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LLNL NESHAPs 2017 Annual Report

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U.S. Department of Energy

Radionuclide Air Emission Report for 2017

(in compliance with 40 CFR 61, Subpart H)

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Executive Summary

Lawrence Livermore National Security, LLC operates facilities at Lawrence Livermore National Laboratory (LLNL) in which radionuclides are handled and stored. These facilities are subject to the U.S. Environmental Protection Agency (EPA) National Emission Standards for Hazardous Air Pollutants (NESHAPs) in Code of Federal Regulations (CFR) Title 40, Part 61, Subpart H, which regulates radionuclide emissions to air from Department of Energy (DOE) facilities. Specifically, NESHAPs limits the emission of radionuclides to the ambient air to levels resulting in an annual effective dose equivalent of 10 mrem (100 µSv) to any member of the public. Using measured and calculated emissions, and building-specific and common parameters, LLNL personnel applied the EPA-approved computer code, CAP88-PC, Version 4.0.1.17, to calculate the dose to the maximally exposed individual member of the public for the Livermore Site and Site 300.

In 2017, LLNL maintained its compliance with 40 CFR 61, Subpart H. All radioactive air emissions resulted in calculated doses far below the annual 10 mrem (100 µSv) site-wide standard. The annual doses to the site-wide maximally exposed individual member of the public at the Livermore Site and Site 300 from planned operations in 2017 are:

- Livermore Site: 1.9×10^{-3} mrem (1.9×10^{-2} µSv)
- Site 300: 4.8×10^{-5} mrem (4.8×10^{-4} µSv)

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Background Information

LLNL is a premier research laboratory that is part of the National Nuclear Security Administration (NNSA) within 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 national security needs, including countering the proliferation of weapons of mass destruction and strengthening homeland security, and conducts major research in atmospheric, earth, and energy sciences; bioscience and biotechnology; and engineering, basic science, and advanced technology. The Laboratory serves as a scientific resource to the U.S. government and a partner to industry and academia.

Because LLNL is a DOE facility, it is subject to the requirements of 40 CFR 61, Subpart H, National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities. This regulation limits emissions of radionuclides to ambient air to levels resulting in an annual effective dose equivalent of 10 mrem (100 µSv) to any member of the public. The regulation also requires annual reporting of the emissions and resulting dose.

1.1 SITE DESCRIPTION

LLNL consists of two sites—an urban site in Livermore, California, referred to as the "Livermore Site;" and a rural experimental test site, referred to as "Site 300," near Tracy, California (**Figure 1**).

Figure 1. Locations of LLNL's Livermore Site and Site 300.

The Livermore Site is just within the eastern city limits of Livermore, a city of about 85,000 in Alameda County. The site occupies 1.3 square miles, including the land that serves as a buffer zone around much of the site. Within a 50-mile radius of the Livermore Site are communities such as Tracy and Pleasanton and the more distant (and more densely populated) cities of Oakland, San Jose, and San Francisco. Of the 7.8 million people within 50 miles of the Laboratory, only about 10% are within 20 miles.

Site 300, LLNL's Experimental Test Site, is in the Altamont Hills of the Diablo Range and straddles the San Joaquin and Alameda county line. The site is 12 miles east of the Livermore Site and occupies 10.9 square miles. The city of Tracy, with a population of about 86,000, is approximately 6 miles to the northeast (measured from the northeastern border of Site 300 to Sutter Tracy Community Hospital). Of the 7.1 million people who live within 50 miles of Site 300, 95% are more than 20 miles away in metropolitan areas such as Oakland, San Jose, and Stockton.

The weather conditions at the Livermore Site and Site 300 are very similar. The climate at both sites is best described as Mediterranean, characterized by mild, rainy winters and warm-to-hot, dry summers. However, the complex topography of Site 300 does influence local wind and temperature patterns. The stronger winds that occur at the higher elevations of Site 300 (**Figure 2**), results in warmer nights and slightly cooler days than the Livermore Site.

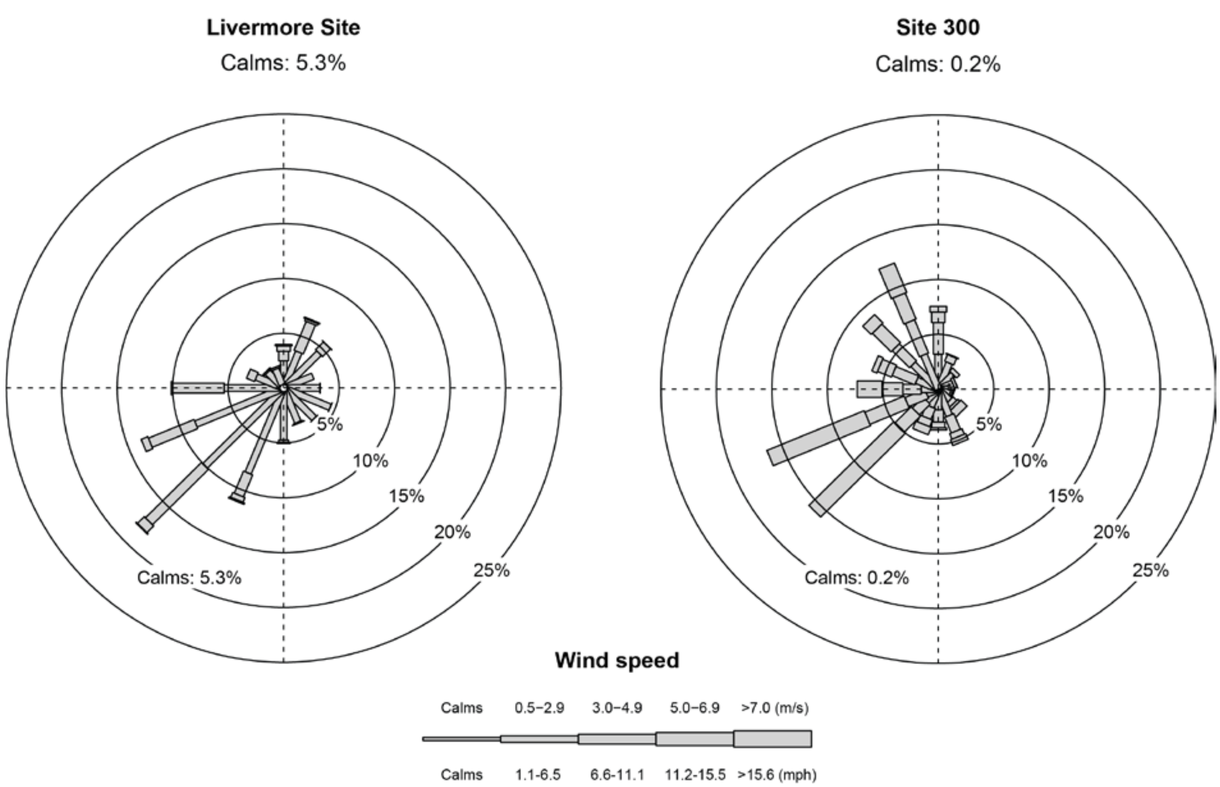

Figure 2. Wind roses for the Livermore Site and Site 300 for 2017.

