4. Air Monitoring and Dose Assessment

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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.

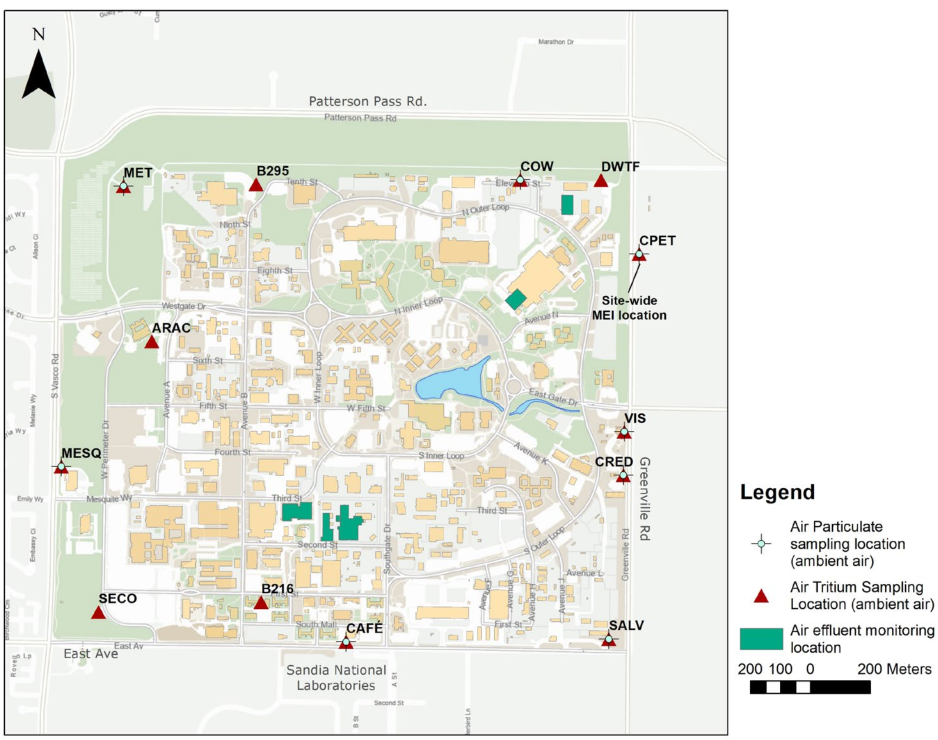

Figure 4-1. Air Effluent and Ambient Air Monitoring Locations at the Livermore Site, 2022

