the "Livermore Site," and a rural test site near Tracy, California, referred to as "Site 300". See **Figure 1-1.**

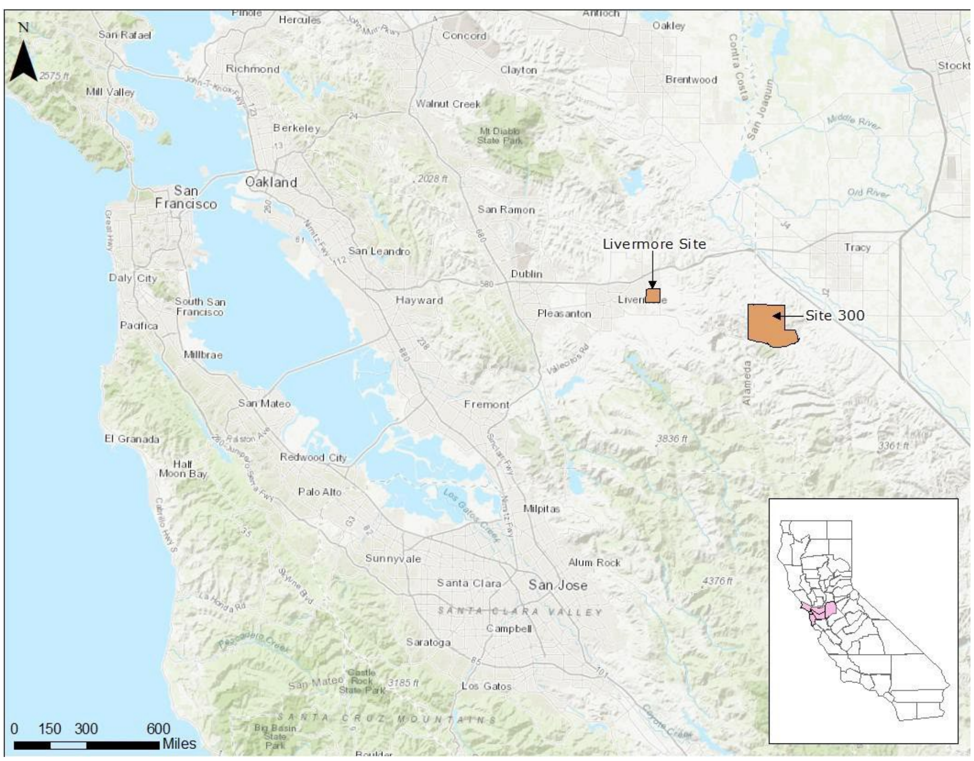

Figure 1-1. Locations of the two LLNL Sites – the Livermore Site and Site 300

The Livermore Site, LLNL's general research site, is within the eastern limits of Livermore, a city with a population of about 90,000 in Alameda County.

The Livermore Site occupies 1.3 mi^2, including the land that serves as a buffer zone along its north and west perimeters.

Within a 50-mi radius of the Livermore Site are cities such as Tracy and Pleasanton and the more distant (and more densely populated) cities of Oakland, San Jose, and San Francisco. Of the 8.6 million people within 50 mi of the Laboratory, only about 13% are within 20 mi.[1]

Site 300, LLNL's Experimental Test Site, is in the Altamont Hills of the Diablo Range in Central California and straddles the San Joaquin and Alameda County line. The site is 12 mi east of the Livermore Site and occupies 10.9 mi^2.

The city of Tracy, with a population of about 85,000, is approximately 6 mi to the northeast of Site 300 (measured from the northeastern border of Site 300 to Sutter Tracy Community Hospital). Of the 8.3 million people who live within 50 mi of Site 300, 93% are more than 20 mi away in large metropolitan areas, which include Oakland, San Jose, and Stockton.[1]

1.2 Meteorology

The climate at both sites is characterized by mild, rainy winters and warm-to-hot, dry summers with strong seasonal wind and rainfall patterns. Wind patterns at both sites tend to be dominated by the thermal draw of the warm San Joaquin Valley that results in wind blowing from the cool ocean toward the warm valley during the warm season, increasing in intensity as the valley heats up. During the winter, the wind blows from the northeast more frequently as cold, dense air spills out of the San Joaquin Valley. The meteorological conditions at Site 300 are also strongly influenced by higher elevation and more pronounced topological relief. Approximately 55% of the rain at both sites falls in January, February, and March and approximately 80% falls in the five months from November through March, with very little rain falling during the warmer months. For a detailed review of rainfall at LLNL, see Bowen (2007). For a detailed review of the climatology at LLNL, see Gouveia and Chapman (1989).

Meteorological towers at both the Livermore Site and Site 300 continuously gather data including wind speed, wind direction, rainfall, humidity, solar radiation, and air temperature. Temperature, rainfall, and wind speed data from the Livermore Site and Site 300 towers during 2022 are summarized in **Table 1-1.** Annual wind data for the Livermore Site and Site 300 are shown in **Figure 1-2.**

[1] The population numbers were derived in using Oak Ridge National Laboratory LandScan data and ESRI ArcMAP software. See Wilson et al. (2023), Appendix C, for population file. The population numbers will be updated in the 2023 ASER.

Table 1-1. Summary of Temperature, Rainfall, and Wind Speed Data at the Livermore Site and Site 300 in 2022

	Livermore Site		Site 300	
Temperature	**°C**	**°F**	**°C**	**°F**
Mean daily maximum	23.0	73.4	22.2	71.9
Mean daily minimum	7.7	45.9	13.2	55.7
Average	14.7	58.5	17.3	63.2
High	44.1	111	41.6	107
Low	-3.9	25.0	0.5	32.8
Rainfall	**cm**	**in**	**cm**	**in**
Total	30.7	12.1	22.8[c]	9.0[c]
Climatological normal [a]	32.4[b]	12.8[b]	26.5[b]	10.4[b]
Wind	**m/s**	**mph**	**m/s**	**mph**
Average speed	2.1	4.8	5.8	13.1
Peak gust speed	20.9	46.8	40.2	90.0

(a) Climatological normal is based on a 30-year period (1991–2020).

(b) 1991–2020 (Mean re-calculated every 10 years).

(c) The Site 300 rain gauge failed on December 10 – December 28 and December 31. Rainfall for these days was estimated using Quantitative Precipitation Estimates from the National Weather Service (https://water.weather.gov/precip/index.php). Estimated rainfall is 4.61 inches (11.7 cm) for these days.

1.3 Topography

The Livermore Site is located in the southeastern portion of the Livermore Valley, a prominent topographic and structural depression, oriented east–west within the Diablo Range. The most prominent valley in the Diablo Range, the Livermore Valley, is bound on the west by the Pleasanton Ridge and on the east by the Altamont Hills. The valley is approximately 14 mi long and varies in width generally between 2.5 and 7 mi. The highest elevation of the valley floor is 720 ft above sea level along its eastern margin near the Altamont Hills; it descends gradually to 300 ft at the southwestern corner. The valley floor is covered primarily by alluvial and floodplain deposits consisting of gravels, sands, silts, and clays with an average thickness of about 325 ft. Ephemeral waterways flowing through the Livermore Site include Arroyo Seco along the southwestern corner and Arroyo Las Positas along the eastern and northern perimeters.

Site 300 consists of a series of steep hills and ridges separated by intervening ravines oriented in a generally northwest–southeast direction. The Altamont Hills, where Site 300 is located, are part of the California Coast Range Province and separate the Livermore Valley to the west from the San Joaquin Valley to the east. The elevation of Site 300 ranges from about 1,740 ft above sea level at the northwestern corner of the site to approximately 490 ft in the southeastern portion. Corral Hollow Creek, an ephemeral stream that drains toward the San Joaquin River Basin, runs along the southern and eastern boundaries of Site 300.

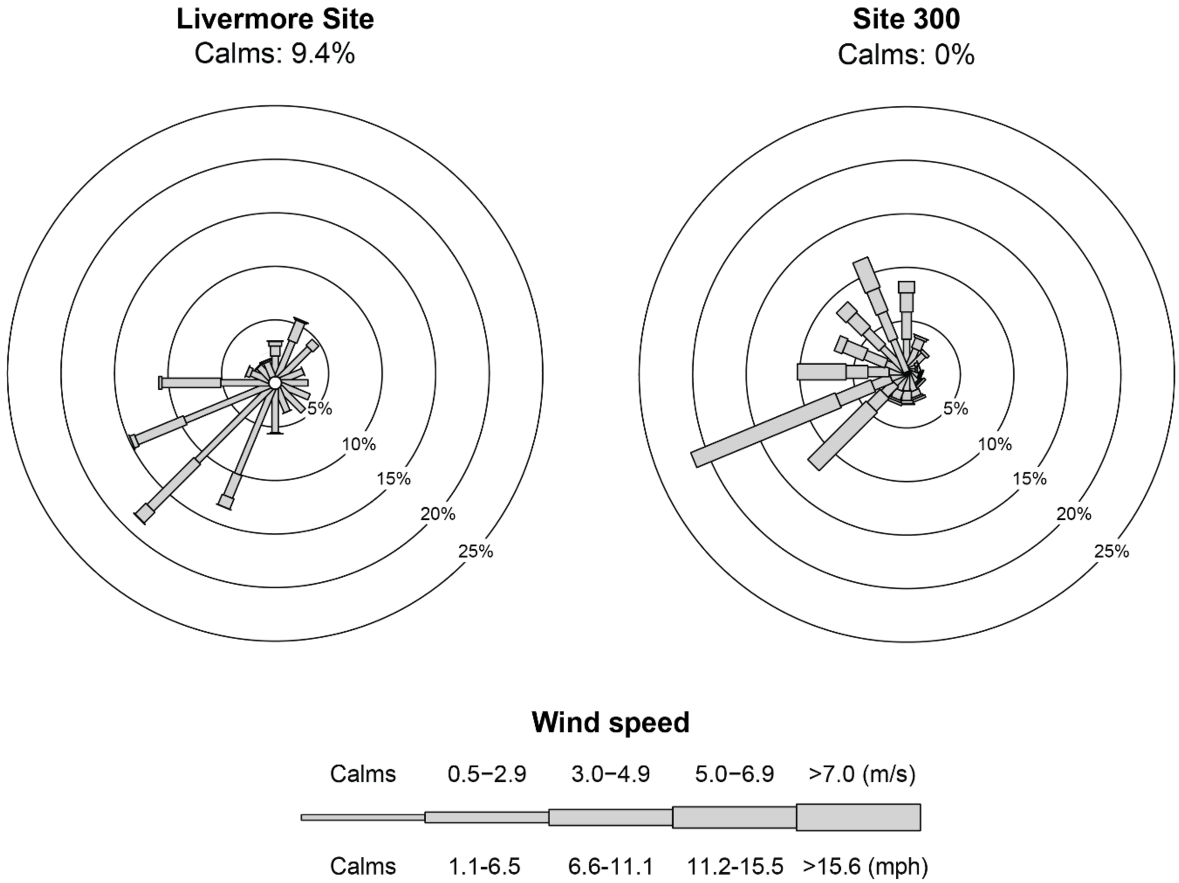

Figure 1-2. Wind Roses Showing Wind Direction and Wind Speed Frequencies at the Livermore Site and Site 300 in 2022

Note: The length of each spoke is proportional to the frequency at which the wind blows from the indicated direction. Different line widths of each spoke represent wind speed classes.

1.4 Hydrogeology

Geologically the Livermore Formation and overlying alluvial deposits contain the primary aquifers of the Livermore Valley groundwater basin. Natural recharge occurs primarily along the basin margins and arroyos during wet winters. In general, groundwater flows toward the central east–west axis of the valley and then westward through the central basin. Groundwater flow in the basin is primarily horizontal, although a significant vertical component probably exists along the basin margins under localized sources of recharge and near heavily used extraction or water production wells. Beneath the Livermore Site, the depth to the water table varies from about 35 to 125 ft below the ground surface. See Thorpe et al. (1990) for a detailed discussion of Livermore Site hydrogeology.

Site 300 is generally underlain by gently dipping sedimentary bedrock dissected by steep ravines. The bedrock primarily consists of interbedded sandstone, siltstone, and claystone. Groundwater occurs principally in the Neroly Formation upper and lower blue sandstone units and in the underlying Cierbo Formation. Significant groundwater is also locally present in permeable

Quaternary alluvium valley fill and underlying decomposed bedrock, especially during wet winters. Minor quantities of groundwater are present within perched aquifers in the unnamed Pliocene nonmarine unit. Perched aquifers contain unconfined groundwater separated from an underlying main body of groundwater by impermeable layers; normally these perched zones are laterally discontinuous. Recharge occurs predominantly in locations where saturated alluvial valley fill is in contact with underlying permeable bedrock or where permeable bedrock strata crop out along the canyon bottom because of structure or topography. The thick Neroly Formation lower blue sandstone unit, stratigraphically near the base of the formation, generally contains unconfined groundwater. Wells located in the southern part of Site 300 that historically pumped water from this aquifer for on-site drinking and process supply are available for backup purposes. In this area in southern Site 300, the Neroly Formation lower blue sandstone is confined. See Webster-Scholten et al. (1994) and Ferry et al. (2006) for a detailed discussion of Site 300 hydrogeology.

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2. Compliance Summary

Lawrence Livermore National Laboratory (LLNL) activities comply with applicable federal, state, and local environmental regulations, internal requirements, Executive Orders, and U.S. Department of Energy (DOE) Orders as specified in Contract DE-AC52-07NA27344. This chapter provides an overview of LLNL's compliance programs and activities during 2022, as well as a listing of all active environmental permits.

2.1 Environmental Restoration and Waste Management

2.1.1 Comprehensive Environmental Response, Compensation and Liability Act

Ongoing remedial investigations and cleanup activities for legacy contamination of environmental media at LLNL fall under the jurisdiction of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Title I of the Superfund Amendments and Reauthorization Act (SARA). CERCLA is commonly referred to as the Superfund Act.

CERCLA compliance activities for the Livermore Site and Site 300 are summarized in **Sections 2.1.1.1** and **2.1.1.2.** Community relations activities conducted by DOE/LLNL are also part of these projects. See **Chapter 7** for more information on the activities and findings of the investigations.

2.1.1.1 Livermore Site Groundwater Project

The Livermore Site came under CERCLA in 1987 when it was placed on the National Priorities List. The Livermore Site Groundwater Project (GWP) complies with provisions specified in a Federal Facility Agreement (FFA) entered into by the U.S. Environmental Protection Agency (EPA), DOE, the California Department of Toxic Substances Control (DTSC), and the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB). As required by the FFA, the GWP addresses compliance issues by investigating potential contamination source areas (e.g., suspected old release sites, solvent-handling areas, leaking underground tank systems), monitoring water quality through an extensive network of wells, and remediating contaminated soil and groundwater. The primary soil and groundwater contaminants (constituents of concern) are volatile organic compounds (VOCs), primarily trichloroethylene (TCE) and perchloroethylene (PCE). Background information on LLNL Livermore Site environmental characterization and restoration activities is presented in the *CERCLA Remedial Investigation Report for the LLNL Livermore Site* (Thorpe et al. 1990). The *LLNL Groundwater Project 2022 Annual Report* (Noyes et al. 2023) presents the status of cleanup at the Livermore Site.

Regulatory Deliverables. In calendar year 2022, the following Livermore Site deliverables were submitted to the regulatory agencies:

- *The Livermore Site Fourth Quarter 2021 Self-Monitoring Report*
- *LLNL Groundwater Project 2021 Annual Report*

- *Sixth Five-Year Review for the Lawrence Livermore National Laboratory, Livermore Site*
- *First, Second, and Third Quarter 2022 Self-Monitoring Reports*
- Work plans for well and borehole drilling at the Livermore Site in Fiscal Year 2022

Treatment Facilities. During 2022, the Livermore GWP maintained 27 groundwater and eight soil vapor treatment facilities. The groundwater extraction wells and dual extraction wells extracted about 961 million L of groundwater during 2022. The dual extraction wells and soil vapor extraction wells together removed approximately 4.0 million m^3 of soil vapor.

In 2022, the Livermore GWP treatment facilities removed about 42 kg of VOCs. Since remediation efforts began in 1989, more than 27.4 billion L of groundwater and approximately 40.5 million m^3 of soil vapor have been treated, removing approximately 3,508 kg of VOCs.

Livermore Site restoration activities in 2022 were focused on enhancing and optimizing ongoing operations at treatment facilities. Evaluation of technologies that may accelerate cleanup of the Livermore Site contaminant source areas and address areas of co-mingled VOC and low-level tritium plumes continued. Beneath the site, groundwater concentration and hydraulic data indicate subtle but consistent declines in VOC concentrations and areal extent of contaminant plumes in 2022. Hydraulic containment along the western and southern boundaries of the site was fully maintained in 2022 and progress was made toward interior plume and source area cleanup. See Noyes et al. (2023) for more information.

Community Relations. Livermore Site community relations activities in 2022 included maintaining information repositories and an administrative record; sending letters to neighbors living to the west of LLNL, providing an update on the progress of the off-site groundwater plume cleanup; and disseminating environment-related news releases and internal/external newsletter articles. Additionally, DOE/LLNL environmental documents, letters, and public notices were posted on a public website: https://enviroinfo.llnl.gov/. DOE/LLNL was unable to conduct CERCLA community tours of the Livermore Site during 2022 due to the COVID-19 pandemic. Tri-Valley Communities Against a Radioactive Environment (Tri-Valley CAREs) did not request any Technical Assistance Grant meetings during 2022.

2.1.1.2 Site 300 Environmental Restoration Project

Remedial activities are ongoing at Site 300, which became a CERCLA site in 1990 when it was placed on the National Priorities List. Remedial activities are overseen by the U.S. EPA, the Central Valley Regional Water Quality Control Board (CVRWQCB), and DTSC, under the authority of an FFA for the site. Contaminants of concern present within the different environmental restoration operable units (OUs) at Site 300 include VOCs (primarily TCE), high-explosive compounds, tritium, depleted uranium, silicone-based oils, nitrate, perchlorate, polychlorinated biphenyls, dioxins, furans, and metals. See Webster-Scholten (1994) and Ferry et al. (1999) for background information on LLNL environmental characterization and restoration activities at Site 300. The *Annual 2022 Compliance Monitoring Report* (Buscheck et al. 2023) presents the cleanup status at Site 300.

Regulatory Deliverables. During calendar year 2022, the following Site 300 deliverables were submitted to the regulatory agencies:

- *Draft Building 834, Pit 6, and Site-Wide Operable Units Consolidated Five-Year Review*
- *Annual 2021 Compliance Monitoring Report*
- *First Semester 2022 Compliance Monitoring Report*
- Work plans for well drilling and decommissioning at Site 300 in 2022

All calendar year 2022 milestones were met or renegotiated with the regulatory agencies.

Treatment Facilities. During 2022, the Site 300 Environmental Restoration Project (ERP) operated 16 groundwater and five soil vapor treatment facilities at Site 300. The groundwater extraction wells and dual extraction wells extracted approximately 26.9 million L of groundwater during 2022. The dual extraction wells and soil vapor extraction wells together removed approximately 2 million m^3 of soil vapor.

In 2022, the Site 300 treatment facilities removed approximately 5.2 kg of VOCs, 0.075 kg of perchlorate, 1,091 kg of nitrate, 0.086 kg of the high-explosive compound RDX, and 0.003 kg of uranium. Since groundwater remediation began in 1990, approximately 1,839 million L of groundwater and 42 million m^3 of soil vapor have been treated, resulting in removal of approximately 648 kg of VOCs, 2.0 kg of perchlorate, 24,500 kg of nitrate, 3.1 kg of RDX, 9.5 kg of silicone oils, and 0.1 kg of uranium.

Site 300 restoration activities in 2022 were focused on enhancing and optimizing groundwater and soil vapor extraction and treatment, continuing bioremediation treatability studies, and monitoring of groundwater remediation progress. Groundwater monitoring data indicate declines in contaminant concentrations in 2022 and progress toward off-site and on-site plume and source area cleanup. See Buscheck et al. (2023) for more information.

Community Relations. Site 300 community relations activities in 2022 included maintaining information repositories and an administrative record. DOE/LLNL environmental documents, letters, and public notices were posted on two public websites: https://erd.llnl.gov/library/ and https://enviroinfo.llnl.gov/. DOE/LLNL did not conduct any CERCLA community tours of Site 300 during 2022. Tri-Valley CARES did not request any Technical Assistance Grant meetings during 2022.

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

Title III of SARA, known as the Emergency Planning and Community Right-to-Know Act (EPCRA), requires owners and operators of facilities who handle certain hazardous chemicals on-site to provide information on the release, storage, and use of these chemicals to organizations responsible for emergency response planning. Executive Order 13834: Efficient Federal Operations directs all federal agencies to comply with the requirements of the EPCRA, including SARA, Section 313, the Toxic Release Inventory (TRI) Program. EPCRA requirements and LLNL compliance are summarized in **Table 2-1.**

LLNL has reported lead release data via Form R for Site 300 since 2002. Form R is used for reporting TRI chemical releases and includes information about waste management and waste minimization activities. Over 99 percent of lead releases are associated with activities at the Site 300 Small Firearms Training Facility (SFTF). Data for the 2021 TRI Form R for lead at Site 300 was submitted to DOE/National Nuclear Security Administration (NNSA) on May 4, 2022.

LLNL reported mercury release data via Form R for the Livermore Site last year. Data for the 2021 TRI Form R for mercury at the Livermore Site was submitted to DOE/NNSA on May 4, 2022.

Table 2-1. Compliance with EPCRA

EPCRA Section	Brief Description of Requirement	LLNL Action
302	Notify SERC of presence of extremely hazardous substances.	Originally submitted May 1987.
303	Designate a facility representative to serve as emergency response coordinator.	Last update submitted 12/29/20 to San Joaquin County for Site 300 and 12/30/20 to the LPFD for the Livermore Site.
304	Report releases of certain hazardous substances to SERC and LEPC.	No EPCRA-listed extremely hazardous substances were released above reportable quantities in 2022.
311	Submit SDSs or chemical list to SERC, LEPC, and Fire Department.	Per the California Governor's Office of Emergency Services, the EPCRA Section 311 requirement is satisfied by the EPCRA Section 312 submittal and the filing of necessary amendments within 30 days of handling a previously undisclosed hazardous material subject to Section 312 inventory requirements.
312	Submit hazardous chemical inventory to local administering agency (county).	Submitted to San Joaquin County and the LPFD on 12/29/21 and 02/28/2022, respectively.
313	Submit Form R to U.S. EPA and California EPA for toxic chemicals released above threshold levels.	Form R for lead at Site 300 submitted to DOE on 05/04/2022 – DOE forwarded it to U.S. EPA and California EPA on 06/08/22. Form R for mercury at the Livermore Site submitted to DOE on 05/04/2022 – DOE forwarded it to U.S. EPA and California EPA on 06/08/22.

Note: See the **Acronyms and Glossary** section for acronym definitions.

2.1.3 California Accidental Release Prevention Program

The California Accidental Release Prevention (CalARP) Program is the combined federal and state program for the prevention of accidental release of regulated toxic and flammable substances. The goal of the combined program is to eliminate the need for two separate and distinct chemical risk management programs. The purpose of the CalARP program is to prevent accidental releases of substances that can cause serious harm to the public and the environment, to minimize the damage if releases occur, and to satisfy Community Right-to-Know laws. The CalARP program is implemented at the local government level by Certified Unified Program Agencies (CUPAs). The related federal regulations are the Clean Air Act (CAA) Section 112(r) and Title 40, Code of Federal Regulations, Part 68 (40 CFR Part 68).

LLNL submitted a revised Livermore Site CalARP Level 1 risk management plan (RMP) in September 2021. The Livermore Site RMP includes lithium hydride and nitric acid.

2.1.4 Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) provides the framework at the federal level for regulating solid wastes, including wastes designated as hazardous. The California Hazardous Waste Control Law (HWCL) and California Code of Regulations (CCR) Title 22 set requirements for managing hazardous wastes and implementing RCRA in California. LLNL works with DTSC and CUPA to comply with these regulations and obtain hazardous waste permits.

The hazardous waste management facilities at the Livermore Site consist of permitted units in Area 625 plus Buildings 693, 695, and 696, which make up the Decontamination and Waste Treatment Facility (DWTF). Permitted waste-management units include container storage, tank storage, and various treatment processes (e.g., wastewater filtration, blending, and neutralization). A new Livermore Site Hazardous Waste Facility Permit was issued to LLNL, effective for 10 years from October 31, 2022 – October 31, 2032. This replaced the original permit that LLNL had been operating under since 1999. This permit does not significantly change hazardous waste operations at the Livermore Site.

The hazardous waste management facilities at Site 300 consist of three operational RCRA-permitted facilities. The Explosives Waste Storage Facility (EWSF) and the Explosives Waste Treatment Facility (EWTF) are permitted to store and treat explosives waste, respectively. The Building 883 container storage area (CSA) is permitted to store routine facility-generated hazardous waste such as spent acids, bases, contaminated oil, and spent solvents. Site 300 has one post-closure permit for the RCRA-closed Building 829 High Explosives Burn Pit. DTSC issued the Hazardous Waste Facility Permit (HWFP) for EWSF, EWTF, and the CSA on June 29, 2017. The HWFP is effective for 10 years from August 7, 2017 – August 7, 2027. DTSC issued the Building 829 post-closure permit on April 28, 2017. The post-closure permit is effective for 10 years from April 27, 2017 – April 27, 2027. Transportation of hazardous or mixed waste over public roads occurs by DTSC-registered transporters, including LLNL.

2.1.5 California Medical Waste Management Act

All LLNL medical waste management operations are conducted in accordance with the California Medical Waste Management Act (MWMA). The program is administered by the California Department of Public Health (CDPH) and is enforced by the Alameda County Department of Environmental Health (ACDEH) at the Livermore Site and the San Joaquin County Environmental Health Department (SJCEHD) at Site 300. LLNL's medical waste permits are renewed annually and cover medical waste generation and treatment activities for the Biosafety Level (BSL) 2 facilities and one BSL 3 facility. LLNL revised the BSL 2 and BSL 3 Medical Waste Management Plans to incorporate new requirements pursuant to California Assembly Bill (AB) 333, which became effective in January 2016. The BSL 2 and BSL 3 Medical Waste

Management Plans and Emergency Action Plans were most recently submitted to the ACDEH in November 2021.

2.1.6 Radioactive Waste and Mixed Waste Management

LLNL manages radioactive waste and mixed waste in compliance with applicable sections of DOE Order 435.1, DOE Manual 435.1-1, DOE Notice 435.1, and the LLNL-developed Radioactive Waste Management Basis for the Lawrence Livermore National Laboratory (LLNL 2019), which summarizes radioactive waste management controls relating to waste generators and treatment and storage facilities.

2.1.7 Release of Property

LLNL does not release property (e.g., vehicles, equipment, soil, or other materials) to the public with residual radioactivity above the authorized limits, compliant with DOE Order 458.1. Pursuant to written procedures, items that are potentially contaminated or activated are either surveyed prior to release to the public or a process knowledge evaluation is conducted to verify that the material has not been exposed to radioactive material or energy capable of inducing radioactivity in the material. In some cases, both a radiological survey and a process knowledge evaluation are performed. Excessed items that meet the requirements for unrestricted release are donated to interested state agencies, federal agencies, or universities; redeployed to other on-site users; or released to LLNL's Donation, Utilization, and Sales group. In 2022, approximately 14,582 equipment release swipes were processed by LLNL's Radiological Measurements Laboratory; the equipment may have subsequently been used on-site or released to the public. Utilizing a graded approach, LLNL only keeps track of high value released items (e.g., those items worth greater than $100,000). In 2022, no high value items were released.

DOE issued a moratorium in January 2000 prohibiting the release of volume-contaminated metals and subsequently suspended the release of metals for recycling purposes from DOE radiological areas in July 2000. No metals subject to the moratorium or suspension were released from LLNL in 2022. Excess property with residual radioactivity above the authorized limits is either transferred to other DOE facilities for reuse or transferred to LLNL's Radioactive and Hazardous Waste Management (RHWM) department for disposal as radioactive waste.

In 2021, DOE distributed a memorandum approving the use of the ANSI/HPS N13.12-2013 volumetric screening levels as pre-approved authorized limits per DOE Order 458.1 for the release and clearance of personal property. In 2022, LLNL obtained approval by the Livermore Field Office (LFO) to utilize these authorized limits. However, no property was released under these limits in 2022.

2.1.8 Federal Facility Compliance Act

LLNL continues to work with DOE to maintain compliance with the Federal Facilities Compliance Act (FFCA) Site Treatment Plan (STP) for LLNL, which was signed in February 1997. LLNL completed eleven milestones during 2022. An additional 149.62 m^3 of newly generated mixed waste was accepted into the approved storage facilities and added to the STP.

LLNL removed approximately 71.04 m^3 of mixed waste from LLNL in 2022.

Reports and certification letters were submitted to DOE as required. LLNL continued using available commercial treatment and disposal facilities that are permitted to accept LLNL mixed waste. These facilities provide LLNL greater flexibility in pursuing the goals and milestones outlined in the STP.

2.1.9 Toxic Substances Control Act

The Federal Toxic Substances Control Act (TSCA) and implementing regulations found in 40 CFR Parts 700 – 789 govern the uses of newly developed chemical substances and TSCA-governed waste. In 2022, 15 containers of TSCA-regulated polychlorinated biphenyl (PCB) waste with an aggregate weight of 3,673 kilograms were transported and disposed at RCRA-permitted, Clean Harbors Treatment, Storage, and Disposal Facilities in Aragonite, Utah and Energy Solutions, Utah.

2.2 Air Quality and Protection

2.2.1 Clean Air Act

All activities at LLNL are evaluated to determine the need for air permits or equipment registrations. Air permits are obtained from the Bay Area Air Quality Management District (BAAQMD) for the Livermore Site and from the San Joaquin Valley Air Pollution Control District (SJVAPCD) and/or BAAQMD for Site 300. The BAAQMD also administers a boiler registration program for natural gas-fueled boilers with rated heat input capacities greater than 2 million British Thermal Units per hour (BTU/hr) and less than 10 million BTU/hr.

Both the BAAQMD and the SJVAPCD are overseen by the California Air Resources Board (CARB), which also oversees the statewide permitting for portable diesel fuel-driven equipment such as portable generators and portable air compressors. In addition, CARB presides over the state-wide registration of in-use off-road diesel vehicles (e.g., diesel-powered forklifts, loaders, backhoes, graders, and cranes), on-road heavy-duty diesel vehicles with a gross vehicle weight rating > 14,000 pounds (e.g., garbage trucks, street sweepers, and bucket trucks) and large spark-ignition (LSI) engine vehicles (e.g., gasoline, propane and electric forklifts, scrubbers/sweepers, and industrial tow tractors).

In 2022, LLNL operated 109 permitted air-pollutant emission sources at the Livermore Site and 33 permitted air-pollutant emission sources at Site 300. In addition, LLNL maintained the registrations for 38 natural gas-fired boilers with the BAAQMD at the Livermore Site. LLNL also maintained registrations with CARB for 13 portable diesel engines powering various portable equipment, 91 in-use off-road diesel vehicles, 13 on-road heavy-duty diesel vehicles, and 128 LSI engine vehicles at the Livermore Site and Site 300.

In 2022, LLNL continued to maintain a Synthetic Minor Operating Permit (SMOP) with the BAAQMD to ensure that facility-wide actual emissions of regulated air pollutants from the Livermore Site did not exceed federal CAA Title V emission limits. The source categories covered under the SMOP include solvents, fuel dispensing, remediation and wastewater, and combustion. BAAQMD initially issued LLNL the SMOP in 2002 after it was determined that LLNL had the potential to emit regulated air pollutants exceeding federal CAA Title V emission limits if all emission sources at the Livermore Site were to operate at maximum capacity. As a result, LLNL agreed to receive federally enforceable permit conditions in the SMOP that limit actual emissions of regulated air pollutants from sources rather than potential emissions from sources. LLNL has demonstrated that its actual emissions are well below CAA Title V emission limits through extensive monitoring and record keeping of source emissions and meeting significantly reduced SMOP air pollutant emissions limits. Therefore, LLNL is not classified as a "major facility" of air pollutant emissions per 40 CFR Part 70.2.

On July 15, 2016, Site 300 was reclassified by SJVAPCD from a Title V Major Facility to a Minor Facility with potential to emit (PTE) less than 10 tons of VOCs per year. As a Minor Facility, Site 300 is no longer required to tally its rolling 12-month emissions. Additionally, Site 300 now conducts compliance inspections biennially instead of annually.

Under the authority of AB 32, California adopted several regulations to reduce greenhouse gas emissions. California's Mandatory Reporting of Greenhouse Gas Emissions Regulation (for calendar years 2008-2011) initially required certain facilities to annually report greenhouse gas emissions from natural gas combustion when annual emissions exceeded 25,000 metric tons of CO_2 equivalent (CO_2e). The regulation was amended, and the reporting threshold was lowered to 10,000 metric tons per year of CO_2e starting with calendar year 2012. Since 2008, the Livermore Site's annual greenhouse gas emissions from natural gas combustion have been slightly below 25,000 metric tons CO_2e, which means that LLNL is not subject to the California Cap-and-Trade program. LLNL began reporting the Livermore Site's greenhouse gas emissions from natural gas combustion for calendar year 2012 and continues to report these emissions annually.

The CARB regulation aims to reduce greenhouse gas emissions from semiconductor operations that use fluorinated gases or fluorinated heat transfer fluids (HTFs). Facilities are required to report fluorinated gas emissions beginning with calendar year 2010 and each calendar year thereafter. In 2022, LLNL's annual emissions of fluorinated gases from semiconductor operations were below the 800 metric ton (MT) CO_2e threshold. Facilities that exceed the 800 MT CO_2e threshold are required to meet strict emission standards for semiconductor operations.

Also under the authority of AB 32, California adopted regulations pertaining to sulfur hexafluoride (SF_6) due to its high global warming potential. LLNL was required to submit an annual report to the CARB describing SF_6 research uses, SF_6 purchases, and measures taken to control the SF_6 emissions from research activities. Furthermore, LLNL was required to record the amounts of SF_6 (and other greenhouse gases) contained in and emitted from gas insulated equipment during calendar year 2022 with an annual emission limit of 1% of its annual average CO_2e capacity. For CY2022, GHG emissions from LLNL's gas-insulated equipment (GIE) is calculated to be 470.6 MT CO_2e which is 0.9% of LLNL's total GIE system CO2e capacity of 52,140.9 MT CO_2e. Therefore, LLNL complied with the CY2022 emissions limit of 1% of its total GIE system CO2e capacity.

Additionally, LLNL continues to implement reductions and controls to minimize CO_2 emissions. For example, LLNL regularly replaces diesel engines, boilers, and hot water heaters with new equipment that is more efficient in terms of fuel use and CO_2 air emissions. Site 300 CO_2 emissions are much lower than the Livermore Site emissions because there is no natural gas service at Site 300.

Like California's regulation, the EPA has a Mandatory Reporting of Greenhouse Gases regulation for stationary emission sources. LLNL is currently below the EPA's mandatory reporting threshold of 25,000 metric tons per year at both the Livermore Site and Site 300.

The federal American Innovation and Manufacturing (AIM) Act of 2020 seeks to reduce hydrofluorocarbon (HFC) greenhouse gas consumption and production to 15% of a 2011-2013 baseline by 2036. The AIM Act authorizes EPA to establish production and consumption allowances, sector-specific controls (e.g., global warming potential limits), refrigerant management practices, and penalties for circumventing AIM Act rules. At LLNL, HFC uses include but are not limited to refrigeration equipment, fire suppression systems, research and development operations, semiconductor etching, precision optics processing, and testing equipment, aerosols, and spray foams. AIM Act HFCs purchased during CY 2022 and in inventory (in containers, not in equipment) on December 31, 2022 are included in Table 2-2.

Table 2-2. AIM Act HFC Purchases and Inventory at the Livermore Site and Site 300, 2022

HFC	Purchases[1] (pounds)	Inventory[1] (pounds)
HFC-43-10mee	133	478
R-134a	740	873
R-23	45	64
R-32	0	6
R-401A	0	660
R-401B	0	90
R-402B	0	39
R-404A	24	522
R-407C	350	575
R-408A	0	116
R-410A	325	425
R-500	0	371
R-503	0	20
R-507	0	25
R-508B	0	30

1 – Purchases and inventory from ChemTrack database.

During CY 2022 LLNL undertook an outreach effort to identify personnel who may potentially be impacted by the AIM Act. A survey was circulated to these personnel regarding their future HFC needs and usage timelines. Impacted personnel were encouraged to plan accordingly and seek potential alternatives to AIM Act HFCs. LLNL uses a significant quantity of HFCs in chillers. Plans are underway to replace four chillers each containing 2,155 pounds of the refrigerant R-134a with chillers that use more climate-friendly refrigerants such as R-513A or R-

514A. This will significantly decrease future purchases of R-134a.

2.2.2 National Emission Standards for Hazardous Air Pollutants, Radionuclides

To demonstrate compliance with 40 CFR Part 61, Subpart H (National Emission Standards for Hazardous Air Pollutants [NESHAPs] for radiological emissions from DOE facilities), LLNL monitors certain air-release points and evaluates the maximum potential dose to the public. The *LLNL NESHAPs 2022 Annual Report* (Wilson et al. 2023) reported that the estimated maximum radiological dose from radioactive air emissions were 2.9 x 10^{-2} µSv (2.9 x 10^{-3} mrem) for the Livermore Site and 2.8 x 10^{-3} µSv (2.8 x 10^{-4} mrem) for Site 300. The totals are well below the 100 µSv/y (10 mrem/y) site-wide dose limits defined by the NESHAPs regulation. The *LLNL NESHAPs 2022 Annual Report* is in Appendix C of this report.

2.3 Water Quality and Protection

LLNL complies with requirements of the federal Clean Water Act (CWA), the Porter-Cologne Water Quality Control Act, the Safe Drinking Water Act (SDWA), the California Aboveground Petroleum Storage Act (APSA), the California Water Code, the California Health and Safety Code (CH&SC), and the City of Livermore ordinances by obtaining permits issued by the appropriate regulatory agencies whose mission is to protect water quality.

2.3.1 Storm Water, Wastewater, and Drinking Water

LLNL complies with the requirements of National Pollutant Discharge Elimination System (NPDES) and Waste Discharge Requirement (WDR) permits and Water Quality Certifications issued by Regional Water Quality Control Boards (RWQCBs) and the State Water Resources Control Board (SWRCB) for discharges to waters of the U.S. and waters of the state. Discharges to the City of Livermore’s sanitary sewer system are governed by permits issued by the Water Resources Division (WRD). The SDWA requires that LLNL register Class V injection wells with the EPA and LLNL obtains permits from the Army Corps of Engineers (ACOE) for work in wetlands and waters of the U.S.

2.3.2 SPCC/APSA

The Spill Prevention, Control, and Countermeasures (SPCC) Rule is published under the authority of Section 311 of the CWA to prevent oil discharges into navigable waters of the U.S. or adjoining shorelines. The APSA program regulates non-transportation related facilities in California with aggregate aboveground petroleum storage capacities greater than or equal to 1,320 gallons that have the potential to discharge petroleum into waters of the state. Both the CWA and APSA require LLNL to prepare and implement SPCC plans at the Livermore Site and Site 300, which include inventories, procedures, methods, and inspections to prevent and mitigate potential discharges of oil for applicable aboveground oil containers and oil-filled equipment systems.

The Livermore Site SPCC Plan had two technical amendments in 2022 (May and October) that were certified by a registered Professional Engineer (P.E.) and included the permanent closure of 12 existing systems and the addition of 13 new systems. The Site 300 SPCC Plan had one technical amendment in 2022 (June) that was certified by a P.E. and included the permanent closure of one existing system and the addition of one new system. The end of year 2022 total oil storage capacities were 707,610 gallons for 498 equipment systems at the Livermore Site and 54,803 gallons for 86 equipment systems at Site 300. The total aboveground petroleum oil storage capacities, as submitted in the California Environmental Reporting System (CERS), were 595,144 gallons for the Livermore Site and 36,391 gallons for Site 300.

2.3.3 Underground Storage Tanks

LLNL has underground storage tanks (USTs) at the Livermore Site and Site 300 that store petroleum products (diesel, gasoline, and ethanol) for vehicle fuel dispensing and to supply emergency backup generators. USTs that store hazardous substances in California are regulated by the EPA, the SWRCB, and the local CUPAs.

There are nine UST systems at the Livermore Site and three UST systems at Site 300 (see **Table 2-3**). The Livermore-Pleasanton Fire Department (LPFD) and the SJCEHD issue permits for operating these USTs, as required by the CCR and the CH&SC (see **Table 2-4**). The tank owner and operator for the permitted UST systems at LLNL is DOE/NNSA and Lawrence Livermore National Security, LLC (LLNS), respectively.

Three of the USTs at the Livermore Site (611TFUD01, 611TFUG01, 611TFUG02) are single-walled systems that are required to be permanently closed by December 31, 2025 in accordance with the CH&SC. Ongoing efforts are being made to close these UST systems to meet the upcoming regulatory deadline.

Table 2-3. UST Inventory at the Livermore Site and Site 300, 2022

Equipment ID	Location	Size	Type	Material	Contents
111TFUD01	B-111	350 Gallons	Emergency Generator	DW Steel-FRP Wrap Tank DW Steel-Fiberglass Piping	Diesel
112TFUD01	B-112	350 Gallons	Emergency Generator	DW Steel-FRP Wrap Tank DW Steel-Fiberglass Piping	Diesel
152TFUD01	B-152	1,000 Gallons	Emergency Generator	DW Steel-FRP Wrap Tank DW Flexible Piping	Diesel
271TFUD02	B-271	1,000 Gallons	Emergency Generator	DW Fiberglass Tank DW Flexible-Fiberglass Piping	Diesel
365TFUD01	B-365	500 Gallons	Emergency Generator	DW Steel-HDPE Tank DW Flexible Piping	Diesel
611TFUD01	B-611	10,000 Gallons	Fueling Station	DW Fiberglass Tank SW Steel Piping	Diesel
611TFUG01	B-611	12,000 Gallons	Fueling Station	DW Fiberglass Tank SW Steel Piping	Unleaded Gasoline

Table 2-3. (cont.) UST Inventory at LLNL Livermore Site and Site 300, 2022

Equipment ID	Location	Size	Type	Material	Contents
611TFUG02	B-611	12,000 Gallons	Fueling Station	DW Fiberglass Tank SW Steel Piping	Unleaded Gasoline
611TFUE01	B-611	12,000 Gallons	Fueling Station	DW Steel-FRP Wrap Tank DW Fiberglass Piping	Ethanol (E-85)
879TFUD01	B-879	5,000 Gallons	Fueling Station	DW Steel-FRP Wrap Tank SW Steel Piping	Diesel
879TFUG01	B-879	15,000 Gallons	Fueling Station	DW Steel Tank DW Fiberglass Piping	Unleaded Gasoline
882TFUD01	B-882	1,500 Gallons	Emergency Generator	DW Steel Tank DW Steel-Fiberglass Piping	Diesel

Note: See the **Acronyms and Glossary** section for acronym definitions.

2.4 Other Environmental Statutes

2.4.1 National Environmental Policy Act and Floodplains and Wetland Assessments

The National Environmental Policy Act (NEPA) of 1969 is the U.S. government's basic environmental charter. When considering a proposed project or action at LLNL, DOE/NNSA must (1) consider how the action would affect the environment, and (2) make certain that environmental information is available to public officials and citizens before decisions are made and actions are taken. The results of the evaluations and notice requirements are met through publication of "NEPA documents," such as environmental impact statements (EISs) and environmental assessments (EAs) under DOE NEPA Implementing Procedures in 10 CFR Part 1021.

In 2005, DOE/NNSA completed the Final Site-Wide Environmental Impact Statement for Continued Operation of Lawrence Livermore National Laboratory and Supplemental Stockpile Stewardship and Management Programmatic Environmental Impact Statement (SWEIS 2005) (U.S. DOE/NNSA 2005). In 2011, DOE/NNSA prepared a Supplement Analysis (SA) (DOE/EIS-0348-SA-03) of the 2005 SWEIS to consider whether the 2005 SWEIS should be supplemented, a new EIS should be prepared, or no further NEPA documentation is required (U.S. DOE/NNSA 2011). The SA concluded that a supplement to the 2005 SWEIS or a new SWEIS was not needed. Both the 2011 SA and the 2005 SWEIS are available online at https://enviroinfo.llnl.gov/nepa. DOE/NNSA is currently preparing a new SWEIS to analyze the impacts of continued operations at LLNL for the foreseeable future. DOE/NNSA issued the Draft SWEIS for public review on November 4, 2022. Preparation of the response to public comments and the Final SWEIS are in progress.

In 2022, no EISs or EAs were completed. One Categorical Exclusion under DOE NEPA Regulations (10 CFR Part 1021) was completed as follows:

- *Site 300 Well 21 (NA 1-22)*

2.4.2 National Historic Preservation Act

The National Historic Preservation Act (NHPA) provides protection and preservation of historic properties that are significant in the nation's history. LLNL resources subject to NHPA consideration range from prehistoric archeological sites to remnants of LLNL's own history of scientific and technological endeavors. The responsibility to comply with the provisions of the NHPA rests with DOE/NNSA as the lead federal agency. LLNL supports the agency's NHPA responsibilities with direction from DOE/NNSA.