The 2017 annual wind data for both sites are displayed as wind roses in **Figure 2**. In the wind rose, the length of each spoke is proportional to the frequency at which the wind blows from the indicated direction; different spoke widths within each spoke represent wind speed classes. These data show that at the Livermore Site, winds blew from the south-southwest through west-southwest about 43% of the time; and at Site 300, from the southwest to the west about 40% of the time. The average wind speed in 2017 at the Livermore Site was 2.2 m/s (4.9 mph), and the average wind speed at Site 300 was 5.5 m/s (12.3 mph). In 2017, the Livermore Site received 47.4 cm (18.7 in) of rain and Site 300 received 29.4 cm (11.6 in).

1.2 SOURCE DESCRIPTION

Many different radioisotopes were present at LLNL in 2017 including biomedical tracers, tritium, mixed fission products, transuranic isotopes, and others—see **Table 1**. Radioisotope handling procedures and work enclosures are determined for each project or activity, depending on the isotopes, the quantities being used, and the types of operations being performed. Work enclosures include glove boxes, exhaust hoods, and laboratory bench tops. Exhaust paths to the atmosphere include High Efficiency Particulate Air (HEPA) filtered ventilation systems, roof vents and stacks without abatement devices, resuspension of deposited depleted uranium in the soil from previous open-air explosives testing at Site 300, and releases to ambient air from a variety of diffuse sources. **Table 2** identifies the buildings, by managing organization, at LLNL where there was a potential for release of radioactive materials to the air in 2017.

Table 1. Radionuclides used at LLNL during 2017.

Ac-227	Ac-228	Ag-108m	Ag-110m	Am-241	Am-242m
Am-243	Au-194	Au-195	Au-196	Au-196m	Au-198
Ba-133	Ba-140	Be-7	Be-10	Bi-207	Bi-214
C-14	Ca-41	Ca-45	Cd-109	Ce-139	Ce-141
Ce-143	Ce-144	Cf-249	Cf-252	Cl-36	Cm-243
Cm-244	Cm-246	Cm-248	Co-55	Co-57	Co-58
Co-60	Cr-51	Cs-134	Cs-135	Cs-137	Eu-152
Eu-154	Eu-155	Fe-52	Fe-55	Gd-148	Gd-153
H-3	Hg-203	Ho-166m	I-125	I-129	I-131
I-132	I-133	Ir-190	Ir-192	Ir-194m	K-40
Kr-85	La-140	Lu-177m	Mn-54	Mo-99	Na-22
Nb-95	Nb-97	Nd-147	Ni-56	Ni-57	Ni-63
Np-236s	Np-237	Np-239	Pa-231	Pa-233	Pb-210
Pb-212	Pb-214	Pm-147	Pm-149	Po-208	Po-210
Pr-143	Pt-193m	Pt-195m	Pu-236	Pu-238	Pu-239
Pu-240	Pu-241	Pu-242	Pu-244	Ra-226	Ra-228
Rh-105	Ru-103	Ru-105	Ru-106	S-35	Sb-125
Sm-145	Sm-151	Sn-113	Sn-121m	Sn-126	Sr-85
Sr-90	Sr-91	Tc-99	Te-132	Th-228	Th-229
Th-230	Th-232	Th-234	Tl-204	Tl-208	U-232
U-233	U-234	U-235	U-236	U-237	U-238
Xe-133	Xe-135	Y-88	Y-91	Y-93	Zr-89
Zr-93	Zr-95	Zr-97			

Table 2. Buildings at LLNL, by managing organization, where there is a potential for the release of radioactive materials to the air.

Director's Office	Physical & Life Sciences	Engineering	Weapons & Complex Integration	National Ignition Facility & Photon Science	Operations & Business
B253	B041[a]	B231	B131HB	B165	B292
B254	B132[a]	B321	B191	B298	B597
B255	B151	B322	B331[b]	B381	
	B154	B327	B332[b]	B391	
	B190	B341	B612	B491	
	B194		B625	B581[b]	
	B235[b]		B693	B582	
	B262[a]		B695/696[b]		
	B282		B697		
	B361		B801[b]		
	B364		B804		
	B378		B810A		
	B379		B810B		
	B432		B836C		
			B836D		
			B851		

[a] Managed by Global Security.

[b] Continuous monitoring occurs at one or more exhaust points at the building.

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Emissions Data

LLNL groups radionuclide emission sources into two categories; major sources or minor sources. Major sources are defined as those that have the potential to emit radionuclides that could result in an annual potential dose of 0.1 mrem (1 µSv) or more to a member of the public at an off-site location; the radionuclide NESHAPs regulation requires continuous monitoring where the annual potential dose exceeds 0.1 mrem (1 µSv). Minor sources are defined as sources that do not have the potential to cause an annual dose of 0.1 mrem (1 µSv). At LLNL, all major sources of emissions are point sources, i.e., stack emission points; however, minor sources include both point sources and diffuse sources.

2.1 MAJOR SOURCES: MEASURED EMISSIONS

In 2017, there were five facilities at the Livermore Site and one facility at Site 300 that had radionuclide air effluent continuous monitoring systems. These facilities are listed in **Table 3**, along with the number of samplers, the types of samplers, and the analytes of interest. Some of these facilities have the potential to emit radionuclides that would cause an annual dose greater than the 0.1 mrem (1 µSv) standard; these sources are major sources following the definition given above. Others have had potential emissions that required monitoring, and the monitoring continues to be maintained to assure that any emissions are well characterized and that the potential effect on the public and the environment is well understood.

Many of the monitored stacks at LLNL have effluent controls, such as HEPA filters, to collect materials before they are emitted to the atmosphere. Air samples for particulate emissions are extracted downstream of HEPA filters and prior to the discharge point to the atmosphere. Particles are collected on high efficiency cellulose membrane filters. The sample filters are removed and analyzed for radioactive particulate activity on a weekly or bi-weekly frequency depending on the facility. In all cases, continuous passive filter aerosol collection systems are used. At some facilities, continuous air monitors (CAMs) also sample the stack air exhaust for radionuclide activity. CAMs have an alarm capability in the event of an unplanned release of radionuclide activity. CAMs are used for facility personnel safety; they are not used for NESHAPs compliance demonstration.

Table 3. Air effluent sampling systems and locations.