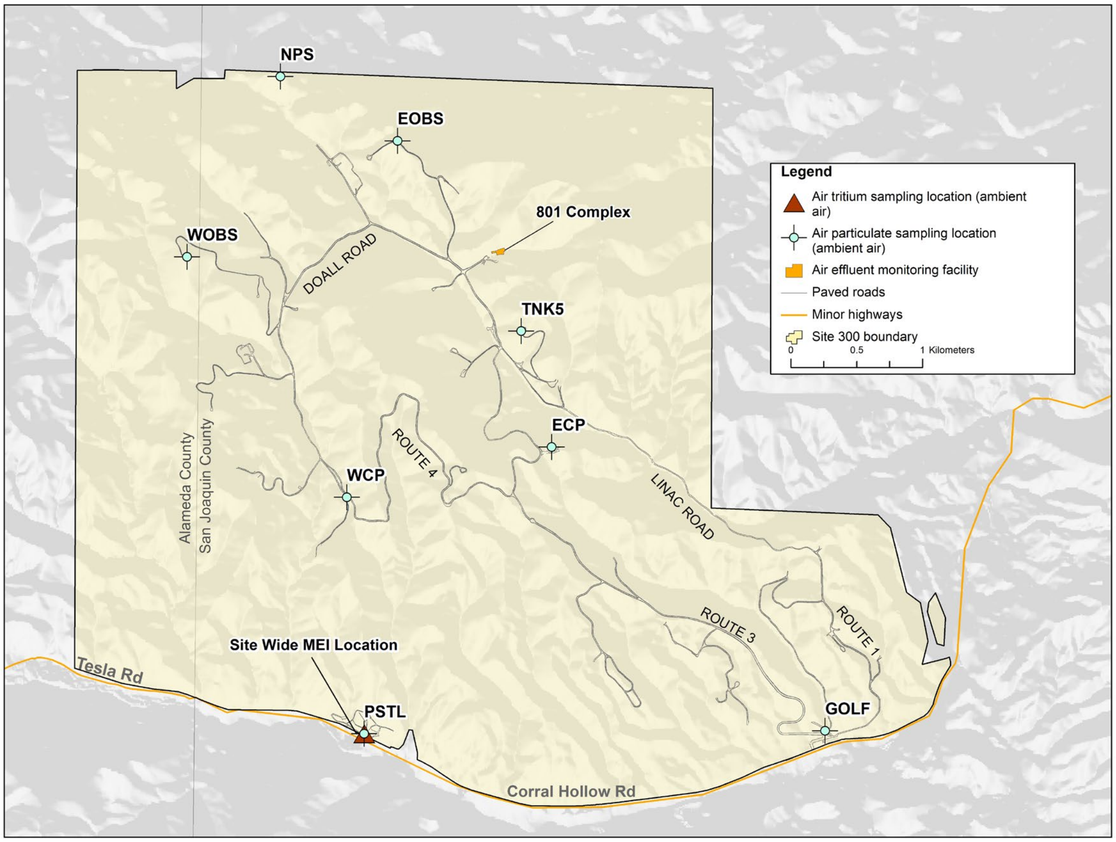

Figure 4-2. Air Effluent and Ambient Air Monitoring Locations at Site 300, 2022

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**.

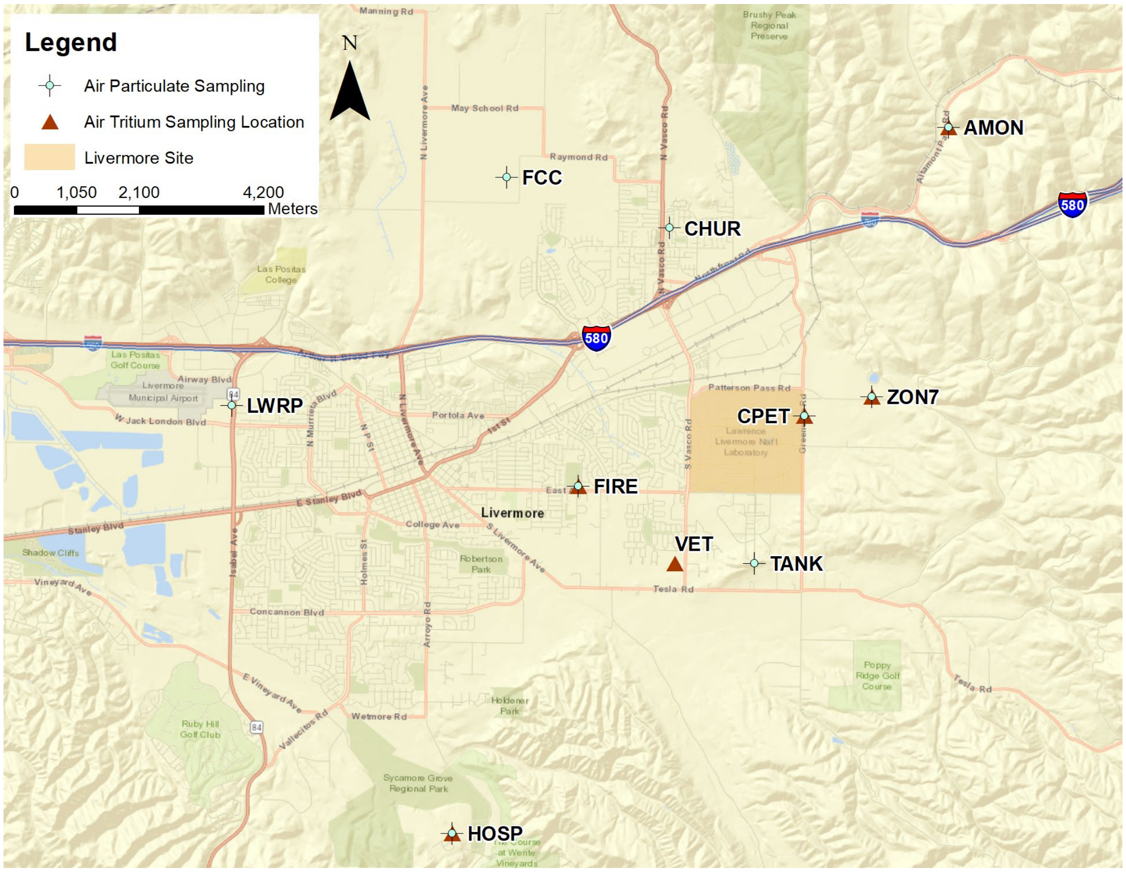

Figure 4-3. Air Particulate and Tritium Monitoring Locations in the Livermore Valley, 2022

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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