LLNL and DOE/NNSA have completed the necessary inventory, evaluations, and consultations to identify National Register of Historic Places (NRHP) eligible buildings and archaeological sites at both the Livermore Site and Site 300. In 2005, in consultation with DOE/NNSA, the California State Historic Preservation Officer (SHPO) formally determined that five archaeological resources, five individual buildings, two historic districts (encompassing 13 non-contiguous individual buildings), and selected objects in another building at LLNL are eligible for listing in the NRHP. As of 2020, based on DOE consultations with the SHPO and the Advisory Council on Historic Preservation (ACHP), all previously eligible facilities have been removed from the eligibility list. As final mitigation for loss of integrity for the historic significance period, LLNL and DOE/NNSA prepared Historic American Engineering Report (HAER) documentation for each of these facilities.

2.4.3 Antiquities Act of 1906

The Antiquities Act provides protection for items of antiquities (i.e., archaeological sites and paleontological remains). The NRHP-eligible archaeological sites noted in Section 2.4.2 are protected under the Antiquities Act. No paleontological remains subject to the provisions of the Antiquities Act were identified in 2022.

2.4.4 Endangered Species Act and Sensitive Natural Resources

LLNL meets requirements of the Federal and State Endangered Species Acts (ESAs), the Eagle Protection Act, the Migratory Bird Treaty Act, and other applicable regulations as they pertain to endangered species, threatened species, and other special-status species (including their habitats) and designated critical habitats that exist at LLNL sites.

On August 29, 2018, the U.S. Fish and Wildlife Service issued a sitewide biological opinion to DOE/NNSA for continued operations and maintenance of the LLNL Experimental Test Site, Site 300. Two projects were completed under this biological opinion in 2022: the Building 812 Monitoring Well (W-812-3811) and Mud Pit and the Building 850 Monitoring Well (W-850-3812) and Mud Pit.

At the Livermore Site, the following projects were conducted under the 2013 biological opinion for infill construction and redevelopment: Building 449 Science Office Facility (STAR), Building 226 New AME Joining Capabilities and Vapor Disposition Facility, Site 200 Compressed Air and Miscellaneous Valve Replacement Project, Building 265 Environmental Safety & Health Office, Building 654 Expansion for Stockpile Science, Building 310 New Nondestructive Evaluation Building, and the Building 321G Manufacturing Building.

Annual flood control maintenance within the Livermore Site reach of Arroyo Las Positas was completed under the 1997 biological opinion, as well as subsequent amendments for the arroyo maintenance project on Arroyo Las Positas.

All Terms and Conditions and Conservation Measures required by the biological opinions described above were successfully implemented in 2022.

2.5 Environmental Permits, Inspections, and Occurrences

LLNL's various missions require a variety of permits. **Table 2-4** is a summary of active permits in 2022 at the Livermore Site and Site 300. The external agencies that issue the permits may also perform inspections required by the permits. **Table 2-5** lists environmental inspections and findings from both LLNL sites in 2022.

Notification of environmental occurrences is required under several environmental laws and regulations as well as DOE Order 232.2A (Occurrence Reporting and Processing of Operations Information). **Table 2-6** provides a list of environmental occurrences reportable under DOE Order 232.2A.

Table 2-4. Active Permits at the Livermore Site and Site 300 in 2022[a]

Type of Permit	
Livermore Site	**Site 300**
Hazardous Waste	
EPA ID No. CA2890012584. Hazardous Waste Facility Permit Number 2022/23-HWM-07 and RCRA Part A/B permit application – to operate hazardous waste management facilities. Agency – DTSC. Registered Hazardous Waste Hauler authorized to transport regulated wastes on public roadway. Permit number 1351. Agency – DTSC. Facility I.D. # 10697. Hazardous Waste Generator Program, on-site treatment of hazardous waste (tiered permitting) program: Conditionally Exempt Specified Wastestream, CE231-1, Hazardous Materials Business Program, Above Ground Petroleum Tank Program, and CA Accidental Release Program. Agency – LPFD CUPA.	EPA ID No. CA2890090002. Hazardous Waste Facility Permit and RCRA Part A/B permit application to operate CSA (Building 883), EWTF and EWSF. Agency – DTSC. EPA ID No. CA2890090002. Hazardous Waste Facility Post-Closure Permit and RCRA Site 300 Building 829 Post-Closure Operation Plan. Agency – DTSC. Facility I.D. # FA0003934 RCRA Hazardous Waste Generator category: waste generation in an amount equal to or more than 50 tons, but less than 250 tons. Agency – SJCEHD CUPA.
Medical Waste	
ACDEH issued a Large Quantity Medical Waste Generator permit (PT0200461/PT0305526) that covers medical waste generation and treatment activities for BSL 2 facilities at B132 North and South, B150 Complex, B360 Complex, B663, and the BSL 3 facility.	Registered with SJCEHD as a Small Quantity Medical Waste Generator.

Table 2-4. (cont.) Active Permits at the Livermore Site and Site 300 in 2022[a]

Livermore Site	Site 300
Air	
BAAQMD renewed the Permit-to-Operate (PTO) issued to LLNL Livermore Site (Plant No. 255) which covers 165 existing various air emission sources (109 permitted sources, 38 registered sources, and 18 exempt sources). BAAQMD conducted compliance inspections on 82 air emission sources. BAAQMD issued a revision to the SMOP in 2015, which was initially issued in 2002 to ensure the NOx and HAPs emissions from the site do not exceed federal Clean Air Act Title V emission limits. BAAQMD issued one Asbestos Renovation Permit and three Asbestos Demolition Permits.	SJVAPCD renewed the PTO issued to LLNL Site 300 (Facility ID N-472) which covers 33 existing various air emission sources. BAAQMD renewed the PTO issued to LLNL Site 300 (Plant No. 15611) which covers one existing standby diesel engine powering an emergency generator. SJVAPCD approved a Prescribed Burn Plan for the burning of 1,905 acres of grassland at LLNL Site 300. SJVAPCD conducted one start-up compliance inspection on two air emission sources. SJVAPCD issued two Asbestos Renovation Permits and five Asbestos Demolition Permits. BAAQMD approved a Prescribed Burn Plan for the burning of 139.1 acres of grassland at LLNL Site 300. CARB renewed two PERP registrations for portable diesel engines powering various portable equipment.
Underground Storage Tanks	
UST permit (1016-09202018) issued by LPFD from September 20, 2018 – September 19, 2023, covering the operation of nine USTs and the approved monitoring program and emergency response plan for these systems.	One operating permit covering three underground petroleum storage tanks assigned individual permit numbers (PT0006785 [879TFUD01], PT0006530 [882TFUD01], and PT0007967 [879TFUG01]).
Sanitary Sewer	
Discharge Permit 1250[b] for discharges of wastewater to the sanitary sewer. Permit 1510G for groundwater discharges from CERCLA restoration activities to the sanitary sewer.	WDR R5-2008-0148 for operation of sewage evaporation and percolation ponds, septic systems, cooling tower discharges, mechanical equipment wastewater discharges, and other low-threat discharges.

Table 2-4. (cont.) Active Permits at the Livermore Site and Site 300 in 2022[a]

Type of Permit	
Livermore Site	**Site 300**
Water	
WDR No. 88-075 for discharges of treated groundwater from Treatment Facility A to recharge basin.[(c)] NPDES General Permit 2014-0057-DWQ (Waste Discharge Identification Number [WDID] 2 01I025682) for discharge of storm water associated with industrial activities. NPDES General Permit 2009-0009-DWQ for discharges of storm water associated with construction activities affecting 0.4 hectares (1 acre) or more. FFA for groundwater investigation/remediation. Domestic Water Supply Permit 02-04-20P-0110701.	WDR No. 93-100 for post-closure monitoring requirements for two Class I landfills.[(d)] WDR R5-2008-0148 for operation of sewage evaporation and percolation ponds, septic systems, cooling tower discharges, mechanical equipment wastewater discharges, and other low-threat discharges. NPDES General Permit 2014-0057-DWQ (WDID 5S39I021179) for discharge of storm water associated with industrial activities. NPDES General Permit 2009-0009-DWQ for discharges of storm water associated with construction activities affecting 0.4 hectares (1 acre) or more. WDR R5-2022-0006 and NPDES No. CAG995002 for limited threat discharges to surface water from the Site 300 drinking water system. Water Code Section 13267 Order, Submittal of Technical and Monitoring Reports for the Active Building 851 Firing Table, Lawrence Livermore National Laboratory Site 300, San Joaquin County. Site 300 Domestic Water Supply Permit Amendment No. 01-10-16PA-003 and the Site 300 Granulated Activated Carbon Treatment Facility – Approval to Operate, October 15, 2019. FFA for groundwater investigation/remediation. Approximately 32 registered Class V injection wells.

Note: See the **Acronyms and Glossary** section for acronym definitions.

(a) Numbers of permits are based on actual permitted units or activities maintained and/or renewed by LLNL during 2022.

(b) Permit 1250 includes some wastewater generated at Site 300 and discharged at the Livermore Site.

(c) Recharge basin referenced in WDR Order No. 88-075 is located south of East Avenue within Sandia National Laboratories/California boundaries. The discharge no longer occurs; however, the agency has not rescinded the permit.

(d) On July 22, 2020, the transfer of Site 300 Closed Landfill Pit 1 from Resource Conservation and Recovery Act (RCRA) Post-Closure Monitoring to Comprehensive Environmental Compensation and Liability Act (CERCLA) was completed. WDR No. 93-100 was rescinded, and Pit 1 post-closure compliance monitoring will be conducted under CERCLA oversight.

Table 2-5. External Agency Inspections at the Livermore Site and Site 300 in 2022

Medium			
Description	**Agency**	**Date**	**Finding**
Air			
Air Pollutant Emission Sources (Livermore Site)	BAAQMD	03/29/22 05/10/22 06/14/22 08/09/22 10/04/22	No violations No violations No violations No violations No violations
Air Pollutant Emission Sources (Site 300)	SJVAPCD	05/03/22	No violations
Hazardous Materials Business Plan			
CUPA Inspection (Livermore Site)	LPFD	10/24/22 – 10/27/22	No violations
CUPA Inspection (Site 300)	SJCEHD	N/A	No violations
Sanitary Sewer			
Annual Inspection of the Sewer Monitoring Complex (Livermore Site)	WRD	10/05/22	No violations
Annual Categorical Sampling and Inspection, Building 153 (Livermore Site)	WRD	10/04/22	No violations
Café Grease Interceptor Inspections, Buildings 125 and 471 (Livermore Site)	WRD	10/05/22	No violations

Table 2-5. (cont.) External Agency Inspections at the Livermore Site and Site 300 in 2022

Description	Agency	Date	Finding
Medium			
SPCC/APSA, UST and Aboveground Tank Closures			
Annual CUPA Inspection – APSA/SPCC Program (Livermore Site)	LPFD	10/24/22 – 10/27/22	No violations
Annual Spill Container Test/Annual Monitoring System Certification (Site 300)	SJCEHD	07/28/22	No violations
Triennial Cathodic Protection Survey for B611 Fuel Station USTs with Single-walled Piping (Site 200)	LPFD	11/28/22	No violations
Annual Spill Container Test/ Annual Monitoring System Certification for Emergency Generator USTs (Livermore Site)	LPFD	07/26/22 – 07/27/22	LPFD issued one violation requiring an epoxy pack inside the sump of 111TFUD01 to be placed inside an electrical junction box. This corrective action was implemented, and documentation was provided to LPFD.
Annual Spill Container Test/ Annual Monitoring System Certification for B611 Fuel Station USTs (Livermore Site)	LPFD	07/26/22 08/11/22	LPFD issued one violation due to the failure of hydrostatic testing of the 611TFUG02 spill container. LPFD issued a corrective action to repair the spill bucket and retest it. This corrective action was implemented, with LPFD representative witnessing repair and retest.
Triennial Secondary Containment Testing for B611 Fuel Station USTs (Livermore Site)	LPFD	09/21/22	No violations
Triennial Line Leak Detection Testing for B611 Fuel Station USTs with Single-walled Piping (Site 200)	LPFD	07/25/22	No violations

Table 2-5. (cont.) External Agency Inspections at the Livermore Site and Site 300 in 2022

Description	Agency	Date	Finding
Medium			
Waste			
CUPA Inspection (Livermore Site)	LPFD	10/24/22 – 10/27/22	No violations
CUPA Inspection (Site 300)	SJCEHD		No inspection in 2022
Hazardous Waste Facilities Compliance Evaluation Inspection (CEI) (Livermore Site)	DTSC	10/25/22 – 10/26/22	A minor violation was issued as the result of an employee not having all permit-required trainings completed within 6 months of assignment to their position.
Hazardous Waste Facilities Compliance Evaluation Inspection (CEI) (Site 300)	DTSC	03/22/22	No violations
Medical Waste Facilities Inspection	ACDEH	11/29/22	No violations
Water			
Permitted Operations (Site 300 Drinking Water)	SWRCB	N/A	No inspection in 2022
Permitted Operations (Livermore Site Drinking Water)	SWRCB	N/A	No inspection in 2022
Waste Discharge Requirements (WDR R5-2008-0148) for Sewage Pond, Percolation Pits, Septic Systems, Cooling Tower Discharges, Mechanical Equipment Wastewater Discharges, and Other Low-threat Discharges	CVRWQCB	04/12/22 10/24/22	No violations No violations
Industrial and Construction General Permits: Storm Water Pollution Prevention Plans (Livermore Site)	SFRWQCB	11/08/22	No violations
Industrial and Construction General Permits: Storm Water Pollution Prevention Plans (Site 300)	CVRWQCB	N/A	No inspection in 2022

Note: See the **Acronyms and Glossary** section for acronym definitions

Table 2-6. Environmental Occurrences Reported in the Occurrence Reporting System in 2022

Date[a]	Occurrence Category/Group	Description
12/08/22	Report Level I Occurrence under Group 9(1) OR 22-51	On December 8, 2022, LLNL received a Summary of Violation following a Compliance Evaluation Inspection (CEI) at the Livermore Site conducted on October 25 – 26, 2022. A minor violation was issued because an employee had not completed all permit-required training within 6 months of assignment to their position. The individual completed the single missing course on 10/26/2022 and not further action was required.
07/29/22	Report Level I Occurrence under Group 9(1) OR 22-29	On July 29, 2022, LLNL received two violations following an inspection by LPFD of the Livermore Site UST systems during the annual monitoring system certification and spill bucket testing conducted on July 26 – 27, 2022. The first violation was for a spill bucket (611TFUG02) hydrostatic test failure. The second violation was for an incorrect wiring configuration inside sump 111TFUD01 that was inconsistent with the manufacturer's installation instructions.

Note: See the **Acronyms and Glossary** section for acronym definitions.

[a] Date the occurrence was categorized, not discovered.

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3. Environmental Program Information

Heather Ottaway

Lawrence Livermore National Laboratory (LLNL) is committed to enhancing its environmental stewardship and reducing any impacts its operations may have on the environment. This chapter describes LLNL's Environmental Management System (EMS) and Pollution Prevention/Sustainability Program (P2S).

3.1 Environmental Management System

LLNL continues to enhance its EMS through systematic process improvements and increased focus on establishing specific environmental objectives and performance measures contained in Environment, Safety & Health (ES&H) Action Plans. Progress toward goals is regularly measured and provided to senior management and other interested parties through a variety of means, including periodic senior management reports and the yearly update of this report. The Laboratory's EMS has successfully maintained its International Organization for Standardization (ISO) 14001 registration since 2009 and is audited annually by a third-party internationally recognized ISO registrar for continued conformance and certification. In Fiscal Year (FY) 2021, the Laboratory was successfully recertified for another three years to the ISO 14001:2018 standard.

3.1.1 ES&H Action Plans

ES&H Action Plans are established each year to detail the objectives and track progress toward meeting environmental goals focused on addressing identified risks and opportunities associated with significant environmental aspects. Each institutional ES&H Action Plan is championed by a senior manager who is responsible for developing objectives, assigning a process owner to successfully lead the project to meet objectives, providing adequate resources such as team members and data, holding the team accountable to goals and objectives, and presenting interim reviews to the senior management team. All ES&H Action Plans are reviewed and approved by the Laboratory Deputy Director. Organizations also have the option to implement action plans targeted to their specific risks and opportunities. Senior managers championed ten ES&H Action Plans during FY2022. **Table 3-1** lists the two ES&H Action Plans that address environmental aspects along with progress made in FY2022 toward meeting the objectives (three other ES&H Action Plans address health & safety issues). The environmental Action Plans in place also help to ensure that related U.S. Department of Energy (DOE) sustainability goals are addressed. LLNL's status toward meeting the DOE sustainability goals, along with planned actions (including ES&H Action Plans) to ensure continued progress toward attaining these goals, can be found in the *LLNL FY2023 Site Sustainability Plan* in **Appendix C.**

Table 3-1. ES&H Action Plan Summary

Action Plan	Related DOE SSP Goal Category	Objectives	FY2022 Progress
AP-10 Hazardous Waste Compliance	Waste Management	Perform post-CUPA (Certified Unified Program Agency) walkthrough six months after the CUPA inspection to ensure continued compliance in waste generator areas.	Completed post-CUPA inspections to establish a baseline for continued improvement in hazardous waste generator compliance.
AP-11 Greenhouse Gas Compliance Emissions Reduction	Greenhouse gas emissions, energy use, adaptation, and resilience	**Greenhouse Gas (GHG) Cap and Trade Compliance:** develop and implement a strategy to comply with California Cap-and-Trade and to minimize the costs of this market-based regulatory regime. **Gas Insulated Equipment (GIE) Sulfur Hexafluoride (SF6) Emissions Management:** develop and implement a GIE SF6 emissions management and reduction plan to reduce GIE SF6 use and minimize the institutional risk associated with GIE SF6 emissions. **Refrigerant Management Compliance:** develop and implement an improved Refrigerant Management Program allowing the Laboratory to comply with current and future federal and state regulations.	Determined baseline conditions and developed strategy to delay entry into California Cap-and-Trade and minimize costs of market-based regulatory regime. Implemented Gas-Insulated Equipment (GIE) SF6 Task Force to identify and propose efforts to reduce GIE SF6 use and minimize the institutional risk associated with GIE SF6 emissions. Developed and implemented improved Refrigerant Management Program, allowing the Laboratory to efficiently comply with current and future federal and state regulations.

3.1.2 EMS Audits and Reviews

The Laboratory successfully completed one external third-party independent surveillance audit of its ISO 14001 EMS program (May 2022) with recommendations from the auditor to continue LLNL's ISO 14001:2015 registration through 2024. This independent audit was conducted by NSF International Strategic Registrations and validated the Laboratory's solid commitment to environmental stewardship.

3.1.2.1 Internal Assessments and Reviews

In February – March 2022, an internal audit (Joint Functional Area Line Management Assessment [JFLMA]) was performed to assess if LLNL continued to meet the requirements of the standard. This audit used a management assessment model to ensure objectivity and impartiality were maintained during the process.

In accordance with LLNL's EMS, the Laboratory's environmental compliance is regularly evaluated through reviews of internal assessments including Management Self Assessments

(MSAs), Management Observations and Inspections (MOIs), regulatory inspections, internal and external monitoring and compliance reports, and facility walk-throughs and work-control assessments. As a result of these reviews, LLNL identified specific practices and recommendations for corrective and preventive measures, demonstrating the Laboratory's commitment to environmental compliance.

3.2 Pollution Prevention/Sustainability Program

LLNL's P2S Program operates within the framework of the Integrated Safety Management System (ISMS) and EMS and in accordance with applicable laws, regulations, and DOE orders as required by contract. It encompasses stewardship and maintenance, waste stream analysis, reporting waste generation and P2S accomplishments, and fostering P2S awareness through presentations, articles, and events. The P2S Program supports institutional and directorate P2S activities via environmental teams and includes implementation and facilitation of source reduction and/or reclamation, recycling, and reuse programs for hazardous and nonhazardous waste; facilitation of sustainable acquisition; contribution to the Site Sustainability Plan; and preparation of P2S opportunity assessments.

The P2S Program at LLNL strives to systematically reduce all types of waste generated and eliminate or minimize pollutant releases to all environmental media from all aspects of the operations at the Livermore Site and Site 300. These efforts help protect public health and the environment by reducing or eliminating waste, improving resource usage, and reducing inventories and releases of hazardous chemicals. These efforts also benefit LLNL by reducing compliance costs and minimizing the potential for civil and criminal liabilities under environmental laws. In accordance with United States Environmental Protection Agency (EPA) guidelines and DOE policy, the P2S Program uses a hierarchical approach to waste reduction (i.e., source elimination or reduction, material substitution, reuse and recycling, and, lastly, treatment and disposal) which is applied to all types of waste. Radioactive and hazardous waste generation is tracked using Radioactive and Hazardous Waste Management's (RHWM's) HazTrack database (a system used to track all waste managed by RHWM). By reviewing the information in this database, program managers and P2S Program staff can monitor and analyze waste streams managed by RHWM to determine cost-effective improvements to LLNL operations. The P2S Program primarily focuses on opportunities to reduce routine waste from ongoing operations and non-routine waste from construction and demolition activities. Data on non-routine hazardous, transuranic, and radioactive waste can be found in the *2022 Annual Yearbook for the LLNL SW/SPEIS* (Bibby, Price 2023).

3.2.1 Routine Hazardous, Transuranic, and Radioactive Waste

Routine waste listed in **Tables 3-2** and **3-3** includes waste from ongoing operations produced by any type of production, analysis, and research and development taking place at LLNL.

Table 3-2. Routine Hazardous Waste at LLNL, FY2018–2022 (Metric Tons [MT])

Waste Category	FY2018	FY2019	FY2020	FY2021	FY2022
Routine hazardous waste generated	167	155	111	253	118

Table 3-3. Routine Transuranic and Radioactive Waste at LLNL, FY2018–2022 (m^3)

Waste Category	FY2018	FY2019	FY2020	FY2021	FY2022[(a)]
Routine LLW generated	526	369	297	736	106
Routine mixed LLW generated	38	40	28	67	7.8
Routine TRU/mixed TRU waste generated	17	22	5	1	1

Note: See the **Acronyms and Glossary** section for acronym definitions

(a) Values for FY2022 are estimated from data originally recorded in pounds.

3.2.2 Diverted Waste

LLNL maintains an active waste-diversion program, encouraging recycling and reuse of both routine and non-routine waste, which prevents waste from going to the landfill. Site sustainability goals require separate accounting for construction/demolition and municipal solid wastes as reflected in **Tables 3-4** and **3-5.**

3.2.2.1 Municipal Solid Waste

Together, the Livermore Site and Site 300 generated 3,184 MT of routine nonhazardous solid waste in FY2022. This volume includes diverted waste (e.g., material diverted through recycling and reuse programs) and landfill waste.

Combined, both sites diverted a total 2,312 MT of routine nonhazardous waste in FY2022, which represents a diversion rate of 73%. The portion of routine nonhazardous waste sent to landfill was 871 MT, see **Table 3-4.** In 2022, LLNL recycled over 4,000 computers, monitors, and laptops, which were resold or managed as universal waste. LLNL recycled 24 MT of large and small batteries, which were also managed as universal waste. Cell phones and tablets that are no longer needed by LLNL are sold to a vendor who refurbishes the items for reuse.

The comingled recycling and composting program initiated in May 2011 continued during 2022, diverting an estimated 125 MT of comingled recycling and 130 MT of compostable material from the landfill. Recycling opportunities for plastics continues to be limited, but LLNL searches for alternatives to disposable plastic items and works with vendors to take back plastic items such as containers and drums that can be reused or recycled.

Table 3-4. Routine Municipal Waste in FY2022, Livermore Site and Site 300 Combined

Destination	Waste Description	Amount in FY2022 (MT)
Diverted	Baled paper	69
	Corrugated cardboard	77
	Cooking grease (including grease traps)	8.4
	Mixed metals	1355.5
	Scrap lead (Pb)	2.3
	Plastic	0
	Office paper	22
	Toner cartridges	5.7
	Greenwaste (chips, compost, mulch, clean wood)	516.5
	Comingled recycling	125.5
	Compost (food scraps, paper towels, food containers)	130
	TOTAL diverted	**2,311.9**
Landfill	Compacted (landfill)	871
	TOTAL landfill	**871**
	TOTAL routine nonhazardous waste	**3,183**

3.2.2.2 Construction and Demolition (C&D) Waste

C&D wastes include excavated soils, wastes, and metals from construction, decontamination, and demolition activities. The Livermore Site and Site 300 generated a total of 1,405 MT of waste related to construction and demolition activities in FY2022. The two sites combined diverted 1,020 MT of non-routine nonhazardous solid waste through reuse or recycling, which represents a diversion rate of 73% in FY2022. LLNS continues to make improvements to better streamline reporting of C&D recycling efforts between LLNS' sustainability team, construction team, and construction subcontractors. Diverted C&D waste includes soil and concrete reused either on-site for other projects or as cover at Class II landfills. See **Table 3-5.**

Table 3-5. Construction and Demolition Waste in FY2022, Livermore Site and Site 300 Combined

Destination	Waste Description	Amount in FY2022 (MT)
Diverted	Class II cover soil (reused on-site or as landfill cover)	469
	Class II concrete (reused at the landfill for roads, pads, etc. or as cover)	466.5
	Scrap metals (recycled)	84.5
	TOTAL diverted	**1,020**
Landfill	Construction and demolition (non-compacted landfill)	385
	TOTAL landfill	**385**
	TOTAL non-routine non-hazardous waste	**1,405**

3.2.3 Sustainable Acquisition

LLNL has a comprehensive Sustainable Acquisition program that includes preferential purchasing of recycled content and bio-based products. In 2022, the Sustainable Acquisition program continued to include a preference for Electronic Product Environmental Assessment Tool (EPEAT) registered computers and monitors, imaging equipment, and televisions. Over 95% of all desktop electronics, imaging equipment, television, server, and cell phone purchases in FY2022 were EPEAT Bronze, EPEAT Silver, or EPEAT Gold, indicating that the products meet or exceed the Institute of Electrical and Electronics Engineers (IEEE) environmental performance standards for electronic products (1680.1-2018; 1680.2-2012; 1680.3-2012).

Additional sustainable acquisition highlights can be found in the *LLNL FY2023 Site Sustainability Plan* in **Appendix C.**

3.2.4 Pollution Prevention/Sustainability Activities

3.2.4.1 Sustainability Accomplishments

LLNL's P2S Program assists the site in meeting Site Sustainability Plan goals related to municipal waste reduction, acquisition, and electronic stewardship by conducting and responding to opportunity assessments; these include direct calls from program areas as well as Green Hotline inquiries. During FY2022 the P2S Program assisted with several sustainability projects that include participating in workgroups to determine a recycling pathway for excess refrigerants, refining construction and demolition waste tracking, installing additional electric vehicle charging infrastructure, and expanding the recycling and composting program to additional buildings.

3.2.4.2 High-Performance Sustainable Buildings and Energy Conservation

One new facility, the Emergency Operations Center, was completed in FY2022 and met LEED Gold certification. This provides an additional 20,550 square feet to the assessed and/or certified total.

A new office building design standard – Standardized Acquisition and Recapitalization (STAR) – was developed by the National Nuclear Security Administration (NNSA) to reduce the complexities typically associated with building at a DOE site and to streamline the design and construction of a STAR office building. The STAR design standard incorporates the 2020 Guiding Principles for Sustainable Federal Buildings. Five STAR facilities are planned for completion in FY2023 and two facilities are planning to obtain LEED Silver certification.

Applying best practices continues to help reduce LLNL's energy intensity and greenhouse gas (GHG) emissions. These best practices include alerting facility managers of excessive use in their facilities, updating and adapting equipment operating schedules to meet the changing requirements of occupants, providing staff with the training and tools they need, and tracking energy use and comparing against expected performance. LLNL's Livermore Site and Site 300 each have a site-wide direct digital control (DDC) system that is used to control temperatures, pressures, and humidity in many buildings. The system is state-of-the-art and in 2022 had approximately 1,200 (compared to 941 in 2021) high-speed, connected digital processors in 63 buildings with several more installations planned.

LLNL has also implemented many on-going sustainability efforts to increase the energy efficiency of data center facilities that include installing Cold Aisle Containment (CAC) systems, increasing ambient temperature and reducing occupancy lighting in several key data center facilities, and implementing server consolidation and server virtualization (i.e., using software to divide one physical server into multiple isolated virtual environments). LLNL continues to identify and decommission data centers that are no longer needed. The $100 million Exascale Computing Facility Modernization (ECFM) project was completed in FY2022 providing additional power and cooling to operate two exascale supercomputers in Building 453 (B453). Although designed with energy saving controls and innovative cooling technology, ECFM will have a significant impact on the future energy and water use at the Livermore Site. In response, LLNL is exploring energy and water conservation opportunities, including the feasibility of wastewater reuse, alternative data center cooling technologies, and energy savings in other areas.

Additional information on energy conservation goals can be found in the *LLNL FY2023 Site Sustainability Plan* in **Appendix C.**

3.2.5 Resilient Operations

Although the P2S Program conducted awareness activities throughout the year, the COVID-19 pandemic caused many activities to be cancelled or converted to virtual platforms. P2S staff participated in several DOE-wide forums. Additionally, P2S staff presented to various groups at symposiums about LLNL's sustainable acquisition efforts, the EMS program, and action plans.

LLNL, Sandia National Laboratories (SNL/CA), and the Livermore Laboratory Employee Services Association (LLESA) (a non-profit employee services group that supports both sites) typically host a joint Bike to Work and Share Your Ride event each May. However, this event was not held in 2020 or 2021 due to COVID-19. In FY2022, LLESA transitioned from hosting an onsite Bike-to-Work Day energizer station to hosting a Biking Challenge during the same month.

The Biking Challenge promoted participation in the official Bike-to-Work Day event and encouraged visits to other Livermore energizer stations. This new format enables employees to participate in the Biking Challenge regardless of their work situation as many employees continue to incorporate telecommuting into their work schedules. LLESA will continue to promote participation in the official Bike-to-Work Day event.

The P2S Program continued to conduct training for staff on Sustainable Acquisition requirements and support the Green Hotline to help employees with questions, suggestions, or ideas regarding LLNL's pollution prevention and waste diversion endeavors, as well as other environmental issues.

New regulations (e.g., Executive Orders 14008, 14030, 14057) required LLNL to complete additional deliverables this fiscal year including a Vulnerability Assessment and Resiliency Plan (VARP) and a 5-year electric vehicle infrastructure plan.

LLNL completed a VARP in September 2022 to identify the most significant climate impacts to the Livermore Site and Site 300 and present resilient solutions to address these impacts. For both sites the climate impacts with the highest calculated risk include increased number of extreme heat days, extreme weather events (and riverine flooding at Site 300), drought (and reduced snowpack for the Livermore Site), actual loss from wildfires, and degraded air quality from wildfires. These hazards are anticipated to impact the on-site workforce, site buildings, specialized or mission-critical equipment, energy generations and distribution systems, IT and telecommunications, water and wastewater systems, transportation and fleet, and availability of critical materials. Additional information on identified resilience solutions can be found in the *LLNL FY2023 Site Sustainability Plan* in **Appendix C.**

A 5-year electric vehicle infrastructure plan was completed to evaluate various parking lots across the LLNL campus and provide solutions to consolidate and increase the overall number of electric vehicle (EV) charging stations. Expanded onsite charging infrastructure is needed to support the transition of fleet vehicles to zero-emission vehicles by 2035 as required by E.O. 14057.

4. Air Monitoring and Dose Assessment

Nick Graves • Kent Wilson

Lawrence Livermore National Laboratory (LLNL) performs continuous air sampling to evaluate its compliance with local, state, and federal laws and regulations and to ensure that human health and the environment are protected. Federal environmental air quality laws and U.S. Department of Energy (DOE) regulations include Title 40, Code of Federal Regulations, Part 61 (40 CFR 61), Subpart H – the National Emission Standards for Hazardous Air Pollutants (NESHAPs) section of the Clean Air Act; applicable portions of DOE Order 458.1; and American National Standards Institute (ANSI) standards (N13.1-1969, and 1999 [reaffirmed 2011]). The *Environmental Radiological Effluent Monitoring and Surveillance* (DOE 2015) handbook provides guidance for implementing DOE Order 458.1.

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

4.1 Air Effluent Monitoring

Air effluent monitoring of atmospheric discharge points is in place for compliance with 40 CFR 61, Subpart H and is used to determine the actual radionuclide releases from individual facilities during routine and nonroutine operations and to confirm the operation of facility emission control systems. Subpart H requires continuous monitoring of facility radiological air effluents if the potential off-site (fence-line) dose equivalent is greater than 1 µSv/y (0.1 mrem/y), as calculated using the U.S. EPA-mandated air dispersion dose model, CAP88-PC, without credit for emission control devices. The results of monitoring air discharge points provide the actual emission source information for modeling, which is used to ensure that the NESHAPs standard of 100 µSv/y (10 mrem/y) total site-wide effective-dose equivalent from the airborne pathway is not exceeded. See **Appendix C** for the *LLNL 2022 NESHAPs Annual Report* (Wilson et al. 2023).

The air effluent sampling program measures only radiological emissions. For LLNL operations with nonradiological discharges, LLNL obtains permits and registrations from local air districts (i.e., BAAQMD and SJVAPCD) for stationary emission sources and from the California Air Resources Board (CARB) for portable emission sources such as diesel air compressors and generators and off-road diesel vehicles. Current permits and registrations do not require monitoring of air effluent but do require monitoring of equipment inventory, equipment usage, material usage, and/or recordkeeping during operations. Based on air toxics emissions inventory and risk assessment required by the California Air Toxics "Hot Spots" Information and Assessment Act of 1987, BAAQMD and SJVAPCD have ranked LLNL as a low-risk facility for nonradiological air emissions.

4.1.1 Air Effluent Radiological Monitoring Results

In 2022, LLNL measured releases of radioactivity from air exhausts at five facilities at the Livermore Site and at one facility at Site 300. Air effluent monitoring locations at the Livermore Site and Site 300 are shown in **Figures 4-1** and **4-2**, respectively.

Three facilities had measurable emissions in 2022. A total of 74.3 Ci (2749 GBq) of measured tritium was released from the stack exhausts at the Tritium Facility. Of this, approximately 39% of tritium was released as vapor (HTO). The remaining 61% released was gaseous tritium (HT).

The National Ignition Facility (NIF) released a total of 8.0 Ci (296 GBq) of tritium from the stack exhaust in 2022. Of this, approximately 75% of tritium was released as HTO. The remaining 25% was released as HT. Additionally in 2022, the NIF released a total of 1.1E-6 Ci (4.1E-5 GBq) of Iodine-131 vapor and 4.0E-7 Ci (1.5E-5 GBq) of Bromine-82.

The Contained Firing Facility (B801A) at Site 300 had measured depleted uranium stack emissions in 2022 consisting of 3.2×10^{-8} Ci (1.2×10^{-6} GBq) of uranium-234, 4.4×10^{-9} Ci (1.6×10^{-7} GBq) of uranium-235, and 2.3×10^{-7} Ci (8.5×10^{-6} GBq) of uranium-238 in particulate form.

None of the other facilities monitored for radionuclides had reportable emissions in 2022. The data tables in **Appendix A, Section A.1** provide summary results of all air effluent monitoring facilities and include upwind locations (control stations) to compare background levels of gross alpha and gross beta to stack effluent gross alpha and gross beta results.

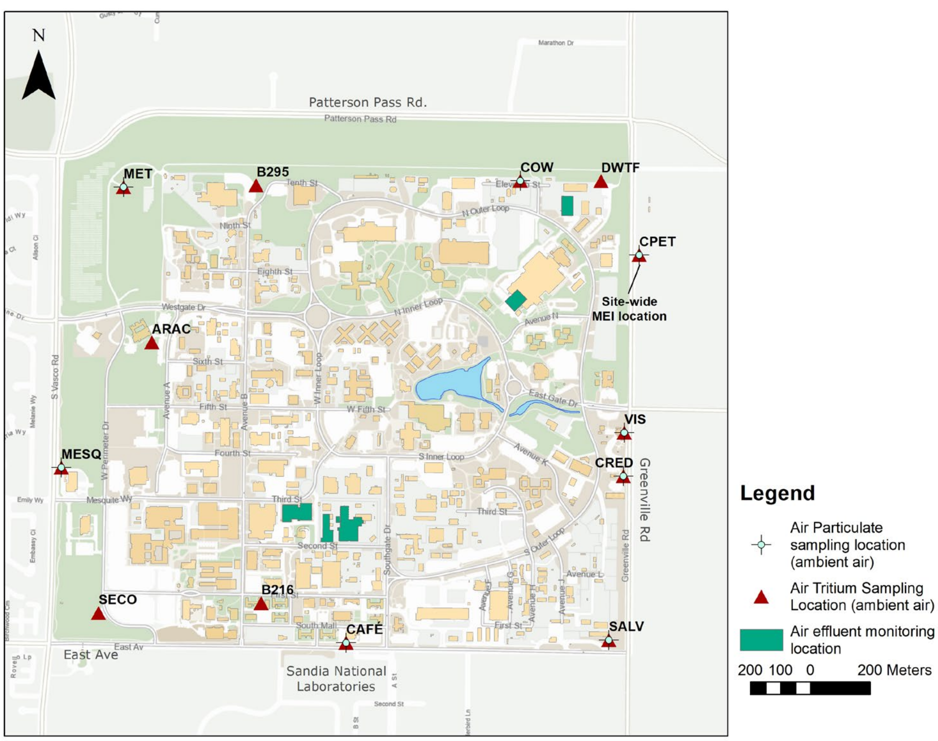

Figure 4-1. Air Effluent and Ambient Air Monitoring Locations at the Livermore Site, 2022

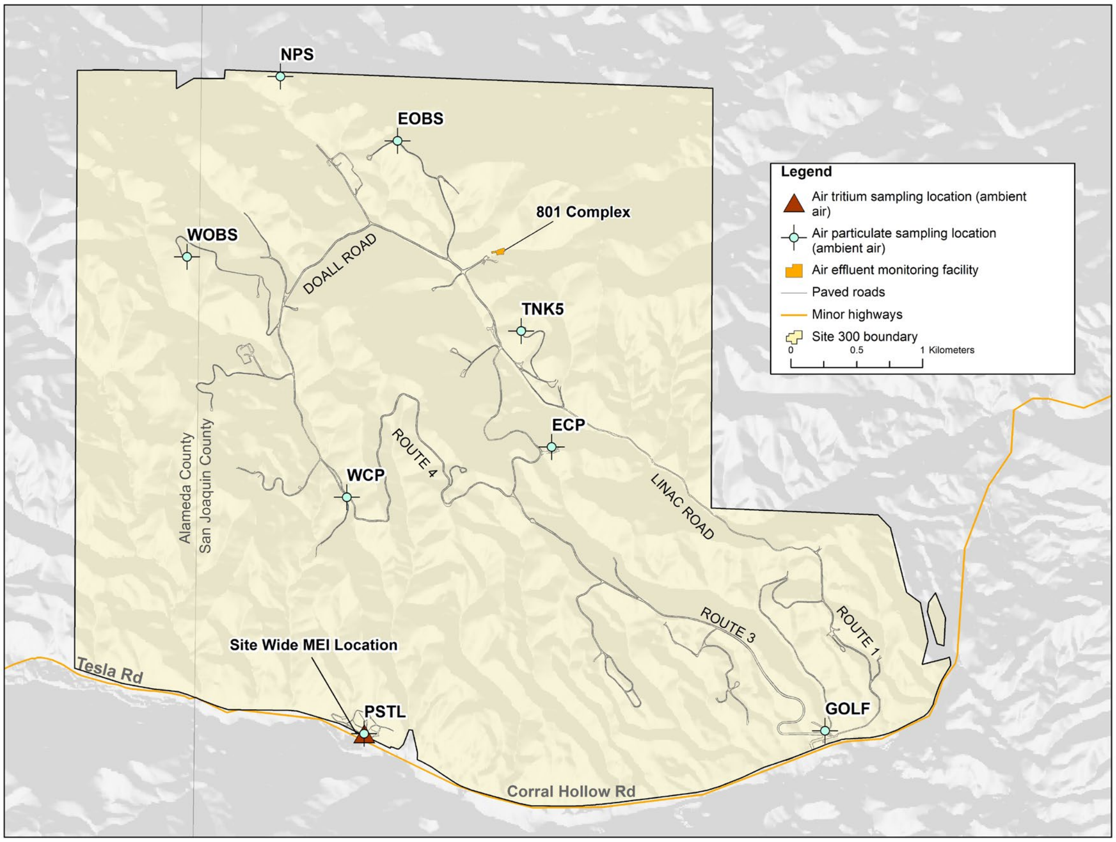

Figure 4-2. Air Effluent and Ambient Air Monitoring Locations at Site 300, 2022

4.1.2 Nonradiological Air Releases and Impact on the Environment

In 2022, the Livermore Site emitted approximately 114.3 kg/d of regulated air pollutants as defined by the Clean Air Act, including nitrous oxides (NOx), sulfur oxides (SOx), particulate matter (PM10), carbon monoxide (CO), and reactive organic gases/precursor organic compounds (ROGs/POCs) (see **Table 4-1**). The stationary emission sources that released the greatest amount of regulated pollutants at the Livermore Site were natural gas-fired boilers, internal combustion engines (such as diesel generators), solvent cleaning, and surface coating operations (such as painting). Pollutant emission information was primarily derived from monthly material and equipment usage records.

Table 4-1. Nonradioactive Air Emissions at the Livermore Site and Site 300, 2022

Pollutant	Estimated releases (kg/d)	
	Livermore Site	Site 300
ROGs/POCs	14.2	0.2
Nitrogen oxides	41.6	1.8
Carbon monoxide	51.7	1.1
Particulates (PM10)	5.2	2.5
Sulfur oxides	1.7	0.02
Total	114.4	5.6

In 2022, Livermore Site air pollutant emissions were low compared to the daily releases of air pollutants from all sources in the entire Bay Area. For example, the average daily emission of NOx in the Bay Area is estimated to be 2.7×10^5 kg/d (BAAQMD 2017). In comparison, the estimated daily release from the Livermore Site is 41.6 kg/d, which is 0.015% of the total Bay Area source emissions for NOx. The BAAQMD estimate for ROGs/POCs daily emissions throughout the Bay Area is approximately 2.35×10^5 kg/d (BAAQMD 2017). In comparison, the daily emission estimate for 2022 from the Livermore Site is 14.2 kg/d, or 0.006% of the total Bay Area source emissions for ROGs/POCs.

Certain operations at Site 300 require permits from the SJVAPCD. The estimated daily air pollutant emissions during 2022 from operations (permitted and exempt stationary sources) at Site 300 are listed in **Table 4-1.** The stationary emission sources that release the greatest amounts of regulated air pollutants at Site 300 include internal combustion engines (such as diesel-powered generators), a gasoline-dispensing facility, and general research operations. Combustion pollutant emissions, including NOx, CO, PM10, SOx, and ROGs/POCs increased in 2022. Diesel-powered generators were the primary source of pollutants.

4.2 Ambient Air Monitoring

LLNL conducts ambient air monitoring at on- and off-site locations to determine whether airborne radionuclides or beryllium are being released to the environs in measurable quantities by LLNL operations. Ambient air monitoring also serves to verify the air concentrations predicted by air dispersion modeling and to determine compliance with the NESHAPs regulations.

Beryllium is the only nonradiological emission from LLNL that is monitored in ambient air. LLNL requested and was granted a waiver by the BAAQMD for source-specific monitoring and recordkeeping for beryllium operations, provided that LLNL can demonstrate that monthly average beryllium concentrations in air are well below regulatory limits of 10,000 pg/m^3. LLNL meets this requirement by sampling for beryllium at perimeter locations.

Based on air-dispersion modeling using site-specific meteorological data, the ambient air samplers, particularly those on the site perimeters, have been placed to monitor locations where elevated air concentrations may occur due to LLNL operations. Sampling locations for each monitoring network are shown in **Figures 4-1**, **4-2**, and **4-3**.