Building	Facility	Analytes	Sample type	Number of samplers
235	Building in Physical and Life Sciences Directorate	Gross α, β on particles	Filter	1
331	Tritium Facility	Gaseous tritium/ tritiated water vapor	Ionization Chamber[a]	4
		Gaseous tritium/ tritiated water vapor	Glycol Bubblers	2
332	Plutonium Facility	Gross α, β on particles	Filters	15
		Gross α, β on particles	CAM[a]	12
581	National Ignition Facility	Gross α, β, Gamma suite on particles	Filter	1
		Radioiodine (volatile)	TEDA cartridge	1
		Gaseous tritium/ tritiated water vapor	Glycol Bubbler	1
		Gaseous tritium/ tritiated water vapor	Ionization Chamber[a]	1
695/696	Decontamination and Waste Treatment Facility	Gross α, β on particles	Filter	1
801A	Contained Firing Facility (Site 300)	Gross α, β on particles	Filter	1

Note: “CAM” denotes continuous air monitors. “TEDA” denotes triethylenediamine.

[a] Alarmed systems used for notification for any unplanned release; they are not used for NESHAPs compliance demonstration.

Gas flow proportional counters and gamma spectroscopy are used to detect radioactive particulate activity collected on the filters. For verification of the operation of the counting system, calibration sources, and background samples are interspersed among the sample filters for analysis. The Radiological Measurements Laboratory (RML) in LLNL’s Radiation Protection Functional Area and the Environmental Monitoring Radio-analytical Laboratory (EMRL) in the Physical and Life Sciences Directorate perform the analyses.

When the result for gross alpha or gross beta on a particulate filter is greater than the minimum detectable concentration (MDC), the filter is recounted. If the second result is also above the MDC, the filter is submitted to the EMRL for isotopic analysis to determine whether the activity on the filter is the result of naturally occurring radionuclides or is reportable as a radionuclide emission from the facility.

Glycol bubblers are used to monitor for tritium releases from the two Tritium Facility (Building 331) stacks, and the National Ignition Facility (NIF) stack. In addition to this NESHAPs compliance monitoring, the two Tritium Facility stacks, and the NIF stack are monitored using ion chambers. The ion chamber monitors are set to alarm at designated tritium concentrations to identify accidental or off-normal releases. Ion chambers are in place for notification only so that any unplanned release may be detected; they are not used for NESHAPs compliance demonstration, but data may serve as supportive information. All the stack samplers monitor continuously.

Because tritium can be released in the form of either tritiated water vapor (HTO) or gaseous tritium (HT), glycol bubblers employ a two-stage glycol impinging process to capture both physical forms. Stack air to be sampled enters the instrument and flows through the first stage impingers, capturing the HTO present. Next, the sampled air is directed through a heated palladium catalyst where oxidation of any HT in the sample takes place, converting gaseous tritium to HTO, which is then collected in the second stage impingers. The impingers are analyzed by the RML using liquid scintillation analysis. This type of sampling quantifies the amount of tritium for both species, HT and HTO.

Tritium in particulate form is monitored when required using high efficiency (better than HEPA grade) cellulose membrane filters. Measurements indicate that tritium exchange (adsorption of tritium in HTO and/or HT captured in the filter medium via a binding reaction) occurs; this was verified by placing two particulate filters in series and comparing the results (applying 2-sigma error) on each filter. If tritiated particulate were present, then the pre-stream filter (the filter that comes into contact with stack air first) would have a higher amount of tritium than the post-stream filter (the filter that comes into contact with stack air immediately after the pre-stream filter). This is because the pre-stream filter would have significantly filtered out particles prior to the post-stream; this would result in less tritium on the post-stream filter. The pre-stream filter and post-stream filter showed the same amount of tritium (within analytical error) indicating tritium exchange.

Triethylenediamine (TEDA) cartridges are used to sample for radioactive iodines in gaseous or vapor state. The TEDA is impregnated into carbon (activating the carbon) by the manufacturer and is housed in a plastic cartridge of standard industry size 2 ¼" diameter by 1" thick (30 × 50 Mesh). Stack air is directed through the TEDA cartridge, which is the second stage of the two-stage filter housing. Both the particulate filter (first stage) and the TEDA cartridge (second stage) are counted by gamma spectroscopy by the EMRL.

In 2017, stack measurements indicate that a total of 43.8 Ci (1621 GBq) of tritium was released from the Tritium Facility (B331). Of this, approximately 85% of tritium was released as HTO. The remaining 15% was HT.

The NIF (B581) released a total of 1.15 Ci (42.6 GBq) of measured tritium from the stack exhaust in 2017. Of this, approximately, 82% of tritium was released as HTO. The remaining 18% was HT. Note: The glycol bubbler that collects tritium from the NIF stack was sent back to the vendor for repair in November 2017 due to a faulty heat controller. The bubbler sampled tritium as HT for a total of 206 days in CY17; the bubbler sampled HTO for a total of 323 days in CY17.

A Monte Carlo probability simulation was developed to estimate the amount of HT and HTO for all non-monitored days. The estimate was based on 10,000 iterations each for HT and HTO. The highest value was used as a conservative approach in comparison to the straight mean (applying the average of measured emissions as an estimate). The HT estimate, as an example, had a straight mean of 83 mCi's. The mean of all Monte Carlo runs was also 83 mCi's as expected. The highest Monte Carlo value was 94 mCi's and is used as the estimate for HT.

The glycol bubbler was repaired and received from the vendor in early CY18, and is now online continuously monitoring tritium from the NIF stack.

The Contained Firing Facility (B801A) at Site 300 had measured depleted uranium stack emissions in 2017 consisting of 3.3×10^{-7} Ci (1.2×10^{-5} GBq) of uranium-234, 2.3×10^{-8} Ci (8.5×10^{-7} GBq) of uranium-235, and 2.3×10^{-6} Ci (8.5×10^{-5} GBq) of uranium-238 in particulate form.

None of the other facilities monitored for radionuclides had reportable emissions in 2017.

2.2 MINOR SOURCES: AMBIENT MEASUREMENT COMPARISON

With EPA's Region IX approval, LLNL uses ambient air monitoring data to demonstrate compliance for minor emissions sources (both non-monitored stack and area sources). The method entails comparing measured ambient air concentrations at the location of the site-wide maximally exposed individual (SW-MEI) to concentration limits set by EPA in its Table 2 of Appendix E to 40 CFR 61. Comparisons are made for tritium and plutonium 239+240 for the Livermore SW-MEI and uranium-238 for the Site 300 SW-MEI (see **Table 6** in Section 3.3.2).

2.3 MINOR SOURCES: SOURCE TERM ESTIMATE

LLNL estimates the source terms for Livermore Site diffuse minor sources using a mathematical optimization routine that minimizes the root-mean-square (*rms*) differences between modeled and measured annual average ambient tritium concentrations (MacQueen et al. 2013; see **Figure 5** in Section 3.3.2 of this report for the ambient air sampling locations). This process has two parts.

First, CAP88-PC is used to model the contribution each source (both point and diffuse) makes to the annual average tritium concentration in HTO at each of the ambient air monitoring locations. Each point source is modeled using source-specific model parameters (activity, stack height, etc.). The diffuse sources are modeled using a unit source (1 Ci), a 1-meter height, a 10-meter diameter, and a fixed plume rise across stability classes A through F. All models use the same LLNL 2017 wind file. The individual contributions (both point and diffuse) at each monitoring location are added to produce an all-sources-combined model estimate of the annual average ambient concentration at each location.

Second, the 1 Ci source term for each diffuse source is adjusted independently using the mathematical search routine. The source terms of the point sources are held fixed as measured. The adjusted diffuse source terms that produce the best fit of the all-sources-combined model concentrations to the measured concentrations are then used to calculate the dose contribution from each diffuse source.

In 2017, the best-fit diffuse source term estimates were 1.59 Ci for the Building 331 Waste Accumulation Area (WAA), 0.41 Ci for Building 298 activities, and 0.15 Ci for Building 612 WAA. The measured and best-fit model annual average ambient air concentrations are shown in **Figure 3**.

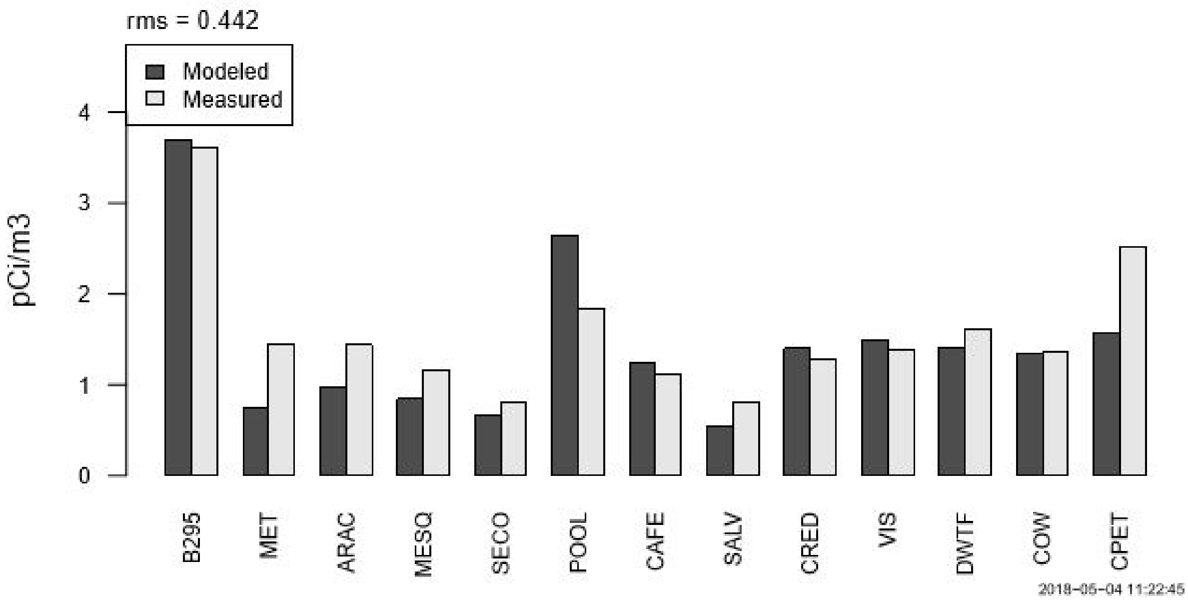

Figure 3. Comparison of measured and modeled annual average concentrations of tritiated water vapor (HTO) in units of pCi/m^3 in air at Livermore Site ambient air locations, 2017.

2.4 MINOR SOURCES: OPEN-AIR TESTS

Another potential source of radioactive air emissions from LLNL operations at Site 300 is the emission of materials from open-air explosives tests. In 2017, there were no open-air explosives tests that contained radioactive materials.

3
Dose Assessment

3.1 GENERAL

To comply with NESHAPs regulations and DOE guidance, the EPA-approved atmospheric dispersion and radiation dose calculation computer code, CAP88-PC, Version 4.0.1.17, was used to calculate the dose at specific distances from release points. For diffuse sources having a significant contribution to total dose, in addition to comparing the emissions to the concentration limits set by EPA in its Table 2 of Appendix E to 40 CFR 61, doses were calculated using either CAP88-PC or DOE standard (DOE-STD-1196-2011) breathing rates and dose conversion factors.

For LLNL to comply with the NESHAPs regulations, the SW-MEI cannot receive an effective dose equivalent greater than 10 mrem/y (100 µSv/y) per site. A SW-MEI is defined as a *hypothetical* member of the public at a single residence, school, business, church, or other such facility who receives the greatest LLNL induced dose from the combination of all evaluated radionuclide source emissions, as determined by modeling. At the Livermore Site, the 2017 SW-MEI is located at the LLNL Visitors Center (VIS), which is approximately 125 feet (38 m) outside the controlled eastern fence line of the site, about 195 feet (59m) within the perimeter of the site property. At Site 300, the 2017 SW-MEI is located at the Site 300 boundary with the Carnegie State Vehicle Recreation Area, managed by the California Department of Parks and Recreation, approximately 1.9 miles (3.2 km) south-southeast of the firing table at Building 851. The locations of the SW-MEI's for both LLNL sites are shown in **Figure 4**.

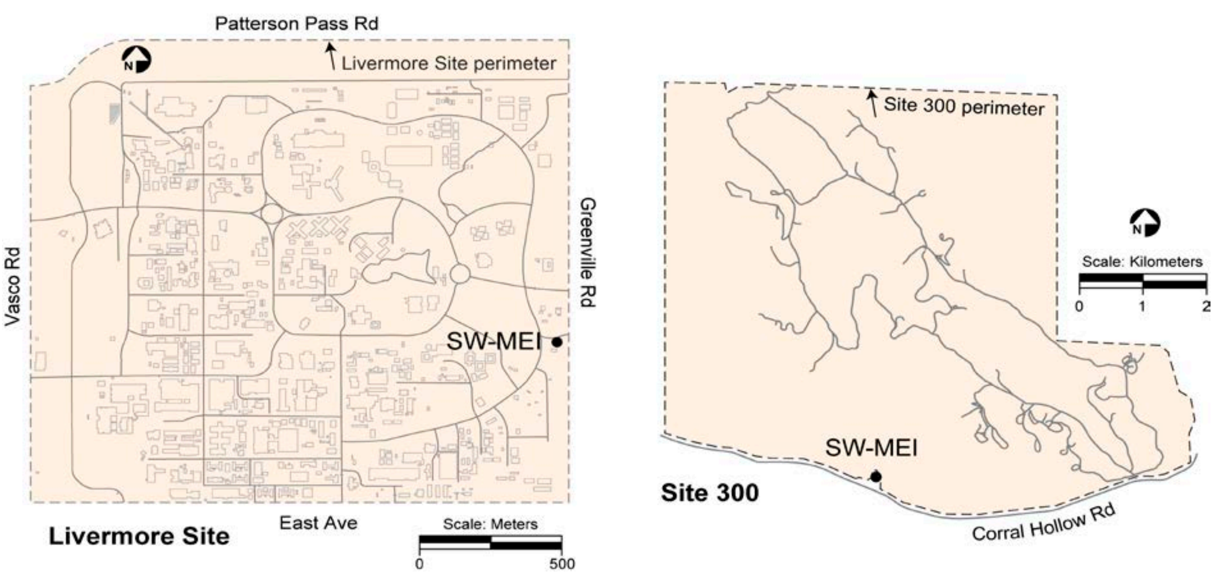

Figure 4. Location of Site-Wide Maximally Exposed Individual (SW-MEI) at the Livermore Site and Site 300, 2017.