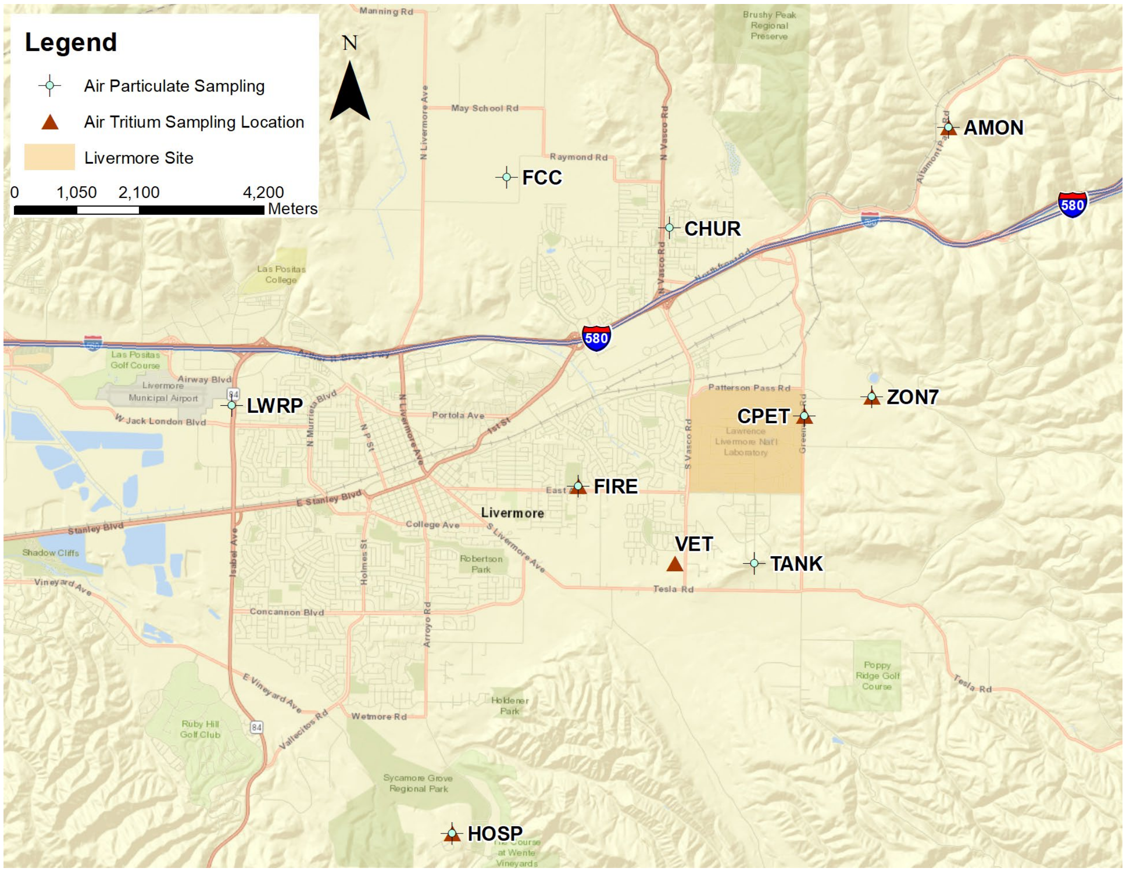

Figure 4-3. Air Particulate and Tritium Monitoring Locations in the Livermore Valley, 2022

4.2.1 Ambient Air Radioactive Particulates

Composite samples for the Livermore Site and Site 300 were analyzed by gamma spectroscopy for an environmental suite of gamma-emitting radionuclide concentrations in air that include fission products, activation products, actinides, and naturally occurring isotopes. The isotopes detected at both sites in 2022 were beryllium-7 (cosmogenic), lead-210, and radium-226, all of which are naturally occurring in the environment.

Composite samples were analyzed by alpha spectroscopy for plutonium-239+240, which was detected in 11 out of 202 samples taken in 2022. Detections at the Livermore Site, Site 300, and Livermore off-site locations for plutonium-239+240 are attributed to factors that include: resuspension of plutonium-contaminated soil (see **Chapter 6**), resuspended fallout from previous atmospheric testing, or resuspended fallout from the Fukushima nuclear accident.

The derived concentration standard (DCS), which complements DOE Order 458.1, specifies the concentrations of a radionuclide that can be inhaled continuously 365 days a year without exceeding the DOE primary radiation protection standard for the public, which is 1 mSv/y (100 mrem/y) effective dose equivalent.

The DCS was formerly published in DOE Order 5400.5 (Radiation Protection of the Public and the Environment) in 1993. The current radiation protection standards approach, which has changed from the previously adopted 1993 guidance, uses age- and gender-specific attributes for the population subgroups of members of the public subject to exposure incorporating more sophisticated biokinetic and dosimetric information from the International Commission on Radiological Protection (ICRP).

The highest values and percentage of the DCS for the plutonium-239+240 detections were as follows:

- Livermore Site perimeter: 55.1 nBq/m^3 (1.5 aCi/m^3), 0.00061% of the DCS.
- Livermore off-site locations: 17.1 nBq/m^3 (0.46 aCi/m^3), 0.00019% of the DCS.
- Site 300 composite: there were no detections of Plutonium-239+240 in 2022.

Uranium-235 and uranium-238 were detected at all sample locations. Uranium ratios, which can be calculated by mass or by atom, are used to determine the type of uranium present in the environment. Natural uranium has a mathematical uranium-235/uranium-238 ratio of 0.00725 and depleted uranium has a typical uranium-235/uranium-238 ratio of 0.002. The annual median uranium-235/uranium-238 isotopic ratios for 2022 at the Livermore Site and Site 300 at the location of the site-wide maximally exposed individual (SW-MEI) member of the public (see **Figure 4-2**) were:

- Livermore Site perimeter composite: 0.0073
- PSTL (located at the SW-MEI): 0.0072

The annual uranium-235/uranium-238 isotopic ratio medians are consistent with naturally occurring uranium.

Site 300 has not had open-air depleted uranium shots since September 2007. However, there are still areas of depleted uranium contaminated soil. Wind-driven resuspension as well as soil disturbance from construction-type activities and fire road maintenance showed a depleted uranium signature in two samples at the location of the SW-MEI (see **Figure 4-2**). The uranium-235 to uranium-238 isotopic ratios were 0.0068 and 0.0069, indicating approximately 11% depleted uranium at the SW-MEI.

All individual uranium-235 and uranium-238 results, including on-site samples showing a depleted uranium signature, were less than one tenth of one percent of the DCS as shown in **Appendix A, Section A.2.**

All locations were sampled for gross alpha and gross beta. The primary sources of alpha and beta activities are naturally occurring radioisotopes. Routine isotopic gamma results indicate the activities are the result of naturally occurring isotopes (uranium, radium, and lead), which are also routinely found in local soils. See **Appendix A, Section A.2.**

4.2.2 Ambient Air Tritium Concentrations

LLNL emits tritium to the air from multiple sources. These include monitored stack sources, such as the Tritium Facility and NIF, unmonitored stack sources having minor emissions of tritium, and area sources. Area (diffuse) sources include stored containers of tritium waste or tritium-contaminated equipment from which HTO diffuses into the atmosphere. LLNL does not directly measure diffuse emissions but estimates the emitted radiation source term from these sources given measurements taken using the ambient air tritium sampling network. The ambient air tritium sampling network measures HTO concentrations in the air from all sources. This information, along with measured stack emissions, is used to estimate the radiation source term from unmonitored sources, which is then used to estimate the total radiation dose to the public. The approach used to characterize the area emission sources is discussed in the *LLNL NESHAPs 2022 Annual Report* (Wilson et al. 2023). See **Appendix C** for a copy of this report. The biweekly air tritium data that are provided in **Appendix A, Section A.2** are summarized in **Table 4-2.**

Table 4-2. Ambient Air Tritium Sampling Summary, 2022

Sampling location	Detection frequency[a]	Concentration (mBq/m^3)				Median as % of DCS[d]	Mean dose[e](nSv)
		Mean	Median	IQR[b]	Maximum[c]		
Livermore Site perimeter	264 of 306	42.1	33.2	39.2	323	0.00043	9.88
Livermore Valley	117 of 153	26.6	17.6	18.3	178	0.00023	6.24
Site 300	8 of 24	7.77	6.20	12.6	39.2	0.000079	< 5

(a) Detection frequency indicates the number of samples that measure greater than 100% of 2-Sigma uncertainty (see Chapter 8).

(b) IQR = Interquartile Range

(c) The maximum concentration in 2022 was 0.0041% of the DCS. (DCS for tritium is 7.8E+06 mBq/m^3, DOE-STD-1196-2011).

(d) Median as a percentage of DCS is not used when the median is a negative value (see Chapter 8).

(e) Based on an annual breathing rate of 8103 m^3 and inhalation dose conversion factor of 1.93×10^{-11} Sv/Bq (DOE-STD-1196-2011). The dose due to HTO absorption through the skin is accounted for. It is estimated to equal one-half of the dose due to inhalation (2001 Environmental Report, Appendix A).

For a location at which the mean concentration is at or below the minimal detectable concentration, dose from tritium is assumed to be less than 5 nSv/y (0.5 µrem/y).

4.2.3 Ambient Air Beryllium Concentrations and Impact on the Environment

LLNL measures the monthly concentrations of airborne beryllium at the Livermore Site and at Site 300. In 2022 the highest value recorded at the Livermore Site perimeter for airborne beryllium was 28 pg/m^3. This value is less than 1% of the BAAQMD ambient concentration limit for beryllium (10,000 pg/m^3). There is no regulatory requirement to monitor beryllium in San Joaquin County; however, LLNL analyzes samples from three Site 300 perimeter locations as a best management practice. In 2022 the highest value recorded at the Site 300 perimeter was 34 pg/m^3. These data are similar to data collected from previous years.

Beryllium is naturally occurring and has a soil concentration of approximately one part per million. The sampled results are believed to be from naturally occurring beryllium that was resuspended from the soil and collected by the samplers. Even if the concentrations of beryllium detected were from LLNL activities, the amount is still less than one percent of the BAAQMD ambient air concentration limit.

4.3 Radiological Air Dose Assessment

Dose is assessed for two types of receptors. First is the dose to the SW-MEI member of the public. Second is the collective or "population" dose received by people who reside within 80 km of either of the two LLNL sites.

In 2022, the SW-MEI at the Livermore Site was located at the Integrative Veterinary Care facility (CPET), which is approximately 115 feet (35m) outside the site perimeter. The SW-MEI at Site 300 was located on the site's south-central perimeter (PSTL), which borders the Carnegie State Vehicular Recreation Area. The two SW-MEI locations are shown in **Figures 4-1** and **4-2. Table 4-3** shows average doses received in the United States from exposure to sources of radiation as well as the collective dose for people residing within 80 km of the Livermore Site.

Table 4-3. Radiation Doses from Ubiquitous Background and Man-Made Radiation Sources

Source category [a]	**Individual dose (µSv)** [b, c]	**Collective dose** [d] **(person-Sv)** [e]
Natural radioactivity [f]		
Cosmic radiation	330	2,834
Terrestrial radiation	210	1,808
Internal (food and water consumption)	290	2,492
Radon and Thoron	2,280	19,626
Medical radiation procedures	3,000	25,800
Consumer	130	1,114
Industrial plus occupational	8	68

(a) From National Council on Radiation Protection and Measurements, Report No. 160, Table 8.1 (NCRP 2009).

(b) 1 µSv = 0.1 mrem.

(c) This dose is an average over the U.S. population.

(d) The collective dose is the combined dose for all individuals residing within an 80-km (50 mi) radius of LLNL's Livermore Site (approximately 8.6 million), calculated with respect to distance and direction from the site.

(e) 1 person-Sv = 100 person-rem.

(f) These values vary with location.

The annual radiological doses from all air emissions at the Livermore Site and Site 300 in 2022 were found to be well below the applicable standards for radiation protection of the public, in particular the NESHAPs 100 μSv/y (10 mrem/y) site-wide standard. Using an EPA-mandated computer model and LLNL site-specific meteorology appropriate to the two sites, the doses to the LLNL SW-MEI members of the public from LLNL operations in 2022 were:

- Livermore Site: 2.9×10^{-2} μSv (2.9×10^{-3} mrem)
- Site 300: 2.8×10^{-3} μSv (2.8×10^{-4} mrem)

The collective effective dose equivalent (EDE) attributable to LLNL airborne emissions in 2022 was calculated to be 0.0019 person-Sv (0.19 person-rem) for the Livermore Site and 9.3×10^{-8} person-Sv (9.3×10^{-6} person-rem) for Site 300. These doses include potentially exposed populations of 8.6 million people for the Livermore Site and 8.3 million people for Site 300 living within 80 km of the site centers.

In 2022, the doses to the SW-MEI, which represent the maximum doses that could be received by members of the public where there is a residence, school, business, or office, resulting from Livermore Site and Site 300 operations, were less than one percent of the NESHAPs 100 μSv/y (10 mrem/y) site-wide standard.

LLNL operations involving radioactive materials had minimal impact on ambient air during 2022. The measured radionuclide particulate and tritium concentrations in ambient air at the Livermore Site and Site 300 were all less than one percent of the DOE primary radiation protection standard for the public (DCS). The SW-MEI doses from both sites for 2022 are less than one-tenth of one percent of the total dose from sources of natural occurring radioactivity shown in **Table 4-3.**

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5. Water Monitoring Programs

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Lawrence Livermore National Laboratory (LLNL) monitors water systems including wastewater, storm water, and groundwater, as well as rainfall and local surface water. Water systems at the Livermore Site and Site 300 operate differently. For example, the Livermore Site is serviced by a publicly owned treatment works (POTW), but Site 300 is not. Therefore, each site treats and disposes of sanitary wastewater differently. Many drivers determine the appropriate methods and locations of the various water monitoring programs, as described below.

In general, water samples are collected according to written, standardized procedures appropriate for the sampling media (LLNL's *Environmental Monitoring Plan*, Brunckhorst 2019). Sampling plans are prepared by the LLNL network analysts who are responsible for developing and implementing monitoring programs or networks. Network analysts determine the sampling analytes and frequency, incorporating any permit-specified requirements. Except for analyses of certain sanitary sewer and retention tank analytes, analyses are usually performed by off-site, California-certified contract analytical laboratories.

5.1 Sanitary Sewer Effluent Monitoring

In 2022, the Livermore Site discharged an average of 886,223 L/d (234,141 gal/d) of wastewater to the City of Livermore sewer system or 4.4% of the total flow into the City's system. This volume includes wastewater generated by Sandia National Laboratories/California (SNL) and a very small quantity from Site 300. In 2022, SNL generated approximately 6.4% of the total effluent discharged from the Livermore outfall. Wastewater from SNL and Site 300 is discharged to the LLNL collection system and combined with LLNL sewage before it is released at a single point to the municipal collection system.

LLNL's effluent contains both domestic waste and process wastewater and is discharged in accordance with Wastewater Discharge Permit (Permit #1250) requirements administered by the Water Resources Division (WRD) of the City of Livermore and the City of Livermore Municipal Code. Most of the process wastewater generated at the Livermore Site is collected in retention tanks and discharged to LLNL's collection system following characterization and approval by LLNL's Environmental Functional Area (EFA) Water Team Staff Wastewater Discharge Authorization Record (WDAR) approval process.

5.1.1 Livermore Site Sanitary Sewer Monitoring Complex

Permit #1250 requires continuous monitoring of the effluent flow rate and pH. Samplers at the Sewer Monitoring Station (SMS) collect flow-proportional composite samples and instantaneous grab samples that are analyzed for metals, radioactivity, total toxic organics, and other water quality parameters.

5.1.1.1 Radiological Monitoring Results

Department of Energy (DOE) orders and federal regulations establish the standards of operation at LLNL (see **Chapter 2**), including the standards for sanitary sewer discharges. Primarily the standards for radioactive material releases are included in sections of DOE Order 458.1.

For sanitary sewer discharges, DOE Order 458.1 provides the criteria DOE has established for the application of best available technology to protect public health and minimize degradation of the environment. The Derived Concentration Standards (DCS), which complement DOE Order 458.1, limit the concentration of each radionuclide discharged to publicly owned treatment works. If the measured monthly average concentration of a radioisotope exceeds its limit, LLNL is required to improve discharge control measures until concentrations are below the DOE limits.

The DOE Order 458.1 requirements to control discharges into sanitary sewers include the following annual discharge limits: 185 GBq (5 Ci) tritium, 37 GBq (1 Ci) carbon-14, or 37 GBq (1 Ci) all other radionuclides combined. The radioisotopes with the potential to be found in sanitary sewer effluent at LLNL and their discharge limits are discussed below. All analytical results are provided in **Appendix A, Section A.3.**

LLNL determines the total radioactivity contributed by tritium, gross alpha emitters, and gross beta emitters from the measured radioactivity in the monthly effluent samples. As shown in **Table 5-1,** the 2022 combined release of alpha and beta sources was 0.193 GBq (0.005 Ci), which is 0.52% of the corresponding DOE Order 458.1 limit (37 GBq [1.0 Ci]). The total tritium activity was 1.867 GBq (0.050 Ci), which is 1.01% of the DOE Order 458.1 limit (185 GBq [5 Ci]).

Table 5-1. Estimated Total Radioactivity in LLNL Sanitary Sewer Effluent, 2022

Radioactivity	Estimate based on effluent activity (GBq)	MDC[(a)] (GBq)
Tritium	1.867	0.713
Gross alpha	0.023	0.052
Gross beta	0.170	0.037

(a) Minimum detectable concentration.

Discharge limits and a summary of the measurements of tritium in the sanitary sewer effluent from LLNL and the Livermore Water Reclamation Plant (LWRP) are reported in LLNL monthly reports. The maximum daily concentration for tritium was 0.059 Bq/mL (1.60 pCi/mL).

Calendar year 2022 data for measured concentrations of cesium-137 and plutonium-239 in the sanitary sewer effluent from LLNL and the LWRP, and plutonium-239 in LWRP sludge are reported in the LLNL January and February 2023 Reports (Rosene 2023b; 2023c). Cesium and plutonium results are from monthly composite samples of LLNL and LWRP effluent and from quarterly composites of LWRP sludge. For 2022, the annual total discharges of cesium-137 and plutonium-239 were significantly below the DOE DCSs. Plutonium discharged in LLNL effluent is ultimately concentrated in LWRP sludge. The highest plutonium concentration observed in 2022 sludge was 0.133 mBq/g (0.0036 pCi/g), which is many times lower than the American National Standards Institute (ANSI) recommended screening level of 100 mBq/g (3 pCi/g) for volumetric radioactivity (ANSI 2013).

LLNL also compares annual discharges with historical values to evaluate the effectiveness of ongoing discharge control programs. **Table 5-2** summarizes the radioactivity in sanitary sewer effluent over the past 10 years. During 2022, a total of 1.867 GBq (0.050 Ci) of tritium was discharged to the sanitary sewer. This amount is similar to historical values, well within regulatory limits, and fully protective of the environment.

Table 5-2. Historical Radioactive Liquid Effluent Releases from the Livermore Site, 2012 – 2022

Year	Tritium (GBq)	Plutonium-239+240 (GBq)
2012	1.57	7.00×10^{-6}
2013	1.94	5.91×10^{-5}
2014	1.54	3.21×10^{-5}
2015	2.21	1.10×10^{-5}
2016	0.64	9.38×10^{-6}
2017	4.50	1.44×10^{-5}
2018	5.46	8.7×10^{-6}
2019	5.54	2.01×10^{-5}
2020	8.01	7.99×10^{-6}
2021	3.67	2.27×10^{-5}
2022	1.87	4.46×10^{-5}

5.1.1.2 Nonradiological Monitoring Results

LLNL monitors sanitary sewer effluent for chemical and physical parameters at different frequencies depending on the intended use of the result. Effluent flow-proportional composite samples are collected on a daily (midnight-to-midnight), weekly (Thursday through Wednesday), monthly (composited from daily), and quarterly (composited from daily) basis; effluent grab samples are also collected each month, once per quarter, and annually. All samples are collected continuously throughout the year. Results from LLNL's 2022 sanitary sewer effluent monitoring program are provided in **Appendix A, Section A.3.** A summary of the analytical results from the permit-specified weekly composite sampling program is presented in **Table 5-3.**

Table 5-3. Summary of Analytical Results for Permit-Specified 24-hour Composite Sampling of the LLNL Sanitary Sewer Effluent, 2022

Parameter (mg/L)	Detection Frequency[(a)]	Minimum	Maximum	Median
Biochemical Oxygen Demand (BOD)	52 of 52[(b)]	19	170	64
Total Suspended Solids (TSS)	52 of 52[(b)]	17	220	34
Total Dissolved Solids (TDS)	12 of 12[(b)]	260	1,100	395

(a) The number of times an analyte was positively identified, followed by the number of samples that were analyzed.

(b) BOD and TSS samples are taken weekly. TDS is sampled monthly.

The permit requires monthly grab samples of effluent to be analyzed for total toxic organic (TTO) compounds (permit limit = 1.0 mg/L). In 2022, LLNL did not exceed any of these discharge limits. Results from the monthly TTO analyses for 2022, provided in **Appendix A, Section A.3,** show that one priority pollutant, chloroform, which is listed by the U.S. Environmental Protection Agency (EPA) as a toxic organic, was identified in LLNL effluent above the 10 µg/L permit-specified reporting limit. One non-regulated organic compound, acetone, was identified in monthly grab samples at concentrations above the 10 µg/L permit-specified reporting limit.

5.1.2 Categorical Processes

The EPA has established pretreatment standards for categories of industrial processes that they have determined are major contributors to point-source water pollution. These federal standards include prescribed sampling, self-monitoring, reporting, and numerical limits for the discharge of category-specific pollutants. At LLNL, the categorical pretreatment standards are incorporated into Permit #1250.

The processes at LLNL that are determined to be regulated under the Categorical Standards may change as programmatic requirements dictate. Categorical processes identified at LLNL (from both the Metal-Finishing Category, 40 CFR 433, and the Electrical and Electronic Components Category, 40 CFR 469) are listed in Permit #1250.

Only processes that discharge to the sanitary sewer require semiannual sampling, inspection, and reporting. During 2022, two processes discharged wastewater to the sanitary sewer: semiconductor processes located in the Building 153 microfabrication processing laboratories and the abrasive jet machining located in Building 161. In 2022, LLNL analyzed compliance samples for all regulated parameters from both processes and demonstrated compliance with all federal categorical and local discharge limits. As an additional environmental safeguard, LLNL sampled the wastewater in each Building 153 wastewater tank designated as receiving regulated waste prior to each discharge to the sanitary sewer. These monitoring data were reported to the WRD in July 2022 and January 2023 Semiannual Wastewater Point-Source Monitoring Reports (Rosene 2022; 2023a). WRD source control staff performed their required annual inspection and sampling of the Building 153 categorical processes in October 2022. The compliance samples were analyzed for all regulated parameters and the results demonstrated compliance with all federal and local pretreatment limits.

If any of the non-discharging regulated processes were to discharge process wastewater to the sanitary sewer, they would be regulated under 40 CFR Part 433 and reported in the Semiannual Wastewater Point-Source Monitoring Report. Currently, wastewater from these processes is either recycled on-site, pumped out by a third-party vendor and taken to a centralized waste treatment facility for disposal, or contained for eventual removal and appropriate disposal by LLNL's Radioactive and Hazardous Waste Management (RHWM).

5.1.3 Discharges of Treated Groundwater

LLNL's groundwater discharge permit (1510G, 2021–2025) allows treated groundwater from the Livermore Site Ground Water Project (GWP) to be discharged to the City of Livermore sanitary sewer system (see **Chapter 7** for more information on the GWP). During 2022, there were no discharges (from on-site or off-site locations) to the sanitary sewer from the Environmental Restoration Department's GWP activities. When such discharges occur, permit compliance is maintained by Treatment Facility Operators through the systematic use of engineering and administrative controls, including WDARs generated for each discharge. This information is reported to the City of Livermore.

5.1.4 Environmental Impact of Sanitary Sewer Effluent

During 2022, no discharges exceeded any discharge limits for either radioactive or nonradioactive materials to the sanitary sewer. The data are comparable to the lowest historical LLNL values. All the values reported for radiological releases are a fraction of their corresponding limits.

The data demonstrate that LLNL continues to have excellent control of both radiological and nonradiological discharges to the sanitary sewer. Monitoring results for 2022 reflect an effective year for LLNL's wastewater discharge control program and indicate no adverse impact to the LWRP or to the environment from LLNL sanitary sewer discharges.

5.2 Site 300 Sewage Ponds and Site 300 Waste Discharge Requirements

Wastewater grab samples were collected for Waste Discharge Requirements (WDR) Order No. R5-2008-0148. This network includes the sewage evaporation and percolation ponds, mechanical equipment discharges to percolation pits, cooling tower discharges to percolation pits, and septic systems as shown in **Figure 5-1.**

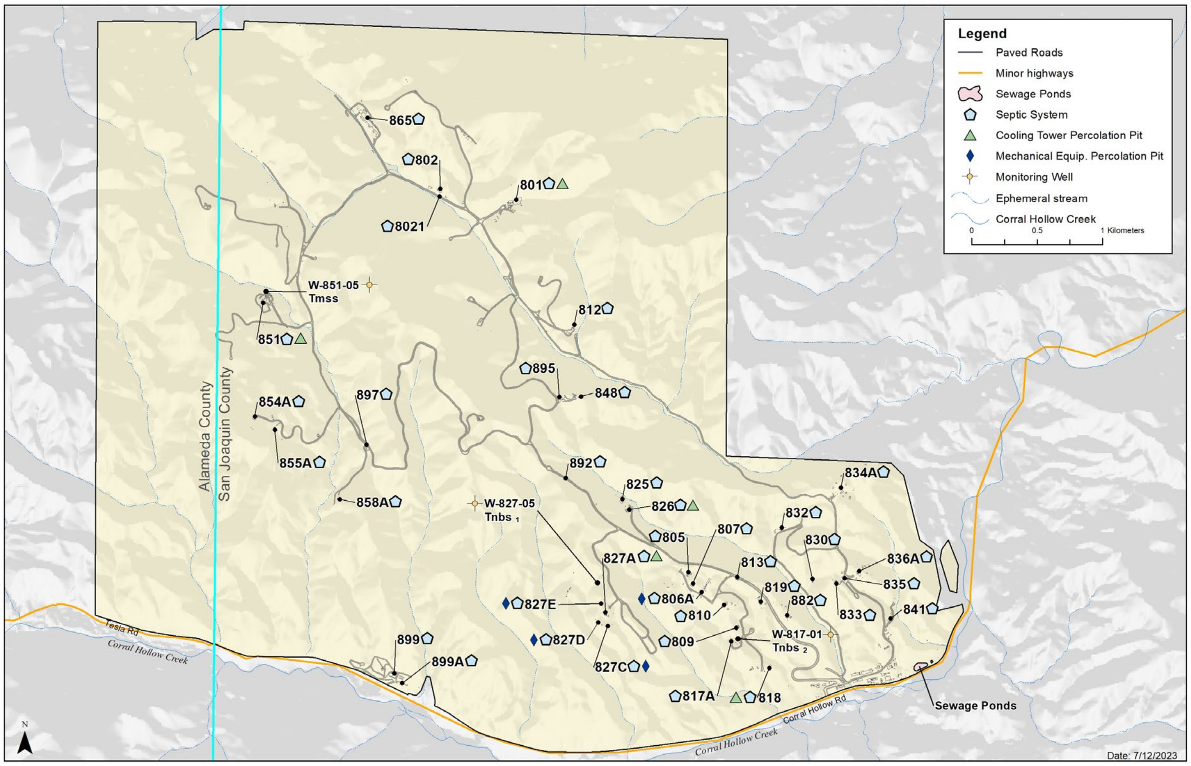

Figure 5-1. WDR-R5-2008-0148 Monitoring Network, 2022

The Site 300 sewage evaporation pond is sampled semiannually at two locations—within the evaporation pond and at the effluent from the evaporation pond prior to flow to the sewage percolation pond. All samples were collected in accordance with the standardized procedures summarized in Brunckhorst (2019).

5.2.1 Sewage Evaporation and Percolation Ponds

Sanitary effluent (nonhazardous wastewater) generated at buildings in the General Services Area (GSA) at Site 300 is managed in an evaporation pond lined with catalytically-blown asphalt. Occasionally, during winter rains when the minimum 12 inches of freeboard depth cannot be maintained, treated wastewater from the sewage evaporation pond may be released into an unlined percolation pond to the east where it enters the ground and the shallow groundwater. Although this potential exists, it did not occur during 2022.

In September 2008, the Central Valley Regional Water Quality Control Board (CVRWQCB) replaced WDR 96-248 with WDR R5-2008-0148. Under the terms of the Monitoring and Reporting Program (MRP) No. R5-2008-0148, LLNL submits semiannual and annual monitoring reports detailing Site 300 discharges of domestic and wastewater effluent to sewage evaporation and percolation ponds in the GSA, mechanical equipment discharges to percolation pits, cooling tower discharges to percolation pits, septic system discharges, and other low-threat discharges to the ground.

The monitoring data collected for the 2022 semiannual and annual reports complied with all MRP conditions and permit requirements (Thomas 2023). Compliance certification accompanied this report, as required by federal and state regulations.

5.2.2 Environmental Impact of Sewage Ponds

There were no discharges from the Site 300 sewage evaporation pond to the percolation pond. Groundwater monitoring related to this area indicated there were no measurable impacts to the groundwater from the sewage pond operations (Thomas 2023).

5.3 Storm Water Compliance and Surveillance Monitoring

The current Storm Water Industrial General Permit (IGP) (2014-0057-DWQ) issued by the State Water Resources Control Board (SWRCB) took effect July 1, 2015 (SWRCB 2014). To achieve compliance, LLNL modified the storm water monitoring plan for both sites. Storm water monitoring at both sites also follows the requirements in the U.S. DOE handbook *Environmental Radiological Effluent Monitoring and Environmental Surveillance* (U.S. DOE 2015) and meets the applicable requirements of DOE Order 458.1. See **Figures 5-2** and **5-3** for storm water sampling locations for the Livermore Site and Site 300, respectively.

For construction projects that disturb one acre of land or more, LLNL also meets storm water compliance monitoring requirements of the California National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges Associated with Construction and Land Disturbance Activities (Order Number 2009-0009-DWQ) (SWRCB 2009). The Energy Independence and Security Act, Section 438 specifically calls for federal development that has a footprint that exceeds 5,000 square feet to maintain or restore predevelopment hydrology.

Under the IGP, LLNL is required to collect and analyze storm water runoff samples at specified locations two times during the period from July 1 to December 31 and two times during the period from January 1 to June 30, if specific criteria are met and the sampling window coincides with regular working hours. The State storm water reporting period is offset from the reporting period in this *Environmental Report*. Runoff samples were collected for three storm events from all five required storm water locations at the Livermore Site on April 21, November 1, and December 1, 2022. Runoff samples were collected for one storm event at Building 883 at Site 300 on April 19, 2022. All other precipitation events at the Livermore Site and Site 300 during 2022 were not qualifying and/or could not be sampled in compliance with the IGP. LLNL is required to visually inspect the storm drainage system up to four times during qualifying storm events to observe runoff quality and once each month during dry periods to identify any dry weather flows. Annual facility inspections are performed to ensure that adequate Best Management Practices (BMPs) are implemented to control storm water pollution.

The CVRWQCB issued a Water Code Section (WCO) 13267 Order for *Submittal of Technical and Monitoring Reports for The Active Building 851 Firing Table, Lawrence Livermore National Laboratory Site 300, San Joaquin County*, requesting a sediment and storm water runoff monitoring program during the Building 851 Firing Table operational period at Site 300.

Under the WCO, LLNL is required to collect a storm water runoff sample and a sediment sample annually, analyze samples for constituents of concern, and report the sampling results to the CVRWQCB (Abri 2021). Only sediment samples were collected from Building 851 on May 12, and May 25, 2022. No runoff producing storm events occurred during the reporting period. See **Figure 5-3** for storm water and sediment sampling location for the Building 851 sample location.

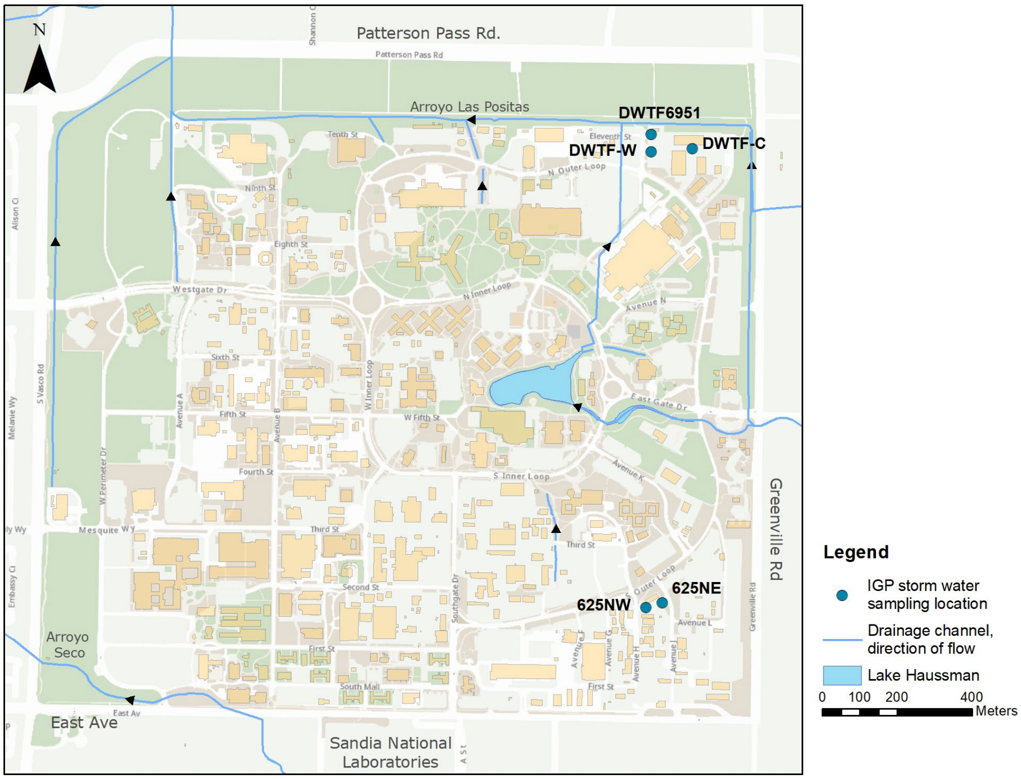

Figure 5-2. Storm Water Sampling Locations at the Livermore Site, 2022

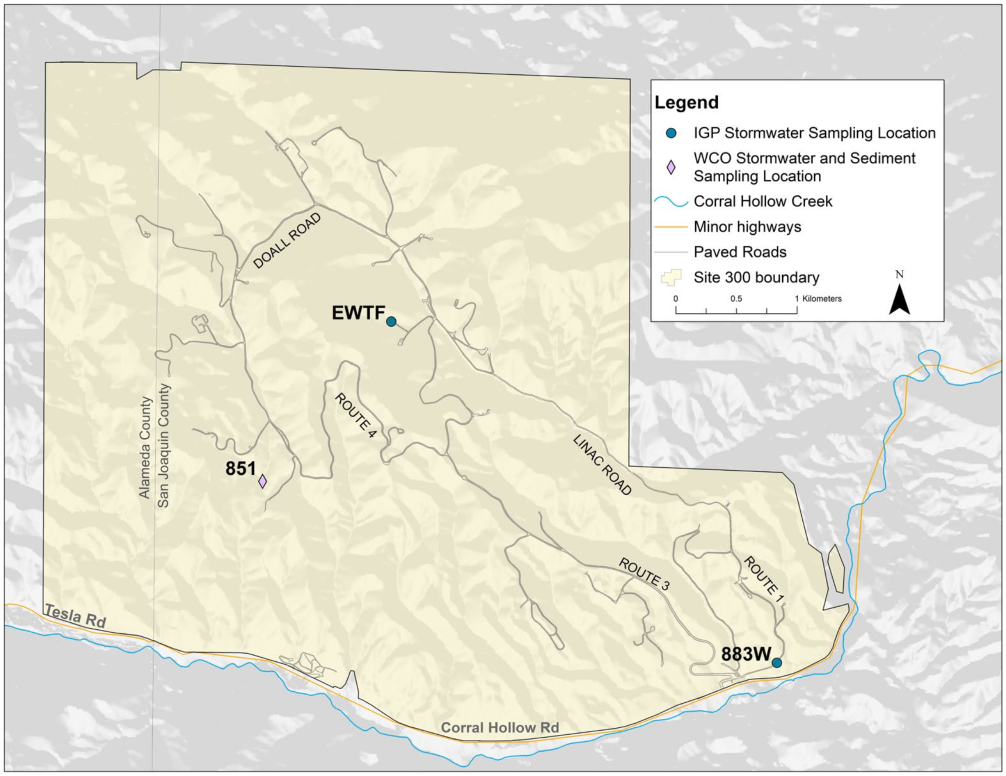

Figure 5-3. Storm Water Sampling Locations at Site 300, 2022

5.3.1 Storm Water Inspections

Each principal directorate at LLNL conducts an annual inspection of its facilities to verify implementation of BMPs and to ensure that those measures are adequate. LLNL's principal associate directors identified some corrections to the BMPs and certified that their facilities complied with the provisions of LLNL's Storm Water Pollution Prevention Plans (SWPPPs) in 2022. LLNL submits storm water analytical results to the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) and to the CVRWQCB through an online database called the Storm Water Multiple Application and Report Tracking System (SMARTS) for each Qualifying Storm Event (QSE).

For each construction project permitted by Order Number 2009-0009-DWQ, LLNL or designated subcontractors conduct visual monitoring of construction sites before, during, and after storms to assess the effectiveness of the BMPs. Annual compliance certifications, if necessary, summarize the inspections.

5.3.2 Storm Water Compliance

LLNL must meet the requirements of the IGP, which identifies two types of Numeric Action Levels (NALs).

Annual NAL exceedance – occurs when the average of all the analytical results for a parameter from samples taken within a reporting year exceeds an annual NAL value for that parameter.

Instantaneous maximum NAL exceedance – occurs when two or more analytical results for TSS, Oil and Grease (O&G), or pH from samples taken within a reporting year exceed the instantaneous maximum NAL value (or are outside the NAL pH range).

An NAL exceedance is determined as follows:

a. For annual NALs, an exceedance occurs when the average of all analytical results from all samples taken at a facility during a reporting year for a given parameter exceeds an annual NAL value listed in Table 2 of the General Permit; or

b. For instantaneous maximum NALs, an exceedance occurs when two or more analytical results from samples taken for any parameter within a reporting year exceed the instantaneous maximum NAL value (for TSS and O&G) or are outside of the instantaneous maximum NAL range (for pH) listed in Table 2 of the General Permit.

Please refer to **Appendix A, Tables A.4.1** to **A.4.5** for storm water sample analytical results. Both the Livermore Site and Site 300 remain at Exceedance Response Action Level 2 for magnesium. LLNL has provided data and analysis that show the exceedance of magnesium is due to aerial deposition from natural sources, not industrial activities at LLNL. Site 300 remains at Exceedance Response Action Level 1 for TSS due to an Annual NAL exceedance during the 2019-2020 reporting year. BMPs were implemented in 2020 to reduce TSS in storm water runoff at both Site 300 sampling locations. The storm water runoff sample taken at Site 300 on April 19, 2022 is the second sample below the TSS NAL. To return Site 300 to Baseline Status, two more samples below the TSS NAL are required.

Storm water visual observations and BMP inspections indicated that LLNL's storm water program continues to protect water quality.

A full report of storm water runoff samples for January 1, 2022 to June 30, 2022 is included in the 2021-2022 Annual Storm Water Report for the Livermore Site and in SMARTS for Site 300. A report of storm water compliance for the Livermore Site and Site 300 from July 1, 2022 to December 31, 2022 will be available in SMARTS after July 15, 2023.

Please refer to **Appendix A, Tables A.4.1** to **A.4.5** for sediment sample analytical results.

A full report of sediment sampling for 2022 is available in the Building 851 Firing Table Sediment Monitoring Report in GeoTracker.[1] A report of sediment compliance for Building 851 Firing Table will be available in GeoTracker after July 15, 2023.

1 GeoTracker is the SWRCB's data management system for sites that impact, or have the potential to impact, water quality in California, with an emphasis on groundwater. https://geotracker.waterboards.ca.gov/

5.4 Groundwater

LLNL conducts surveillance groundwater monitoring in the Livermore Valley and at Site 300 through networks of wells and springs that include off-site private wells and on-site Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) wells. To meet the goal of maintaining a comprehensive, cost-effective monitoring program, LLNL determines the number and locations of surveillance wells, the analytes to be monitored, the frequency of sampling, and the analytical methods to be used. A wide range of analytes is monitored to assess the impact, if any, of current LLNL operations on local groundwater resources. Because surveillance monitoring is geared to detect substances at very low concentrations in groundwater, contamination can be detected before it significantly impacts groundwater resources. Groundwater monitoring wells at the Livermore Site, in the Livermore Valley, and at Site 300 are included in LLNL's *Environmental Monitoring Plan* (Brunckhorst 2019).

In 2009, LLNL implemented a CERCLA comprehensive compliance monitoring plan at Site 300 (Dibley et al. 2009) to fulfill DOE and regulatory requirements for on-site groundwater surveillance. LLNL also monitors two surveillance networks to supplement the CERCLA compliance monitoring and provide additional data to characterize potential impacts of LLNL operations. LLNL monitoring related to CERCLA activities is described in **Chapter 7**. Additional monitoring programs at Site 300 comply with numerous federal and state controls such as state-issued permits associated with closed landfills containing solid wastes and with continuing discharges of liquid waste to sewage ponds and percolation pits; the latter are discussed in **Section 5.2.1**. Compliance monitoring is specified in WDRs issued by the CVRWQCB and in landfill closure and post-closure monitoring plans. (See **Chapter 2**, **Table 2-2** for a summary of LLNL permits.)

The WDRs and post-closure plans specify wells and discharges to be monitored, constituents of concern (COCs), monitoring frequency, inspection schedule, and reporting requirements. These monitoring programs include quarterly, semiannual, and annual monitoring of groundwater, monitoring of various influent waste streams, and visual inspections. LLNL performs the maintenance necessary to ensure the physical integrity of closed facilities, such as those that have undergone CERCLA or Resource Conservation and Recovery Act (RCRA) closure, and their monitoring networks.

During 2022, representative samples of groundwater were obtained from monitoring wells in accordance with the *LLNL Livermore Site and Site 300 Environmental Restoration Project Standard Operating Procedures* (Goodrich and Lorega 2016). The procedures include sampling techniques and information about groundwater monitoring parameters. Different sampling techniques were employed at different wells depending on whether they were fitted with submersible pumps or had to be bailed. All the chemical and radioactivity analyses of groundwater samples were performed by California-certified analytical laboratories. For comparison purposes only, some of the results were compared with drinking water limits (maximum contaminant levels [MCLs]).

5.4.1 Livermore Site and Environs

5.4.1.1 Livermore Valley

LLNL has monitored tritium in water hydrologically downgradient of the Livermore Site since 1988. HTO (tritiated water) is potentially the most mobile groundwater contaminant from LLNL operations. Groundwater samples were obtained during 2022 from 11 of 15 wells in the Livermore Valley (see **Figure 5-4**) and measured for tritium concentration. Wells 11B1 and 12G1 were not sampled in 2022 because they were offline at the time of sampling. Additionally, Well 17D12 was not sampled in 2022 because it was inadvertently removed from the sampling schedule. Well 17D12 has been added back to the sampling schedule and is planned to be sampled in 2023. Although Well 7C2 was sampled, the container broke in transit to the laboratory and no analytical results were able to be processed.

Tritium measurements of Livermore Valley groundwater are provided in **Appendix A, Section A.5.** The measurements continue to show very low activities compared with the 740 Bq/L (20,000 pCi/L) drinking water MCL. The maximum tritium concentration estimated off-site was in the groundwater at well 2R1, located approximately 12.9 km (8 mi) west of LLNL (see **Figure 5-4**). The estimated activity at well 2R1 was 0.8 ± 2.6 Bq/L (21.6 pCi/L) in 2022 which is less than 0.15% of the MCL.

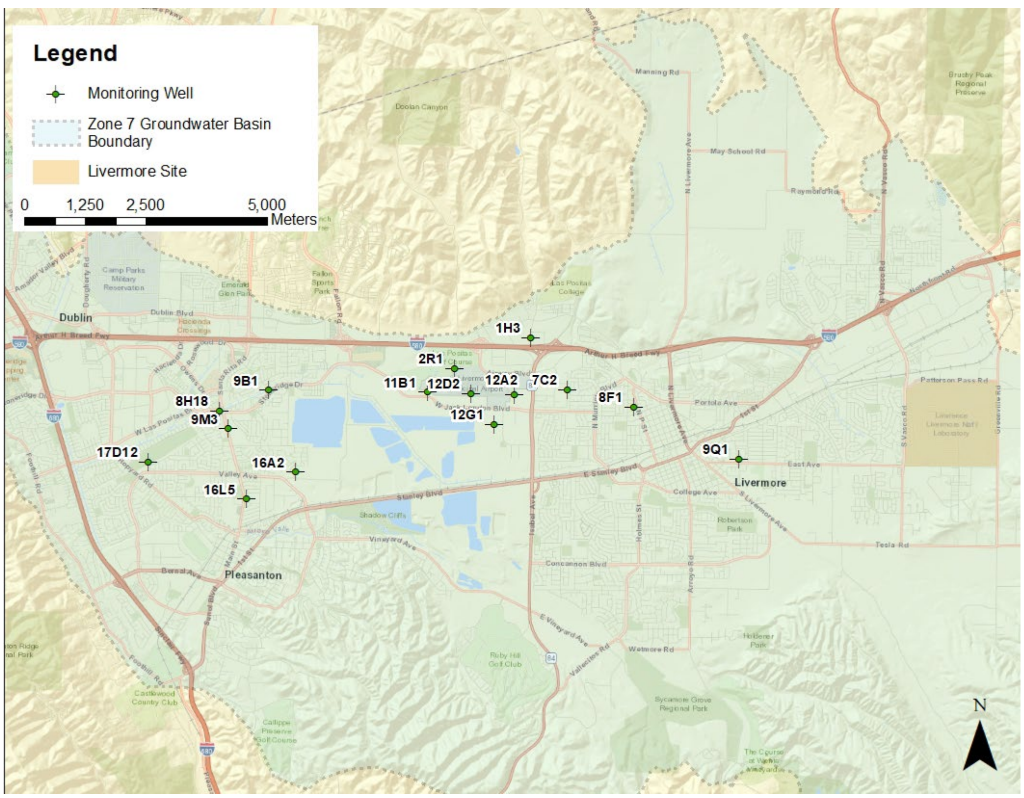

Figure 5-4. Off-Site Tritium Monitoring Wells in the Livermore Valley, 2022

5.4.1.2 Livermore Site Perimeter

LLNL's groundwater surveillance monitoring program was designed to complement the Livermore Site GWP (see **Chapter 7**). The intent of the program is to monitor for potential groundwater contamination from LLNL operations. The perimeter portion of the surveillance groundwater monitoring network consists of three upgradient (background) monitoring wells (wells W-008,- W-221, and W-017) near the eastern boundary of the site and seven downgradient monitoring wells located near the western boundary (wells 14B1, W-121, W-151, W-1012, W-571, W-556, and W-373) (see **Figure 5-5**). As discussed in **Chapter 7**, the alluvial sediments have been divided into nine hydrostratigraphic units (HSUs), which are water bearing zones that exhibit similar hydraulic and geochemical properties. The nine HSUs dip gently westward. Screened intervals (depth range from which groundwater is drawn) for these monitoring wells range from the shallow HSU-1B to the deeper HSU-5. Two of the background wells, W-008 and W-221, are screened partially in HSU-3A; well W-017 is considered a background well for the deeper HSU-5. To detect contaminants as quickly as possible, the seven western downgradient wells (except well 14B1, screened over a depth range that includes HSU-2, HSU-3A, and HSU-3B) were screened in shallower HSU-1B and HSU-2, the uppermost water-bearing HSUs at the western perimeter. These perimeter wells were sampled and analyzed at least once during 2022 for general minerals (including nitrate) and for certain radioactive constituents (gross alpha, gross beta, and tritium). In 2022, wells W-556 and W-008 were not sampled due to pump failures. Analytical results for the Livermore Site perimeter wells are provided in **Appendix A, Section A.5.** Although there have been variations in these concentrations since regular surveillance monitoring began in 1996, the concentrations detected in the 2022 groundwater samples from the upgradient wells represent current background values.