3.2 CAP88-PC INPUT PARAMETERS

Input parameters to CAP88-PC include the emissions discussed in Section 2, and building-specific and common parameters, discussed below. To estimate dose, CAP88-PC, Version 4.0.1.17, provides a library of the radionuclides at LLNL. In addition, when calculating dose from particulate alpha- and beta-emitting radionuclides, LLNL assigns gross alpha and gross beta measurements to the radionuclides handled in the facility when they can be specifically identified, or to plutonium-239+240 and strontium-90, respectively. The use of plutonium-239+240 and strontium-90 to represent alpha and beta emissions provides a health-conservative estimate of the dose.

3.2.1 Building-Specific Parameters

For dose assessment, LLNL uses building-specific information about radionuclide releases, as well as building-specific parameters for stack height, stack exhaust rate, stack diameter, and distances to the fence line. The building specific parameters are presented in **Attachment 1**.

3.2.2 Common Parameters

The input parameters that are common among LLNL sources are the agricultural parameters. Meteorological data from the LLNL Livermore Site meteorological tower are used to model Livermore Site sources, and meteorological data from the LLNL Site 300 meteorological tower are used to model Site 300 sources. The site-specific values for annual precipitation were 18.4 in. [46.8 cm] for the Livermore Site and 11.6 in. [29.4 cm] for Site 300. The site-specific values for annual average ambient temperature were 59.4°F [15.2°C] for the Livermore Site and 66.7°F [19.3°C] for Site 300. The CAP88-PC default for absolute humidity of 8 grams per cubic meter was used, and is a reasonable representation of conditions at LLNL. The value for lid (mixing) height of 2,461 feet (750 m) was chosen for the Livermore Site, whereas the lid height value for Site 300 was 3,281 feet (1,000 m). The 2017 wind data are provided in **Attachment 2**.

For agricultural parameters in CAP88-PC, LLNL used area-weighted mean values based on data from the U.S. Department of Agriculture (USDA 2012) and the U.S. Census Bureau (USCB 2014) for periodic update. These were last updated in 2014.

County-specific agricultural data were obtained from the USDA sources. The borders of California counties were downloaded from the USCB website. For each county that intersects an 80 km radius circle around LLNL, the area of the overlapping portion of the county was calculated using geographic information system (GIS) software. Each of these areas was divided by the sum of the areas to determine the proportion of the 80 km radius circle representing each county. These proportions were then used to calculate the area weighted averages of the county-specific agricultural data. The results are shown in **Table 4**.

Table 4. Agricultural parameter values representing LLNL used in CAP88-PC.

Parameter	Value
Beef cattle density (number of cows/km^2)	4.02
Milk cattle density (number of cows/km^2)	13.16
Land fraction cultivated for vegetable crops	0.0021

For individual and collective doses from ingestion, it was assumed that 100% of milk is imported (i.e., free from LLNL-generated radioactivity), and that vegetables and meat are 25% home-grown and 75% imported.

3.2.3 Distances and Directions

In 2014, LLNL reviewed and updated its database of distances from sources to the fence-line and potential receptor locations using GIS and Google Earth software. Adjustments of up to about 15 meters were made to a few source locations. No further adjustments have been made.

3.3 COMPLIANCE ASSESSMENT

3.3.1 Major Sources

Doses from LLNL's major sources, which are point sources, were evaluated using CAP88-PC and the input parameters discussed above. The modeled doses to the SW-MEI for the facilities where there were measured emissions are shown in **Table 5**. The specific results for all sources are provided in **Attachment 1**.

Table 5. Monitored point source doses for 2017.

Site	Facility	Dose (mrem)
Livermore Site	Tritium Facility (B331)	1.5×10^{-3}
Livermore Site	NIF (B581)	1.1×10^{-5}
Site 300	CFF (B801A)	2.8×10^{-7}

3.3.2 Minor Sources

LLNL has many minor sources; most of them are point sources and a few are diffuse. As stated previously, with EPA's Region IX approval, LLNL demonstrates compliance for minor emissions sources (both diffuse and non-monitored stack sources) through the comparison of ambient air monitoring data with concentration limits set by EPA in Table 2 of Appendix E to 40 CFR 61. This is done for tritium and plutonium-239+240 for the Livermore SW-MEI and uranium-238 for the Site 300 SW-MEI.

The 2017 average monitoring results for tritium and plutonium from the sampling location at the Livermore Site SW-MEI (VIS) were used for the purposes of this minor source comparison. (See **Figure 5** for a map of all Livermore Site sampling locations). In 2017, there was one plutonium-239+240 result above the detection limit at the VIS location.

The remaining plutonium-239+240 samples for 2017 were below the detection limit. The results of these comparisons are shown in **Table 6.**

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.

At Site 300, wind-driven re-suspension of soil contaminated with depleted uranium is in the minor source category. From 2008 to 2014, but in contrast to previous years, no ambient measurements for uranium showed a contribution from depleted uranium at the SW-MEI (see **Figure 4** for the location of the Site 300 SW-MEI).

In 2017, there was one air sample that had a depleted uranium signature. The uranium-235/uranium-238 isotopic ratio was 0.0066; this results in approximately 14% depleted uranium with the other 86% of the sample as naturally occurring uranium.

The depleted uranium signature sample is shown in **Table 6**.

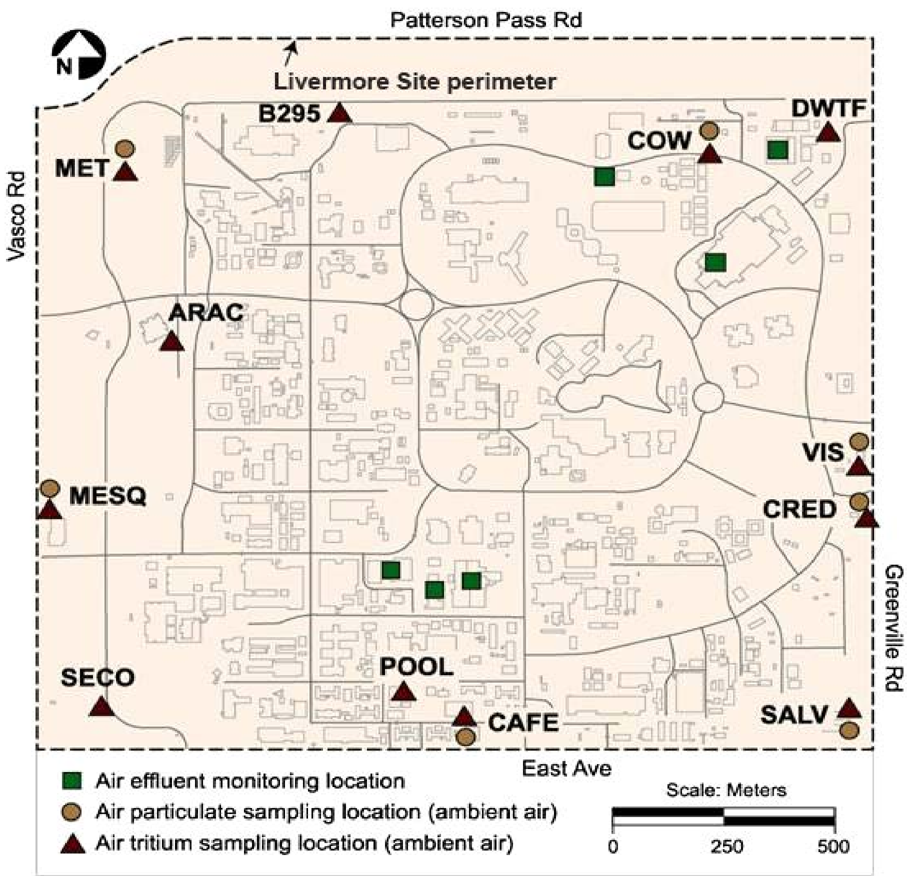

Figure 5. Radiological air monitoring locations at the Livermore Site.

The measured concentrations at the SW-MEI are presented in Table 6. Also shown in Table 6 are EPA's standards from Table 2 of Appendix E to 40 CFR 61. As demonstrated by the calculation of the fraction of the standard, LLNL's measured concentrations in air for tritium, plutonium-239+240, and uranium-238 are all less than 0.001 (0.1%) of the standard for these radionuclides.

Table 6. Mean concentrations of radionuclides of at the location of the SW-MEI in 2017 compared to EPA's concentration standard.

Location	Nuclide	EPA's Table 2 concentration standard	Mean measured concentration	Measured concentration as a fraction of the standard	Detection limit
Livermore Site SW-MEI	Tritium	1.5×10^{-9} Ci/m³	1.4×10^{-12} Ci/m³ [a]	9.3×10^{-4}	1×10^{-12} Ci/m³
Livermore Site SW-MEI	Plutonium-239	2.0×10^{-15} Ci/m³	3.0×10^{-20} Ci/m³ [b]	1.5×10^{-5}	5×10^{-19} Ci/m³
Site 300 SW-MEI	Uranium-238	8.3×10^{-15} Ci/m³	3.1×10^{-19} Ci/m³ [c]	3.7×10^{-5}	3×10^{-20} Ci/m³

a The measured tritium value includes contributions from all major and minor sources including stack and diffuse releases measured at the location of the SW-MEI.

b There was one Pu-239 detection at the location of the Livermore SW-MEI in 2017 from resuspended previously contaminated soil.

c Based on one sample that had a depleted uranium signature at the location of the Site 300 SW-MEI in 2017 from resuspended previously contaminated soil.

The source terms for the diffuse sources of tritium were developed as described in Section 2.3, and the doses were calculated using CAP88-PC. The total diffuse source dose for 2017 including the Pu resuspension sample at the SW-MEI was 3.6×10^{-4} mrem (3.6×10^{-3} µSv) for the Livermore Site. The diffuse dose at the SW-MEI at Site 300 from resuspended depleted uranium was 4.8×10^{-5} mrem (4.8×10^{-4} µSv). **Attachment 1** lists the doses from diffuse sources.

3.3.3 SW-MEI Dose

Doses from LLNL's airborne emissions are well below the 10 mrem (100 µSv) NESHAPs annual dose standard. The annual doses (point source plus diffuse source) to the hypothetical SW-MEI at the Livermore Site and at Site 300 are:

- Livermore Site: 1.9×10^{-3} mrem (1.9×10^{-2} µSv)
- Site 300: 4.8×10^{-5} mrem (4.8×10^{-4} µSv)

The EPA-approved software calculates the dose assuming a person resides there all year for 24 hours a day, and eats a specified fraction of meat and vegetables grown at the location (see agricultural parameters in Section 3.2.2). Thus, the calculated dose to this hypothetical person, the SW-MEI, is a conservative dose in comparison to an actual resident.

Table 7 presents 2017 doses with those of previous years. Diffuse source doses were not reported for the Livermore Site for 1990 and 1991 and were not reported for Site 300 for 1990 through 1992.

Table 7. Doses (in mrem) calculated for the Site-Wide Maximally Exposed Individual (SW-MEI) for the Livermore site and Site 300, 1990 to 2017.

Year	Total Dose	Point Source Dose	Diffuse Source Dose
Livermore Site			
2017	1.9×10^{-3}	1.5×10^{-3}	3.6×10^{-4}
2016	2.8×10^{-3}	2.6×10^{-3}	2.3×10^{-4}
2015	1.7×10^{-3}	1.4×10^{-3}	3.3×10^{-4}
2014	2.7×10^{-3}	2.4×10^{-3}	2.8×10^{-4}
2013	1.8×10^{-3}	1.61×10^{-3}	1.44×10^{-4}
2012	0.0054[a]	0.005[a]	0.00041
2011	0.017[a]	0.015[a]	0.0019
2010	0.011[a]	0.0033[a]	0.0074
2009	0.0042[a]	0.0015[a]	0.0027
2008	0.0013[a]	0.00033[a]	0.00095
2007	0.0031[a]	0.0013[a]	0.0018
2006	0.0045[a]	0.0016[a]	0.0029
2005	0.0065[a]	0.0027[a]	0.0038
2004	0.0079[a]	0.0021[a]	0.0058
2003	0.044[a]	0.024[a]	0.02
2002	0.023[a]	0.010[a]	0.013
2001	0.017[a]	0.0057[a]	0.011
2000	0.038[a]	0.017[a]	0.021
1999	0.12[a]	0.094[a]	0.028
1998	0.055[a]	0.031[a]	0.024
1997	0.097	0.078	0.019
1996	0.093	0.048	0.045
1995	0.041	0.019	0.022
1994	0.065	0.042	0.023
1993	0.066	0.04	0.026
1992	0.079	0.069	0.01
1991	0.234	—[b]	—[b]
1990	0.24	—[b]	—[b]

Table 7. (cont.) Doses (in mrem) calculated for the Site-Wide Maximally Exposed Individual (SW-MEI) for the Livermore Site and Site 300, 1990 to 2017.