Historically, hexavalent chromium has been detected above the MCL (50 µg/L) in groundwater samples from western perimeter well W-373. However, concentrations of this analyte started dropping below the MCL in 2002. Except for 2006, hexavalent chromium levels at well W-373 have been below the MCL from 2002–2022. The 2022 sample from this location had a concentration of 27 µg/L, which is consistent with the range of hexavalent chromium concentrations (5 µg/L to 52 µg/L) detected at well W-373 since 2002. The groundwater sample collected in 2022 from the nearby well W-1012, also along the western perimeter of the Livermore Site, showed a hexavalent chromium concentration of 8 µg/L. The other well along the western perimeter of the Livermore Site, W-556, was not sampled in 2022 due to a pump failure.

From 1996 through 2004, concentrations of nitrate detected in groundwater samples from downgradient well W-1012 were greater than the MCL of 45 mg/L. The nitrate concentration detected in the 2022 sample from this well (21 mg/L) was again, as in the past 17 years, below the MCL. During 2022, the concentration of nitrate in the on-site shallow background well W-221 was 35 mg/L, which is down from levels observed in the past four years. Detected concentrations of nitrate in western perimeter wells ranged from 16 mg/L (in well W-373) to 47 mg/L (in well W-151), which is consistent with results reported in previous years.

During 2022, gross alpha, gross beta, and tritium results for the Livermore Site's perimeter wells were consistent with results from past years. The concentrations continue to remain below drinking water MCLs.

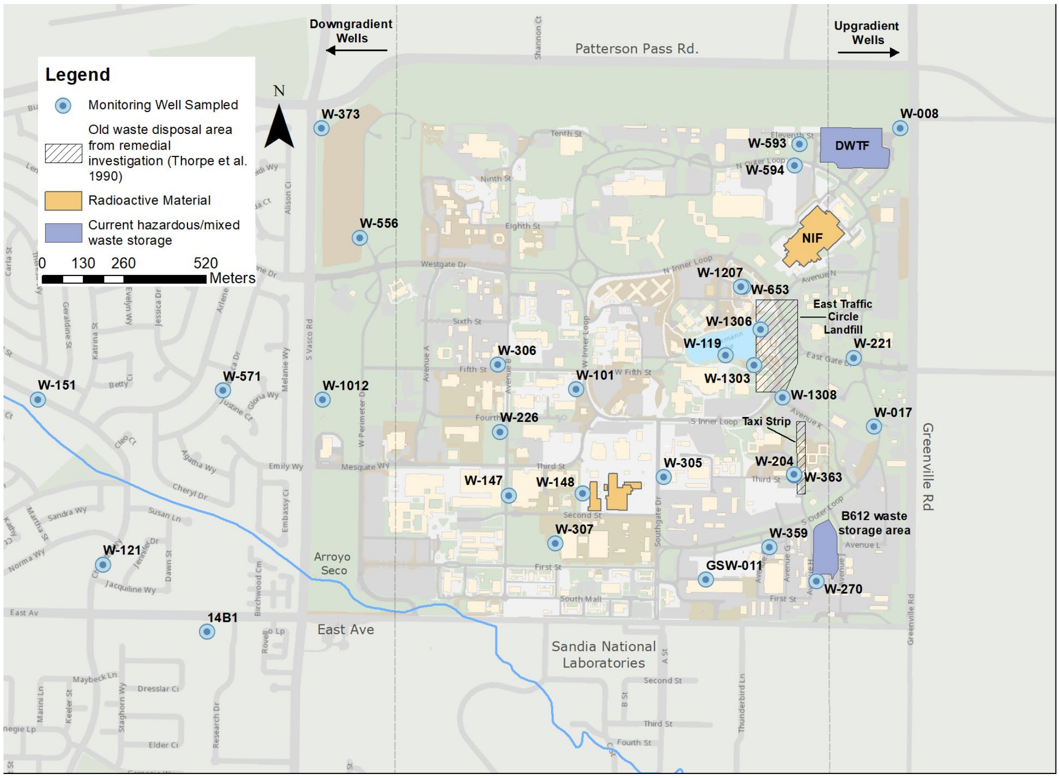

Figure 5-5. Routine Surveillance Groundwater Monitoring Wells at the Livermore Site, 2022

5.4.1.3 Livermore Site

Groundwater sampling locations within the Livermore Site include areas where releases to the ground may have occurred in the recent past, where previously detected COCs have low concentrations that do not require CERCLA remedial action, and where baseline information needs to be gathered for the area near a new facility or operation. Wells selected for monitoring are screened in the uppermost aquifers and are downgradient from and as near as possible to the potential release locations. Well locations are shown in **Figure 5-5.** All analytical results are provided in **Appendix A, Section A.5.**

The Taxi Strip and East Traffic Circle Landfill areas (see **Figure 5-5**) are two potential sources of historical groundwater contamination. Samples from monitoring wells screened in HSU-2 (W-204) and HSU-3A (W-363) downgradient from the Taxi Strip area are analyzed for copper, lead, zinc, and tritium. Samples from monitoring wells screened at least partially in HSU-2 (W-119, W-1207, W-1303, W-1306, and W-1308) within and downgradient from the East Traffic Circle Landfill are analyzed for the same elements as the Taxi Strip area wells. All wells were sampled in 2022. Tritium concentrations remained well below the drinking water MCLs at all seven locations that were sampled. In 2019 and 2020, zinc was the only metal detected at these wells. No metals were detected at these monitoring wells in 2021 or 2022.

Near the National Ignition Facility (NIF), LLNL measures pH, conductivity, and tritium concentration of nearby groundwater to establish a baseline. Downgradient of NIF, groundwater samples are collected from wells W-653 and W-1207 (screened in HSU-3A and HSU-2, respectively). Downgradient from the Decontamination and Waste Treatment Facility (DWTF), wells W-593 and W-594 (screened in HSU-3A and HSU-2, respectively) are sampled for tritium annually. Tritium concentrations at the wells near NIF and DWTF were well below the drinking water MCL.

The former storage area around Building 514 and the hazardous waste/mixed waste storage facilities around Building 612 are also potential sources of contamination. The area and facilities are monitored by wells W-270 and W-359 (both screened in HSU-5) and well GSW-011 (screened in HSU-3A). These wells were sampled and analyzed for gross alpha, gross beta, and tritium. No significant contamination was detected in the groundwater samples collected downgradient from these areas in 2022.

Groundwater samples are obtained annually from monitoring well W-307 (screened in HSU-1B), downgradient from Building 322. Soil samples previously obtained from this area showed concentrations elevated above the Livermore Site's background levels for total chromium, copper, lead, nickel, zinc, and occasionally other metals. LLNL removed contaminated soils near Building 322 in 1999 and replaced them with clean fill. The area was then paved over, making it less likely that metals would migrate from the site. In 2022, concentration of metals at well W-307 were consistent with concentrations reported in recent years. The concentration of hexavalent chromium at well W-307 decreased from 17 µg/L in 2021 to 14 µg/L in 2022. The concentration of manganese, which had shown some fluctuations in 2012 and 2013, remained below the analytical reporting limit in 2022. LLNL will continue to monitor trends.

Groundwater samples were obtained downgradient from a location where sediments containing metals (including cadmium, chromium, copper, lead, mercury, and zinc) had accumulated in a storm water catch basin near Building 253. Wells W-226 and W-306 (screened in HSU-1B and HSU-2, respectively) are sampled annually for metals. In 2022, boron concentrations at W-306 remained consistent with past monitoring results. In 2022, the chromium concentration at well W-226 (21 µg/L) was again above the analytical reporting limit. The concentration of chromium at well W-306 (2 ug/L) remained low and was consistent with 2022 monitoring results. The concentration of hexavalent chromium at well W-226 was above the analytical reporting limit in 2022. However, the concentration remained below drinking water MCLs and was consistent with past monitoring results.

Additional surveillance groundwater sampling locations, established in 1999, are in areas surrounding the Plutonium Facility and Tritium Facility. Potential contaminants include plutonium and tritium from these facilities, respectively. Plutonium is much more likely to bind to the soil than migrate into the groundwater. Tritium, as HTO, can migrate into groundwater if spilled in sufficient quantities. Upgradient of these facilities, well W-305 is screened in HSU-2. Downgradient wells W-101, W-147, and W-148 are screened in HSU-1B. As in 2012 through 2020, well W-101 was dry and could not be sampled in 2022. In August 2000, elevated tritium was detected in the groundwater sampled at well W-148 (115 ± 5.0 Bq/L [3,100 ± 135 pCi/L]). This was likely caused by local infiltration of storm water containing elevated tritium. Tritium concentrations in groundwater in this area had remained at or near the same level through 2005, but samples collected from well W-148 in 2006 through 2022 have shown significantly lower values – a downward trend ranging from approximately one-tenth to one-half of the August 2000 value due to the natural decay and dispersion of tritium. Well W-147 tritium results for 2022 were also consistent with past years. LLNL continues to collect groundwater samples from these wells periodically for surveillance purposes, primarily to demonstrate that tritium concentrations remain below MCLs.

5.4.2 Site 300 and Environs

For surveillance and compliance groundwater monitoring at Site 300, LLNL uses onsite CERCLA wells and springs and off-site private wells and springs. Representative groundwater samples are obtained at least once per year at every monitoring location; they are routinely measured for various inorganic constituents (primarily metals), a wide range of organic compounds, general radioactivity (gross alpha and gross beta), uranium, and tritium. Groundwater from the shallowest water-bearing zone is the target of most of the monitoring because it would be the first to show contamination from LLNL operations at Site 300.

Brief descriptions of the Site 300 groundwater monitoring networks that are reported in this chapter are given below. (All analytical data from 2022 are included in **Appendix A, Section A.6.**)

5.4.2.1 Elk Ravine Drainage Area

The Elk Ravine drainage area, a tributary to the Corral Hollow Creek drainage system, includes most of northern Site 300 (see **Figure 5-6**). Storm water runoff in the Elk Ravine drainage area collects in arroyos and generally infiltrates quickly into the ground. Groundwater from wells in the Elk Ravine drainage area is monitored for COCs to determine the impact of current LLNL operations on the water-bearing zones in the area. Elk Ravine and the immediate area contain eight closed landfills, Pits 1 through 5 and 7 through 9, and the firing tables where explosives tests were or are conducted. None of these closed landfills have a liner, which is consistent with the disposal practices when the landfills were constructed. The following descriptions of monitoring networks within Elk Ravine begin with the headwaters area and proceed downstream. (See **Chapter 7** for a review of groundwater monitoring conducted under CERCLA in this drainage area.)

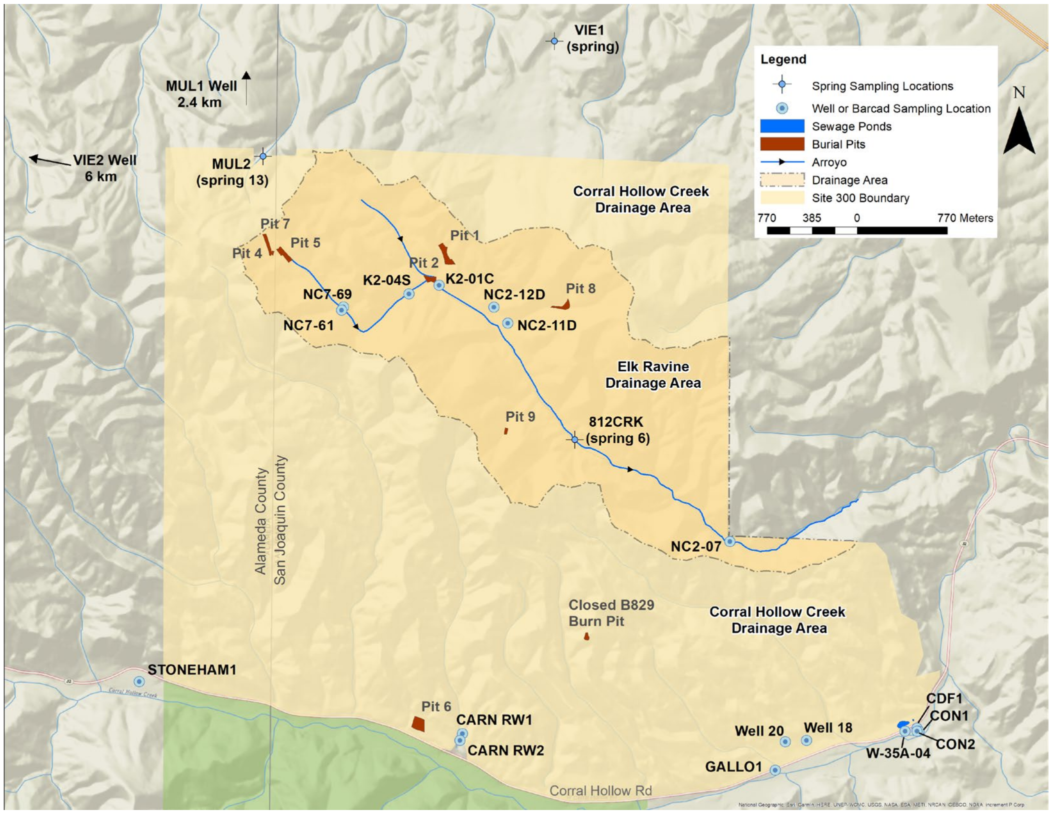

Figure 5-6. Surveillance Groundwater Wells and Springs at Site 300, 2022

Pit 7 Complex. The Pit 7 landfill was closed in 1992 in accordance with U.S. EPA and California Department of Health Services (now Department of Toxic Substances Control, or DTSC) approved RCRA Closure and Post-Closure Plans using the LLNL CERCLA Federal Facility Agreement (FFA) process. From 1993 until 2009, monitoring requirements were specified in WDR 93-100, administered by the CVRWQCB (1993, 1998), and in *LLNL Site 300 RCRA Closure and Post-Closure Plans—Landfill Pits 1 and 7* (Rogers/Pacific Corporation 1990). An Amendment to the Interim Record of Decision (ROD) for the Pit 7 Complex (Site 300 U.S. DOE, 2007) was signed in 2007 under CERCLA. The remedial actions specified in the Interim ROD, including a hydraulic drainage diversion system, extraction and treatment of groundwater, and Monitored Natural Attenuation for tritium in groundwater were implemented in 2008. In 2010, detection monitoring and reporting for the Pit 7 Complex were transferred to CERCLA. Sampling analytes and frequencies are documented in the CERCLA Compliance Monitoring Plan and Contingency Plan for Site 300 (Dibley et al. 2009). The objective of this monitoring continues to be the early detection of any new release of COCs from Pit 7 to groundwater.

For compliance purposes, during 2022 LLNL obtained annual or more frequent groundwater samples from the Pit 7 detection monitoring well network. Samples were analyzed for tritium, volatile organic compounds (VOCs), fluoride, high explosive compounds (HMX and RDX), nitrate, perchlorate, uranium (isotopes or total), metals, lithium, and polychlorinated biphenyls (PCBs). A detailed account of Pit 7 compliance monitoring conducted during 2022, including a summary of data analysis, well locations, maps of the distribution of COCs in groundwater, and analytical data tables is presented in the CERCLA 2022 Site 300 Annual Compliance Monitoring Report (CMR) that was submitted to the regulatory agencies by the LLNL Environmental Restoration Department (Buscheck et al. 2023).

Elk Ravine. Groundwater samples were obtained on various dates in 2022 from the widespread Elk Ravine surveillance monitoring network shown in **Figure 5-6** (NC2-07, NC2-11D, NC2-12D, NC7-61, NC7-69, 812CRK [SPRING6], K2-04S, K2-01C). Monitoring at well K2-04D ceased in 2014 due to a pump becoming stuck in the well; the well was decommissioned in July 2020. Samples from NC2-07 were analyzed for inorganic constituents (mostly metals), general radioactivity (gross alpha and gross beta), tritium and uranium activity, and explosive compounds (HMX and RDX). Samples from 812CRK were analyzed for inorganic constituents (mostly metals), VOCs (EPA Method 624), general radioactivity (gross alpha and gross beta), and tritium and uranium activity. Wells NC7-61, K2-01C, NC2-12D, NC2-11D, and 812CRK were sampled for nitrate. Wells NC7-61, NC7-69, K2-01C, and NC2-07 were sampled for explosive compounds (HMX and RDX). All wells were analyzed for perchlorate. Additionally, all wells were sampled for general radioactivity (gross alpha and gross beta) and tritium and uranium activity except for well K2-01C, which was not sampled for gross alpha and gross beta.

No new release of COCs from LLNL operations in Elk Ravine to groundwater is indicated by the chemical and radioactivity data obtained during 2022. The major source of contaminated groundwater beneath Elk Ravine is from historical operations in the Building 850 firing table area (Webster-Scholten 1994; Taffet et al. 1996).

The 2022 tritium concentrations for well NC7-61 were 350 ± 69 Bq/L in April and 330 ± 65 Bq/L in October. These concentrations were similar to the tritium concentrations measured in 2021 (370 ± 73 Bq/L, and 400 ± 77 Bq/L). Tritium remains elevated with respect to the background concentration. Tritium, as HTO, has been released in the vicinity of Building 850. Most of the Elk Ravine surveillance network tritium measurements made during 2022 support earlier CERCLA studies showing that the tritium in the plume is diminishing over time because of natural decay and dispersion (Ziagos and Reber-Cox 1998). CERCLA modeling studies indicate that the tritium will decay to background levels before it can reach a site boundary. The 2022 HMX concentrations for NC7-61 were 6.5 ug/L in April and 5.3 ug/L in October, which are consistent with past monitoring results. Detections of the nonradioactive element vanadium at wells NC2-07, 812CRK, and K2-01C were also consistent with past monitoring results.

Groundwater surveillance measurements of gross alpha, gross beta, and uranium activity in Elk Ravine are low and indistinguishable from background levels. (Note that gross beta measurements do not detect the low-energy beta emission from tritium decay.) Additional detections of nonradioactive elements including arsenic, barium, chromium, selenium, and zinc are all within the ranges of background concentrations for wells and springs at Site 300 presented in the Site-Wide Feasibility Study (Ferry et al. 1999). Background concentrations and activities of metals and radiological substances in ground water were determined through an evaluation of wells and springs identified as being hydrologically isolated from suspected areas of contamination.

Pit 1. The Pit 1 landfill was closed in 1993 in accordance with a DTSC-approved RCRA Closure and Post-Closure Plan using the LLNL CERCLA FFA process. Monitoring requirements are specified in WDR 93-100 (CVRWQCB; 1993, 1998, and 2010) and in Rogers/Pacific Corporation (1990). In 2020, the CVRWQCB issued a letter rescinding the Pit 1 monitoring under WDR 93-100 and transferring the monitoring to CERCLA (CVRWQCB 2020a). The main objective of this detection monitoring is the early identification of any release of constituents from Pit 1 to groundwater. LLNL obtained groundwater samples quarterly during 2022 from the Pit 1 monitoring well network. Samples were analyzed for inorganic constituents (mostly metals), general radioactivity (gross alpha and gross beta), activity of certain radioisotopes (tritium, radium, uranium, and thorium), explosive compounds (HMX and RDX), and VOCs. Compliance monitoring showed no new releases of any constituents from Pit 1 in 2022; a detailed summary of Pit 1 detection monitoring conducted during 2022, including well locations, data analysis, and tables of analytical data, can be found in the 2022 annual CMR (Buscheck et al. 2023).

5.4.2.2 Corral Hollow Creek Drainage Area

Pit 6. Compliance monitoring requirements for the closed Pit 6 landfill in the Corral Hollow Creek drainage area are specified in Dibley et al. (2009) and MacQueen et al. (2013). Two Pit 6 groundwater monitoring programs, which operate under CERCLA, ensure compliance with all regulations. They are (1) the Detection Monitoring Plan (DMP), designed to detect any new release of COCs to groundwater from wastes buried in the Pit 6 landfill, and (2) the Corrective Action Monitoring Plan (CAMP), which monitors the movement and fate of historically released COCs. To comply with monitoring requirements, LLNL collected groundwater samples monthly, quarterly, semiannually, and annually during 2022 from specified Pit 6 monitoring wells. These samples were analyzed for VOCs, tritium, beryllium, mercury, total uranium, gross alpha/beta radioactivity, perchlorate, and nitrate.

During 2022, no new contaminant releases from Pit 6 were detected. A detailed account of Pit 6 compliance monitoring, including well locations, tables of groundwater analytical data, and maps showing the distribution of COCs is summarized in the 2022 Site 300 Annual CMR (Buscheck et al. 2023).

Building 829 Closed High Explosives Burn Facility. Compliance monitoring requirements for the closed burn pits in the Corral Hollow Creek drainage area are specified in the *Hazardous Waste Facility Post-Closure Permit for the B829 Facility* (DTSC 2017). To comply with the permit, LLNL obtained groundwater samples during 2022 from the three wells in the Building 829 monitoring network. Groundwater samples from these wells, screened in the deep regional aquifer, were analyzed for inorganic constituents (mostly metals), turbidity, explosive compounds (HMX, RDX, and TNT), VOCs (EPA Method 624.1), extractable organics (EPA Method 625), and general radioactivity (gross alpha and gross beta).

In 2021, the concentrations for several metal constituents initially exceeded their statistical limits (SLs). However, there were no SL exceedances for any constituents in 2022. In 2019, there was a confirmed manganese SL exceedance at well W-829-15. In 2020 and 2022, manganese was not detected at well W-829-15 above the reporting limit. The 2021 manganese concentration at well W-829-15 initially exceeded the SL, but this result was invalidated after conducting two independent retests. The 2020 – 2022 monitoring results at well W-829-15 support LLNL's claim that the slight exceedance of manganese above the SL in 2019 was likely a result of desorption and dissolution of naturally occurring manganese-bearing minerals in the aquifer. Manganese had not previously been detected at well W-829-15 until 2019 and the manganese concentrations from 2020 – 2022 are consistent with sampling history.

In 2018 and 2019, there were confirmed manganese SL exceedances at well W-829-22. In 2020 and 2022, manganese was not detected at W-829-22 above the reporting limit (RL). The 2021 manganese concentration at well W-829-22 initially exceeded the SL, but this result was invalidated after conducting two independent retests. As LLNL has concluded in the past, the 2018 and 2019 validated manganese detections at W-829-22 were likely the result of local background variability and not an actual manganese release from the B829 burn pit. LLNL will continue to monitor manganese concentrations annually.

In 2019, there was a confirmed barium SL exceedance at well W-829-1938. The 2020 and 2022 barium results at well W-829-1938 were lower than the SL. The 2021 barium concentration at well W-829-1938 initially exceeded the SL, but this result was invalidated after conducting two independent retests. The 2020 – 2022 monitoring results support LLNL's conclusion that the past exceedance did not indicate an actual barium release from the B829 burn pit and that barium concentrations are within the range of local background variability. LLNL will continue to monitor barium annually.

In 2020, LLNL missed an initial chromium SL exceedance at W-829-22 and was not able to resample. The routine second quarter 2020 chromium result was 1.7 µg/L, which slightly exceeded the SL of 1.5 µg/L. LLNL records indicate that chromium has only been detected four times at W-829-22 since monitoring began in 1999. The only other chromium SL exceedance at W-829-22 occurred in 2003 (2.0 µg/L). In 2021 and 2022, chromium at well W-829-22 was <1 µg/L, which supports LLNL's prior claim that the 2020 chromium SL exceedance was likely the result of local background variability and not an actual chromium release from the B829 burn pit.

There were no organic or explosive COCs detected above reporting limits in any samples. All results for the radioactive COCs (gross alpha and gross beta) were below their SL values. For a detailed account of compliance monitoring of the closed burn pit during 2022, including well locations and tables and graphs of groundwater COC analytical data, see Will (2023).

Water Supply Well. Well 20 is a drinking water supply well located in the southeastern part of Site 300 (**Figure 5-6**). It is a deep, high production well screened in the Neroly lower sandstone aquifer ($Tnbs_1$) and can produce up to 1,500 L/min (396 gal/min) of potable water. For surveillance purposes, prior to 2019, LLNL obtained groundwater samples quarterly from Well

20 and analyzed samples for inorganic COCs (mostly metals), VOCs, general radioactivity (gross alpha and gross beta), and tritium. In 2019, LLNL determined that surveillance monitoring for Well 20 was no longer necessary because the well is sampled and analyzed for COCs under the monitoring program defined in Domestic Water Supply Permit Amendment No. 01-10-16PA-003.

In March 2020, Site 300's primary water supply changed from Well 20 to Hetch Hetchy surface water purchased from the San Francisco Public Utilities Commission (SFPUC). LLNL still uses Well 20 when Hetch Hetchy water is unavailable. Results for 2022 surveillance measurements of groundwater from Well 20 do not differ significantly from previous years. As in past years, Well 20 showed no evidence of contamination. In addition to the permit-required sampling, Well 20 was sampled for nitrate, HMX, and RDX; all results were non-detect in 2022.

5.4.2.3 Off-site Surveillance Wells and Springs

For surveillance purposes, LLNL obtains groundwater samples from three off-site springs (MUL1, MUL2, and VIE1) and nine off-site wells (VIE2, CARNRW1, CARNRW2, CDF1, CON1, CON2, GALLO1, STONEHAM1, and W-35A-04) (**Figure 5-6**). All off-site surveillance springs and wells were sampled in 2022. All off-site monitoring locations are near Site 300, except for VIE2 which is located at a private residence 6 km west of the site. VIE2 represents a typical potable water supply well in the Altamont Hills.

Samples from CARNRW2 and GALLO1 are typically analyzed at least quarterly for inorganic constituents (metals, nitrate, and perchlorate), general radioactivity (gross alpha and gross beta), and tritium. CARNRW2 is also analyzed for explosive compounds (HMX and RDX) and uranium. CARNRW1 samples are analyzed monthly for VOCs (EPA Method 624), perchlorate, and tritium.

Groundwater samples were obtained at least annually during 2022 from the following off-site surveillance monitoring locations: STONEHAM1, CON1, W-35A-04, and CDF1 (south of Site 300). Samples were analyzed for inorganic constituents, general radioactivity (gross alpha and gross beta), tritium, and explosive compounds (HMX and RDX). Additionally, samples from W-35A-04 and STONEHAM1 were analyzed for uranium.

No constituents attributable to LLNL operations at Site 300 were detected in the off-site groundwater supplies. In 2021, perchlorate was detected at STONEHAM1 for the first time since monitoring began in 2011. However, perchlorate was not detected at STONEHAM1 in 2022. LLNL will continue to track perchlorate concentrations and monitor trends at STONEHAM1. In 2022, nickel was detected at well W-35A-04 after a history of largely non-detect samples since 2010. LLNL will continue to track nickel concentrations and monitor trends at W-35A-04. Radioactivity measurements in samples collected from off-site groundwater wells are generally indistinguishable from naturally occurring activities.

5.5 Other Monitoring Programs

5.5.1 Rainwater

Air moisture containing HTO is rapidly entrained and washed out locally during rain events. Rain gauge sampling is not required by DOE Order 458.1, or any other federal, state, or local regulation or permit; however, LLNL collects rainwater in rain gauges at fixed locations at both the Livermore Site and Site 300 to supplement information for storm events sampled for runoff. The collected rainwater is analyzed for tritium using EPA Method 906.0, a liquid scintillation counting method, and the analytical results are compared to the EPA drinking water MCL of 740 Bq/L (20,000 pCi/L) for tritium.

In calendar year 2022, the rain gauges were placed at the sample locations SALV, MET, DWTF, and SECO at the Livermore Site as shown in **Figure 5-7.** Site 300 rain gauges were located at ECP, PSTL, and GOLF as shown **Figure 5-8.**

The samples for calendar year 2022 were collected at the Livermore Site after the April 21, November 3, and December 1 qualifying storms. The highest measured tritium concentration,7.5 Bq/L, was for the April 21 storm and was collected at the DWTF sample location This concentration is approximately 1% of the EPA established drinking water MCL. All analytical results are provided in **Appendix A, Section A.7.**

The rainwater sample collected at Site 300 was after the April 20 qualifying storm. All three samples were non-detections for tritium with analytical error applied. All analytical results are provided in **Appendix A, Section A.7.**

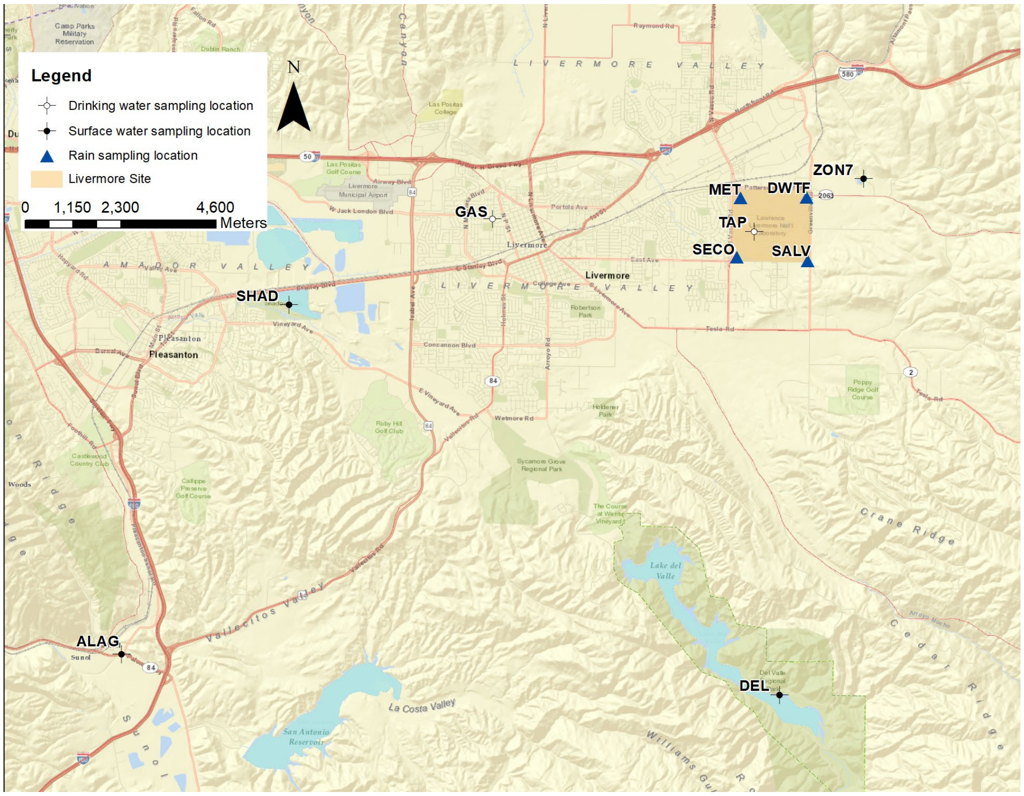

Figure 5-7. Livermore Site and Livermore Valley Sampling Locations for Rain, Surface Water, and Drinking Water, 2022

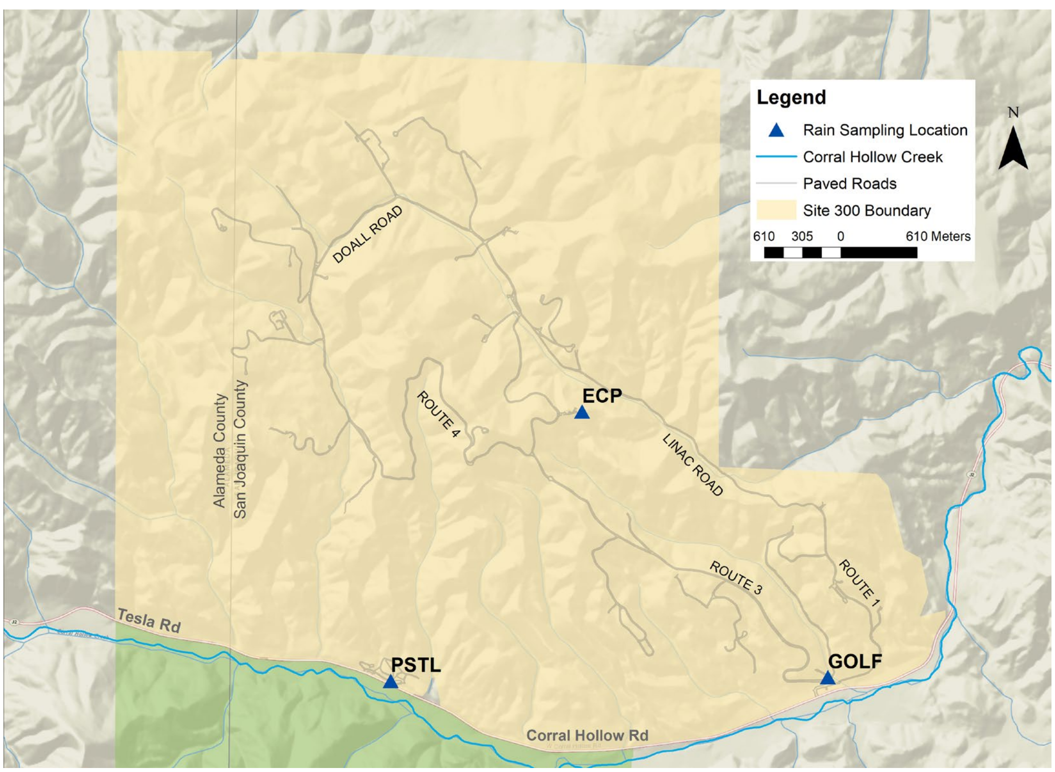

Figure 5-8. Rainwater Sampling Locations at Site 300, 2022

5.5.2 Livermore Valley Surface Waters

LLNL conducts additional surface water surveillance monitoring in support of DOE Order 458.1. Surface and drinking water near the Livermore Site and in the Livermore Valley were sampled at the locations shown in **Figure 5-7** in 2022. Off-site sampling locations DEL, ALAG, SHAD, and ZON7 are surface water bodies; of these, DEL and ZON7 are also drinking water sources. The Springtown Pond (DUCK) is an artificial duck pond that was removed by the City of Livermore in 2018 and therefore the location was removed from the surface water sampling plan. GAS and TAP are drinking water outlets; radioactivity data from these two sources are used to calculate drinking water statistics (see **Table 5-4**).

Samples are analyzed according to standardized procedures summarized in Brunckhorst (2019). In 2022, LLNL sampled GAS and TAP semiannually and ALAG, DEL, SHAD, and ZON7 annually. All locations were sampled for tritium, gross alpha, and gross beta. All analytical results are provided in **Appendix A, Section A.7.**

The median tritium concentration in all water location samples was estimated to be below the analytical laboratory's minimum detectable activities, or minimum quantifiable activities. The maximum tritium concentration detected in any sample collected in 2022 was 0.39 Bq/L (10.5 pCi/L), which is less than 1% of the drinking water MCL. All gross alpha results were less than the drinking water MCL. Historically, concentrations of gross alpha and gross beta radiation in drinking water sources have fluctuated around the analytical laboratory's minimum detectable activities. At such low levels, the counting error associated with the measurement is nearly equal to, or in many cases greater than, the calculated values so that no trends are apparent in the data. The maximum activities detected for gross alpha and gross beta occurred in samples collected at GAS (gross alpha at 0.0892 Bq/L [2.41 pCi/L] and gross beta at 0.1420 Bq/L [3.84 pCi/L]). These maximum values were less than 17% and 8% of their respective gross alpha and gross beta drinking water MCLs (see **Table 5-4**).

Table 5-4. Radioactivity in Surface and Drinking Waters in the Livermore Valley, 2022

Location	Metric	Tritium (Bq/L)[(a)]	Gross alpha (Bq/L)[(a)]	Gross beta (Bq/L)[(a)]
All locations	Median	-1.295	0.0362	0.093
	Minimum	-2.82	-0.0253	0.0031
	Maximum	0.39	0.0892	0.142
	Interquartile range	0.73	0.0385	0.0790
Drinking water outlet locations	Median	-0.835	0.0183	0.0814
	Minimum	-1.74	-0.0253	0.0031
	Maximum	0.39	0.0892	0.142
	Drinking water MCL	740	0.555	1.85

(a) A negative number means the sample radioactivity was less than the background radioactivity

5.5.3 Site 300 Drinking Water System Discharges

In 2022, LLNL maintained coverage under General Order R5-2022-0006, NPDES Permit No. CAG995002 for occasional large volume discharges from the Site 300 drinking water system that may reach surface water drainage courses. Discharges with the potential to reach surface waters that are subject to these sampling and monitoring requirements are:

- Drinking water storage tank discharges
- System-flush and line-dewatering discharges
- Dead-end flush discharges

More information is included in the quarterly self-monitoring reports to the CVRWQCB. All 2022 releases from the Site 300 drinking water system percolated into the drainage ditches or dry streambeds and did not reach Corral Hollow Creek, the potential receiving water.

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6. Terrestrial Monitoring

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Lawrence Livermore National Laboratory (LLNL) monitors several aspects of the terrestrial environment at the Livermore Site, Site 300, and in the vicinity of both sites. LLNL measures the radioactivity present in soil, vegetation, and wine, and the gamma radiation exposure at ground-level receptors from terrestrial and atmospheric sources. LLNL also monitors the abundance and distribution of rare plants and protects special habitats on-site.

The LLNL terrestrial radioactivity-monitoring program is designed to measure any changes in environmental levels of radioactivity. All monitoring activities follow U.S. Department of Energy (DOE) guidance criteria. On-site monitoring activities detect radioactivity released from LLNL operations that may contribute to radiological dose to the public or biota. Monitoring at distant locations not impacted by LLNL operations detects naturally occurring background radiation and is used to evaluate the impact of operations.

Terrestrial pathways from LLNL operations to potential radiological dose to the public include resuspension of soils, infiltration of constituents from runoff water through arroyos to groundwater, ingestion of locally grown foodstuffs, and external exposure to contaminated surfaces. Potential ingestion doses are calculated from measured concentrations in vegetation and wine. Doses from exposure to ground-level external radiation are obtained from thermoluminescent dosimeters (TLDs). Potential dose to biota is calculated using a screening method that requires knowledge of radionuclide concentrations in soils and surface water.

Sampling for all media is conducted according to written, standardized procedures summarized in Brunckhorst (2019). Sampling locations for soils, vegetation, and direct radiation for the Livermore Site, the Livermore Valley, and Site 300 are illustrated in **Figures 6-1, 6-2,** and **6-3,** respectively.

LLNL also monitors the abundance and distribution of special status plant and wildlife species and conducts research on the protection of rare plants and animals. Biota monitoring and research on LLNL property is conducted to ensure compliance with requirements of the U.S. Endangered Species Act (ESA), the California Endangered Species Act (CESA), the Eagle Protection Act, the Migratory Bird Treaty Act, and other applicable regulations as they pertain to endangered, threatened, and other special status species, their habitats, and designated critical habitats that exist at both LLNL sites.

6.1 Soil Monitoring

Soil sampling locations were selected to represent both background radioactivity (distant locations unlikely to be impacted by LLNL operations) and areas that have the potential to be impacted by LLNL operations. Sampling locations also include areas with known contamination, such as the Livermore Water Reclamation Plant (LWRP) and explosives testing areas at Site 300.

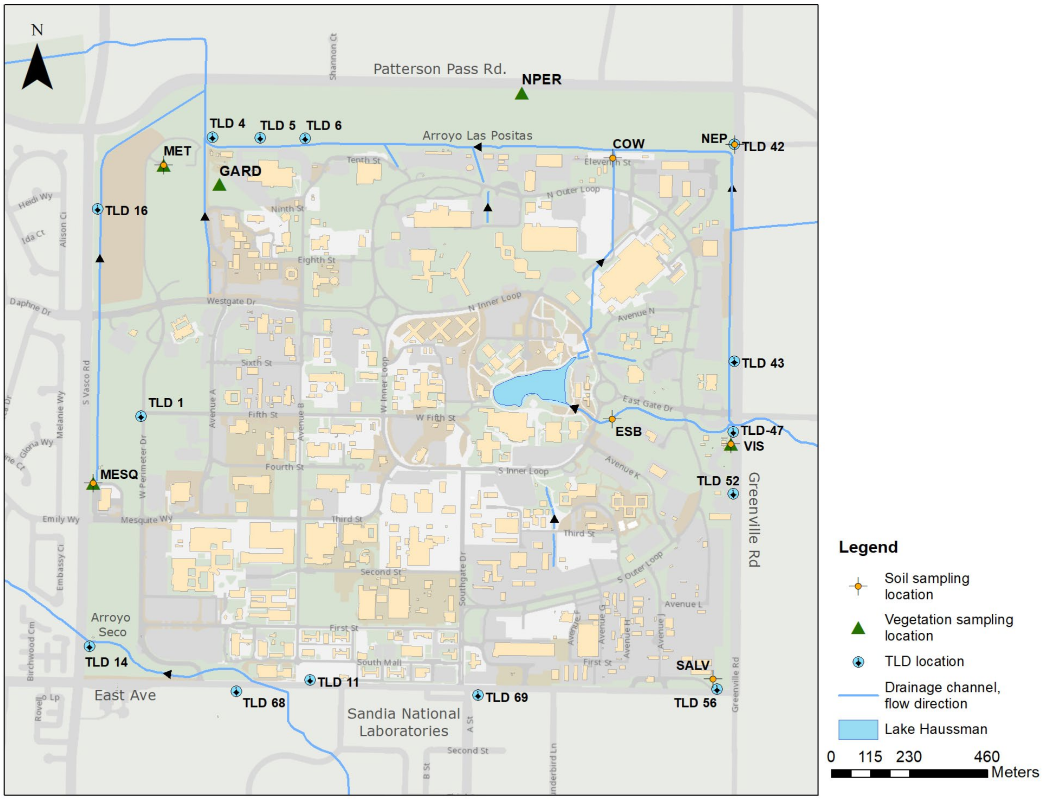

Figure 6-1. Soil, Vegetation, and TLD Sampling Locations, Livermore Site

Surface soil samples are collected from the top five centimeters of soil because aerial deposition is the primary pathway for potential radionuclide contamination. Resuspension of materials from the surface into the air is the primary exposure pathway to nearby human populations. At each sampling location, two 1 m^2 areas are selected to collect the samples. Each sample is a composite consisting of 10 subsamples that are collected at the corners and center of each square using an 8.25 cm-diameter stainless steel core sampler. At four of the sampling locations, a sample is taken at a depth of 15 cm for tritium analysis. This deeper sample enables laboratory extraction of sufficient pore water from the soil for tritium analysis.