Year	Total Dose	Point Source Dose	Diffuse Source Dose
Site 300			
2017	4.8×10^{-5}	2.8×10^{-7}	4.8×10^{-5}
2016	2.2×10^{-4}	9.3×10^{-8}	2.2×10^{-4}
2015	4.8×10^{-4}	1.3×10^{-7}	4.8×10^{-4}
2014	7.1×10^{-8}	7.1×10^{-8}	—[c]
2013	4.0×10^{-8}	4.0×10^{-8}	—[c]
2012	1.3×10^{-6}	1.3×10^{-6}	—[c]
2011	9.0×10^{-8}	9.0×10^{-8}	—[c]
2010	5.7×10^{-7}	5.7×10^{-7}	—[c]
2009	2.7×10^{-7}	2.7×10^{-7}	—[c]
2008	4.4×10^{-8}	4.4×10^{-8}	—[c]
2007	0.0035	0.0031	0.00035
2006	0.016	0.014	0.002
2005	0.018	0.0088	0.0094
2004	0.026	0.025	0.00086
2003	0.017	0.017	0.00034
2002	0.021	0.018	0.0033
2001	0.054	0.05	0.0037
2000	0.019	0.015	0.0037
1999	0.035	0.034	0.0012
1998	0.024	0.019	0.005
1997	0.02	0.011	0.0088
1996	0.033	0.033	0.00045
1995	0.023	0.02	0.003
1994	0.081	0.049	0.032
1993	0.037	0.011	0.026
1992	0.021	0.021	—[d]
1991	0.044	0.044	—[d]
1990	0.057	0.057	—[d]

[a] The dose includes HT emissions modeled as HTO. Modeling HT emissions as such results in an overestimation of the dose. This methodology is used for purposes of compliance, as directed by EPA Region IX. Beginning in CY13, the EPA NESHAPs compliance modeling code CAP88-PC Version 4.0.1.17 now allows tritium to be modeled in both species, HT and HTO.

[b] Point and diffuse source doses were not reported separately from the total dose for the Livermore Site for 1990 and 1991.

[c] Diffuse emissions dose was not calculated because ambient monitoring did not yield SW-MEI results indicating the presence of depleted uranium. This is primarily due to no atmospheric shots with DU since 2008, and no significant amounts of contaminated soil disturbance.

[d] No diffuse emissions were evaluated at Site 300 for years before 1993.

4

Certification

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

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Frances Alston

I certify under penalty of law that I have personally examined and am familiar with the information submitted herein, and based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment. See 18 U.S.C. 1001.

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Tom Grim

5

Additional Information

5.1 UNPLANNED RELEASES

There were no unplanned releases in 2017.

6

Supplemental Information

6.1 COLLECTIVE DOSE ASSESSMENT

Collective population dose is calculated using CAP88-PC as the average radiation dose to a person in a specified area, multiplied by the number of people in that area. In accordance with DOE and EPA guidance documents, all radionuclides potentially emitted in 2017 were assumed to be released from a central location. The total population within 50 miles (80 km) of the Livermore Site is approximately 7.8 million, and the total population within 50 miles (80 km) of Site 300 is approximately 7.1 million. The populations were derived using Oak Ridge National Laboratory LandScan 2010 data and ESRI ARCMAP software. The population file is provided in Attachment 3. The estimated collective dose attributable to LLNL airborne emissions in 2017 to persons living within 50 miles (80 km) of the Livermore Site is 0.13 person-rem (0.0013 person-Sv) and to persons living within 50 miles (80 km) of Site 300 is 7.2×10^{-5} person-rem (7.2×10^{-7} person-Sv).

6.2 40 CFR 61 SUBPARTS Q AND T

LLNL does not have storage and disposal facilities for radium containing materials that would be a significant source of radon. LLNL does not have or store any uranium mill tailings.

6.3 PERIODIC CONFIRMATORY MEASUREMENT

Results of NESHAPs periodic confirmatory measurements (PCM) are intended to support or confirm two objectives: 1) that those operations not continuously monitored do not, in fact, need to be continuously monitored and 2) that radionuclide usage-inventory-based estimates of emissions and their corresponding doses are conservative.

For sources evaluated to have a potential to result in a dose less than the regulatory value of 0.1 mrem/y that requires continuous monitoring under Subpart H, LLNL achieves the PCM objectives by fulfilling the requirements stated in 40 CFR 61.93, paragraph (e) with its ambient air monitoring program. The ambient air monitoring effort includes more than 30 sampling locations with more than 40 samplers placed in strategic areas (see the Air Monitoring Programs section in the LLNL Site Annual Environmental Report [https://saer.llnl.gov/] for a description of LLNL's ambient air radiological monitoring).

6.4 FACILITY COMPLIANCE

In 2017, LLNL maintained its compliance with 40 CFR 61 Subpart H. All emissions resulted in calculated doses well below the 10 mrem (100 µSv) standard. **Attachment 1** provides the dose estimates for each individual source.

References

LandScan™ Global Population Database, 2010, http://www.ornl.gov/sci/landscan/landscan_documentation.shtml

EPA 1989: U.S. Environmental Protection Agency, National Emission Standard for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities, 40 CFR Part 61, Subpart H (1989, as amended).

National Council on Radiation Protection and Measurements (NCRP), Principles and Application of Collective Dose in Radiation Protection, NCRP Report No. 121 (1995).

USDA 2012. United States Department of Agriculture. The Census of Agriculture. 2012. http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf (Issued May 2014).

MacQueen, D., N. Bertoldo, and A. Wegrecki (2013). "A Best Fit Approach to Estimating Multiple Diffuse Source Terms Using Ambient Air Monitoring Data and an Air Dispersion Model." Operational Radiation Safety, Vol. 105, suppl. 2, August 2013.

Errata

There were no errata in the calendar year 2016 report.