Figure 6-2. Soil, Vegetation, and TLD Locations, Livermore Valley

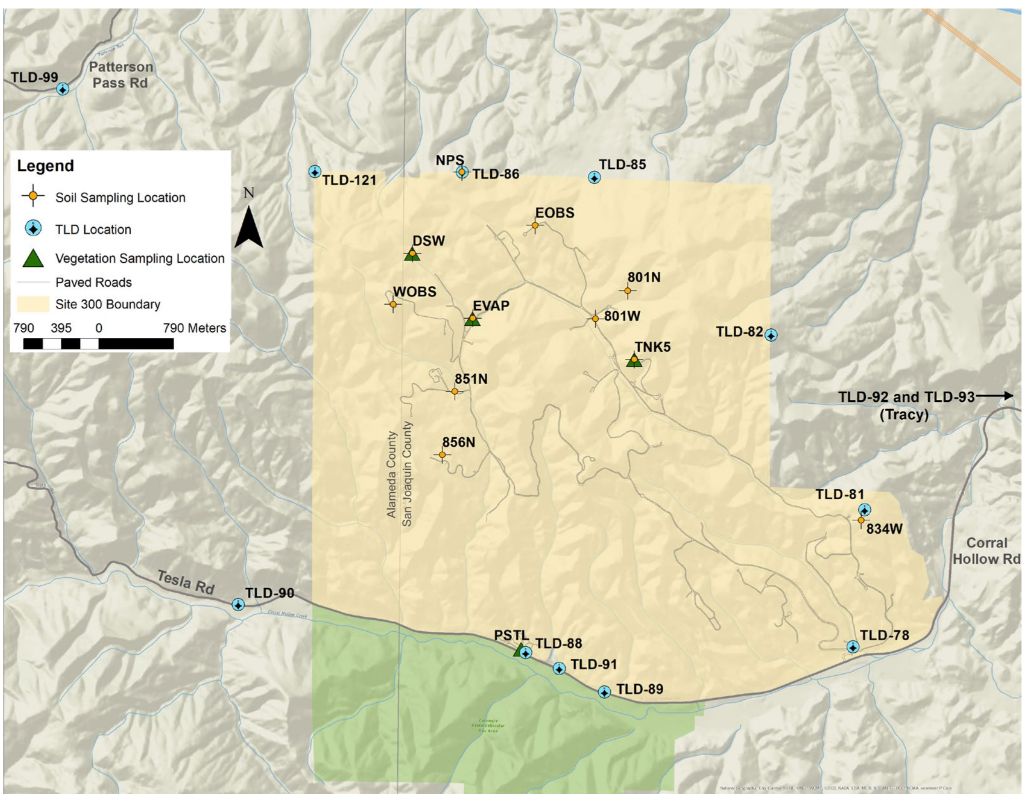

Figure 6-3. Soil, vegetation, and TLD Locations, Site 300 and Off-Site

Surface soil samples in the Livermore Valley were analyzed for plutonium and alpha-, beta- and gamma-emitting radionuclides. Samples at selected locations at the Livermore Site were also analyzed for gross alpha, gross beta, and tritium. Samples from Site 300 were analyzed for beryllium and alpha-, beta- and gamma-emitting radionuclides.

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

6.1.1 Radiological Analytical Results

6.1.1.1 Livermore Valley

The 2022 radionuclide analyses data for the soil samples collected from the Livermore Valley sampling locations are provided in **Appendix A, Section A.8.**

The concentrations and distributions of all observed radionuclides are within the ranges reported in previous years and generally reflect worldwide fallout and naturally occurring concentrations. Elevated levels of plutonium-239+240, resulting from an estimated 1.2×10^9 Bq (32 mCi) plutonium release to the sanitary sewer in 1967 and earlier releases, were again detected at the LWRP sampling locations in 2022. The highest detected plutonium-239+240 concentration was 7.2 ± 0.26 mBq/dry g (0.19 pCi/dry g) at sampling location LWRP1. Americium-241 was also detected at this location at 3.30 ± 0.53 mBq/dry g (0.0891 pCi/dry g) and is most likely caused by the natural radiological decay of the trace levels of plutonium that were present in historical releases to the sewer.

6.1.1.2 Livermore Site

The 2022 radionuclide analyses data for the soil samples collected at the Livermore Site sampling locations are provided in **Appendix A, Section A.8.** The concentrations and distributions of all observed radionuclides are within the ranges reported in previous years.

Sampling at location ESB, which is in the drainage area for the southeast quadrant of the Livermore Site, shows the effects of historical operation of solar evaporators for plutonium-containing liquid waste (which was discontinued in 1976). The measured value for plutonium-239+240 at this location was 1.60 ± 0.078 mBq/dry g (0.043 pCi/dry g).

All reported tritium results were within the range of previous data. Detected tritium concentrations ranged from 1.6 ± 1.5 Bq/L (43.2 ± 40.5 pCi/L) at sampling location VIS to 6.8 ± 1.9 Bq/L (183.6 ± 51.3 pCi/L) at sampling location NEP.

6.1.1.3 Site 300

The soils data for Site 300 for 2022 are provided in **Appendix A, Section A.8.**

The concentrations and distributions of all radionuclides observed in Site 300 soil are within the ranges reported in previous years. At most sampling locations, the uranium-235/uranium-238 (U235/U238) ratio reflects the natural ratio of 0.00725. It should be noted that there is significant uncertainty in calculating the ratio due to the difficulty of measuring low activities of uranium-238 by gamma spectrometry.

The data collected showed three sampling locations (801N, 801W, and 851N) that may indicate the presence of depleted uranium. The U235/U238 ratios ranged from 0.0044 ± 0.0020 µg/dry g to 0.0065 ± 0.0032 µg/dry g. The depleted uranium at Site 300 results from past use of uranium material in atmospheric explosive experiments.

6.1.2 Non-radiological Analytical Results

Beryllium monitoring is only conducted at Site 300 (see **Figure 6-3**) and has been conducted since 1991. The non-radiological soils data for Site 300 are provided in **Appendix A, Section A.8.**

Detected beryllium concentrations were within the ranges previously reported. Detected concentrations ranged from 0.50 mg/kg at sampling location NPS to 1.0 mg/kg at sampling location 801N. The 801N sampling location is in an area that has historically been used for explosives testing.

6.1.3 Environmental Impact on Soil

6.1.3.1 Livermore Site

Routine surface soil sample analyses indicate that the impact of LLNL operations on this medium in 2022 has not changed from previous years and remains insignificant. Most analytes of interest or concern were detected at background concentrations, in trace amounts, or could not be measured above detection limits.

The highest detected value for plutonium-239+240 was 7.20 ± 0.26 mBq/dry g (0.194 pCi/dry g) at sampling location WRP1. The detected concentration is approximately 1.5% of the National Council on Radiation Protection (NCRP) recommended screening limit of 470 mBq/g (12.7 pCi/g) for property used for commercial purposes (NCRP 1999).

LLNL has investigated the presence of radionuclides in local soils frequently over the years, including possible impacts of the distribution to the public of sludge contaminated by the 1967 plutonium release (see Table 6-5 in the *Environmental Report 2006* [Mathews et al. 2007] for a list of previous studies). The studies have consistently shown that the concentrations of radionuclides in local soils are below levels of health concern. In fact, the concentrations are of such low levels of health concern that the Agency for Toxic Substances and Disease Registry

(ATSDR 2003) strongly recommended against further study of local soils for the purpose of identifying locations where plutonium-contaminated sludge from the 1967 release may remain.

6.1.3.2 Site 300

The concentrations of radionuclides and beryllium detected in soil samples collected at Site 300 in 2022 are within the range of previous data and are generally representative of background levels. The U235/U238 mass ratios are indicative of depleted uranium located near the firing tables resulting from historical testing. The highest detected uranium-235 concentration was 0.037 ± 0.013 µg/dry g at sampling location EVAP and is well below the NCRP-recommended screening level for commercial sites (8.2 µg/dry g). The highest detected uranium-238 concentration was at sampling location 801N (8.4 ± 2.2 µg/dry g) and is also well below the NCRP-recommended screening level for commercial sites (313 µg/dry g).

A draft Remedial Investigation/Feasibility Study (RI/FS) was submitted for the Building 812 Operable Unit (OU 9) in 2008 (Taffet et al. 2008). This RI/FS specified the nature and extent of contamination, risk assessment, and remedial alternatives for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cleanup of the OU. Upon review of the draft RI/FS, DOE and the regulatory agencies agreed that additional characterization was needed prior to submitting an updated draft RI/FS. In 2011, the Environmental Restoration Department (ERD) began additional characterization of soil and surface water in the Building 812 OU. Further characterization activities continued into 2022. Upon completion, a draft and final RI/FS will be prepared. See **Chapter 7** for further details regarding this project.

6.2 Vegetation and Foodstuff Monitoring

Vegetation and foodstuff monitoring is conducted to monitor the potential radiation dose to the public through ingestion. The foodstuff product monitored is wine because it is the main agricultural product in the Livermore Valley surrounding LLNL.

Vegetation sampling locations at the Livermore Site (see **Figure 6-1**) and in the Livermore Valley (see **Figure 6-2**) are divided for comparison into the following three groups:

- Near locations (AQUE, GARD, MESQ, NPER, MET, and VIS) are on-site or less than 1 km from the Livermore Site perimeter.
- Intermediate locations (I580, TESW, and ZON7) are in the Livermore Valley and 1 to 5 km from the Livermore Site perimeter.
- Far locations (FCC and CAL) are more than 5 km from the Livermore Site perimeter; FCC is about 5 km away and CAL is more than 25 km away. Both locations are generally upwind of the Livermore Site.

Tritium in vegetation due to LLNL operations is most likely to be detected at the near and intermediate locations and is highly unlikely to be detected at the far locations.

Site 300 has four monitoring locations for vegetation (PSTL, TNK5, DSW, and EVAP) (see **Figure 6-3**). Vegetation at locations DSW and EVAP exhibit variable tritium concentrations due to occasional uptake of contaminated groundwater by the roots. At the other two locations, TNK5 and PSTL, the only likely potential source of tritium uptake is the atmosphere, although groundwater in the vicinity of PSTL is contaminated with low levels of tritium.

Vegetation is sampled and analyzed quarterly. Water is extracted from vegetation by freeze-drying and then analyzed for tritiated water (HTO) using liquid scintillation techniques.

Wines for sampling in 2022 were purchased from a supermarket in Livermore. The wines represent the Livermore Valley, other regions of California, and the Chablis and Bordeaux regions in France. Wines were prepared for sampling using a method that separates the water fraction from the other wine components and were analyzed using an ultra-low-level scintillation counter.

6.2.1 Vegetation Monitoring Results

2022 median and mean concentrations of tritium in vegetation based on samples collected at the Livermore Site, the Livermore Valley, and Site 300 are shown in **Table 6-1.** See **Appendix A, Section A.9,** for quarterly tritium concentrations in plant water. The highest mean tritium concentration near the Livermore Site in 2022 was 7.7 Bq/L at the near location VIS by the east perimeter of the site. The highest mean concentration measured in the Livermore Valley was 5.3 Bq/L at ZON7. For Site 300, the highest mean concentration in 2022 was 38 Bq/L at DSW.

Median concentrations of tritium in vegetation at sampling locations at the Livermore Site and in the Livermore Valley have decreased noticeably since 1989 (see **Figure 6-4**). Since 1993, median concentrations at the far locations have been below the detection limit of approximately 2.0 Bq/L. Median concentrations at the intermediate locations have been below the detection limit since 1998, except in 2002, 2020, 2021, and 2022 when the median concentrations ranged from 2.1 Bq/L to 2.5 Bq/L. Median concentrations at the near locations have been at or slightly above the detection limit since 2012.

At Site 300, the median concentrations of tritium in vegetation at all sampling locations (DSW, EVAP, PSTL, and TNK5) were at or below the detection limit.

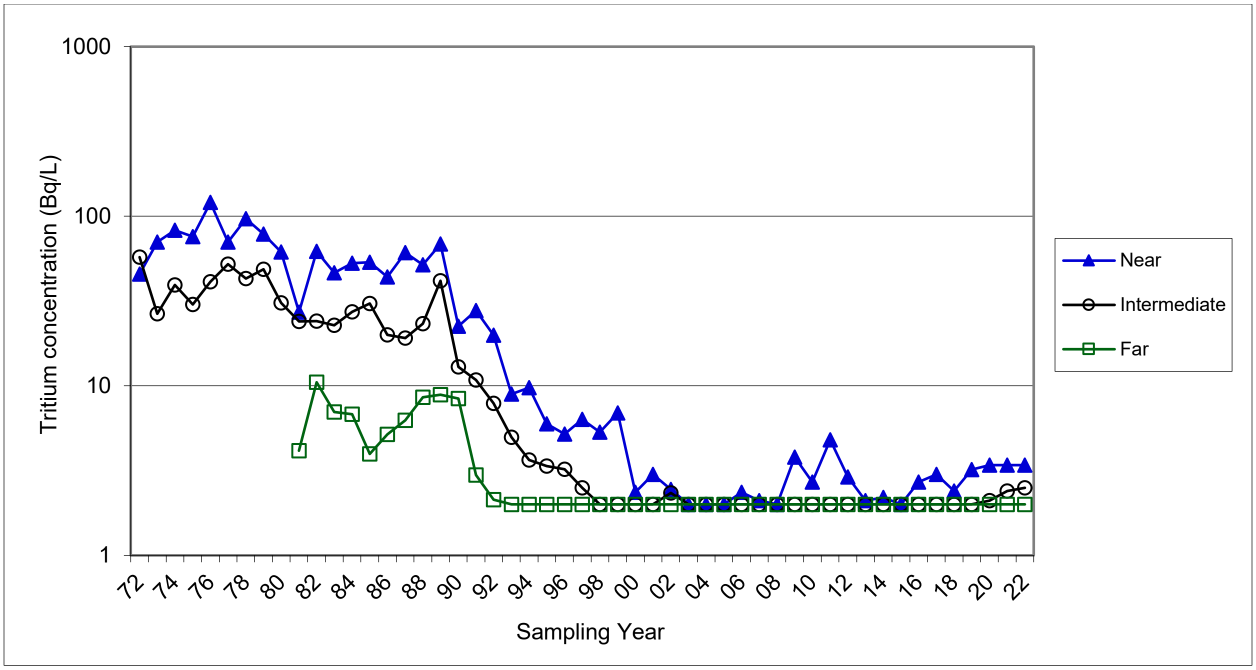

Figure 6-4. Median Tritium Concentrations in Livermore Site and Livermore Valley Plant Water Samples, 1972 – 2022

Note: When median values are below the lower limit of detection (2.0 Bq/L [54 pCi/L]), values are plotted as 2.0 Bq/L.

Table 6-1. Median and Mean Concentrations of Tritium in Plant Water for the Livermore Site, Livermore Valley, and Site 300 in 2022

Sampling Locations		Concentration of Tritium in Plant Water (Bq/L)		Mean Annual Ingestion Dose (a) (nSv/y)
		Median	Mean	
NEAR (onsite or <1 km from Livermore Site perimeter)	AQUE	1.9	6.3	38
	GARD	2.6	3.4	20
	MESQ	3.0	3.6	22
	MET	3.4	3.8	23
	NPER	4.4	6.5	39
	VIS	5.1	7.7	46
INTERMEDIATE (1–5 km from Livermore Site perimeter)	I580	3.2	4.5	27
	TESW	2.0	2.0	12
	ZON7	3.8	5.3	32
FAR (>5 km from Livermore Site perimeter)	CAL	0.16	0.15	<10(b)
	FCC	1.2	1.2	<10(b)
Site 300	DSW(c)	1.2	38	(d)
	EVAP(c)	0.82	10	(d)
	PSTL	0.26	0.36	(d)
	TNK5	-0.27	0.15	(d)

Note: Table includes mean annual ingestion doses calculated for 2022.

(a) Ingestion dose is based on conservative assumptions that an adult's diet is exclusively vegetables with this tritium concentration and that meat and milk are derived from livestock fed on grasses with the same concentration of tritium. See **Table 6-3.**

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

(c) Plants at these locations are rooted in areas of known subsurface contamination.

(d) Dose is not calculated at these locations because there is no pathway dose to the public.

6.2.2 Wine Monitoring Results

Tritium concentrations in wines purchased in 2022 are shown in **Table 6-2.** The highest measured concentration in Livermore Valley wine was 3.5 Bq/L (94 pCi/L) from a wine made from grapes harvested in 2019. The highest measured concentration in California (other than the Livermore Valley) wine was 1.9 Bq/L (52 pCi/L) from a wine made from grapes harvested in 2018 from Sonoma County. The highest measured concentration in French wine was 2.3 Bq/L (63 pCi/L) from Petit Chablis appellation wine grapes harvested in 2020.

Based on analyses of wines purchased annually since 1977, tritium concentrations in the French wines are typically higher than tritium concentrations in the Livermore Valley wines. However, in 2022 the average tritium concentration in French wines was less than the average tritium concentration in Livermore Valley wines. Additionally, tritium concentrations in the California (other than the Livermore Valley) wines are typically lower than tritium concentrations in the Livermore Valley wines; this was also the case in 2022.

The Livermore Valley wines represent vintages from 2017, 2018, 2019 and 2021; the California wines represent vintages from 2018 and 2021; and the French wines represent vintages from 2018 and 2020. Tritium concentrations must be decay-corrected to the year of harvest to correlate with tritium concentrations in air and soil to which the grape was exposed. In 2022, decay-corrected concentrations ranged from 1.8 to 4.3 Bq/L for Livermore Valley wine samples, 1.6 and 2.4 Bq/L for the two California wine samples, and 1.9 and 2.6 Bq/L for the two French wine samples.

Table 6-2. Tritium in Retail Wine, 2022[a, b]

Sample	Concentration by Area of Production (Bq/L)		
	Livermore Valley	California	Europe
1	1.30 ± 0.48	1.90 ± 0.52	2.30 ± 0.53
2	2.80 ± 0.53	1.50 ± 0.50	1.50 ± 0.51
3	1.80 ± 0.50	-	-
4	1.80 ± 0.50	-	-
5	3.50 ± 0.55	-	-
6	1.90 ± 0.50	-	-
Dose (nSv/y)[c]	5.0	2.7	3.3

(a) Radioactivity is reported here as the measured concentration and an uncertainty (±2σ counting error).

(b) Wines from a variety of vintages were purchased and analyzed for the 2022 sampling. Concentrations are those measured in March 2023.

(c) Calculated based on consumption of 52 L wine per year at maximum concentration. Doses account for organically bound tritium (OBT) and HTO.

6.2.3 Environmental Impact on Vegetation and Wine

6.2.3.1 Vegetation

Hypothetical annual ingestion doses for mean concentrations of tritium in vegetation are shown in **Table 6-1.** These hypothetical doses, from ingestion of HTO in vegetables, milk, and meat, were calculated from annual mean measured concentrations of HTO in vegetation using the transfer factors from **Table 6-3** based on U.S. Nuclear Regulatory Commission Regulatory Guide 1.109 (U.S. NRC 1977). The hypothetical annual ingestion dose, based on the highest observed mean HTO concentration in vegetation for 2022, was 46 nSv (4.6 µrem).

Table 6-3. Bulk Transfer Factors used to Calculate Inhalation and Ingestion Doses from Measured Concentrations in Air, Vegetation, and Drinking Water

Exposure Pathway	Bulk Transfer Factors(a) Times Observed Mean Concentrations
Inhalation and skin absorption	230 $nSv\cdot y^{-1}\cdot Bq^{-1}\ m^3$ × concentration in air (Bq/m^3)
Drinking water	15 $nSv\cdot y^{-1}\cdot Bq^{-1}\cdot L$ × concentration in drinking water (Bq/L)
Food ingestion	6 $nSv\cdot y^{-1}\cdot Bq^{-1}\cdot L$ × concentration in vegetation (Bq/L)(b) Factor obtained by summing contributions of 1.3 $nSv\cdot y^{-1}\cdot Bq^{-1}\cdot L$ for vegetables, 1.4 $nSv\cdot y^{-1}\cdot Bq^{-1}\cdot L$ for meat, and 3.3 $nSv\cdot y^{-1}\cdot Bq^{-1}\cdot L$ for milk

(a) See Sanchez et al. (2003), Appendix C for the derivation of bulk transfer factors that have been updated with current DOE-accepted dose coefficients of 2.11×10^{-11} Sv/Bq for ingestion and of 1.93×10^{-11} Sv/Bq for inhalation found in U.S. DOE (2011).

(b) For vegetation dose calculations, the assumption is that the vegetation is 100% water. Therefore, Bq/L equals Bq/kg fresh weight.

Doses calculated based on Regulatory Guide 1.109 neglect the contribution from OBT. However, according to a panel of tritium experts, "the dose from OBT that is ingested in food may increase the dose attributed to tritium by not more than a factor of two, and in most cases by a factor much less than this" (ATSDR 2002, p. 27). Thus, the maximum estimated ingestion dose (including OBT) from LLNL operations in 2022 is 92 nSv/y (9.2 µrem/y). This maximum dose is about 1/33,000 of the average annual background dose in the United States from natural sources and about 1/110 the dose from a panoramic dental x-ray. Ingestion doses of Site 300 vegetation were not calculated because neither people nor livestock ingest vegetation at Site 300.

6.2.3.2 Wine

For Livermore Valley wines purchased in 2022, the highest concentration of tritium (3.5 Bq/L [94 pCi/L]) was just 0.47% of the Environmental Protection Agency (EPA) standard for maximal permissible level of tritium in drinking water (740 Bq/L [20,000 pCi/L]). Drinking one liter per day of the Livermore Valley wine with the highest concentration purchased in 2022 would have resulted in a dose of 35 nSv/y (3.5 µrem/y). A more realistic dose estimate, based on moderate drinking (one liter per week) (1) at the mean of the Livermore Valley wine concentrations (2.2 Bq/L [59 pCi/L]) would have been 3.1 nSv/y (0.31 µrem/y). Both doses account for the added contribution of OBT (2).

The potential dose (including the contribution of OBT) from drinking Livermore Valley wines in 2022, even at the high consumption rate of one liter per day and at the highest observed concentration, would be about 1/290 of a single dose from a panoramic dental x-ray.

1 Moderate consumption is higher than the average consumption of wine in California (15.7 L/yr) (Avalos 2005).

2 Dose from wine was calculated based on the measured concentration of HTO multiplied by 1.3 to account for the potential contribution of OBT that was removed so that the tritium in wine could be counted using liquid scintillation counting. The ingestion dose coefficient for HTO is 2.1×10^{-11} Sv/Bg per U.S. DOE (2011).

6.3 Biota Dose

Potential dose to biota resulting from LLNL operations is calculated according to DOE Standard 1153-2019, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (U.S. DOE 2019). RESRAD-BIOTA computer code is used to complete these calculations.

Limits on absorbed dose to biota are 10 mGy/day (1 rad/day) for aquatic animals and terrestrial plants and 1 mGy/day (0.1 rad/day) for terrestrial and riparian animals. In the RESRAD-BIOTA code, each radionuclide in each medium (e.g., soil, sediment, and surface water) is assigned a Biota Concentration Guide (BCG). Measured radionuclide concentrations in the soil and water media are divided by the BCG and the resulting fractions for each medium are summed for each ecosystem (aquatic and terrestrial). For aquatic and riparian animals, the sum of the fractions for water exposure is added to the sum of the fractions for sediment exposure. Similarly, fractions for water and soil exposures are summed for terrestrial animals. If the sum of the fractions for the aquatic and terrestrial systems are each less than one (i.e., the dose to the biota does not exceed the screening limit), then the site has passed the screening analysis for protection of biota.

6.3.1 Estimate of Dose to Biota

At LLNL in 2022, radionuclides considered for dose contribution to biota from soil were americium-241, cesium-137, hydrogen-3 (tritium), potassium-40, plutonium-238, plutonium-239+240, thorium-232, uranium-235, uranium-238, and strontium-90 (based on gross beta). Radionuclides considered for dose contribution to biota from water were tritium, plutonium-239 (surrogate for gross alpha), and strontium-90 (surrogate for gross beta).

For the LLNL assessment, the maximum concentration of each radionuclide measured in soil and storm water run-off samples at both the Livermore Site and Site 300 were used in the dose screening calculations for the terrestrial and aquatic fractions. This approach resulted in a conservative assessment because the maximum concentrations in the media originate from different locations within a large area. This accounts for the exposure at both the Livermore Site and Site 300 and no plant or animal would likely be exposed to both simultaneously.

For 2022, the total sum of the fractions for the aquatic ecosystem animals was 0.079 with the limiting concentrations from radionuclides in water. The total sum of the fractions for the terrestrial ecosystem animals and plants was 0.16 with the limiting concentrations from radionuclides in soil. These fractions for both ecosystems are below one. Therefore, even using the most conservative assumptions, LLNL’s impacts on biota are minimal.

6.4 Ambient Radiation Monitoring

Motivated by DOE Order 458.1, LLNL’s ambient radiation monitoring program monitors trends in average ambient dose from gamma radiation to detect radiation exposure that may be attributed to LLNL operations. This monitoring is conducted using TLDs, which are placed in the following areas: the Livermore Site perimeter (**Figure 6-1**), the Livermore Valley (**Figure 6-2**), Site 300, and the Site 300 vicinity including Tracy (**Figure 6-3**). In each area, there are multiple TLD locations where individual TLDs are placed.

6.4.1 Ambient Radiation Monitoring Methods

Exposure to external gamma radiation is measured using Panasonic UD-814-A1 TLDs. These TLDs contain three crystal elements of thulium-activated calcium sulfate ($CaSO_4$: Tm) and one element of lithium borate phosphor ($^nLi_2B_4O_7$). For the purposes of gamma radiation dose monitoring, only the three $CaSO_4$ elements are considered. TLDs are placed approximately one meter above ground and deployed and retrieved quarterly, consistent with DOE guidance and American National Standards Institute (ANSI) recommendations.

When gamma radiation interacts with the TLD, energy is trapped within the structure of the TLD crystal. Upon heating, the trapped energy is released in the form of light. Measurements of the light are converted to radiation exposure, in milliroentgen (mR), based on a calibration standard of 662 keV cesium-137 gamma energy. Radiation exposure measurements are then converted to dose, in milliSieverts (mSv; 1 mSv = 100 mrem), and normalized to represent a standard 91-day quarter. The result is the estimated dose to the public due to external gamma radiation for the duration of one quarter.

6.4.2 Ambient Radiation Monitoring Results

Table 6-4 presents the annual dose (in mSv) for 2022 and the previous four years for the Livermore Site perimeter, the Livermore Valley, Site 300, and the Site 300 vicinity including Tracy. Tabular data for each sampling location are provided in **Appendix A, Section A.9.** The annual dose for each area is obtained by summing the quarterly doses from each TLD location and then averaging the annual sums for that area. For a typical year, if data is missing for any quarters at a particular location, the annual dose at that location is taken as four times the average of the results available.

Table 6-4. 5-Year Annual Ambient Radiation Dose Summary with Standard Deviation (SD) in Units of mSv and Numbers of Samples [(a)]

Area	Measurement	Year				
		2018	2019	2020[(b) (c)]	2021	2022
Livermore Site	Dose ± 1 SD (mSv)	0.581 ± 0.014	0.578 ± 0.015	0.665 ± 0.018	0.631 ± 0.016	0.634 ± 0.018
	Number of Samples	54	55	28	56	54
Livermore Valley	Dose ± 1 SD (mSv)	0.570 ± 0.035	0.547 ± 0.037	0.724 ± 0.12	0.634 ± 0.078	0.613 ± 0.040
	Number of Samples	31	31	14	31	32
Site 300	Dose ± 1 SD (mSv)	0.691 ± 0.029	0.689 ± 0.029	0.818 ± 0.078	0.776 ± 0.031	0.750 ± 0.037
	Number of Samples	30	29	14	33	34
Site 300 off-site	Dose ± 1 SD (mSv)	0.680 ± 0.13	0.658 ± 0.11	0.944 ± 0.18	0.732 ± 0.13	0.755 ± 0.21
	Number of Samples	7	7	3	8	7
Tracy	Dose ± 1 SD (mSv)	0.639 ± 0.039	0.643 ± 0.034	0.750 ± 0.091	0.595 ± 0.20	0.703 ± 0.06
	Number of Samples	8	8	4	7	4

(a) The number of samples may change from year to year for the same location if TLD data is rejected or the TLD is damaged or missing at the time of collection.

(b) In 2020, the method for calculating the quarterly doses was updated to better reflect recommendations in ANSI/HPS N13.37-2014 (R2019), resulting in higher annual averages.

(c) In 2020, there are fewer samples than other years because one set of TLDs was deployed for an extended period. Due to COVID-19 pandemic restrictions, the first quarter TLDs were in the field for three quarters. The reported results still represent the entire calendar year.

Some natural variation in exposure and dose is expected. For example, the Neroly Formation in and around Site 300 contains naturally occurring thorium that increases the external radiation dose at Site 300 relative to the Livermore Valley.

6.4.3 Environmental Impact from Laboratory Operations

TLD measurements for 2022 indicate there were no detectable elevations in ambient radiation dose resulting from LLNL operations. Radiation doses for each area are consistent with those of previous years.

In 2020, the method for calculating the quarterly doses was updated to better reflect recommendations in ANSI/HPS N13.37-2014 (R2019), resulting in higher annual averages. If these were calculated using previous methods, the results for 2020, 2021, and 2022 would be consistent with those of previous years.

6.5 Special Status Wildlife and Plants

Special status wildlife and plant monitoring at LLNL focuses on species considered to be rare, threatened, or endangered (including species listed under the federal ESA or CESA) and species considered of special concern by the California Department of Fish and Wildlife (CDFW) and the U.S. Fish and Wildlife Service (USFWS).

The California red-legged frog (*Rana draytonii*), which is listed as threatened under the ESA and is a CDFW species of special concern (SSC), is known to occur at the Livermore Site (see **Figure 6-5**). The California tiger salamander (*Ambystoma californiense*) is listed as threatened under both the ESA and CESA and has been observed in areas adjacent to the Livermore Site. Portions of the Livermore Site are considered potential upland habitat for the California tiger salamander due to the proximity of known observations and breeding pools. There is no breeding habitat for the California tiger salamander at the Livermore Site. The Swainson's hawk (*Buteo swainsoni*), a species listed under the CESA but not the federal ESA, is also known to occur at the Livermore Site.

Five species listed under the federal ESA are known to occur at Site 300: the California tiger salamander, California red-legged frog, Alameda whipsnake (*Masticophis lateralis euryxanthus)*, valley elderberry longhorn beetle (*Desmocerus californicus dimorphus)*, and the large-flowered fiddleneck (*Amsinckia grandiflora*). All of Site 300 is designated critical habitat for the California red-legged frog and portions of Site 300 are critical habitat for the large-flowered fiddleneck and the Alameda whipsnake. Although there are no recorded observations of the federally endangered San Joaquin kit fox (*Vulpes macrotis mutica*) at Site 300, this species is known to have historically occurred in the adjacent Carnegie and Tracy Hills areas (USFWS 1998). Because the San Joaquin kit fox has been observed in proximity to Site 300, potential impacts to this species should be considered. Three additional species are listed under the CESA, but not the federal ESA, and are known to occur at Site 300. Two species listed as threatened under the CESA, the tricolored blackbird (*Agelaius tricolor*) and the Swainson's hawk, regularly occur at Site 300. A third species, the California-endangered willow flycatcher (*Empidonax traillii*), was observed at Site 300 once and is expected to occur infrequently as a migrant in riparian habitat at Site 300.

Protected habitat for species listed under the federal and California ESAs at Site 300 is shown in **Figure 6-6.** Vertebrate species and rare invertebrate species known to occur at Site 300, including state and federally listed species and other SSC are listed in **Appendix B.** A similar list for the Livermore Site is available in Appendix I of the Draft Sitewide Environmental Impact Statement for Continued Operations of the Lawrence Livermore National Laboratory (SWEIS) (DOE 2022).

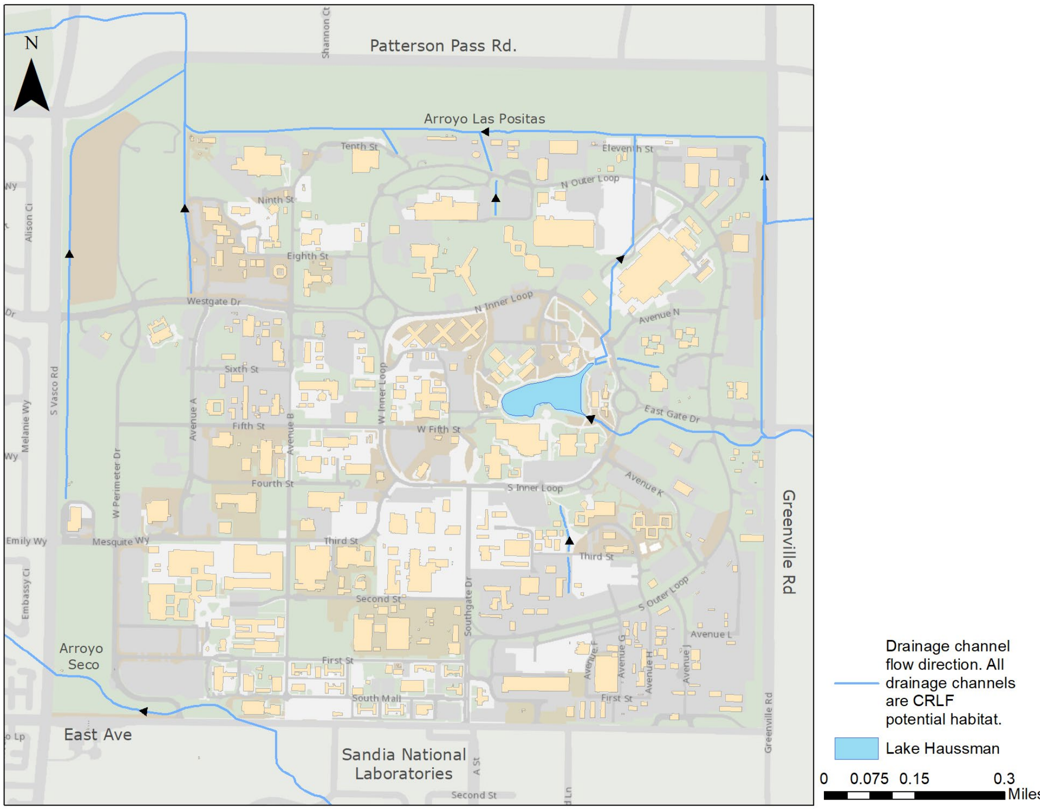

Figure 6-5. Potential California Red-Legged Frog Aquatic Habitat, Livermore Site

Including the endangered large-flowered fiddleneck, four rare plant species and three uncommon plant species are known to occur at Site 300. The four rare species include the large-flowered fiddleneck, the big tarplant (*Blepharizonia plumosa*), the diamond-petaled California poppy (*Eschscholzia rhombipetala*), and the shining navarretia (*Navarretia nigelliformis* ssp. *radians*) – all have a California Rare Plant Rank (CRPR) of 1B (CNPS 2022). A fifth species, the round-leaved filaree *(California macrophylla),* was previously considered rare, but its status was downgraded and is no longer considered rare (CNPS 2022).

The three uncommon plant species – California androsace (*Androsace elongata* subsp. *acuta*), stinkbells (*Fritillaria agrestis*), and hogwallow starfish (*Hesperevax caulescens*) – have a CRPR of 4.2 (CNPS 2022). Past surveys have failed to identify any rare plants at the Livermore Site (Preston 1997, 2002).

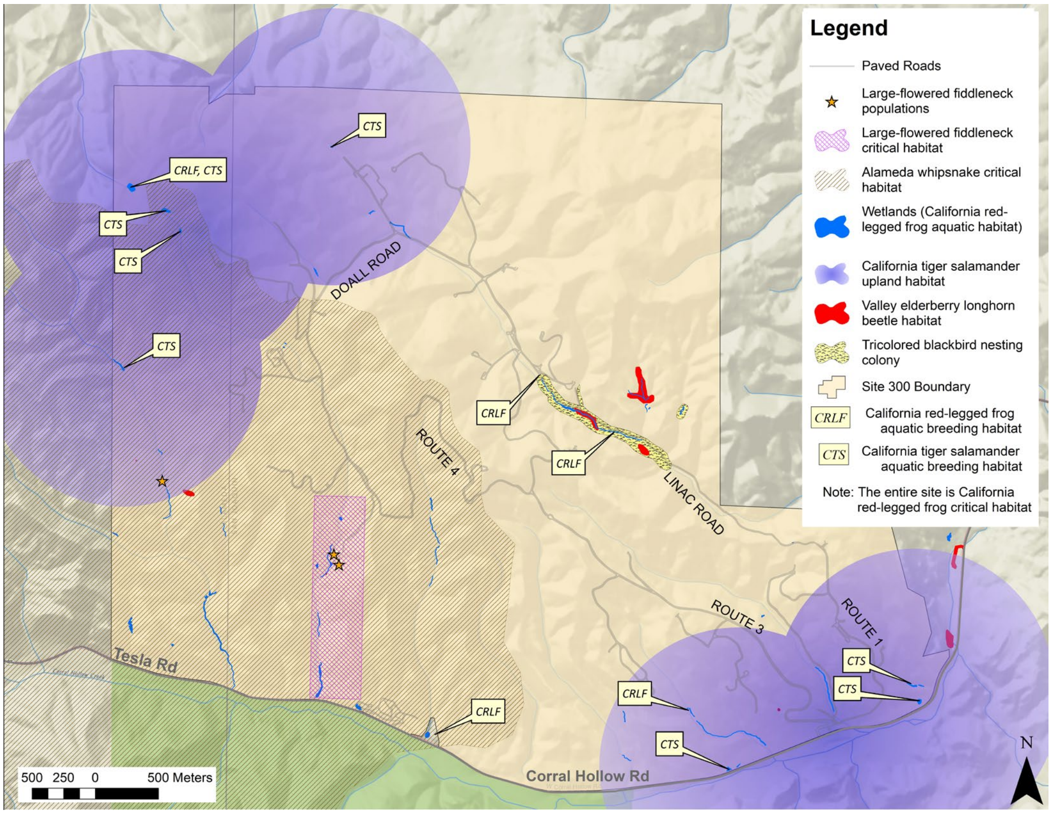

Figure 6-6. Protected Habitat for Species Listed Under the Federal and California Endangered Species Acts, Site 300

6.5.1 Surveillance Monitoring

6.5.1.1 Avian Monitoring

LLNL conducts seasonal nesting bird surveys and monitoring to ensure compliance with the Migratory Bird Treaty Act and prevent impacts to nesting birds.

Livermore Site Nesting Bird Surveys. LLNL conducted routine site-wide breeding raptor surveys during the 2022 nesting bird season at the Livermore Site. Two pairs of Swainson's hawks nested at the Livermore Site in 2022 – one failed and one successfully fledged one nestling. The nest failure was located on the southern edge of the site along East Avenue in a tree on Sandia National Laboratory (SNL) property. The second nest, which fledged one nestling, was located at the northern perimeter of the Livermore Site along Arroyo Las Positas. While white-tailed kites are typically observed at the Livermore Site, no white-tailed kite nests were discovered in 2022. Three common raven nests located near B581, B362, and the on-site substation successfully fledged young. Two red-tailed hawk nests were known on-site – one along East Avenue and one at the corner of Greenville Road and Lupin Way. Both nests are presumed to have fledged a single nestling based on observations and typical nest timing for the species (Preston and Beane, 2020). One red-shouldered hawk nest near B481 failed during the nestling stage.

Site 300 Burrowing Owl Bird Surveys. Sitewide surveys for nesting burrowing owls (*Athene cunicularia)* were conducted at Site 300 in 2022. The burrowing owl is protected by the federal Migratory Bird Treaty Act and is a California SSC. Sitewide burrowing owl surveys are conducted annually to ensure nesting owls are not impacted by site operations and maintenance. Five nesting burrowing owl pairs were observed at Site 300 in 2022. Compared to 2021, the number of nesting pairs decreased in 2022. The five nesting pairs in 2022 were observed to successfully rear at least 11 fledglings. In 2021, the six successful burrowing owl pairs reared at least six fledglings. Although there were fewer pairs in 2022, they were overall more successful than the 2021 breeding population.

Site 300 Nesting Bird Surveys. In addition to the burrowing owl monitoring described above, nesting raptor and corvid locations were recorded at Site 300 on a weekly basis during the nesting bird season and during construction monitoring in 2022. Nesting raptor surveys were conducted in areas of programmatic activity and do not include remote areas of the site. Incidental observations of nesting raptors in remote areas of Site 300 were also recorded during fire trail surveys, but these survey results do not represent the distribution of raptors throughout Site 300. The following were observed during these surveys: five pairs of nesting red-tailed hawks, one pair of nesting great-horned owls (*Bubo virginianus*), five pairs of common ravens, and one barn owl nest. Four of the five suspected red-tailed hawk nests fledged successfully, the great-horned owl pair was observed to rear one fledgling, three of the five common raven nests successfully fledged in 2022, and the fate of the barn owl nest was unknown.

Site 300 Tricolored Blackbird Surveys. Tricolored blackbirds regularly nest in the wetland habitat located within the Elk Ravine riparian corridor at Site 300. LLNL biologists annually monitor tricolored blackbird nesting success at this location. In 2022, only incidental tricolored blackbird surveys were conducted. These surveys indicated that tricolored blackbirds were present in Elk Ravine in March 2022. Although observations of nest-building behaviors were observed, no birds were detected in early April, suggesting that nesting attempts were not successful in 2022.

6.5.1.2 Amphibian Monitoring

Livermore Site California red-legged frog monitoring. In 2021, LLNL conducted extensive diurnal and nocturnal surveys for California red-legged frogs in Arroyo Las Positas, Arroyo Seco, Lake Haussmann, and drainages throughout the site in support of SWEIS data collection. In 2022, routine diurnal and nocturnal surveys for California red-legged frogs were conducted. Diurnal surveys for California red-legged frog egg masses were also conducted at the Livermore Site in 2022. No California red-legged frogs or egg masses were observed during 2022 survey efforts.

Although no California red-legged frogs were observed at the Livermore Site in 2022, this species has been observed infrequently over the last several years, indicating that the California red-legged frog continues to be an uncommon resident of the Livermore Site. Two juvenile California red-legged frogs were observed in Lake Haussmann in the fall of 2014, which is evidence of successful California red-legged frog reproduction. Although no evidence of

California red-legged frog reproduction has been observed since 2014, adult California red-legged frogs have continued to be infrequently observed.

Two adult California red-legged frogs were observed during maintenance activities in Arroyo Las Positas in the fall of 2016. In 2017 and 2018, ongoing California red-legged frog monitoring and invasive species control was conducted; no California red-legged frogs were observed at the Livermore Site during these years. There were multiple sightings of adult California red legged frogs in 2019. Two sightings occurred in Arroyo Las Positas – one during a non-routine survey inspection and the other during a routine amphibian survey during breeding season. An additional observation occurred at Lake Haussmann during invasive wildlife control in the summer of 2019. One adult California red-legged frog was observed within Arroyo Las Positas during 2020.

In 2021 observations of the American bullfrog (*Lithobates catesbeianus*), a non-native invasive species, decreased dramatically at the Livermore Site. Lawrence Livermore National Security (LLNS) continued minimal operations in 2021 due to the COVID-19 pandemic, which reduced the amount of treated groundwater discharge and water flow into Arroyo Las Positas. There continued to be a dramatic decline of American bullfrogs across the site in 2022. Additionally, confirmed sightings of a North American river otter (*Lontra canadensis)* were made in Lake Haussmann, which may have contributed to declining bullfrog numbers.

Site 300 amphibian monitoring. LLNL conducts routine monitoring for the presence and breeding success of special status amphibians at Site 300 including the California red-legged frog and the California tiger salamander. Due to drought conditions, many Site 300 wetlands and seasonal pools remained dry in 2022. Therefore, few observations of California red-legged frogs and California tiger salamanders were made in 2022.

LLNL conducted diurnal and nocturnal surveys within suitable aquatic habitat for California red-legged frogs throughout the site (Pools A, CP, CR, HC1, M1a, M1b, M2, M3, O, OS, S, SG, and an artificial impoundment – Pit 7 v-ditch).

During the 2022 surveys, one adult California red-legged frog and one egg mass were observed in Pools M1a and M1b. Tadpoles, which were determined to be California red-legged frogs based on size, were present during later surveys at this location. Pools S and SG had no inundation present during the 2022 survey period and additional surveys were suspended at these locations. Pool M3 did not retain inundation long enough to allow for successful amphibian breeding in 2022. There were no observations of California red-legged frog egg masses, tadpoles, subadults, or adults at any of the other surveyed locations in 2022.

Diurnal surveys were also conducted to monitor the breeding success of California tiger salamanders at several seasonal pools at Site 300. In 2022, diurnal surveys were conducted at nine seasonal pools (Pools A, H, M2, HC1, S, OS, M3, Lower Pool D, and Upper Pool D) and an artificial impoundment (Pit 7 v-ditch). These pools regularly support California tiger salamander breeding in years with average or above average rainfall. Although California tiger salamander eggs were recorded in Pool OS and in the Pit 7 v-ditch, neither location held water for long enough for larval salamanders to survive to become adults. No California tiger salamanders of any life-stage were found in any of the other surveyed locations due to insufficient inundation.

6.5.1.3 Rare Plant Monitoring

Large-Flowered Fiddleneck. This species has recently been known to occur in only four native populations. This includes two populations at Site 300 (the Drop Tower and Draney Canyon populations), a population located on mitigation property owned by the Contra Costa Water District, and a newly discovered population located near Antioch on property recently acquired by the East Bay Regional Park District. No large-flowered fiddleneck plants have been observed at Draney Canyon on Site 300 since a landslide occurred there in 1997. The Drop Tower native population also contained no large-flowered fiddleneck plants in 2022.

LLNL established an experimental population of the large-flowered fiddleneck at Site 300 beginning in the early 1990s. LLNL maintains the experimental population by periodically planting large-flowered fiddleneck seeds and seedlings in established plots within the population. As a result of enhancement efforts, the size of the experimental population fluctuates. Seeds were last planted in November 2012 and 280 seedlings were planted in January 2017. The Drop Tower experimental population contained approximately 25 large-flowered fiddleneck plants in the spring of 2022.

Big Tarplant. The distribution of big tarplant was mapped at Site 300 using a handheld global positioning system (GPS) from September – November 2022. Approximately 8,000 – 26,000 big tarplants were observed. While this species is extremely rare throughout its range, it can be abundant at Site 300, especially in or near areas where prescribed burns are routinely conducted and where wildfires have recently occurred. As is typical with annual plant species, the abundance of big tarplants varies significantly from year to year depending on environmental conditions. For example, while the Site 300 big tarplant population was estimated to contain approximately 2,700 individual plants in 2014, there were approximately 214,000 big tarplants in 2010.

Diamond-Petaled California Poppy. Although the species is not listed under the federal or California ESAs, it is extremely rare and is currently known to occur only at Site 300 and in a few locations in Contra Costa and San Luis Obispo counties. Four populations of this species are known to occur at Site 300; these populations are referred to as Sites 1 – 4. Site 3 was discovered in 2004 and typically contains the largest population of this rare species. As with the big tarplant and other annual plants, the number of diamond-petaled California poppy plants present in these populations is expected to vary from year to year. In 2015, approximately 46,100 diamond-petaled California poppies were observed within all Site 300 populations. The 2015 population was the largest observed since sitewide monitoring began in 2004. The relatively large population in 2015 was attributed to less dense annual grass coverage due to drought conditions. In contrast, only four diamond-petaled California poppies were observed at Site 300 in 2017. The mean number of diamond-petaled California poppy plants observed at Site 300 from 2004 – 2021 is 5,829. This includes the high population of approximately 46,000 plants in 2015, which is approximately 44,500 more than the second highest population number recorded in 2021. The median number of diamond-petaled California poppy plants observed at Site 300 from 2004 – 2021 is 845. In 2022, approximately 1,708 diamond-petaled California poppies were observed in all Site 300 populations.

6.5.2 Invasive Species Control Activities

Invasive species control is an important part of LLNL's effort to protect special status species at both sites. Prevention of additional colonization by invasive species is also important to protect native species throughout the region. At the Livermore Site, the American bullfrog is a significant threat to California red-legged frogs. At Site 300, the feral pig (*Sus scrofa*) threatens numerous protected habitat types. The exotic largemouth bass (*Micropterus salmoides*) has been successfully removed from Lake Haussmann at the Livermore Site since 2017.

At the Livermore Site, bullfrog control measures were implemented from May – September 2021. Adult bullfrogs were dispatched to Lake Haussmann and Arroyo Las Positas. Typically, bullfrog egg masses would also be removed, but no egg masses were observed in 2022. Additionally, to remove bullfrog tadpoles and invasive fish, the LLNL reach of Arroyo Las Positas was allowed to dry out in September 2022 by temporarily halting groundwater discharges to the arroyo.

At Site 300, feral pig control measures were implemented from March – October 2022. Adults and associated litters were dispatched. Site 300 continues to protect its critical habitats and rare species by implementing consistent swine control practices.

6.5.3 Habitat Enhancement Projects and Compliance Activities

6.5.3.1 Power Pole Modifications for Migratory Bird Protection

To minimize adverse impacts to migratory birds, Site 300 implements an avian protection policy to support avian-friendly transmission lines, insulators, power poles, and other features that are designed to minimize collision and electrocution fatalities of birds of prey.

From 2014 – 2022, over 50 power poles have been modified for bird protection at Site 300 as part of a site-wide revitalization project. These bird-friendly modifications include creating safe perch sites and limiting access to areas with possible electrical hazards. Specifically, the following actions have been taken:

1. Dropping the cross arm to create an elevated center pole perch.
2. Running underarm (under cross arm) conductor jumpers away from perch sites.
3. Adding elevated center phase conductors with kingpins above perch sites.
4. Upgrading cross arm geometry to "straight line" conductors online and buck (multi-directional) poles, thereby avoiding extra conductor infrastructure.
5. Cleaning up wiring (i.e., wire removal or guards) or adding bushing covers to switch poles.
6. Installing long, ten-foot cross arms to increase the separation between phases.

6.5.3.2 Arroyo Las Positas Maintenance and Habitat Management

LLNL conducts annual maintenance and habitat management within the Arroyo Las Positas at the Livermore Site to reduce potential flooding of LLNL facilities and to improve the habitat value for the federally threatened California red-legged frog and other native species. Maintenance was conducted in three 300-foot reaches of Arroyo Las Positas in September 2022. For the eighth consecutive year, willows and cottonwoods were planted to eventually shade the arroyo and reduce cattail growth, which will also reduce the need for future maintenance. Additionally, willows and cottonwoods will provide cover that can be utilized by the California red-legged frog and other native wildlife. All work conducted within the channel of Arroyo Las Positas is monitored by a biologist approved by the USFWS to conduct monitoring under the Arroyo Las Positas Biological Opinion. In 2022, no California red-legged frogs were seen or heard during a diurnal pre-activity and monitoring survey at this location. After the 2015 – 2016 and 2018 – 2022 maintenance was completed, willows and cottonwoods were planted along the south bank of the arroyo. The 2022 survivorship of planted willows and cottonwoods met project requirements. Two maintenance sections received plantings for the first time during 2022 maintenance. Willow and cottonwood coverage, as a dominant vegetation type, increased from 16.1% in 2015 to 41.4% in 2022. By implementing invasive tree species removal, she-oak (*Casaurina* sp.) coverage has been reduced to 6.5% of the total length of the project site in 2022 compared to 15% in 2015.

6.5.3.3 Elk Ravine Habitat Enhancement Pools

In late August 2005, LLNL implemented a habitat enhancement project for California red-legged frogs at Site 300 in accordance with a 2002 USFWS biological opinion (BO) and permits issued by the Army Corps of Engineers (ACOE) and the Regional Water Quality Control Board (RWQCB). California red-legged frogs were translocated to the new habitat enhancement pools in Elk Ravine (Pools M1a and M1b) in February and March 2006. In the summer of 2014 and fall of 2021, both pools were dredged to remove extra sediment. This increased pool depths to the original 8 – 10 feet, improving the value of this habitat for California red-legged frog breeding. During dredging operations, overgrown vegetation (including cattails, nettles, and willows) was removed to increase breeding habitat suitability. Monitoring demonstrated that California red-legged frogs successfully reproduced in these pools from 2006 – 2019. No California red-legged frog eggs or tadpoles were encountered within the mitigation pools at mid Elk Ravine in 2020 and 2021 due to drought conditions. In 2022, one California red-legged frog adult, tadpoles, and one egg mass were observed within Elk Ravine (Pools M1a and M1b). Although California red-legged frogs were not observed to reproduce in the habitat enhancement pools in 2019 or 2020, they were able to successfully find breeding habitat in Elk Ravine upstream of Pools M1a and M1b in 2020. California red-legged frog adults, tadpoles, and one egg mass were observed within Pool CR in Elk Ravine upstream of Pools M1a and M1b in 2020.

6.5.3.4 Pool M2 Habitat Enhancement

Three ephemeral pools (Pools A, H, and M2) located in the northwest corner of Site 300 provide California tiger salamander breeding habitat. Pools A and H are seasonal pools that have supported California tiger salamander breeding for many years. A habitat enhancement project was conducted at Pool M2 in 2005 to improve the suitability of this pool for California tiger salamander breeding. A second habitat enhancement project was conducted in 2013 at Pool M2 when the clay liner of this pool was augmented to limit infiltration or loss of water through the bottom of the pool. Pool M2 was filled in 2006, 2010 – 2011, and 2015 – 2017 and California tiger salamanders successfully reproduced at this location. In 2007 – 2009, 2012 – 2014, 2018, and 2020 the pool received inadequate inundation and evaporated before the salamander larvae could reach maturity and leave the pool. In 2019, California tiger salamander eggs were observed in Pools M2, H, A, and HC1. Additionally, Pools M2 and A had sightings of California tiger salamander larvae. Although California tiger salamander larvae were observed in all three pools, only Pools A and HC1 were inundated long enough for these larvae to mature into adult salamanders. In 2021 and 2022, no California tiger salamanders, eggs, or larvae were observed in any of these pools and no pools held enough water for salamanders to undergo metamorphosis.

6.5.3.5 Pool HC1 Habitat Enhancement

In 2006, LLNL completed culvert replacement projects within Draney Canyon at Site 300 (the Oasis and Round Valley) where unpaved fire trails crossed intermittent drainages. In 2006, a pool was created within the channel of Draney Canyon to provide California red-legged frog breeding habitat. The Oasis pool was disturbed by feral pigs soon after its construction and no longer holds water to a depth to support California red-legged frog reproduction. Amphibian surveys were conducted at the Oasis in 2020. Although California red-legged frog reproduction was not observed at the Oasis, adult and subadult frogs were found during 2020 surveys. The 2006 Round Valley project included the creation of Pool HC1 to mitigate the impacts at the Oasis site and to serve as enhanced habitat for protected amphibian species.

An additional habitat enhancement project was conducted at Pool HC1 in 2012. The clay liner of this pool was augmented to limit infiltration or loss of water through the bottom of the pool. In 2016, Pool HC1 completely filled and California tiger salamander eggs and larvae were observed. In 2017, Pool HC1 initially filled but did not hold water long enough for salamander larvae to successfully mature. Seasonal pools at Site 300, including Pool HC1, received inadequate inundation in 2018 and evaporated before the salamander larvae could reach maturity and leave the pool. In 2019, Pool HC1 held water long enough for California tiger salamanders to undergo metamorphosis during the season. However, Pool HC1 did not hold water long enough for California tiger salamanders to undergo metamorphosis during the 2020 – 2022 seasons and no salamander eggs or larvae were observed in these years.

6.5.3.6 Pool M3 Habitat Enhancement

In the fall of 2014, LLNL formally set aside 48.5 acres and completed the enhancement of the Pool M3 breeding site for California tiger salamanders. In 2016, California tiger salamanders successfully reproduced in this pool, which represented the second successful breeding attempt since completion of the 2014 restoration activities. In 2017, California tiger salamander eggs were observed at Pool M3, but the pool did not hold water long enough for salamander larvae to mature. In the summer of 2017, the clay liner at Pool M3 was enhanced to increase the hydroperiod of this pool. From 2019 – 2022 Pool M3 did not fill to a depth or duration suitable for California tiger salamander reproduction.

6.5.4 Environmental Impacts on Special Status Wildlife and Plants

In 2022, LLNL avoided significant impacts to special status wildlife, plants, and their habitats by conducting monitoring and implementing avoidance and minimization measures. Habitat enhancement, avian protection, and invasive species control efforts benefited protected species. LLNL continues to monitor and maintain several restoration sites, habitat enhancements, and conservation areas that are beneficial to native plants and animals at the Livermore Site and Site 300 to ensure the protection of listed and special status species.

7. Groundwater Investigation and Remediation

Mark Buscheck • Charles Noyes

Lawrence Livermore National Laboratory (LLNL) samples and analyzes groundwater from areas of known or suspected contamination. Portions of the two sites where soil or groundwater contain or may contain chemicals of concern are actively investigated to define the hydrogeology, nature, and extent of the contamination and its source. Where necessary, remediation strategies are developed and evaluated through preparation of a Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) removal action or through the CERCLA feasibility study process. An approved remedy for each area is developed in consultation with the regulatory agencies and the community.

This chapter reviews the distribution of contaminants in groundwater and the progress LLNL has made in removing contaminants from groundwater and from the unsaturated zone (soil vapor) at the Livermore Site and Site 300. The sites are similar in that the contamination is mostly confined on-site. The sites differ in that Site 300, with an area of 28.3 km^2 (10.9 mi^2), is much larger than the Livermore Site and has been divided into nine Operable Units (OUs) based on the nature and extent of contamination, and topographic and hydrologic considerations. The Livermore Site, at 3.3 km^2 (1.3 mi^2), is effectively one OU.

7.1 Livermore Site Environmental Restoration Project

Initial releases of hazardous materials occurred at the Livermore Site in the mid-to-late 1940s during operations at the Livermore Naval Air Station (Thorpe et al. 1990). There is also evidence that localized spills, leaking tanks and impoundments, and landfills contributed volatile organic compounds (VOCs), fuel hydrocarbons, metals, and tritium to the unsaturated zone and groundwater in the post-Navy era. The Livermore Site was placed on the U.S. Environmental Protection Agency (EPA) National Priorities List in 1987.

An analysis of all environmental media showed that groundwater and both saturated and unsaturated soils are the only media that require remediation (Thorpe et al. 1990). Compounds that currently exist in groundwater at various locations beneath the site at concentrations above drinking water standards (maximum contaminant levels [MCLs]) are trichloroethylene (TCE), tetrachloroethene (PCE), 1,1-dichloroethylene, cis-1,2-dichloroethylene, 1,1-dichloroethane, 1,2-dichloroethane, carbon tetrachloride, vinyl chloride, and tritium. PCE is also present at low concentrations slightly above the MCL in an off-site groundwater plume that extends from the southwestern corner of the Livermore Site. LLNL operates groundwater extraction wells in both on-site and off-site areas. In addition, LLNL maintains an extensive network of groundwater monitoring wells in the off-site area west of Vasco Road.

7.1.1 Physiographic Setting

The general topography of the Livermore Site is described in **Chapter 1**. The Livermore Valley groundwater system consists of several semiconfined aquifers. Rainfall from the surrounding hills and seasonal surface water in the arroyos recharge the groundwater system which flows toward the east-west axis of the valley.

The thickest sediments and aquifers are present in the central and western portions of the Livermore Valley, where they form an important resource for the Zone 7 Water Agency. These sediments comprise two aquifers: the Livermore Formation and overlying alluvium. The Livermore Formation averages about 1,000 m in thickness and occupies an area of approximately 250 km^2. The alluvium, which is about 100 m thick, is the principal water-producing aquifer within the valley.

7.1.2 Hydrogeology of the Livermore Site

Sediments at the Livermore Site are grouped into four grain-size categories: clay, silt, sand, and gravel. Groundwater flow beneath the site occurs primarily in alluvial sand and gravel deposits, which are bounded by lower permeability clay and silt deposits. The alluvial sediments have been subdivided into nine hydrostratigraphic units (HSUs) beneath the Livermore Site. HSUs are defined as sedimentary sequences whose permeable layers show evidence of being hydraulically interconnected and geochemically similar. Six of the nine HSUs contain contaminants at concentrations above their MCLs: HSU-1B, -2, -3A, -3B, -4, and -5 (Blake et al. 1995; Hoffman et al. 2003). HSU-1A, -6, and -7 do not contain contaminants of concern above action levels.

7.1.3 Remediation Activities and Monitoring Results

In 2022, LLNL operated and/or maintained 27 groundwater treatment facilities (TFs). The groundwater extraction wells and dual (groundwater and soil vapor) extraction wells produced 961 million L of groundwater and the TFs removed approximately 25 kg of VOCs. Since remediation began in 1989, approximately 27.4 billion L of groundwater have been treated, resulting in removal of more than 1,848 kg of VOCs. Additional information concerning flow and mass removal by TF area is presented in Noyes et al. (2023).

LLNL also operated and/or maintained eight soil vapor treatment facilities (VTFs) in 2022. The soil vapor extraction wells and dual extraction wells produced more than 4.0 million m^3 of soil vapor and the TFs removed approximately 17 kg of VOCs. Since initial operation, nearly 40.5 million m^3 of soil vapor have been extracted and treated, removing more than 1,660 kg of VOCs from the subsurface. Additional information concerning flow and mass removal by TF area is presented in Noyes et al. (2023).

Five TFs remained offline in 2022:

- Vapor Treatment Facility D (VTFD) Helipad
- TF5475-1
- TF5475-3
- VTF5475
- TF518 North

VTFD[1] Helipad remained offline in support of the *in situ* bioremediation Enhanced Source Area Remediation (ESAR) treatability test at the TFD Helipad Source area. The four remaining facilities were discussed in Valett et al. (2009). With the U.S. EPA concurrence, restart of these four facilities has been deferred pending the results of ESAR treatability tests. LLNL continues to monitor groundwater for VOCs and tritium. See Noyes et al. (2023) for more information on the Livermore Site groundwater and soil VTFs.

Restoration activities in 2022 at the Livermore Site continued to be primarily focused on enhancing and optimizing ongoing operations at TFs, while continuing to evaluate technologies that could be used to accelerate cleanup of the Livermore Site source areas and to address the mixed-waste management issue discussed in the *Draft Focused Feasibility Study of Methods to Minimize Mixed Hazardous and Low Level Radioactive Waste from Soil Vapor and Ground Water Treatment Facilities at the Lawrence Livermore National Laboratory Site* (Bourne et al. 2010).

In 2022, the ESAR treatability tests continued at TFD Helipad (*in situ* bioremediation), TFE Eastern Landing Mat (thermally-enhanced remediation), and TFC Hotspot (emplacement of zero valent iron [ZVI] for *in situ* VOC destruction).

Additional Livermore Site environmental restoration activities performed in 2022 included:

- Drilling and installing three new monitoring wells in the TFD area.
- Continued enhancement and optimization of ongoing operations at TFs across the site.
- Continued reevaluation of the inhalation risk for VOCs potentially migrating from the subsurface into indoor ambient air, including sampling of a prioritized list of buildings.

Groundwater concentration and hydraulic data indicate subtle but consistent declines in VOC concentrations and areal extent of the contaminant plumes in 2022. Hydraulic containment along the western and southern boundaries of the site was fully maintained in 2022, and progress was made toward interior plume and source area clean up. See Noyes et al. (2023) for the status of cleanup progress.

7.1.4 Environmental Impacts

LLNL strives to reduce risks arising from chemicals released to the environment, to conduct all restoration activities to protect environmental resources, and to preserve the health and safety of all site workers. LLNL's environmental restoration project is committed to preventing present and future human exposure to contaminated soil, soil vapor, and groundwater, preventing further contaminant migration of concentrations above drinking water standards, reducing concentrations of contaminants in groundwater and soil vapor, and minimizing contaminant migration from the unsaturated zone to the underlying groundwater.

Remedial solutions that have been determined to be most appropriate for individual areas of contamination are implemented. The selected remedial solutions, which include groundwater and soil vapor extraction and treatment, have been agreed upon by the Department of Energy (DOE)

1 VTFD Helipad stands for vapor treatment facility D Helipad, a soil vapor extraction facility. TFD Helipad stands for treatment facility D which is a groundwater treatment facility. They are different and distinct facilities.

and the regulatory agencies with public input. These solutions are designed to reduce risks to human health and the environment, satisfy remediation objectives, and meet regulatory standards for chemicals in water and soil, as well as other state and federal requirements.

7.2 Site 300 Environmental Restoration Project

Several contaminants were released to the environment during past LLNL Site 300 operations including waste fluid disposal to dry wells, surface spills, piping leaks, debris burial in unlined landfills, detonations at firing tables, and discharges of rinse water to unlined lagoons. Environmental investigations at Site 300 began in 1981 and as a result, VOCs, high explosive compounds, tritium, depleted uranium, organosilicate oil, nitrate, perchlorate, polychlorinated biphenyls, dioxins, furans, and metals were identified as contaminants of concern in soil, rock, groundwater, or surface water. This contamination is confined within the site boundaries with the exception of VOCs that are present in off-site monitoring wells near the southern Site 300 boundary. LLNL maintains an extensive network of on-site and off-site wells to monitor this contamination. As stated in the introduction to this chapter, all characterized contaminant release sites that have a CERCLA pathway have been assigned to one of nine OUs based on the nature, extent, and sources of contamination, and topographic and hydrologic considerations. Site 300 was placed on the EPA National Priorities List in 1990. Cleanup activities began at Site 300 in 1982 and are ongoing.

Background information for LLNL environmental characterization and restoration activities at Site 300 can be found in *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300* (Webster-Scholten et al. 1994), *Final Remedial Investigation/Feasibility Study for the Pit 7 Complex at Lawrence Livermore National Laboratory Site 300* (Taffet et al. 2005), and *Final Site-Wide Remediation Evaluation Summary Report for Lawrence Livermore National Laboratory Site 300* (Ferry et al. 2006).

7.2.1 Physiographic Setting and Geology of Site 300

Site 300 is located in the southeastern Altamont Hills of the Diablo Range. The topography of Site 300 consists of a series of steep hills and canyons generally oriented northwest to southeast. The site is underlain by gently dipping sedimentary bedrock dissected by steep ravines. The near-surface bedrock consists primarily of interbedded conglomerates, sandstones, siltstones, and claystones of the late Miocene Neroly Formation (Tn), and a Pliocene nonmarine unit (Tps). Late Miocene sandstone-dominated strata of the Cierbo Formation (Tmss) exist locally in the shallow subsurface. The bedrock units are locally overlain by mid- to late-Pleistocene terrace deposits and late-Pleistocene to Holocene floodplain, ravine fill, landslide, and colluvial deposits.

The bedrock within Site 300 has been slightly deformed into several gentle, low-amplitude folds. The locations and characteristics of these folds, in combination with the regional fault and fracture patterns, locally influence groundwater flow within the site.

7.2.2 Contaminant Hydrogeology of Site 300

Site 300 is a large and hydrogeologically diverse site. Due to the steep topography and structural complexity, stratigraphic units and groundwater contained within many of these units are discontinuous across the site. Consequently, site-specific hydrogeologic conditions govern the occurrence and flow of groundwater and the fate and transport of contaminants beneath each OU.

An HSU is a laterally extensive water-bearing zone that occurs in one or more discrete stratigraphic units that are hydraulically connected and exhibit similar aqueous geochemistry. At Site 300, the defined HSUs consist of one or more stratigraphic units that compose a single hydraulic system within one or more OUs. At Site 300, groundwater movement and contaminant migration in groundwater are discussed in the context of HSUs.

Groundwater contamination at Site 300 occurs primarily in three types of HSUs:

1. Mixed Quaternary alluvium, terrace deposits, and landslide deposits and underlying coherent and weathered bedrock HSUs including alluvium and weathered bedrock (Qal/WBR HSU), alluvium and sandstone (Qal-$Tnbs_1$ HSU), terrace deposits and sandstone (Qt-$Tnbs_1$ HSUs), terrace deposits and claystone (Qt-$Tnsc_1$ HSU), and landslide deposits and sandstone (Qls/$Tnbs_1$ HSU). [Note: Tn refers to Tertiary Neroly Formation bedrock].
2. Perched groundwater in fluvial sands and gravels (Tpsg HSU), semi-lithified silts and clay of the Tpsg-Tps HSU, and silts and clay and underlying silty claystone (Tps-$Tnsc_2$ HSU). [Note: Tp refers to Tertiary Pliocene sediments].
3. Bedrock including the $Tnbs_2$, $Tnsc_{1ab}$, $Tnsc_{1b}$, $Tnbs_1$, $Tnbs_1$/$Tnbs_0$, and $Tnbs_1$/$Tnsc_0$ HSUs.

Groundwater in bedrock is typically present under confined conditions in the southern part of the site but is often unconfined elsewhere. Recharge occurs where saturated alluvial valley fill is in contact with underlying permeable bedrock, and where bedrock strata crop out. Water levels within Site 300 shallow water-bearing zones have generally been declining due to groundwater pumping and limited recharge owing to the recent California drought. During 2022, in response to the near-average October 1, 2021 – September 30, 2022 (2022 water year) rainfall totals, water levels in shallow water-bearing zones throughout Site 300 remained fairly constant.

7.2.3 Remediation Activities and Monitoring Results

Cleanup activities were initiated at Site 300 in 1982 and are underway, have been completed, or are in the process of being implemented at the nine OUs. These activities include:

- Operating 21 groundwater and soil vapor extraction and TFs.
- Capping and closing four landfills, six high explosives rinse water lagoons, and one high explosives burn pit.
- Removal and/or closure of numerous dry wells throughout the site.
- Removal of contaminated soil from source areas throughout the site.

- Installation of a drainage diversion system at the Pit 7 Complex to prevent groundwater from rising into the landfills and releasing contaminants in the waste.
- Remediation (consolidation and solidification) of 29,000 cubic yards of polychlorinated biphenyl (PCB)-, dioxin-, and furan-contaminated soil in a Corrective Action Management Unit (CAMU) at Building 850.
- Treatability studies for the *in situ* bioremediation of VOCs and perchlorate in groundwater.
- Installation and sampling of over 700 groundwater monitoring wells to track plume migration and remediation progress.

These remediation efforts have resulted in (1) the elimination of risk to on-site workers from contaminant exposure at multiple locations throughout Site 300, (2) a reduction in maximum concentrations of the primary contaminant (VOCs) in Site 300 groundwater by 50% to 99%, (3) the remediation of VOCs in groundwater in the Eastern General Services Area to meet cleanup standards, and (4) a reduction of maximum tritium activity concentrations in groundwater emanating from the Building 850 area to below cleanup standards.

In 2022, the Site 300 Environmental Restoration Project operated 12 groundwater facilities, four groundwater collection systems, and five soil vapor treatment or extraction-only facilities extracting and treating approximately 26.9 million L of groundwater and 2.0 million m^3 of contaminated soil vapor. The Site 300 TFs removed approximately 5.2 kg of VOCs, 0.075 kg of perchlorate, 1,091 kg of nitrate, 0.086 kg of the high explosive compound RDX, and 0.003 kg of uranium in 2022. Since groundwater remediation began in 1990, approximately 1,839 million L of groundwater and 42 million m^3 soil vapor have been treated, resulting in removal of approximately 648 kg of VOCs, 2.0 kg of perchlorate, 24,500 kg of nitrate, 3.1 kg of RDX, 9.5 kg of silicone oils, and 0.1 kg of uranium. Tritium in groundwater continues to decay on-site, reducing tritium activity concentrations in Site 300 groundwater. Detailed groundwater volume and contaminant mass removal totals, by OU, are presented in Buscheck et al. (2023).

To date, cleanup remedies have been fully implemented and are operational in eight of the nine OUs at Site 300 (the General Services Area, Building 834, Pit 6 Landfill, High Explosives Process Area, Building 850/Pit 7 Complex, Building 854, Building 832 Canyon OUs, and Site-Wide OU 8, which is comprised of four site-wide subareas). The CERCLA pathway for the Building 812 OU (OU 9), was negotiated with the regulatory agencies in 2011. At Building 812, characterization activities were initiated in 2011 and have continued in subsequent years. These activities include:

- Sampling surface soil, groundwater, and surface water for chemical and radiological analyses.
- Sampling plants and invertebrates for uranium analysis.
- Drilling and hand augering additional boreholes, collecting samples for chemical and radiological analysis, and conducting High Purity Germanium (HPGe) detector gamma radiation surveying for uranium-238 in subsurface soil to better determine its vertical extent.

- Gamma radiation surveying with a sodium iodide (NaI) detector to better define the extent of uranium-238 in Building 812 surface soil.
- Surface water discharge and velocity monitoring.
- Analyzing the chemical and radiological data collected to determine the nature and extent of contamination.

The results of characterization activities in the Building 812 OU are being analyzed and will be presented in a Remedial Investigation/Feasibility Study (RI/FS) report once updated background concentration and activity ranges for metals and radionuclides in Site 300 soil are determined and documented in a final report. Sampling and analysis of soil from nearby Mount (Mt.) Diablo State Park was completed in 2021 to provide additional analytical data for calculating updated background concentrations and activities of metals and radionuclides. Mt. Diablo State Park was selected for the soil sampling because it has similar geology, soil types, and ecology to Site 300.

Additional Site 300 Environmental Restoration Project activities performed in 2022 included:

- Installing one new groundwater monitoring well in the Building 850 area.
- Installing one new groundwater monitoring well in the Building 854 area.
- Installing two new groundwater monitoring wells in the Building 815 area.
- Installing one new groundwater monitoring well in the Building 812 area.
- Properly abandoning one former groundwater monitoring well in the Building 812 area.
- Inspecting and maintaining the Pit 7 Drainage Diversion System and Building 850 CAMU.
- Continuing the Building 850 *In Situ* Perchlorate Bioremediation Treatability Test.
- Continuing evaluation of subsurface VOC and hydrologic data to determine the next phase of treatment in the T2 area of Building 834.
- Completed upgrades to the Building 832 source area groundwater and soil VTFs.
- Continued reevaluation of the inhalation risk to workers from VOCs potentially migrating from the subsurface into indoor ambient air. In 2022, the EPA determined that the current remedies for areas with potential VOC indoor air inhalation risk continue to be protective in the short-term.

All calendar year 2022 Site 300 milestones were met or renegotiated with the regulatory agencies (see **Chapter 2**).

Groundwater concentration, activity concentration, and hydraulic data collected from Site 300 and analyzed during 2022 provided evidence of continued progress in reducing contaminant concentrations in Site 300 groundwater and soil vapor, controlling, and cleaning up contaminant sources, and mitigating risk to on-site workers. A more detailed description of remediation progress at the Site 300 OUs in 2022 is available in the *Annual 2022 Compliance Monitoring Report for LLNL Site 300* (Buscheck et al. 2023).

7.2.4 Environmental Impacts

LLNL strives to reduce elevated risks arising from chemicals released to the environment at Site 300, to conduct its activities to protect ecological resources, and to protect the health and safety of site workers. LLNL's cleanup remedies at Site 300 are designed and implemented to reduce risks to human health and the environment, satisfy remediation action objectives, meet cleanup standards for chemicals and radionuclides in water and soil, and prevent contaminant migration in groundwater to the extent technically and economically feasible.

These actions include:

- Groundwater and soil vapor extraction and treatment.
- Source control through the capping of lagoons and landfills, removal and remediation of contaminated soil, and hydraulic drainage diversion.
- Monitoring natural attenuation.
- Monitoring and institutional controls.

These remedies are selected by DOE and the regulatory agencies with public input.

8. Quality Assurance

Bart Draper • Tyler Jackson

Quality assurance (QA) is a system of activities and processes that ensure products or services meet or exceed customer specifications. Quality control (QC) consists of activities that verify deliverables are of acceptable quality and meet criteria established in the quality planning process. This chapter describes the QA program used when collecting and analyzing data in this report, lists the environmental analytical laboratories and waste management facilities Lawrence Livermore National Laboratory (LLNL) used in 2022, and describes how the data tables in **Appendix A** were developed.

8.1 Quality Assurance Program Description

The LLNL Institutional QA section of the Mission Assurance department is responsible for developing, implementing, and assessing the institutional aspects of the quality management system. The LLNL Environmental Functional Area (EFA) is responsible for developing, implementing, and assessing the institutional Environmental Management System (EMS). Within the EFA, the Water Resources and Environmental Planning (WREP) group is responsible for developing the Environmental Monitoring Plan (EMP, Brunckhorst 2019) and this report. The Technical Services Department (TSD) implements the EMP.

The key documents of the EFA quality management system are illustrated by the diagram in **Figure 8.1** and highlighted in bold blue font. The primary interaction between the EFA QA Project Plan (QAPP) and the institutional EMS relates to the EMP and this report. The EMS credits the EMP with implementing the monitoring, measurement, analysis, and evaluation requirements of International Organization for Standardization (ISO) 14001. The EMS also credits this report with implementing the external communication requirements of ISO 14001.

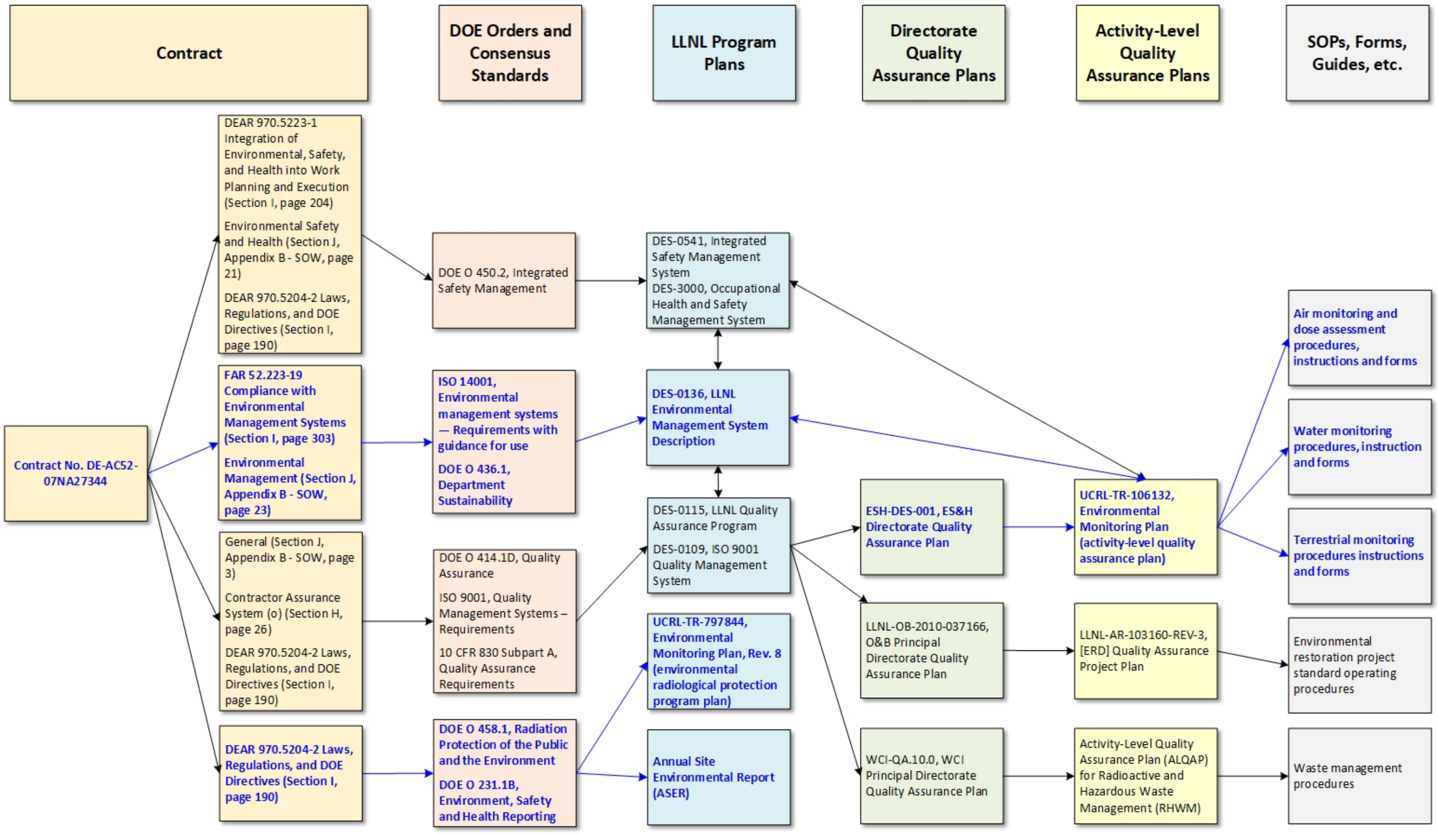

Figure 8.1. Quality Assurance Documents for ASER Work Processes

The QAPP is designed around the Plan – Do – Check – Act model (**Figure 8.2**) consistent with the United States Environmental Protection Agency (EPA) *Environmental Information Quality Policy* (CIO 2105.3) and its implementing procedure (CIO 2105-P-01.3), and with both ISO 14001 and ISO 9001 international standards for environmental and quality management systems.

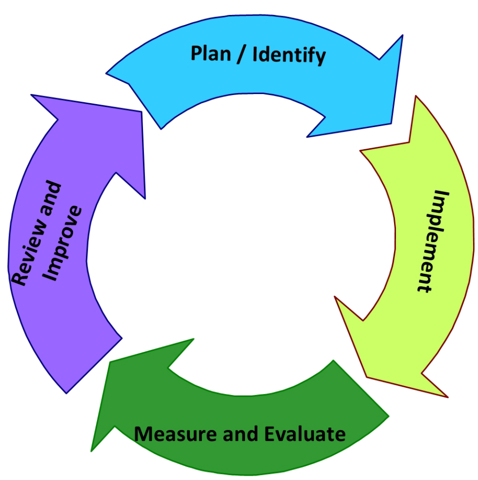

Figure 8.2. Plan – Do – Check – Act Model

This cycle can be described as follows:

- Plan and Identify
  - Establish the objectives of EFA compliance and monitoring systems.
  - Assure the required resources are available to deliver results in accordance with LLNL policies and Department of Energy (DOE) and stakeholder requirements.
  - Identify and address risks and opportunities.
- Implement
  - Implement what was planned in accordance with established work control documents.
- Measure and Evaluate
  - Monitor and compare the resulting work products and services against policies, objectives, requirements, and planned activities.
  - Report the results (e.g., management assessments, external assessments, or inspections.)
- Review and Improve
  - As needed, take actions to improve performance (e.g., revise and update plans and work control documents based on lessons learned.)

Nonconformance reporting and tracking is a formal process used to ensure that problems are identified, resolved, and prevented from recurring. The LLNL EFA tracks problems using the LLNL DevonWay Issues Tracking System (ITS). ITS items are initiated when potential compliance issues are identified.

Nonconformances identified by EFA are captured and used to provide trending information for environmental compliance evaluations. Many minor sampling or data problems are resolved without generating an ITS item. The LLNL QA requirements stipulate that laboratories generating data must have a formal nonconformance program to track and document issues in their analyses. Such programs are separate from the LLNL ITS.

LLNL avoids sampling problems by requiring formal and informal training on sampling procedures. Errors that occur during sampling generally do not result in lost samples. However, this may require extra work for laboratory, sampling, and data management personnel to correct sampling errors.

The LLNL environmental data QA program is generally consistent with the *Uniform Federal Policy (UFP) for Implementing Environmental Quality Systems* (2005) and is designed to ensure that:

- Environmental data are of known and documented quality and suitable for their intended uses.
- Environmental data collection and technology programs meet stated requirements.

Most of the monitoring networks described in this report were planned and developed prior to issuance of EPA QA/G-4, *Guidance on Systematic Planning Using the Data Quality Objectives Process* (2006). The data quality objectives process and the Visual

Sample Plan (VSP) software tools are used to develop new sampling plans, especially those related to site infrastructure improvements.

8.2 Analytical Laboratories

LLNL addresses commercial analytical laboratory problems as they arise. Many of the problems concern minor documentation errors and are corrected once they are identified. Other problems, such as missed holding times, late analytical results, incorrect analysis, and typographical errors on data reports, account for the remaining issues and are not tracked as nonconformances. These problems are corrected by the commercial laboratory reissuing reports or correcting paperwork and do not impact sample results.

In 2022, LLNL had Blanket Service Agreements (BSAs) with seven commercial analytical laboratories; five of these laboratories were utilized in 2022. Additionally, LLNL secured commercial analytical laboratory services via purchase order and worked with three in-house LLNL laboratory organizations in 2022. **Table 8-1** identifies the scope of services provided by both commercial and in-house laboratories in 2022.

Table 8-1. Commercial and On-Site Laboratories Utilized in 2022

Contract No.	Laboratory	Scope of Services
H100596	Pace Bakersfield Laboratory[1] Bakersfield, CA 93308	Analysis of non-radiologically contaminated environmental samples
H100621	Eurofins TestAmerica Arvada, CO 80002	Analysis of non-radiologically contaminated environmental samples
H100719	Alpha Analytical Laboratories Livermore, CA 94551	Analysis of non-radiologically contaminated environmental samples
H100570	GEL Laboratories, LLC Charleston, SC 29407	Analysis of potentially radiologically contaminated environmental samples and radiological analysis of environmental samples
H100571	ALS Environmental[2] Fort Collins, CO 80524	Analysis of potentially radiologically contaminated environmental samples and radiological analysis of environmental samples
In-house LLNL Organization	Analytical Laboratory (ALAB) Livermore, CA 94550	Analysis of non-radiologically contaminated environmental samples
In-house LLNL Organization	Environmental Monitoring Radiological Laboratory (EMRL) Livermore, CA 94550	Radiological analysis of environmental samples
In-house LLNL Organization	Radiological Measurements Laboratory (RML) Livermore, CA 94550	Radiological analysis of environmental samples

[1] BC Laboratories was acquired by Pace in 2022.

[2] ALS Environmental in Fort Collins, CO discontinued operations in 2022.

8.2.1 Analytical Laboratory Accreditations and Proficiency Demonstrations

All commercial analytical laboratory services used by LLNL are provided by facilities certified by the State of California. LLNL works closely with these analytical laboratories to minimize problems and ensure that QA/QC objectives are maintained. **Table 8-2** provides the certifications and accreditations held by laboratories used by LLNL in 2022.

Table 8-2. Laboratory Certifications and Accreditations in 2022

Laboratory	Certifications/Accreditations
Pace Analytical Services, LLC	Certificate of Environmental Accreditation, California State Environmental Laboratory Accreditation Program (ELAP) Certified to meet the requirements of Nevada Administrative Code, NAC 445A, by the State of Nevada Department of Conservation and Natural Resources Division of Environmental Protection Perry Johnson Laboratory Accreditation, Inc., accredited for meeting the requirements of ISO/International Electrotechnical Commission (IEC) 17025:2017 "General Requirements for the competence of Testing and Calibration Laboratories" and the DOE Quality Systems Manual (QSM) for Environmental Laboratories Version 5.4, October 2021
Eurofins TestAmerica - Denver	American Association for Laboratory Accreditation (A2LA) accredited for compliance with ISO/IEC 17025:2017, The NELAC Institute (TNI) 2009 and 2016 Environmental Testing Laboratory Standard, the requirements of the Department of Defense (DoD ELAP), and the requirements of the Department of Energy Consolidated Audit Program (DOECAP) as detailed in Version 5.4 of the DoD/DOE QSM for Environmental Laboratories Certificate of Environmental Accreditation, California ELAP Certified to meet the requirements of Nevada Administrative Code, NAC 445A, by the State of Nevada Department of Conservation and Natural Resources Division of Environmental Protection
Alpha Analytical Laboratories	Certificate of Environmental Accreditation, California ELAP
GEL Laboratories, LLC	Certificate of Environmental Accreditation, California ELAP A2LA accredited for compliance with ISO/IEC 17025:2017, the 2009 and 2016 TNI Environmental Testing Laboratory Standard, the requirements of the DoD ELAP, and the requirements of the DOECAP as detailed in Version 5.3 of the DoD/DOE QSM Certified to meet the requirements of Nevada Administrative Code, NAC 445A by the State of Nevada Department of Conservation and Natural Resources Division of Environmental Protection South Carolina Department of Health and Environmental Control Radioactive Material License
ALAB	Certificate of Environmental Accreditation, California ELAP
EMRL	Certificate of Environmental Accreditation, California ELAP

Table 8-2. (cont.) Laboratory Certifications and Accreditations in 2022

Laboratory	Certifications/Accreditations
RML	Not currently accredited. Accreditation is not required as data is used only for informational screening of weekly sewer samples not for compliance reporting. Monthly compliance samples are analyzed by EMRL.

LLNL uses the results of nationally recognized inter-laboratory comparison programs to identify and monitor trends in laboratory performance and to highlight any performance deficiencies. If a laboratory performs unacceptably for a particular test in two consecutive performance evaluation studies, LLNL may stop work and select another laboratory to perform the affected analyses until the original laboratory has demonstrated that the problem has been corrected. If a commercial laboratory continues to perform unacceptably or fails to prepare and implement acceptable corrective action responses, the LLNL Supply Chain Management Department formally notifies the laboratory of its unsatisfactory performance. If the problem persists, the commercial laboratory's BSA could be terminated for that test. If an in-house LLNL laboratory continues to perform unacceptably, use of that laboratory could be suspended until the problem is corrected.

Laboratories are required to participate in inter-laboratory comparison programs. DOE Mixed Analyte Performance Evaluation Program (MAPEP) reports that include the results from all participating laboratories can be found here: https://www.id.energy.gov/resl/mapep/mapepreports.html. MAPEP is a DOE program, and the results are publicly available from laboratories that choose to participate. **Table 8-3** provides an overview of the MAPEP results for the two commercial laboratories that provide radiochemical analytical services to LLNL and for one in-house LLNL laboratory. LLNL considers MAPEP results unacceptable when two or more analytes in a field of testing do not meet MAPEP acceptance criteria. Unacceptable results are investigated by LLNL.

Table 8-3. Laboratory Participation in the Mixed Analyte Performance Evaluation Program

Mixed Analyte Performance Evaluation Program	Eurofins TestAmerica – Denver	GEL Laboratories, LLC	EMRL
March 2022			
22-MaS46 – Mixed Analyte Soil Standard	No report	Inorganics acceptable except Sb and Se, radiological acceptable except ^{99}Tc and ^{55}Fe	Radiological acceptable except ^{238}Pu

Table 8-3. (cont.) Laboratory Participation in the Mixed Analyte Performance Evaluation Program

Mixed Analyte Performance Evaluation Program	Eurofins TestAmerica – Denver	GEL Laboratories, LLC	EMRL
22-MaW46 – Mixed Analyte Water Standard		Inorganics and radiological acceptable	Radiological acceptable except ^{3}H, ^{238}Pu, and $^{239/240}Pu$
22-GrW46 – Gross Alpha/Beta Water Standard	No report	Radiological acceptable	Radiological acceptable
22-RdF46 – Radiological Air Filter Standard	No report	Radiological acceptable	Radiological acceptable except ^{57}Co
22-GrF46 – Gross Alpha/Beta Air Filter	No report	Radiological acceptable	No report
22-RdV46 – Radiological Vegetation Standard	No report	Radiological acceptable except ^{90}Sr	No report
22-MaSU46 – Mixed Analyte Synthetic Urine Standard	No report	Radiological acceptable	No report
August 2022			
22-MaS47 – Mixed Analyte Soil Standard	No report	Inorganics acceptable except Sb; radiological acceptable except ^{234}U, ^{235}U, and ^{238}U	Radiological acceptable except ^{134}Cs, ^{57}Co, ^{54}Mn, ^{40}K, and ^{65}Zn
22-MaW47 – Mixed Analyte Water Standard	No report	Inorganics acceptable and radiological acceptable	Radiological acceptable except ^{65}Zn
22-GrW47 – Gross Alpha/Beta Water Standard	No report	Radiological acceptable	Radiological acceptable
22-RdF47 – Radiological Air Filter Standard	No report	Inorganics and radiological acceptable	Radiological acceptable
22-GrF47 – Gross Alpha/Beta Air Filter	No report	Radiological acceptable	No report
22-RdV47 – Radiological Vegetation Standard	No report	Radiological acceptable	No report
22-MaSF47 – Mixed Analyte Synthetic Fecal Standard	No report	Radiological (^{237}Np) unacceptable	No report

8.2.2 Analytical Laboratory Observations, Assessments, and/or Audits

LLNL monitors the DOECAP. All commercial laboratories used by LLNL are qualified vendors and are either certified by the National Environmental Laboratory Accreditation Program (NELAP) or accredited by the California Department of Health Services Environmental Laboratory. Audit reports, checklists, and Corrective Action Plans are maintained under the DOECAP program for commercial labs.

An external analytical laboratory provides the following services:

- QA management systems and general laboratory practices
- Organic analyses
- Inorganic and wet chemistry analyses
- Radiochemical analyses
- Laboratory information management systems and electronic deliverables
- Hazardous and radioactive materials management

Table 8-4 summarizes the results of assessment conducted in 2022.

Analytical laboratories routinely perform QC tests to document and assess the quality and validity of their sample results. Before the results can be authenticated and accepted into the monitoring database, each data set received from the analytical laboratory is systematically evaluated and compared to establish measurement quality objectives, such as accuracy, precision, and comparability. When possible, quantitative criteria are used to define and assess data quality.

Table 8-4. Laboratory Observations, Assessments and/or Audits in 2022

Laboratory	Accrediting Body	Assessment Type	Results
BC Laboratories	Perry Johnson Laboratory Accreditation, Inc.	Surveillance assessment	0 Major finding 10 Minor findings 1 Observation
Eurofins TestAmerica – Denver	American Association for Laboratory Accreditation	Scope expansion	0 Major findings 7 Minor findings 0 Observations
Alpha Analytical Laboratories – Ukiah	International Accreditation Services	CA ELAP renewal and amendment application	10 Corrective action requests
Alpha Analytical Laboratories – Livermore	International Accreditation Services	ELAP assessment	5 Corrective action requests
GEL Laboratories, LLC	American Association for Laboratory Accreditation	Interim	0 Major findings 1 Minor finding 0 Observations
ALAB	Not third party assessed in 2022	Not applicable	Not applicable
EMRL	International Accreditation Service	External on-site	3 Corrective actions
RML	Not third party assessed in 2022	Not applicable	Not applicable

LLNL reviews deficiencies and non-conformances and investigates corrective actions when they occur in testing utilized by LLNL.

8.2.3 LLNL Environmental and Waste Characterization Program Performance

LLNL monitors the relative percent difference between the results of duplicate sample pairs and the number of completed sample analyses as a percentage of planned analyses. These measures of precision and completeness are described below.

8.2.3.1 Duplicates

Duplicate (collocated) samples are distinct samples of the same matrix collected as closely as possible to the same point in space and time. Collocated samples that are processed and analyzed by the same laboratory provide information about the precision of the entire measurement system, including sampling, matrix homogeneity, handling, shipping, storage, preparation, and analysis (U.S. EPA 1987). Collocated samples may also identify inconsistencies such as mislabeled samples or data entry errors. **Appendix E** presents summary statistics for collocated sample pairs from the Livermore Site, Livermore Valley, and Site 300, grouped by sample matrix and analyte. **Appendix E** is based on data pairs where both values are considered "detections." Pairs where relative percent difference (RPD) is calculated are determined by the following criteria:

- Sampled at the same location.
- Sampled at the same time.
- Analyzed for the same method.
- Both routine and duplicate sample values are detected above the reporting limit.
- There are no data flags.

LLNL uses a 30 percent RPD control limit as an indicator of an out-of-control duplicate pair. Therefore, RPD values above 30 percent indicate that there may be some degree of uncertainty regarding the analytical results.

RPD values can represent real differences. For example, a collocated sample had a high concentration in one container (this should be limited through standard sampling procedures) or there was error associated with the analytical method.

RPD values can also represent differences caused by error. For example, error was introduced during field sampling or analysis in the analytical laboratory. An RPD of zero is expected for collocated sampling in a perfect environment with uniform media.

LLNL calculates RPD:

$$RPD = \frac{|R - D|}{\left[\frac{(R + D)}{2}\right]} x\ 100$$

R is the routine sample result and D is the duplicate collocated sample result.

Appendix E summarizes the total percentage of in-control pairs for programs, media, and analytes.

8.2.3.2 Completeness

Completeness is a measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under normal conditions. **Appendix F** summarizes the percent completeness for many of the data sets described in this report and presented in **Appendix A**. Lower percent completeness values are expected for non-routine monitoring because sampling and analysis for infrastructure projects may be planned but delayed or canceled. For example, event-based stormwater sampling may be planned, but a qualifying storm may not occur.

8.3 Waste Management Facilities

Table 8-5. Waste Management Facilities Utilized by LLNL in 2022

Clean Harbors Aragonite, LLC 11600 North Aptus Road Aragonite, UT 84029	**Clean Harbors Wilmington, LLC** 1737 E. Denni Street Wilmington, CA 90744
Energy Solutions, LLC-UT Clive Disposal Facility 423 West 300 South, Suite 200 Salt Lake City, UT 84116	**Clean Harbors Grassy Mountain, LLC** Interstate 80, Exit 41 3mi. East, 7mi. North of Knolls Grassy Mountain, UT 84029
Perma-Fix Northwest, Inc. 2025 Battelle Blvd. Richland, WA 99354	**Evoqua Water Technologies, LLC** 2430 Rose Place Roseville, MN 55113
Clean Harbors Colfax, LLC 3763 Highway 471 Colfax, LA 71417	**US Ecology Nevada, Inc.** Highway 95, 11 Mi. South of Beatty Beatty, NV 89003
Kinsbursky Brothers, Inc. 1314 N. Lemon St. Anaheim, CA 92801	**Safety-Kleen of California, Inc.** 6880 Smith Ave Newark, CA 94560
Clean Harbors La Porte, L.P. 500 Independence Parkway South La Porte, TX 77581	**Clean Harbors Buttonwillow, LLC** 2500 West Lokern Road Buttonwillow, CA 93206
Clean Harbors, El Dorado LLC 309 American Circle El Dorado, AR 71730	**NNSS for U.S. DOE Waste Management** Nevada Test Site Zone 2 Mercury, NV 89023
Clean Harbors of San Jose, LLC 1021 Berryessa Road San Jose, CA 95133	**Nuclear Waste Partnership, LLC., on behalf of U.S. DOE** 30 Miles East of Carlsbad on Jal Highway Eddy County, NM 88221
Clean Harbors, Lone Mountain, LLC 40355 S. County Rd 236 Waynoka, OK 73860	

Four of the waste management facilities utilized by LLNL were assessed by the DOECAP in 2022. **Table 8-6** provides a summary of the types of assessments conducted and the results. Priority I findings are factual statements from the audit documenting a deficiency from a requirement that represents a substantial risk and liability to DOE. Priority II findings are factual statements that document a deviation from a requirement that could lead to a Priority I finding if not addressed and corrected. Observations document deviations from best management practices or opportunities for improvement. There were no Priority I findings for waste management facilities utilized by LLNL in 2022.

Table 8-6. Waste Management Facility Observations, Assessments, and/or Audits in 2022

Waste Management Facility	Accrediting Body	Assessment Type	Results
Energy Solutions, LLC-UT	DOECAP	• Quality Assurance Management Systems • Sampling and Analytical Data Quality • Waste Operations • Environmental Compliance and Permitting • Radiological Control • Industrial and Chemical Safety • Transportation Management	0 Priority I Findings 2 Priority II Findings 4 Observations
Perma-Fix Northwest, Inc.	DOECAP	• Quality Assurance Management Systems • Sampling and Analytical Data Quality • Waste Operations • Environmental Compliance and Permitting • Radiological Control • Industrial and Chemical Safety • Transportation Management	0 Priority I Findings 4 Priority II Findings 5 Observations
Clean Harbors Colfax, LLC	DOECAP	• Quality Assurance Management Systems • Sampling and Analytical Data Quality • Waste Operations • Environmental Compliance and Permitting • Industrial and Chemical Safety	0 Priority I Findings 0 Priority II Findings 5 Observations
Clean Harbors La Porte, LLC	DOECAP	• Quality Assurance Management Systems • Sampling and Analytical Data Quality • Waste Operations • Environmental Compliance and Permitting • Industrial and Chemical Safety	0 Priority I Findings 2 Priority II Findings 4 Observations

8.4 Data Presentation

The data tables in **Appendix A** were created using computer scripts that retrieve data from a database, convert the data into Système International (SI) units when necessary, calculate summary statistics, format the data, and organize it into rows and columns. The tables are then reviewed by the responsible analyst before inclusion in **Appendix A**. Analytical laboratory data and values calculated from the data are normally displayed with two, or at most three, significant digits. Significant trailing zeros may be omitted.

8.4.1 Radiological Data

Most of the data tables in **Appendix A** that have radiological data display the result plus or minus (±) an associated 2σ (two sigma) uncertainty. The uncertainty value represents intrinsic variation in the measurement process, most of which is due to the random nature of radioactive decay (see **Section 8.6**). The uncertainty value is not used in summary statistic calculations.

Some radiological results are derived from the number of sample counts minus the number of background counts inside the measurement apparatus. In such cases, samples with a concentration at or near background sometimes have more background counts than sample counts, resulting in a negative value. Such results are reported in the data tables and used in the calculation of summary statistics.

8.4.2 Non-radiological Data

Non-radiological data reported by the analytical laboratory as being below the analytical reporting limit is displayed in tables with a less-than symbol (<) and referred to as a "non-detection." Reporting limit values are used in the calculation of summary statistics, as explained below.

8.5 Statistical Comparisons and Summary Statistics

Standard statistical comparison techniques such as regression analysis, *t*-tests, and analysis of variance are used where appropriate to determine the statistical significance of trends or differences between means. When a statistical comparison is made, the results are described as either "statistically significant" or "not statistically significant." Other uses of the word "significant" in this report do not imply that statistical tests have been performed but relate to the concept of practical significance and are based on professional judgment.

Summary statistics are calculated according to (Brunckhorst 2019). The usual summary statistics are the median, which is a measure of central tendency, and interquartile range (IQR), which is a measure of dispersion (variability). However, data tables may present other measures at the discretion of the analyst. In this report, at least four values are required to calculate the median and at least six values are required to calculate the IQR.

The median indicates the middle of the data set (i.e., half of the measured results are above the median and half are below). The IQR is the range that encompasses the middle 50 percent of the data set. The IQR is calculated by subtracting the 25th percentile of the data set from the 75th percentile of the data set. When necessary, the percentiles are interpolated from the data. Different software vendors may use slightly different formulas for calculating percentiles. Radiological data sets that include values less than zero may have an IQR greater than the median.

Summary statistics are calculated from values that, if necessary, have already been rounded, such as when units have been converted from picocuries (pCi) to Becquerels (Bq) and are then rounded to an appropriate number of significant digits. Non-detections may impact the calculation of summary statistics.

Adjustments to the calculation of the median and IQR for data sets that include nondetections are described below:

- Data sets can fall into three categories: sets containing only detected values, sets where there is a mix of detections above the reporting limit and non-detections below the reporting limit, and sets containing only non-detections.
- For data sets where all values are known, calculations of summary statistics follow standard calculation methods for the median and IQR.
- For data sets where there is a mix of non-detections and detections, the reporting limit is substituted for non-detect data points in summary statistic calculations. The median is then calculated following the standard method with the distinction that if the result is a substituted reporting limit, the median will be reported with a less than (<) sign to indicate the median represents an upper bound. The IQR is only calculated when greater than 25 percent of the data set contains detections.
- For data sets that contain only non-detections, the calculation of the median and IQR is not appropriate.
- If the number of values is odd, the middle value (when sorted from smallest to largest) is the median. If the middle value and all larger values are detections, the middle value is reported as the median. Otherwise, the median is assigned a less-than (<) sign.
- If the number of values is even, the median is halfway between the middle two values when the values are sorted from smallest to largest. If both the middle two values and all larger values are detections, the median is reported. Otherwise, the median is assigned a less-than (<) sign.
- If any value used to calculate the 25th percentile is a non-detection or any value larger than the 25th percentile is a non-detection, the IQR cannot be calculated and is not reported.

8.6 Reporting Uncertainty in Data Tables

Measurement uncertainties associated with analytical laboratory results are represented in two ways. The first way is significant digits, which are derived from the resolution of the measuring device. For example, if an ordinary household ruler with a metric scale is used to measure the length of an object in centimeters and the ruler has tick marks every one-tenth of a centimeter, then the length can reliably and consistently be measured to the nearest tenth of a centimeter (i.e., to the nearest tick mark). An attempt to be more precise is not likely to yield reliable or reproducible results because it would require a visual estimate of a distance between tick marks. The appropriate way to report a measurement using this ruler would be 2.1 cm, which would indicate that the "true" length of the object is closer to 2.1 cm than to 2.0 cm or 2.2 cm (i.e., between 2.05 and 2.15 cm). A measurement of 2.1 cm has two significant digits and the implied uncertainty is ± 0.05 cm. A more precise measuring device may be able to measure an object to the nearest one-hundredth of a centimeter. In that case, a measurement of 2.12 cm would be reported. This value would have three significant digits and the implied uncertainty is ± 0.005 cm. A result reported as 3.0 cm has two significant digits. The trailing zero is significant and implies that the true length is closer to 3.0 than to 2.9 or 3.1 cm (i.e., between 2.95 and 3.05 cm.)

When performing calculations with measured values that have significant digits, all digits are used. The number of significant digits in the calculated result is the same as that of the measured value with the fewest number of significant digits.

Most unit conversion factors do not have significant digits. For example, the conversion from milligrams to micrograms requires multiplying by the fixed (constant) value of 1,000. The value 1,000 is exact; it has no uncertainty and therefore the concept of significant digits does not apply.

The second method of representing uncertainty is based on random variation. For radiological measurements, there is variation due to the random nature of radioactive decay. As a sample is measured, the number of radioactive decay events is counted and the reported result is calculated from the number of decay events that were observed. If the sample is recounted, the number of decay events will almost always be different because radioactive decay events occur randomly. Uncertainties of this type are reported as 2σ (two sigma) uncertainties. A ± 2σ uncertainty represents the range of results expected to occur approximately 95 percent of the time if a sample were to be recounted repeatedly. For example, a radiological result of 2.6 ± 1.2 Bq/g would indicate with approximately 95 percent confidence that the true value ranges from 1.4 to 3.8 Bq/g (i.e., 2.6 – 1.2 = 1.4 and 2.6 + 1.2 = 3.8).

When necessary, radiological results are converted from pCi to Bq by multiplying by 0.037. This introduces additional digits that are not significant and should not be shown in data tables. For example, 5.3 pCi/g x 0.037 Bq/pCi = 0.1961 Bq/g. The initial value, 5.3, has two significant digits so the value 0.1961 would be rounded to two significant digits, that is, 0.20. However, the rounding rule changes when there is a radiological uncertainty associated with a radiological result. In this case, data are presented according to the method recommended in Multi-Agency Radiological Laboratory Analytical Protocols (MARLAP) Section 19.3.7 (U.S. NRC/U.S. EPA 2004). The uncertainty is first rounded to the appropriate number of significant digits and then the result is rounded to the same number of decimal places. For example, after unit conversion the result is 0.1961 ± 0.05436 and the appropriate number of significant digits is two. First, 0.05436 is rounded to 0.054 (two significant digits). Since 0.054 has three decimal places, 0.1961 is then rounded to three decimal places (0.196). The data table would present the result as 0.196 ± 0.054.

When rounding a value with a final digit of 5, the software used to prepare the data tables implements the ISO/IEC/IEEE 60559:2011 rule – round to the even digit. For example, 2.45 would be rounded down to 2.4 and 2.55 would be rounded up to 2.6.

Sampling measurements are often compared when analyzing environmental monitoring data. Uncertainty must be considered in these comparisons. The uncertainty interval provides an estimate with a degree of confidence that the true concentration is within the interval. When comparing sampling measurements with different reported measurements and the uncertainty intervals overlap, it cannot be concluded that these measurements are different.

8.7 Quality Assurance Process for the Environmental Report

This section describes the actions that are taken to ensure the accuracy of this data-rich environmental report.

Analytical laboratories send reports electronically, which are loaded directly into an LLNL database. Since laboratory reporting is not perfect, the TSD Data Management Team (DMT) carefully checks incoming data throughout the year to ensure that electronic copies match printed laboratory reports. Additionally, EFA technical staff review the laboratory's internal QC results to identify potential errors and ensure that analytical QC standards are met. When necessary, analytical laboratories are asked to review results or reanalyze samples. Results that do not meet QC standards may be flagged or rejected.

As described in **Section 8.4**, computer scripts are used to pull data from the database into tables, including unit conversion and summary statistic calculations. All data tables in **Appendix A** were prepared in this manner. These tables are checked annually by the appropriate analyst. Analysts verify that the data tables match the data received from DMT and that summary calculations are correct.

LLNL staff also QC tables and figures in the body of the report. Staff check figure captions and table titles, data accuracy and completeness, figure labels and table headings, units, significant digits, and consistency with text. Any edits are incorporated into the ASER by the editor.

There are multiple levels of document review performed to ensure the accuracy and clarity of this report. Authors, scientific editors, and the DOE Livermore Field Office (LFO) all participate in multiple review cycles throughout document production.

8.8 Errata

Appendix D contains the protocol for errata in LLNL Environmental Reports and the errata for LLNL Site Annual Environmental Report 2021.

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Acronyms and Glossary

Symbols and Units of Measure

ºC	degree centigrade
ºF	degree Fahrenheit
σ	sigma
aCi	attocurie (10^{-18} Ci)
µBq	microbecquerel (10^{-6} Bq)
µg/g	microgram per gram (10^{-6} g/g)
µg/dry g	microgram per dry gram (10^{-6} g/dry g)
µg/L	microgram per liter (10^{-6} g/L)
µg/m^3	microgram per cubic meter (10^{-6} g/m^3)
µrem	microrem (10^{-6} rem)
µSv/y	microsievert per year
Bq	becquerel (*See also* definition in **Key Terms** section.)
Bq/g	becquerel per gram
Bq/dry g	becquerel per dry gram
Bq/kg	becquerel per kilogram
Bq/L	becquerel per liter
Bq/m^3	becquerel per cubic meter
Bq/mL	becquerel per milliliter
Ci	curie (*See also* definition in **Key Terms** section.)
cm	centimeter
ft	foot
g	gram
gal	gallon
gal/d	gallon per day
gal/min	gallon per minute
GBq	gigabecquerel (10^{9} Bq)
in.	inch
keV	kiloelectronvolt (10^{3} eV) (*See also* definition of “electronvolt” in **Key Terms** section.)
kg	kilogram (10^{3} g)
kg/d	kilogram per day (10^{3} g/d)
km	kilometer (10^{3} m)
L	liter
L/d	liter per day
L/y	liter per year
m	meter
mBq	millibecquerel (10^{-3} Bq)
mBq/g	millibecquerel per gram (10^{-3} Bq/g)
mBq/dry g	millibecquerel per dry gram (10^{-3} Bq/dry g)
mBq/m^3	millibecquerel per cubic meter (10^{-3} Bq/m^3)
mCi	millicurie (10^{-3} Ci)
mg/L	milligram/liter (10^{-3} g/L)
mi	mile
mph	mile per hour
mR	milliroentgen (10^{-3} R) (*See also* definition of “roentgen” in **Key Terms** section.)
mrem	millirem (10^{-3} rem) (*See also* definition of “rem” in **Key Terms** section.)
mrem/y	millirem per year (10^{-3} rem/y)
m/s	meter per second

mSv	millisievert (10^{-3} Sv)
mSv/y	millisievert per year (10^{-3} Sv/y)
MT	metric ton
nBq	nanobecquerel (10^{-9} Bq)
nSv	nanosievert (10^{-9} Sv)
nSv/y	nanosievert per year (10^{-9} Sv/y)
pCi	picocurie (10^{-12} Ci)
pCi/g	picocurie per gram (10^{-12} Ci/g)
pCi/dry g	picocurie per dry gram (10^{-12} Ci/dry g)
pCi/L	picocurie per liter (10^{-12} Ci/liter)
person-Sv	person-sievert (*See also* definition in **Key Terms** section.)
person-Sv/y	person-sievert/year
pg/L	picogram per liter (10^{-12} g/L)
pg/m^3	picogram per cubic meter (10^{-12} g/m^3)
Sv	sievert (*See also* definition in **Key Terms** section.)
TBq	terabecquerel (10^{12} Bq)

Acronyms and Abbreviations

%RSD	Percent relative standard deviation
ACCDA	Alameda County Community Development Agency
ACDEH	Alameda County Department of Environmental Health
ACHP	Advisory Council on Historic Preservation
ACOE	Army Corps of Engineers
AFV	alternative fuel vehicle
ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
AIM Act	American Innovation and Manufacturing Act
APHIS	Animal and Plant Health Inspection Service
ATSDR	Agency for Toxic Substances and Disease Registry
BAAQMD	Bay Area Air Quality Management District (*See also* definition in **Key Terms** section.)
BCG	Biota Concentration Guide
BGS	Below Ground Surface
BO	biological opinion
BSA	Blanket Service Agreement
BSL	Biosafety Level
BWXT	BWX Technologies
CAA	Clean Air Act
CalARP	California Accidental Release Prevention
CAMP	Corrective Action Monitoring Plan
CAMU	Corrective Action Management Unit
CARB	California Air Resources Board
CCR	California Code of Regulations
CDC	Centers for Disease Control
CDFW	California Department of Fish and Wildlife
CDPH	California Department of Public Health
CEI	Compliance Evaluation Inspection
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980 (*See also* definition in **Key Terms** section.)

CFF	Contained Firing Facility
CFR	Code of Federal Regulations
CHSC	California Health and Safety Code
CNPS	California Native Plant Society
CO	carbon monoxide
COC	constituent of concern
COD	chemical oxygen demand
CSA	container storage area
CUPA	Certified Unified Program Agencies
CVRWQCB	Central Valley Regional Water Quality Control Board (*See also* definition in **Key Terms** section.)
CWA	(Federal) Clean Water Act
CWG	Community Working Group
DCS	Derived Concentration Technical Standard
DMP	Detection Monitoring Plan
DMT	Data Management Team
DOE	(U.S.) Department of Energy (*See also* definition in **Key Terms** section.)
DOECAP	(U.S.) Department of Energy Consolidated Auditing Program
DOT	(U.S.) Department of Transportation
DPR	(California) Department of Pesticide Regulation
DRB	Drainage Retention Basin
DTSC	(California Environmental Protection Agency) Department of Toxic Substances Control
DW	Double-walled
DWTF	Decontamination and Waste Treatment Facility
E85	Vehicle fuel, 85% ethanol and 15% gasoline
EA	environmental assessment
EDE	effective dose equivalent (*See also* definition in **Key Terms** section.)
EDO	Environmental Duty Officer
EFA	Environmental Functional Area
EIS	environmental impact statement
ELAP	Environmental Laboratory Accreditation Program
EMP	Environmental Management Plan
EMS	Environmental Management System
EPA	Environmental Protection Agency (*See also* definition in **Key Terms** section.)
EPCRA	Emergency Planning and Community Right-to-Know Act of 1986 (*See also* definition in **Key Terms** section.)
EPEAT	Electronic Product Environmental Assessment Tool
EPL	effluent pollutant limit
EPP	Environmentally Preferable Purchasing
ERD	(LLNL) Environmental Restoration Department
ERP	Environmental Restoration Project
ES&H	Environment, Safety and Health
ESA	Endangered Species Act
ESAR	Enhanced Source Area Remediation
EWSF	Explosives Waste Storage Facility
EWTF	Explosives Waste Treatment Facility
FFA	Federal Facility Agreement (*See also* definition in **Key Terms** section.)
FFCA	Federal Facilities Compliance Act
FGC	Federal Green Challenge
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FRP	Fiberglass reinforced plastic

FY	fiscal year (*See also* definition in **Key Terms** section.)
GIE	gas-insulated equipment
GPS	global positioning system
GPs	Guiding principles
GSA	(U.S.) General Services Administration
GSF	Gross square feet
GWP	(Livermore Site) Ground Water Project
HABS/HAER	Historic American Building Survey/Historic American Engineering Report
HAP	hazardous air pollutant
HDPE	High density polyethylene
HHRA	Human health risk assessment
HPGe	high-purity germanium
HSU	hydrostratigraphic unit
HT/TT	tritiated hydrogen gas
HTO/TTO	tritiated water or tritiated water vapor
HWCL	Hazardous Waste Control Law (*See also* definition in **Key Terms** section.)
ICRP	International Commission on Radiological Protection
IEEE	Institute of Electrical and Electronics Engineers
IGP	Industrial General Permit
ILA	industrial, landscaping, and agricultural
IQR	Interquartile range (*See also* definition in **Key Terms** section.)
ISMS	Integrated Safety Management System
ISO	International Organization for Standardization
ITS	Institutional Tracking System
JFLMA	Joint Functional Area Line Management Assessment
LEED	Leadership in Energy and Environmental Design
LEED-EB	Leadership in Energy and Environmental Design for Existing Buildings
LEPC	Local Emergency Planning Committee
LFO	Livermore Field Office
LFPD	Livermore Pleasanton Fire Department
LLNL	Lawrence Livermore National Laboratory
LLNS	Lawrence Livermore National Security, LLC
LLW	Low Level Waste
LWRP	Livermore Water Reclamation Plant
MAPEP	Mixed Analyte Performance Evaluation Program
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols
MCL	maximum contaminant level (*See also* definition in **Key Terms** section.)
MDC	minimum detectable concentration
MOIs	Management, Observation, and Inspections
MRP	Monitoring and Reporting Program
MSAs	Management Self Assessments
MWMA	Medical Waste Management Act
MWMP	Medical Waste Management Plan
NAI	sodium iodide
NAL	numeric action level
NCRP	National Council on Radiation Protection and Measurements
NELAP	National Environmental Laboratory Accreditation Program
NEPA	National Environmental Policy Act (*See also* definition in **Key Terms** section.)
NESHAPs	National Emissions Standards for Hazardous Air Pollutants
NHPA	National Historic Preservation Act

NIF	National Ignition Facility
NNSA	National Nuclear Security Administration
NOV	Notice of Violation
NOx	nitrous oxides
NPDES	National Pollutant Discharge Elimination System (*See also* definition in **Key Terms** section.)
NRHP	National Register of Historic Places
O&B	Operations & Business Principal Directorate
OBT	organically bound tritium
ODS	ozone depleting substance
ORNL	Oak Ridge National Laboratory
OU	Operable Unit
P2S	pollution prevention/sustainability
PA	Programmatic Agreement
PEP	Performance Evaluation Plan
PCB	polychlorinated biphenyl
PCE	perchloroethylene (or perchloroethene); also called tetrachloroethylene or tetrachloroethene
PM-10	particulate matter with diameter equal to or less than 10 micrometer
POCs	Precursor organic compounds (*See also* definition in **Key Terms** section.)
PPMRP	Pollution Prevention and Monitoring and Reporting Program
PQL	practical quantitation limit (*See also* definition in **Key Terms** section.)
PRAD	(LLNL) Permits and Regulatory Affairs Division
PUE	Power Utilization Effectiveness
PV	Photovoltaic
PVC	polyvinyl chloride
QA	quality assurance (*See also* definition in **Key Terms** section.)
QC	quality control (*See also* definition in **Key Terms** section.)
RCRA	Resource Conservation and Recovery Act of 1976 (*See also* definition in **Key Terms** section.)
REC	Renewable Energy Credit
REVAL	Remediation Evaluation Process
RHWM	(LLNL) Radioactive and Hazardous Waste Management Division
RMP	risk management plan
RL	reporting limit
RMP	risk management plan
ROD	Record of Decision
ROGs	reactive organic gases (*See also* definition in **Key Terms** section.)
RPM	Remedial Project Managers
RWQCB	Regional Water Quality Control Board (*See also* definition in **Key Terms** section.)
SARA	Superfund Amendment and Reauthorization Act of 1986 (*See also* definition in **Key Terms** section.)
SDS	Safety Data Sheet
SDWA	Safe Drinking Water Act
SERC	State Emergency Response Commission
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board (*See also* definition in **Key Terms** section.)
SFTF	Small Firearms Training Facility
SHPO	State Historic Preservation Officer
SI	Système International d'Unités (*See also* definition in **Key Terms** section.)
SJCEHD	San Joaquin County Environmental Health Department (*See also* definition in **Key Terms** section.)
SJCOES	San Joaquin County, Office of Emergency Services

SJVAPCD	San Joaquin Valley Air Pollution Control District (*See also* definition in **Key Terms** section.)
SMARTS	Storm Water Multiple Application and Report Tracking System
SMOP	Synthetic Minor Operating Permit
SMS	(LLNL) Sewer Monitoring Station
SOx	sulphur oxides
SPCC	Spill Prevention Control and Countermeasure
STP	Site Treatment Plan
SVOCs	semi-volatile organic compounds
SW	Single-walled
SW-MEI	site-wide maximally exposed individual member (of the public) (*See also* definition in **Key Terms** section.)
SWPPP	Storm Water Pollution Prevention Plan
SWRCB	State Water Resources Control Board
TAG	Technical Assistance Grant
TCE	trichloroethene (or trichloroethylene)
TDS	Total Dissolved Solids
TEF	toxicity equivalency factor
TEQ	toxicity equivalency
TF	treatment facility
TLD	thermoluminescent dosimeter (*See also* definition in **Key Terms** section.)
TNI	The NELAC Institute
TRI	Toxics Release Inventory
Tri-Valley CAREs	Tri-Valley Communities Against a Radioactive Environment
TRU	transuranic (waste) (*See also* definition in **Key Terms** section.)
TSCA	Toxic Substances Control Act
TSDF	Treatment, Storage, and Disposal Facility
TSF	Terascale Simulation Facility
TSS	total suspended solids (*See also* definition in **Key Terms** section.)
TTO	total toxic organic (compounds)
UCD	under dispenser containment
USTs	underground storage tanks
USFWS	U.S. Fish and Wildlife Service
USGBC	U.S. Green Building Council
VOC	volatile organic compound (*See also* definition in **Key Terms** section.)
VTF	vapor treatment facility
WAA	waste accumulation area (*See also* definition in **Key Terms** section.)
WDAR	Waste Discharge Authorization Requirement
WDR	Waste Discharge Requirement
WRD	Water Resources Division (*See also* definition in **Key Terms** section.)

Metric and U.S. Customary Unit Equivalents

	From metric unit to U.S. customary equivalent unit		From U.S. customary unit to metric equivalent unit	
Category	**Metric**	**U.S.**	**U.S.**	**Metric**
Length	1 centimeter (cm)	0.39 inches (in.)	1 inch (in.)	2.54 centimeters (cm)
	1 millimeter (mm)	0.039 inches (in.)		25.4 millimeters (mm)
	1 meter (m)	3.28 feet (ft)	1 foot (ft)	0.3048 meters (m)
		1.09 yards (yd)	1 yard (yd)	0.9144 meters (m)
	1 kilometer (km)	0.62 miles (mi)	1 mile (mi)	1.6093 kilometers (km)
Volume	1 liter (L)	0.26 gallons (gal)	1 gallon (gal)	3.7853 liters (L)
		8.11×10^{-7} acre-feet	1 acre-foot	1.23×10^{6} liters (L)
	1 cubic meter (m^3)	35.32 cubic feet (ft^3)	1 cubic foot (ft^3)	0.028 cubic meters (m^3)
		1.35 cubic yards (yd^3)	1 cubic yard (yd^3)	0.765 cubic meters (m^3)
Weight	1 gram (g)	0.035 ounces (oz)	1 ounce (oz)	28.3 gram (g)
	1 kilogram (kg)	2.21 pounds (lb)	1 pound (lb)	0.454 kilograms (kg)
	1 metric ton (MT)	1.10 short ton (2000 pounds)	1 short ton (2000 pounds)	0.90718 metric ton (MT)
Area	1 hectare (ha)	2.47 acres	1 acre	0.40 hectares (ha)
Radioactivity	1 becquerel (Bq)	2.7×10^{-11} curie (Ci)	1 curie (Ci)	3.7×10^{10} becquerel (Bq)
Radiation dose	1 gray (Gy)	100 rad	1 rad	0.01 gray (Gy)
Radiation dose equivalent	1 sievert (Sv)	100 rem	1 rem	0.01 sievert (Sv)
Temperature	^{o}Fahrenheit = (^{o}Centigrade x 1.8) + 32		^{o}Centigrade = (^{o}Fahrenheit – 32) / 1.8	

Multiplying Prefixes

Symbol	Prefix	Factor	Symbol	Prefix	Factor
y	yocto	10^{-24}	da	deca	10^{1}
z	zepto	10^{-21}	h	hecto	10^{2}
a	atto	10^{-18}	k	kilo	10^{3}
f	femto	10^{-15}	M	mega	10^{6}
p	pico	10^{-12}	G	giga	10^{9}
n	nano	10^{-9}	T	tera	10^{12}
μ	micro	10^{-6}	P	peta	10^{15}
m	milli	10^{-3}	E	exa	10^{18}
c	centi	10^{-2}	Z	zetta	10^{21}
d	deci	10^{-1}	Y	yotta	10^{24}

Key Terms

Absorbed dose. Amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material, in which the absorbed dose is expressed in units of rad or gray (1 rad = 0.01 gray).

Accuracy. Closeness of the result of a measurement to the true value of the quantity measured.

Action level. Defined by regulatory agencies, the level of pollutants which, if exceeded, requires regulatory action.

Alluvium. Sediment deposited by flowing water.

Alpha particle. Positively charged particle emitted from the nucleus of an atom, having mass and charge equal to those of a helium nucleus (two protons and two neutrons).

Ambient air. Surrounding atmosphere, usually the outside air, as it exists around people, plants, and structures; for monitoring purposes, it does not include air immediately adjacent to emission sources.

Analyte. Specific component measured in a chemical analysis.

Aquifer. Saturated layer of rock or soil below the ground surface that can supply usable quantities of groundwater to wells and springs, and be a source of water for domestic, agricultural, and industrial uses.

Bay Area Air Quality Management District (BAAQMD). Local agency responsible for regulating stationary air emission sources (including the LLNL Livermore Site) in the San Francisco Bay Area.

Becquerel (Bq). SI unit of activity of a radionuclide, equal to the activity of a radionuclide having one spontaneous nuclear transition per second.

Beta particle. Negatively charged particle emitted from the nucleus of an atom, having charge, mass, and other properties of an electron.

Categorical discharge. Discharge from a process regulated by EPA rules for specific industrial categories.

Central Valley Regional Water Quality Control Board (CVRWQCB). Local agency responsible for regulating ground and surface water quality in the Central Valley.

Comingled recycling. Single-stream (also known as "fully **commingled**" or "single-sort") **recycling** refers to a system in which all paper fibers, plastics, metals, and other containers are mixed in a collection truck, instead of being sorted by the depositor into separate commodities.

Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). Administered by EPA, this federal law**,** also known as Superfund, requires private parties to notify the EPA of conditions that threaten to release hazardous substances or after the release of hazardous substances, and undertake short-term removal and long-term remediation.

Cosmic radiation. Radiation with very high energies originating outside the earth's atmosphere; it is one source contributing to natural background radiation.

Curie (Ci). Unit of measurement of radioactivity, defined as the amount of radioactive material in which the decay rate is 3.7×10^{10} disintegrations per second or 2.22×10^{12} disintegrations per minute; one Ci is approximately equal to the decay rate of 1 gram of pure radium.

Depleted uranium. Uranium having a lower proportion of the isotope uranium-235 than is found in naturally occurring uranium. The masses of the three uranium isotopes with atomic weights 238, 235, and 234 occur in depleted uranium in the weight-percentages 99.8, 0.2, and 5×10^{-4}, respectively. Depleted uranium is sometimes referred to as D-38 or DU.

Derived concentration technical standard (DCS). Concentrations of radionuclides in water and air that could be continuously consumed or inhaled for one year and not exceed the DOE primary radiation standard to the public (100 mrem/y EDE).

Dose. 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 equivalent. Product of absorbed dose in rad (or gray) in tissue and a quality factor representing the relative damage caused to living tissue by different kinds of radiation, and perhaps other modifying factors representing the distribution of radiation, etc. expressed in units of rem or sievert (1 rem = 0.01 sievert).

Dosimeter. Portable detection device for measuring the total accumulated exposure to ionizing radiation.

Downgradient. In the direction of groundwater flow from a designated area; analogous to downstream.

Effective dose equivalent (EDE). Estimate of the total risk of potential effects from radiation exposure, it is the summation of the products of the dose equivalent and weighting factor for each tissue. The weighting factor is the decimal fraction of the risk arising from irradiation of a selected tissue to the total risk when the whole body is irradiated uniformly to the same dose equivalent. These factors permit dose equivalents from nonuniform exposure of the body to be expressed in terms of an effective dose equivalent that is numerically equal to the dose from a uniform exposure of the whole body that entails the same risk as the internal exposure (ICRP 1996). The effective dose equivalent includes the committed effective dose equivalent from internal deposition of radionuclides and the effective dose equivalent caused by penetrating radiation from sources external to the body, and is expressed in units of rem (or sievert).

Effluent. Liquid or gaseous waste discharged to the environment.

Electronvolt (eV). A unit of energy equal to the amount of kinetic energy gained by an electron when it passes through a potential difference of 1 volt in a vacuum.

Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA). Act that requires facilities that produce, use, or store hazardous substances to report releases of reportable quantities or hazardous substances to the environment.

Environmental impact statement (EIS). 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.

Federal facility. Facility that is owned or operated by the federal government, subject to the same requirements as other responsible parties when placed on the Superfund National Priorities List.

Federal facility agreement (FFA). Negotiated agreement that specifies required actions at a federal facility as agreed upon by various agencies (e.g., EPA, RWQCB, DOE).

Fiscal year (FY). LLNL's fiscal year is from October 1 through September 30.

Freon-11. Trichlorofluoromethane.

Freon-113. 1,1,2-trichloro-1,2,2-trifluoroethane; also known as CFC 113.

Gamma ray. High-energy, short-wavelength, electromagnetic radiation emitted from the nucleus of an atom, frequently accompanying the emission of alpha or beta particles.

Geotracker. The SWRCB's data management system for sites that impact, or have the potential to impact, water quality in California, with emphasis on groundwater. GeoTracker contains records for sites that require cleanup, such as Leaking Underground Storage Tank (LUST) Sites, Department of Defense Sites, and Cleanup Program Sites. GeoTracker also contains records for various unregulated projects as well as permitted facilities including: Irrigated Lands, Oil and Gas production, operating Permitted USTs, and Land Disposal Sites. https://geotracker.waterboards.ca.gov/

Groundwater. All subsurface water.

Groundwater dual extraction well: Extraction of groundwater using a downhole pump with concurrent application of vacuum to the well. Groundwater and soil vapor are removed in separate pipe manifolds and treated.

Hazardous waste. Waste that exhibits ignitability, corrosivity, reactivity, and/or EP-toxicity (yielding toxic constituents in a leaching test), and waste that does not exhibit these characteristics but has been determined to be hazardous by EPA. Although the legal definition of hazardous waste is complex, according to EPA the term generally refers to any waste that, if managed improperly, could pose a threat to human health and the environment.

(California) Hazardous Waste Control Law (HWCL). Legislation specifying requirements for hazardous waste management in California.

Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX). High-explosive compound.

Inorganic compounds. Compounds that either do not contain carbon or do not contain hydrogen along with carbon, including metals, salts, and various carbon oxides (e.g., carbon monoxide and carbon dioxide).

International Commission on Radiological Protection (ICRP). International organization that studies radiation, including its measurement and effects.

Interquartile range (IQR). Distance between the top of the lower quartile and the bottom of the upper quartile, which provides a measure of the spread of data.

Isotopes. Forms of an element having the same number of protons in their nuclei, but differing numbers of neutrons.

Lake Haussmann. Man-made, lined pond used to capture storm water runoff and treated water at the Livermore site. Formerly called Drainage Retention Basin (DRB).

Less than detection limits. Phrase indicating that a chemical constituent was either not present in a sample, or is present in such a small concentration that it cannot be measured by a laboratory's analytical procedure, and therefore is not identified or not quantified at the lowest level of sensitivity.

Livermore Water Reclamation Plant (LWRP). City of Livermore's municipal wastewater treatment plant, which accepts discharges from the LLNL Livermore site.

Low-level waste. Radioactive waste that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, by product material, or naturally occurring radioactive material.

Maximum contaminant level (MCL). Highest level of a contaminant in drinking water that is allowed by the U.S. Environmental Protection Agency or California Department of Health Services.

Metric units. Except for temperature for which specific equations apply, U.S. customary units can be determined from metric units by multiplying the metric units by the U.S. customary equivalent. Similarly, metric units can be determined from U.S. customary equivalent units by multiplying the U.S. customary units by the metric equivalent. (*See also* **Metric and U.S. Customary Unit Equivalents** table in this Glossary.)

Mixed waste. Waste that has the properties of both hazardous and radioactive waste.

National Environmental Policy Act (NEPA). Federal legislation enacted in 1969 that requires all federal agencies to document and consider environmental impacts for federally funded or approved projects and the legislation under which DOE is responsible for NEPA compliance at LLNL.

National Pollutant Discharge Elimination System (NPDES). Federal regulation under the Clean Water Act that requires permits for discharges into surface waterways.

Nuclear Regulatory Commission (NRC). Federal agency charged with oversight of nuclear power and nuclear machinery and applications not regulated by DOE or the Department of Defense.

Nuclide. 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.

Part A permit. Application submitted by generators in the RCRA permitting process.

Part B permit. Second, narrative section submitted by generators in the RCRA permitting process that covers in detail the procedures followed at a facility to protect human health and the environment.

Perched aquifer. Aquifer that is separated from another water-bearing stratum by an impermeable layer.

Person-Sievert (person-Sv). The product of the average dose per person times the number of people exposed. 1 person-Sv = 100 person-rem.

pH. Measure of hydrogen ion concentration in an aqueous solution. The pH scale ranges from 0 to 14. Acidic solutions have a pH less than 7; basic solutions have a pH greater than 7; and neutral solutions have a pH of 7.

Pliocene. Geological epoch of the Tertiary period, starting about 12 million years ago.

PM-10. Fine particulate matter with an aerodynamic diameter equal to or less than 10 micrometers.

Point source. Any confined and discrete conveyance (e.g., pipe, ditch, well, stack).

Practical quantitation limit (PQL). Level at which the laboratory can report a value with reasonably low uncertainty (typically 10–20% uncertainty).

Pretreatment. Any process used to reduce a pollutant load before it enters the sewer system.

Quality assurance (QA). System of activities whose purpose is to provide the assurance that standards of quality are attained with a stated level of confidence.

Quality control (QC). Procedures used to verify that prescribed standards of performance are attained.

Quaternary. Geologic era encompassing the last 2 to 3 million years.

Rad. Unit of absorbed dose and the quantity of energy imparted by ionizing radiation to a unit mass of matter such as tissue, and equal to 0.01 joule per kilogram, or 0.01 gray.

Radioactive decay. Spontaneous transformation of one radionuclide into a different nuclide (which may or may not be radioactive), or de-excitation to a lower energy state of the nucleus by emission of nuclear radiation, primarily alpha or beta particles, or gamma rays (photons).

Radioactivity. Spontaneous emission of nuclear radiation, generally alpha or beta particles, or gamma rays, from the nucleus of an unstable isotope.

Radionuclide. Unstable nuclide. See also **nuclide** and **radioactivity**.

Reactive organic gases/precursor organic compounds (ROGs/POCs). Classes of chemicals that are precursors to the production of ozone and the photochemical formation of smog.

Regional Water Quality Control Board (RWQCB). California regional agency responsible for water quality standards and the enforcement of state water quality laws within its jurisdiction. California is divided into nine RWQCBs; the Livermore site is in the San Francisco Bay Region, and Site 300 is in the Central Valley Region.

Rem. Unit of radiation dose equivalent and effective dose equivalent describing the effectiveness of a type of radiation to produce biological effects; coined from the phrase “roentgen equivalent man,” and the product of the absorbed dose (rad), a quality factor (Q), a distribution factor, and other necessary modifying factors. 1 rem = 0.01 sievert.

Resource Conservation and Recovery Act of 1976 (RCRA). Program of federal laws and regulations that govern the management of hazardous wastes, and applicable to all entities that manage hazardous wastes.

Risk assessment. Qualitative and quantitative evaluation of the risk posed to human health and/or the environment by the actual or potential presence and/or use of specific pollutants.

Roentgen (R). Unit of measurement used to express radiation exposure in terms of the amount of ionization produced in a volume of air.

San Francisco Bay Regional Water Quality Control Board (SFBRWQCB). Local agency responsible for regulating ground and surface water quality in the San Francisco Bay Area.

San Joaquin County Environmental Health Department (SJCEHD). Local agency that enforces underground-tank regulations in San Joaquin County, including Site 300.

San Joaquin Valley Air Pollution Control District (SJVAPCD). Local agency responsible for regulating stationary air emission sources (including Site 300) in San Joaquin County.

Sanitary waste. Most simply, waste generated by routine operations that is not regulated as hazardous or radioactive by state or federal agencies.

Saturated zone. Subsurface zone below which all rock pore-space is filled with water; also called the phreatic zone.

Sensitivity. Capability of methodology or instrumentation to discriminate between samples having differing concentrations or containing varying amounts of analyte.

Sievert (Sv). SI unit of radiation dose equivalent and effective dose equivalent, that is the product of the absorbed dose (gray), quality factor (Q), distribution factor, and other necessary modifying factors. 1 sievert = 100 rem.

Sigma (σ) denotes the standard deviation of a statistical distribution.

Site-wide maximally exposed individual (SW-MEI). Hypothetical person who receives, at the location of a given publicly accessible facility (such as a church, school, business, or residence), the greatest LLNL-induced effective dose equivalent (summed over all pathways) from all sources of radionuclide releases to air at a site. Doses at this receptor location caused by each emission source are summed, and yield a larger value than for the location of any other similar public facility. This individual is assumed to continuously reside at this location 24 hours per day, 365 days per year.

Specific conductance. Measure of the ability of a material to conduct electricity; also called conductivity.

Superfund. Common name used for the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). California has also established a “State Superfund” under provisions of the California Hazardous Waste Control Act.

Superfund Amendments and Reauthorization Act (SARA). Enacted in 1986, these laws amended and reauthorized CERCLA for five years.

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.

Système International d'Unités (SI). International system of physical units which include meter (length), kilogram (mass), kelvin (temperature), becquerel (radioactivity), gray (radioactive dose), and sievert (dose equivalent).

Thermoluminescent dosimeter (TLD). Device used to measure external beta or gamma radiation levels, and which contains a material that, after exposure to beta or gamma radiation, emits light when processed and heated.

Total dissolved solids (TDS). Portion of solid material in a waste stream that is dissolved and passed through a filter.

Total suspended solids (TSS). Total mass of particulate matter per unit volume suspended in water and wastewater discharges that is large enough to be collected by a 0.45-micron filter.

Tritium. Radioactive isotope of hydrogen, containing one proton and two neutrons in its nucleus, which decays at a half-life of 12.3 years by emitting a low-energy beta particle.

Transuranic waste (TRU). Material contaminated with alpha-emitting transuranium nuclides, which have an atomic number greater than 92 (e.g., plutonium-239), half-lives longer than 20 years, and are present in concentrations greater than 100 nCi/g of waste.

Universal waste. Hazardous waste that is widely produced by households and many different types of businesses. Universal waste includes televisions, computers and other electronic devices as well as batteries, fluorescent lamps, mercury thermostats, and other mercury-containing equipment. California's Universal Waste Rule allows individuals and businesses to transport, handle, and recycle universal waste in a manner that differs from the requirements for most hazardous wastes.

Unsaturated zone. Portion of the subsurface in which the pores are only partially filled with water and the direction of water flow is vertical; is also referred to as the vadose zone.

U.S. Department of Energy (DOE). Federal agency responsible for conducting energy research and regulating nuclear materials used for weapons production.

U.S. Environmental Protection Agency (EPA). 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.

Vadose zone. Partially saturated or unsaturated region above the water table that does not yield water to wells.

Volatile organic compound (VOC). Liquid or solid organic compounds that have a high vapor pressure at normal pressures and temperatures and thus tend to spontaneously pass into the vapor state.

Waste accumulation area (WAA). Officially designated area that meets current environmental standards and guidelines for temporary (less than 90 days) storage of hazardous waste before pickup by the Radioactive and Hazardous Waste Management Division for off-site disposal.

Wastewater treatment system. 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 Resources Division: The City of Livermore governmental organization dedicated to meeting Livermore's water, wastewater, and storm water utility needs.

Water table. Water-level surface below the ground at which the unsaturated zone ends and the saturated zone begins, and the level to which a well that is screened in the unconfined aquifer would fill with water.

Weighting factor. Tissue-specific value used to calculate dose equivalents which represents the fraction of the total health risk resulting from uniform, whole-body irradiation that could be contributed to that particular tissue.

Zone 7. Common name for the Alameda County Flood Control and Water Conservation District, Zone 7, which is the water agency for the Livermore–Amador Valley with responsibility for regional flood control and drinking water supply.

APPENDIX A
Data Tables Checked

The data tables listed in this appendix are accessible at https://aser.llnl.gov/, the website for the LLNL annual environmental report.

A.1 Air Effluent (Chapter 4)

A.1.1 Summary of gross alpha and gross beta (µBq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 235, 2022

A.1.2 Summary of tritium in air effluent samples (Bq/m^3) from the monitored emission points at Livermore Site, Building 331, 2022

A.1.3 Summary of gross alpha and gross beta (µBq/m^3) in air effluent samples from the monitored emission points at Livermore Site, Building 332, 2022

A.1.4 Summary of gross alpha and gross beta (µBq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 581, 2022

A.1.5 Summary of representative gamma suite for radioactive particulate (µBq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 581, 2022

A.1.6 Summary of tritium in air effluent samples (Bq/m^3) from the monitored emission point at Livermore, Building 581, 2022

A.1.7 Summary of tritium exchange on particulate air filter (Bq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 581, 2022

A.1.8 Summary of Iodine-131 (µBq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 581, 2022

A.1.9 Summary of gross alpha and gross beta (µBq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 695, 2022

A.1.10 Summary of gross alpha and gross beta (µBq/m^3) in air effluent samples from the monitored emission point at Site 300, Building 801, 2022

A.2 Ambient Air (Chapter 4)

A.2.1(a) Bi-weekly gross alpha concentrations (µBq/m^3) from air particulate samples from the Livermore perimeter locations, 2022

A.2.1(b) Bi-weekly gross beta concentrations (µBq/m^3) from air particulate samples from the Livermore perimeter locations, 2022

A.2.2 Tritium concentrations (mBq/m^3) in air on the Livermore Site, 2022

A.2.3 Beryllium concentration (pg/m^3) in air particulate samples at the Livermore Site and Site 300, 2022

A.2.4 Plutonium-239+240 concentrations (nBq/m^3) in air particulate samples from the Livermore Site perimeter and Site 300 perimeter composite, 2022

A.2.5 Uranium mass concentrations (pg/m^3) and atom ratios in air particulate samples from Livermore Site (composite) and Site 300 onsite and offsite locations, 2022

A.2.6(a) Bi-weekly gross alpha concentrations (µBq/m^3) from air particulate samples from the Livermore Valley downwind locations, 2022

A.2.6(b) Bi-weekly gross beta concentrations (µBq/m^3) from air particulate samples from the Livermore Valley downwind locations, 2022

A.2.7 Tritium concentrations (mBq/m^3) in air, Livermore Valley, 2022

A.2.8(a) Bi-weekly gross alpha concentrations (µBq/m^3) from air particulate samples from the Livermore Valley upwind locations and the special interest location, 2022

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APPENDIX B
Wildlife Survey Results

Table B-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source[(b)]
Invertebrates	Valley Elderberry Longhorn Beetle	*Desmocerus californicus dimorphus*	FT	2002a
	California linderiella	*Linderiella occidentalis*	None	2016a, 2010, 2002d
	California Clam Shrimp	*Cyzicus californicus*	None	2002d
Amphibians	California Tiger Salamander	*Ambystoma californiense*	FT, ST	2021e, 2002g
	California Newt	*Taricha torosa*	None	2005b
	California Slender Salamander	*Batrachoseps attenuatus*	None	2008
	Arboreal Salamander	*Aneides lugubris*	None	2005b
	Western Spadefoot	*Spea hammondii*	CDFW:SSC (under review)	2021e, 2002g
	California Toad	*Anaxyrus boreas halophilus*	None	2021e, 2002g
	Sierran Treefrog	*Pseudacris sierra*	None	2021e, 2002g
	California Red-legged Frog	*Rana draytonii*	FT, CDFW:SSC	2021e, 2002g
Reptiles	Western Pond Turtle	*Actinemys marmorata*	CDFW:SSC	2005b
	Skilton's (Western) Skink	*Plestiodon skiltonianus*	None	2021a, 2021f, 2002c, 2002g
	Variegated (Gilbert's) Skink	*Plestiodon gilberti cancellosus*	None	2021a, 2021f, 2002c, 2002g
	California Whiptail	*Aspidoscelis tigris munda*	None	2021a, 2021f, 2002c, 2002g
	California (Southern) Alligator Lizard	*Elgaria multicarinata*	None	2021a, 2002c, 2002g
	San Francisco (Northern) Alligator Lizard	*Elgaria coerulea*	None	2021a
	California Legless Lizard	*Anniella pulchra*	CDFW:SSC	2021a, 2002c
	Blainville's (Coast) Horned Lizard	*Phrynosoma blainvillii*	CDFW:SSC	2021a, 2021e, 2002c
	Common Side- blotched Lizard	*Uta stansburiana*	None	2021a, 2021f, 2002c, 2002g
	Coast Range Fence Lizard	*Sceloporus occidentalis bocourtii*	None	2021a, 2021f, 2002c, 2002g
	California Kingsnake	*Lampropeltis californiae*	None	2021f, 2002c, 2002g
	Long-nosed Snake	*Rhinocheilus lecontei*	None	2021f, 2002c, 2002g
	Western Black- headed Snake	*Tantilla planiceps*	None	2002c
	California Glossy Snake	*Arizona elegans occidentalis*	CDFW:SSC	2021a, 2021f, 2002c, 2002g

B. Wildlife Survey Results

Table B-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[a]	Source[b]
Reptiles (cont.)	Pacific Gophersnake	*Pituophis catenifer*	None	2021a, 2021f, 2002c, 2002g
	Western Yellow-bellied Racer	*Coluber constrictor mormon*	None	2021f, 2002c, 2002g
	San Joaquin Coachwhip	*Masticophis flagellum ruddocki*	CDFW:SSC	2021a, 2021f, 2002g
	Alameda Whipsnake	*Masticophis lateralis euryxanthus*	FT, ST	2021a, 2021f, 2002c
	California Nightsnake	*Hypsiglena ochrorhyncha nuchalata*	None	2021a, 2021f, 2002c, 2002g
	Pacific Ring-necked Snake	*Diadophis punctatus amabilis*	None	2020c, 2005b
	Northern Pacific Rattlesnake	*Crotalus oreganus*	None	2021a, 2021f, 2002c, 2002g
Birds	Pied-billed Grebe	*Podilymbus podiceps*	MBTA	2003a
	Great Egret	*Ardea alba*	MBTA	2021g, 2003a
	American White Pelican	*Pelecanus erythrorhynchos*	MBTA, CDFW:SSC	2016
	Double-crested Cormorant	*Phalacrocorax auritus*	MBTA	2003a
	Red-shouldered Hawk	*Buteo lineatus*	MBTA	2020a, 2016, 2003a
	Golden Eagle	*Aquila chrysaetos*	MBTA, BGEPA, CDFW:FP	2021g, 2016, 2003a
	Rough-legged Hawk	*Buteo lagopus*	MBTA	2016, 2003a
	Ferruginous Hawk	*Buteo regalis*	MBTA	2020a, 2016, 2003a
	Red-tailed Hawk	*Buteo jamaicensis*	MBTA	2021e, 2016, 2003a
	Swainson's Hawk	*Buteo swainsoni*	MBTA, ST	2016, 2003a
	White-tailed Kite	*Elanus leucurus*	MBTA,CDFW:FP	2003a
	Cooper's Hawk	*Accipiter cooperii*	MBTA	2020a, 2016, 2003a
	Sharp-shinned Hawk	*Accipiter striatus*	MBTA	2016, 2003a
	Northern Harrier	*Circus hudsonius*	MBTA, CDFW:SSC, BCC	2021g, 2016, 2003a
	Turkey Vulture	*Cathartes aura*	MBTA	2021g, 2016, 2003a
	Osprey	*Pandion haliaetus*	MBTA	2016, 2003a
	Bufflehead	*Bucephala albeola*	MBTA	2021g, 2003a
	Common Goldeneye	*Bucephala clangula*	MBTA	2003a
	Mallard	*Anas platyrhynchos*	MBTA	2021g, 2016, 2003a

Table B-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source[(b)]
Birds (cont.)	Northern Shoveler	*Spatula clypeata*	MBTA	2003a
	Cinnamon Teal	*Spatula cyanoptera*	MBTA	2021g, 2003a
	Prairie Falcon	*Falco mexicanus*	MBTA	2020b, 2016, 2003a
	American Peregrine Falcon	*Falco peregrinus anatum*	MBTA, CDFW:FP	2016
	Merlin	*Falco columbarius*	MBTA	2011
	American Kestrel	*Falco sparverius*	MBTA	2021g, 2016, 2003a
	Wild Turkey	*Meleagris gallopavo*	None	2003a
	California Quail	*Callipepla californica*	None	2021g, 2003a
	Virginia Rail	*Rallus limicola*	MBTA	1992
	Sora	*Porzana carolina*	MBTA	2009
	Killdeer	*Charadrius vociferus*	MBTA	2020a, 2003a
	American Avocet	*Recurvirostra americana*	MBTA	2002f
	Greater Yellowlegs	*Tringa melanoleuca*	MBTA	2003a
	Wilson’s Snipe	*Gallinago delicata*	MBTA	2003a
	Long-billed curlew	*Numenius americanus*	MBTA, CDFW:SSC	2014
	Western Gull	*Larus occidentalis*	MBTA	2016
	Mourning Dove	*Zenaida macroura*	MBTA	2021g, 2016, 2003a
	Rock Pigeon	*Columba livia*	None	2016, 1992
	Eurasian Collared-dove	*Streptopelia decaocto*	None	2021g, Woollett 2017
	Greater Roadrunner	*Geococcyx californianus*	MBTA	2021g, 2003a
	Barn Owl	*Tyto alba*	MBTA	2021e, 2003a
	Short-eared Owl	*Asio flammeus*	MBTA, CDFW:SSC, BCC	2003a
	Great Horned Owl	*Bubo virginianus*	MBTA	2021e, 2003a
	Long-eared Owl	*Asio otus*	MBTA, CDFW:SSC, BCC	2003a
	Burrowing Owl	*Athene cunicularia*	MBTA, CDFW:SSC, BCC	2021e, 2016, 2003a
	Western Screech-Owl	*Megascops kennicottii*	MBTA	2003a
	Common Poorwill	*Phalaenoptilus nuttallii*	MBTA	2003a

B. Wildlife Survey Results

Table B-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[a]	Source[b]
Birds (cont.)	White-throated Swift	*Aeronautes saxatalis*	MBTA	2016, 2003a
	Allen's Hummingbird	*Selasphorus sasin*	MBTA, BCC	1992
	Rufous Hummingbird	*Selasphorus rufus*	MBTA	2003a
	Costa's Hummingbird	*Calypte costae*	MBTA	2003a
	Anna's Hummingbird	*Calypte anna*	MBTA	2021g, 2016, 2003a
	Lewis's Woodpecker	*Melanerpes lewis*	MBTA	2018
	Northern Flicker	*Colaptes auratus*	MBTA	2016, 2003a
	Nuttall's Woodpecker	*Dryobates nuttallii*	MBTA, BCC	2003a
	Acorn Woodpecker	*Melanerpes formicivorus*	MBTA	1992
	Ash-throated Flycatcher	*Myiarchus cinerascens*	MBTA	2003a
	Cassin's Kingbird	*Tyrannus vociferans*	MBTA	2003a
	Western Kingbird	*Tyrannus verticalis*	MBTA	2016, 2003a
	Western Wood-pewee	*Contopus sordidulus*	MBTA	1992
	Willow Flycatcher	*Empidonax traillii*	SE, MBTA	2005a
	Say's Phoebe	*Sayornis saya*	MBTA	2020a, 2016, 2003a
	Pacific-slope Flycatcher	*Empidonax difficilis*	MBTA	2003a
	Black Phoebe	*Sayornis nigricans*	MBTA	2021g, 2016, 2003a
	Loggerhead Shrike	*Lanius ludovicianus*	MBTA, CDFW:SSC	2020a, 2016, 2003a
	California (Western) Scrub-Jay	*Aphelocoma californica*	MBTA	2021g, 2003a
	Common Raven	*Corvus corax*	MBTA	2021e, 2016, 2003a
	American Crow	*Corvus brachyrhynchos*	MBTA	2021g, 2003a
	California Horned Lark	*Eremophila alpestris actia*	MBTA	2021g, 2016, 2003a
	Tree Swallow	*Tachycineta bicolor*	MBTA	2003a
	Cliff Swallow	*Petrochelidon pyrrhonota*	MBTA	2021g, 2016, 2003a
	Barn Swallow	*Hirundo rustica*	MBTA	2016
	Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	MBTA	2016, 2003a

Table B-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source[(b)]
Birds (cont.)	Oak Titmouse	*Baeolophus inornatus*	MBTA, BCC	2003a
	Bushtit	*Psaltriparus minimus*	MBTA	2003a
	House Wren	*Troglodytes aedon*	MBTA	2016, 2003a
	Rock Wren	*Salpinctes obsoletus*	MBTA	2003a
	Bewick's Wren	*Thryomanes bewickii*	MBTA	2003a
	Ruby-crowned Kinglet	*Regulus calendula*	MBTA	2020a, 2003a
	Blue-gray Gnatcatcher	*Polioptila caerulea*	MBTA	2019
	Hermit Thrush	*Catharus guttatus*	MBTA	2003a
	Western Bluebird	*Sialia mexicana*	MBTA	2021g, 2003a
	Varied Thrush	*Ixoreus naevius*	MBTA	2003a
	American Robin	*Turdus migratorius*	MBTA	2021g, 2003a
	Swainson's Thrush	*Catharus ustulatus*	MBTA	2003a
	Mountain Bluebird	*Sialia currucoides*	MBTA	2021g, 2003a
	California Thrasher	*Toxostoma redivivum*	MBTA, BCC	2021g, 2003a
	Northern Mockingbird	*Mimus polyglottos*	MBTA	2021g, 2003a
	European Starling	*Sturnus vulgaris*	None	2021g, 2016, 2003a
	Cedar Waxwing	*Bombycilla cedrorum*	MBTA	2021g, 2003a
	Phainopepla	*Phainopepla nitens*	MBTA	2003a
	MacGillivray's Warbler	*Geothlypis tolmiei*	MBTA	2003a
	Common Yellowthroat	*Geothlypis trichas*	MBTA	2021g, 2003a
	Wilson's Warbler	*Cardellina pusilla*	MBTA	2021g, 2003a
	Orange-crowned Warbler	*Leiothlypis celata*	MBTA	2003a
	Yellow Warbler	*Setophaga petechia*	MBTA, CDFW:SSC,	2003a
	Yellow-rumped Warbler	*Setophaga coronata*	MBTA	2021g, 2003a
	Black-throated Gray Warbler	*Setophaga nigrescens*	MBTA	2003a
	Song Sparrow	*Melospiza melodia*	CDFW:SSC, MBTA	2003a
	Lincoln's Sparrow	*Melospiza lincolnii*	MBTA	2003a

B. Wildlife Survey Results

Table B-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source[(b)]
Birds (cont.)	Fox Sparrow	*Passerella iliaca*	MBTA	2003a
	White-crowned Sparrow	*Zonotrichia leucophrys*	MBTA	2021g, 2016, 2003a
	Golden-crowned Sparrow	*Zonotrichia atricapilla*	MBTA	2021g, 2016, 2003a
	Dark-eyed Junco	*Junco hyemalis*	MBTA	2021g, 2003a
	Black-throated Sparrow	*Amphispiza bilineata*	MBTA	2003a
	California Towhee	*Melozone crissalis*	MBTA	2021g, 2003a
	Vesper Sparrow	*Pooecetes gramineus*	MBTA	1992
	Lark Sparrow	*Chondestes grammacus*	MBTA	2003a
	Bell's Sparrow	*Artemisiospiza belli*	MBTA	2003a
	Savannah Sparrow	*Passerculus sandwichensis*	MBTA	2016, 2003a
	Grasshopper Sparrow	*Ammodramus savannarum*	MBTA, CDFW:SSC	2003a
	Rufous-crowned Sparrow	*Aimophila ruficeps*	MBTA	2016, 2003a
	Lazuli Bunting	*Passerina amoena*	MBTA	2003a
	Blue Grosbeak	*Passerina caerulea*	MBTA	2003a
	Black-headed Grosbeak	*Pheucticus melanocephalus*	MBTA	1992
	Western Tanager	*Piranga ludoviciana*	MBTA	2021g, 2003a
	Bullock's Oriole	*Icterus bullockii*	MBTA, BCC	2021g, 2003a
	Brown-headed Cowbird	*Molothrus ater*	MBTA	2021g, 2003a
	Red-winged Blackbird	*Agelaius phoeniceus*	MBTA	2016, 2003a
	Tricolored Blackbird	*Agelaius tricolor*	BCC, CDFW:SSC, MBTA, ST	2021e, 2016, 2003a
	Western Meadowlark	*Sturnella neglecta*	MBTA	2021g, 2016, 2003a
	Brewer's Blackbird	*Euphagus cyanocephalus*	MBTA	2016, 2003a
	Lesser Goldfinch	*Spinus psaltria*	MBTA	2021g, 2016, 2003a
	House Finch	*Haemorhous mexicanus*	MBTA	2021g, 2016, 2003a
Mammals	Broad-footed Mole	*Scapanus latimanus*	None	2011
	Big Brown Bat	*Eptesicus fuscus*	None	2021b
	Townsend’s Big-eared Bat	*Corynorhinus townsendii*	CDFW:SSC	2021b

Table B-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source[(b)]
Mammals (cont.)	Hoary Bat	*Lasiurus cinereus*	None	2021b, 2003b
	Western Red Bat	*Lasiurus blossevillii*	CDFW:SSC	2021b, 2003b
	Silver-haired Bat	*Lasionycteris noctivagans*	None	2021b
	Small-footed Myotis	*Myotis ciliolabrum*	None	2021b
	California Myotis	*Myotis californicus*	None	2021b, 2003b
	Long-legged Myotis	*Myotis Volans*	None	2021b
	Fringed Myotis	*Myotis thysanodes*	None	2021b
	Yuma Myotis	*Myotis yumanensis*	None	2021b, 2003b
	Long-eared Myotis	*Myotis evotis*	None	2021b
	Canyon Bat	*Parastrellus hesperus*	None	2021b, 2003b
	Pallid Bat	*Antrozous pallidus*	CDFW:SSC	2021b, 2003b
	Brazilian Free-tailed Bat	*Tadarida brasiliensis*	None	2021b, 2003b
	Western Mastiff Bat	*Eumops perotis*	CDFW:SSC	2021b
	Audubon's (Desert) Cottontail	*Sylvilagus audubonii*	None	2021c, 2002b, 2002g
	Black-tailed Jackrabbit	*Lepus californicus*	None	2002b, 2002g
	California Ground Squirrel	*Ostospermophilus beecheyi*	None	2021c, 2021g, 2002g
	Botta's Pocket Gopher	*Thomomys bottae*	None	2002e, 2002g
	Heermann's Kangaroo Rat	*Dipodomys heermanni*	None	2021c, 2002e, 2002g
	San Joaquin Pocket Mouse	*Perognathus inornatus*	None	2002b
	California Pocket Mouse	*Chaetodipus californicus*	None	2021d, 2002e, 2002g
	House Mouse	*Mus musculus*	None	2002e, 2002g
	California Vole	*Microtus californicus*	None	2021f
	Deer Mouse	*Peromyscus maniculatus*	None	2002e, 2002g
	Western Harvest Mouse	*Reithrodontomys megalotis*	None	2021d, 2021f, 2002e, 2002g
	Dusky-footed Woodrat	*Neotoma fuscipes*	None	2002e, 2002g
	Diablo Range Woodrat	*Neotoma fuscipes perplexa*	None	2021d
	Brush Mouse	*Peromyscus boylii*	None	2021d, 2002e, 2002g
	Bryant's Woodrat	*Neotoma bryanti intermedia*	None	2021d

B. Wildlife Survey Results

Table B-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source[(b)]
Mammals (cont.)	Red Fox	*Vulpes vulpes*	None	2005b
	Gray Fox	*Urocyon cinereoargenteus*	None	2005b
	Coyote	*Canis latrans*	None	2021c, 2021g, 2002b, 2002g
	Raccoon	*Procyon lotor*	None	2021c, 2002g
	American Badger	*Taxidea taxus*	CDFW:SSC	2021c, 2021e, 2002b, 2002g
	Long-tailed Weasel	*Mustela frenata*	None	2002g
	Western Spotted Skunk	*Spilogale gracilis*	None	2002g
	Striped Skunk	*Mephitis mephitis*	None	2021c, 2002g
	Mountain Lion	*Puma concolor*	Candidate CESA	2002g
	Bobcat	*Lynx rufus*	None	2021c, 2002b, 2002g
	Wild Pig	*Sus scrofa*	None	2021c, 2021g, 2002b, 2002g
	Mule Deer	*Odocoileus hemionus*	None	2021c, 2021g, 2002b, 2002g

(a) **Regulatory Status**

BGEPA = Protected under the *Bald and Golden Eagle Protection Act*
BCC = USFWS Bird of Conservation Concern (USFWS 2021 BCC lists)
Candidate CESA = Candidate for listing under the California Endangered Species Act
CDFW:FP = California Department of Fish and Wildlife-Fully Protected Species (CDFW Special Animals List, January 2022)
CDFW:SSC = California Department of Fish and Wildlife-Species of Special Concern (CDFW Special Animals List, January 2022)
FT = Threatened under the Federal Endangered Species Act
MBTA = Protected under the *Migratory Bird Treaty Act*
SE = Endangered under the State Endangered Species Act
ST = Threatened under the State Endangered Species Act

(b) **Source (Year of documentation does not indicate absence in other years.)**

1992: DOE 1992
2002a: Arnold 2002
2002b: Clark et al. 2003
2002c: Swaim 2002
2002d: Weber 2002
2002e: West 2003
2003a: LLNL 2002
2003b: Rainey and Pierson 2003
2010: Dexter 2010

2016a: ESA 2016
2016b: Garcia & Associates (GANDA) 2016
2021a: ECORP 2021a
2021b: ECORP 2021b
2021c: 2021c
2021d:.2021d
2021e: LLNL 2021b
2021f: Murphy 2021

Observations by LLNL Wildlife Biologists:
2002f: Scott, J.
2002g: Van Hattem, M. and J. Woollett
2005a: Van Hattem, M.
2005b: Woollett, J.
2008: Burkholder, L
2009: Woollett, J.
2011: Woollett, J.
2014: Woollett, J.
2018: Murphy, C.
2019: Murphy, C.
2020a: Aquino, P.
2020b: Murphy, C.
2020c: Paterson, L.
2021g: Aquino, P.

APPENDIX C
Extra Resources

The documents listed below are accessible at https://aser.llnl.gov, the website for the LLNL annual environmental report.

LLNL Fiscal Year 2023 Site Sustainability Plan
Ottaway, H., B. Howing (2022) *Lawrence Livermore National Laboratory FY2023 Site Sustainability Plan.* Livermore, CA: Lawrence Livermore National Laboratory, UCRL-AR-842616.

LLNL Groundwater Project 2022 Annual Report
Noyes, C., K. Quamme, E. Yeh, A. Porubcan, J. Radyk, Z. Demir, and A. Verce (eds) (2023). *LLNL Groundwater Project 2022 Annual Report*. Livermore, CA: Lawrence Livermore National Laboratory, UCRL-AR-126020-22.

LLNL NESHAPs 2022 Annual Report
Wilson, K., N. Graves, J. Jursca, A. Wegrecki (2023). *LLNL NESHAPs 2022 Annual Report.* Livermore, California: Lawrence Livermore National Laboratory, UCRL-AR-850066.

Site 300 Compliance Monitoring Program for the Closed Building 829 Facility Annual Report 2022
Will, E. (2023). *Lawrence Livermore National Laboratory Experimental Test Site 300 Compliance Monitoring Program for the Closed Building 829 Facility, Annual Report 2022.* Livermore, CA: Lawrence Livermore National Laboratory, UCRLAR-143121-23-3.

Site 300 2022 Compliance Monitoring Annual Report
Buscheck, M., S. Chamberlain, Z. Demir, S. Harris, J. McKaskey, M. Murphy, L. Paterson, A. Porubcan, K. Quamme, J. Radyk, M. Taffet, and A. Verce (2023). *2022 Annual Compliance Monitoring Report, Lawrence Livermore National Laboratory Site 300.* Livermore, CA: Lawrence Livermore National Laboratory, UCRL-AR-206319-22.

Site 300 Compliance Monitoring Report for Waste Discharge Requirements Order No. R5-2008-0148 Second Semester/Annual Report 2022
Thomas, A. (2023). *LLNL Experimental Test Site, Site 300 Compliance Monitoring Report for Waste Discharge Requirement (WDR) Order No. R5-2008-0148, Second Semester/Annual Report 2022*, Livermore, CA: Lawrence Livermore National Laboratory, LLNL-AR-411431-23-3.

Supplementary Topics on Radiological Dose
Sanchez, L., P.E. Althouse, N.A. Bertoldo, R.G. Blake, S.L. Brigdon, R.A, Brown, C.G. Campbell, T. Carlson, E. Christofferson, L.M. Clark, G.M. Gallegos, A.R. Grayson, R.J. Harrach, W.G. Hoppes, H.E. Jones, J. Larson, D. Laycak, D.H. MacQueen, S. Mathews, M. Nelson, L. Paterson, S.R. Peterson, M.A. Revelli, M.J. Taffet, P.J. Tate, R. Ward, R.A. Williams, and K. Wilson (2003). *Environmental Report 2002*. Livermore, CA: Lawrence Livermore National Laboratory, UCRL-50027-02, Appendix D.

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APPENDIX D
Errata

Protocol for Errata in LLNL Environmental Reports

The LLNL Environmental Report is primarily published online. A limited number of copies are printed and distributed. If errors are found after publication, the electronic version is corrected. Since the printed versions cannot be corrected, errata for these versions are published in a subsequent report. Therefore, the equivalency of all published versions of the report is maintained.

In 1998, LLNL established the following protocol for post-publication revisions to the environmental report: (1) the environmental report website must clearly convey what corrections, if any, have been made and provide a link to a list of the errata, (2) the electronic report must be the most current version, incorporating all corrections, and (3) the electronic and printed versions must be the same in that the printed version plus errata, if any, provide the same information as the electronic version.

LLNL environmental reports from 1994 through 2022 can be accessed at https://aser.llnl.gov/

Record of Changes to Environmental Report 2021

No changes have been made to the online version of *Environmental Report 2021*.

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APPENDIX E
Percentage of In-Control Duplicate Pairs for Field Collocated Samples

Monitoring Program	Media	Analyte	Percent of Pairs within Control Limit[(a)]
Livermore Site and Site 300 Ambient Air	Air Filters	Beryllium	100%
Livermore Site and Site 300 Ambient Air	Air Filters	Uranium-235	100%
Livermore Site and Site 300 Ambient Air	Air Filters	Uranium-235/238	100%
Livermore Site and Site 300 Ambient Air	Air Filters	Uranium-238	100%
Livermore Site and Site 300 Ambient Air	Air Filters	Gross alpha	50%
Livermore Site and Site 300 Ambient Air	Air Filters	Gross beta	69%
Air Tritium	Silica Gel	Tritium	89%
Livermore Site, Livermore Valley, and Site 300 Ambient Radiation	Dosimeters	Radiation dose, average	100%
Livermore Site, Livermore Valley, and Site 300 Ambient Radiation	Dosimeters	Radiation dose, 90-days	100%
Groundwater from Off-site Wells and Springs	Groundwater	Arsenic	79%
Groundwater from Off-site Wells and Springs	Groundwater	Barium	100%
Groundwater from Off-site Wells and Springs	Groundwater	Boron	100%
Groundwater from Off-site Wells and Springs	Groundwater	Bromide	100%
Groundwater from Off-site Wells and Springs	Groundwater	Calcium	100%
Groundwater from Off-site Wells and Springs	Groundwater	Chloride	100%
Groundwater from Off-site Wells and Springs	Groundwater	Chromium	100%
Groundwater from Off-site Wells and Springs	Groundwater	Copper	100%
Groundwater from Off-site Wells and Springs	Groundwater	Fluoride	80%
Groundwater from Off-site Wells and Springs	Groundwater	Gross alpha	33%
Groundwater from Off-site Wells and Springs	Groundwater	Gross beta	50%
Groundwater from Off-site Wells and Springs	Groundwater	Magnesium	100%
Groundwater from Off-site Wells and Springs	Groundwater	Molybdenum	100%
Groundwater from Off-site Wells and Springs	Groundwater	Nickel	100%
Groundwater from Off-site Wells and Springs	Groundwater	Nitrate (as NO3)	100%
Groundwater from Off-site Wells and Springs	Groundwater	Ortho-Phosphate	100%
Groundwater from Off-site Wells and Springs	Groundwater	Perchlorate	75%
Groundwater from Off-site Wells and Springs	Groundwater	pH	100%
Groundwater from Off-site Wells and Springs	Groundwater	Potassium	100%
Groundwater from Off-site Wells and Springs	Groundwater	Selenium	100%
Groundwater from Off-site Wells and Springs	Groundwater	Sodium	100%
Groundwater from Off-site Wells and Springs	Groundwater	Specific Conductance	100%
Groundwater from Off-site Wells and Springs	Groundwater	Sulfate	100%

E. Percentage of In-Control Duplicate Pairs for Field Collected Samples

Monitoring Program	Media	Analyte	Percent of Pairs within Control Limit[a]
Groundwater from Off-site Wells and Springs	Groundwater	Total Alkalinity (as $CaCO_3$)	100%
Groundwater from Off-site Wells and Springs	Groundwater	Total coliform	0%
Groundwater from Off-site Wells and Springs	Groundwater	Total Hardness (as $CaCO_3$)	100%
Groundwater from Off-site Wells and Springs	Groundwater	Total dissolved solids (TDS)	100%
Groundwater from Off-site Wells and Springs	Groundwater	Turbidity	0%
Groundwater from Off-site Wells and Springs	Groundwater	Uranium-233/234	75%
Groundwater from Off-site Wells and Springs	Groundwater	Uranium 235 and 236	100%
Groundwater from Off-site Wells and Springs	Groundwater	Uranium-238	100%
Groundwater from Off-site Wells and Springs	Groundwater	Zinc	33%
Pre-construction Soil	Soil	Arsenic	100%
Pre-construction Soil	Soil	Barium	86%
Pre-construction Soil	Soil	Beryllium	100%
Pre-construction Soil	Soil	Chromium	100%
Pre-construction Soil	Soil	Cobalt	86%
Pre-construction Soil	Soil	Copper	100%
Pre-construction Soil	Soil	Diesel Fuel	100%
Pre-construction Soil	Soil	Fluoride	0%
Pre-construction Soil	Soil	Gross alpha	100
Pre-construction Soil	Soil	Gross beta	0%
Pre-construction Soil	Soil	Hexavalent chromium	0%
Pre-construction Soil	Soil	Lead	100%
Pre-construction Soil	Soil	Mercury	33%
Pre-construction Soil	Soil	Molybdenum	100%
Pre-construction Soil	Soil	Nickel	86%
Pre-construction Soil	Soil	Nitrate (as N)	100%
Pre-construction Soil	Soil	Oil	100%
Pre-construction Soil	Soil	Silver	100%
Pre-construction Soil	Soil	Solids, percent	100%
Pre-construction Soil	Soil	Tetrachloroethene	0%
Pre-construction Soil	Soil	Trichloroethene	0%
Pre-construction Soil	Soil	Vanadium	100%
Pre-construction Soil	Soil	Zinc	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Acetone	60%

E. Percentage of In-Control Duplicate Pairs for Field Collected Samples

Monitoring Program	Media	Analyte	Percent of Pairs within Control Limit[a]
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Actinium-228	70%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Arsenic	78%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Barium	67%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Beryllium	62%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Bismuth-212	52%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Bismuth-214	77%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Cadmium	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Cesium-137	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Chromium	83%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Cobalt	76%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Copper	76%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Gross alpha	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Gross beta	67%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Hexavalent Chromium	67%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Lead	72%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Lead-212	80%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Lead-214	86%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Mercury	46%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Moisture by weight	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Molybdenum	57%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Nickel	76%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Nitrate (as N)	50%

E. Percentage of In-Control Duplicate Pairs for Field Collected Samples

Monitoring Program	Media	Analyte	Percent of Pairs within Control Limit[(a)]
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Oil	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Plutonium-239/240	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Potassium-40	97%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Radium-224	0%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Radium-226	80%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Radium-228	70%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Selenium	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Silver	79%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Solids, Percent	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Tetrachloroethene	33%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Thallium 208	69%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Thorium-228	71%
Livermore Site, Livermore Valley and Site 300 Soil	Soil	Thorium 230	67%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Thorium 232	62%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Thorium 234	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Trichloroethene	29%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Tritium	0%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Uranium 234 and 233 (in activity)	68%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Uranium-235 (in activity)	100%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Uranium-238 (in activity)	76%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Vanadium	78%
Livermore Site, Livermore Valley, and Site 300 Soil	Soil	Zinc	83%

E. Percentage of In-Control Duplicate Pairs for Field Collected Samples

Monitoring Program	Media	Analyte	Percent of Pairs within Control Limit[(a)]
Livermore Site, Livermore Valley, and Site 300 Vegetation	Vegetation	Moisture by weight	100%
Livermore Site, Livermore Valley, and Site 300 Vegetation	Vegetation	Tritium	80%
Livermore Site Storm Water Runoff	Storm Water	Ammonia nitrogen (as N)	100%
Livermore Site Storm Water Runoff	Storm Water	Arsenic	100%
Livermore Site Storm Water Runoff	Storm Water	Gross alpha	100%
Livermore Site Storm Water Runoff	Storm Water	Gross beta	50%
Livermore Site Storm Water Runoff	Storm Water	Lead	100%
Livermore Site Storm Water Runoff	Storm Water	Magnesium	100%
Livermore Site Storm Water Runoff	Storm Water	Nitrate plus Nitrite (as N)	50%
Livermore Site Storm Water Runoff	Storm Water	Total suspended solids	100%
Livermore Site Storm Water Runoff	Storm Water	Chemical oxygen demand	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Aluminum	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Arsenic	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Barium	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Gross alpha	50%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Gross beta	83%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Boron	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Bromodichloromethane	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Bromoform	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Calcium	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Chloroform	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Copper	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Dibromochloromethane	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Fecal coliform	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Iron	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Magnesium	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Potassium	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Sodium	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Total coliform	0%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Total dissolved solids (TDS)	0%

E. Percentage of In-Control Duplicate Pairs for Field Collected Samples

Monitoring Program	Media	Analyte	Percent of Pairs within Control Limit[(a)]
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Total suspended solids	0%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Volatile solids	100%
Sanitary Sewer Discharge to Livermore WRD	Sewer Effluent	Zinc	100%

(a) Control limit is set at 30%. An RPD (relative percent difference) > 30% is out of control. See Chapter 8, Section 8.2.3 for more information about RPDs. Data date: June 16, 2023

APPENDIX F
Number of Samples Collected with Valid Analytical Results Versus Planned

Program Description	Sample Matrix	Analysis Method	Sampling Frequency	Number Completed	Number Planned	Percent Complete
Routine						
Air Particulate	Air Filter	ICP-MS, beryllium	Monthly	136	136	100
Air Particulate	Air Filter	Gross α / β	Biweekly	712	737	97
Air Particulate	Air Filter	Gamma spec suite of nine radionuclides	Monthly	36	36	100
Air Particulate	Air Filter	Alpha spec isotopes of Pu	Monthly	226	228	99
Air Particulate	Air Filter	ICP-MS isotopes of uranium	Monthly	130	132	98
Air Tritium	Silica gel	Tritium on silica gel by LCS	Biweekly	539	546	99
Liv Valley Annual Wells	Groundwater	Tritium in groundwater by LSC	Annually	13	15	87
Annual Soils	Soil	Tritium by LSC	Annually	5	5	100
Annual Soils	Soil	Gross α / β	Annually	5	5	100
Annual Soils	Soil	Gamma spectroscopy for a suite of ten radionuclides	Annually	30	30	100
Annual Soils	Soil	Alpha spectroscopy for isotopes or plutonium	Annually	18	18	100
Annual Soils	Soil	Total metals	Annually	12	12	100
B581 STACK data	Air Filter	Gross α / β	Weekly	51	52	98
B581 STACK data	Air Filter	Tritium by LSC	Weekly	51	52	98
B581 STACK data	Air Filter	Gamma spectroscopy for a suite of five radionuclides	Weekly	51	52	98
B581 STACK data	Air Filter	Iodine 131 by gamma spectroscopy	Weekly	51	52	98
TEDA Air Filter	Air Filter	Iodine 131 by gamma spectroscopy	Weekly	35	52	67
Wine	Wine	Tritium by LSC	Annually	12	12	100
Vegetation	Vegetation	Tritium by LSC	Quarterly	72	72	100
Valley Other Waters	Drinking Water	Gross α / β	Semi-annually	4	4	100
Valley Other Waters	Drinking Water	Tritium by LSC	Semi-annually	4	4	100

F. Number of Samples Collected with Valid Analytical Results Versus Planned

Program Description	Sample Matrix	Analysis Method	Sampling Frequency	Number Completed	Number Planned	Percent Complete
Valley Other Waters	Groundwater	Gross α / β	Annually	5	6	83
Valley Other Waters	Groundwater	Tritium by LSC	Annually	5	6	83
Sewer Non-Rad	Wastewater	Solids by Methods 2540 and 160.4	Monthly (increased to weekly mid-year)	55	58	95
Sewer Non-Rad	Wastewater	Cyanide by Method 335.4	Quarterly	5	5	100
Sewer Non-Rad	Wastewater	Organochlorine pesticides by Method 608	Monthly	14	14	100
Sewer Non-Rad	Wastewater	Volatile organic compounds by Method 624	Monthly	18	19	95
Sewer Non-Rad	Wastewater	Semi-volatile organics by Method 625	Monthly	13	13	100
Sewer Non-Rad	Wastewater	Tritium by LSC	Annually	2	1	200
Sewer Non-Rad	Wastewater	Gross α / β and tritium	Weekly plus monthly duplicates	64	64	100
Sewer Non-Rad	Wastewater	Biochemical oxygen demand by SM 5210B	Weekly	54	57	95
Sewer Non-Rad	Wastewater	Metals by Method 200.8	Quarterly	6	8	75
Sewer Rad	Wastewater	Cesium 137 by gamma spectroscopy	Monthly	36	36	100
Sewer Rad	Wastewater	Gross α / β	Monthly	36	36	100
Sewer Rad	Wastewater	Gamma spectroscopy suite of nine radionuclides	Quarterly	4	3	133
Sewer Rad	Wastewater	Plutonium isotopes by alpha spectroscopy	Monthly (quarterly for L-WRDC-SW)	40	39	103
Sewer Rad	Wastewater	Tritium by LSC	Monthly composite of daily	11	12	92
Sewer Rad	Wastewater	Tritium by LSC	Monthly	36	36	100
Sewer Rad	Wastewater	Gross α / β and tritium	Monthly gross α / β, daily tritium, plus duplicates	453	456	99
TLDs all Sites	Dosimeters	Thermoluminescent dosimetry	Quarterly	260	261	100
Site 300 Cooling Towers	Wastewater	Anions, metals, solids, pH, alkalinity	Semi-annually	82	82	100

F. Number of Samples Collected with Valid Analytical Results Versus Planned

Program Description	Sample Matrix	Analysis Method	Sampling Frequency	Number Completed	Number Planned	Percent Complete
Site 300 Mechanical Equipment Room Discharges	Wastewater	Anions, metals, solids, pH, alkalinity	Semi-annually	48	48	83
Site 300 B851 Stormwater Runoff and Sediment Monitoring	Stormwater and soil	Metals, perchlorate explosives, isotopes of uranium	Annually	0 runoff 5 soil	5 runoff 5 soil	0 runoff 100 soil
Pretreatment	Wastewater	VOCs, SVOC and metals	Semi-annually	12	12	100
Non-Routine						
Pre-construction Soils	Soil	Soil reuse analytical suite	As needed	5,662	6,207	91
Site 300 Sewage Pond Discharge	Wastewater	DO, conductivity, pH, fecal coliform BOD, metals	As needed	23	30	77
Industrial Management Area Storm Water Runoff	Stormwater	NPDES permit analytical suite	Storm dependent	19	32	59
Rain	Rain	Tritium by LSC	Storm dependent	19	54	35

*See Chapter 8, Section 8.2.3.2 for more information about completeness. Data date: June 16, 2023

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