Attachments

Building	Room/Area	Stack ID	Operation	Radionuclides	Monitoring for Potental of Release	Stack Height (m)	Stack Diameter (m)	Stack Velocity (m/s)	Control Device(s)	Control Device Abatement Factor	Measured or Estimated Annual Emissions (Ci)	10 mrem/y Site-Wide Dose Requirement Distance to SW-MEI (m)	Direction to SW-MEI	EDE (mrem)	0.1 mrem/y Monitoring Requirement Distance to MEI (m)	Direction to MEI	EDE (mrem)
LIVERMORE SITE POINT SOURCES																	
Building 235 is part of the Physical and Life Sciences Directorate. Operations in the facility include examination of material structure, surface, and subsurface; precision cutting, ion implanting, and metallurgical studies																	
235	1130	FHE-1A/1B, FHE2A/2B,and	Preparation of plutonium	Gross alpha	[a]	10.7	0.30	7.5	Double HEPA	0.0001	0.0E+00	1429	NE	0.0E+00	[b]	[b]	[b]
		FGBE-1A/1B through	samples for diamond anvil studies	Gross beta	[a]						0.0E+00						
		FHE-1000/2002															
Building 331 is operated by the Weapons and Complex Integration (WCI) Directorate. The building houses the tritium research facility and associated laboratories.																	
331	All[c]	Stack 1	Tritium research and development	H-3	[d]	30.0	1.22	6.7	None	1	1.13E+01	978	ENE	1.5E-03	434	SSW	1.6E-03
		Stack 2	Decontamination of parts	H-3	[d]	30.0	1.22	11.0	None	1	3.26E+01						
Building 332 is operated by the WCI Directorate for plutonium research. Exhausts from glove box operations and the workplace are double or triple filtered by high efficiency particulate air (HEPA) filters. Exhausts are monitored with both continuous filter sampling and continuous real-time monitors (CAMs).																	
332	Increment 1 Rooms	FHE-1000/2000	Plutonium research	Transuranics	[a]	8.8	0.8 x 1.1	16.6	Double HEPA	0.0001	0.0E+00	1283	NE	0.0E+00	[b]	[b]	[b]
332	Increment 1 Glove boxes	FGBE-1000/2000	Plutonium research	Transuranics	[a]	11	0.3	5.9	Triple HEPA	0.000001	0.0E+00	1283	NE	0.0E+00	[b]	[b]	[b]
332	Loft	FE-4,5W	Loft exhaust	Transuranics	[a]	11	0.6 x 0.9	4.1	HEPA	0.01	0.0E+00	1283	NE	0.0E+00	[b]	[b]	[b]
		FE-4,5E	Loft exhaust	Transuranics	[a]	11	0.6 x 0.9	3.8	HEPA	0.01	0.0E+00	1283	NE	0.0E+00	[b]	[b]	[b]
332	Increment 1 Glove boxes	FGBE-3000/4000	Plutonium research	Transuranics	[a]	11	0.3	4.9	Triple HEPA	0.000001	0.0E+00	1283	NE	0.0E+00	[b]	[b]	[b]
332	Increment 3	FFE-1000/2000	Plutonium research	Transuranics	[a]	10.1	0.9	11.6	Room—Double HEPA	0.0001	0.0E+00	1283	NE	0.0E+00	[b]	[b]	[b]
	Room and Glove boxes	FGBE-7000/8000	Plutonium research	Transuranics	[a]	10.1	0.27	4.6	Glove Box—Triple HEPA	0.000001	0.0E+00			0.0E+00	[b]	[b]	[b]
Building 581 is operated by the National Ignition Facility and Photon Science Directorate. Operations of the facility include inertial confinement fusion experiments and stockpile stewardship. Stack exhaust is abated with pre-filters and HEPA filters, activated carbon filters, and molecular sieves. The stack exhaust is continuously monitored for radionuclides.																	
581	NIF	FE-1	ICF Research	Gross alpha	[a]	35	1.3	11.5	Pre-filter plus HEPA	0.0001	0.0E+00	544	SE	0.0E+00	426	ENE	[b,h]
				Gross beta	[a]						0.0E+00			0.0E+00			[b,h]
				Gamma	[f]						0.0E+00			0.0E+00			[b,h]
				Tritium	[d]				Double Molecular Sieves	0.01	1.15E+00			1.1E-05			6.2E-5[b]
				Radioiodines	[g]				Double Activated Carbon Filters	0.01	0.0E+00			0.0E+00			[b,h]
Building 695/696 is the Decontamination Waste Treatment Facility operated by Radiological and Hazardous Waste Management in WCI. All operations are HEPA filtered and have pre-filters in place, some operations have additional HEPA filtration																	
695/696	DWTF	FHE 1000/2000/3000	Waste treatment	Gross alpha	[a]	20.0	1.98	10.1	Pre-filter plus HEPA	0.01	0.0E+00	277	SE	0.0E+00	[b]	[b]	[b,h]
				Gross beta	[a]					0.1	0.0E+00			0.0E+00			[b,h]
SITE 300 POINT SOURCES																	
Building 801 is the Contained Firing Facility, where explosives tests are conducted. This facility and the 851 Firing Table are operated by the Weapons and Complex Integration Directorate																	
801	Contained Firing Facility	FEFH-1, FE-2	Explosive tests	U-234	[a]	16.8	1.60	5.0	Pre-filter plus HEPA	0.01	3.3E-07	3806	SSW	2.8E-07	1717	ENE	2.3E-6[b]
				U-235	[a]					0.1	2.3E-08						
				U-238	[a]						2.3E-06						
LIVERMORE SITE DIFFUSE SOURCES																	
Building 331 - Contaminated equipment outside and inside the facility awaiting decontamination or transport and storage by Radioactive and Hazardous Waste Management																	
331	Outside	Area Source	Storage of contaminated parts	Tritium	[j]	NA	NA	NA	None	1	1.59E+00	966	ENE	2.1E-04	968	WNW	6.9E-04
Building 298 is operated by the National Ignition Facility where Tritium Target fabrications occur																	
298	Outside	Area Source	Storage of low level waste	Tritium	[j]	NA	NA	NA	None	1	4.1E-01	1290	SE	9.1E-06	225	NNE	1.5E-03
The Building 612 Yard is operated by the Radioactive and Hazardous Waste Management Divison. The Yard consists of several areas where containers having radioactive watses are stacked and stored. The containers can outgas tritium.																	
612	Yard	Area Source	Storage of low level waste	tritium	NA	NA	NA	NA	None	1	1.5E-01	577	NNE	9.9E-05	203	SSW	2.5E-04
The Southeast Quadrant of the Livermore Site has slightly elevated levels of Pu-239 in the surface soil and can be resuspended. The source of the Pu-239 was past waste management operations																	
Southeast Quadrant		Area Source	Resuspension	Pu-239	[i]	NA	NA	NA	None	1	NA	NA	NA	4.6E-05	NA	NA	NA
SITE 300 DIFFUSE SOURCES																	
Diffuse sources consist of resuspension of depleted uranium from historical explosive tests.																	
Site 300	All	Area Source	Soil resuspension	U-234	[i]	NA	NA	NA	None	1	NA	NA	NA	4.8E-05	NA	NA	NA
				U-235	[i]						NA						
				U-238	[i]						NA						

NOTE: To convert curies to becquerels use 1 Ci=3.7E+10 Bq and to convert millirem to sieverts use 1 Sv=1.0E+05 mrem.

[a]Gross alpha and Gross beta emissions are continuously monitored at the stack.

[b]Because monitoring takes place after abatement, an unabated EDE cannot be determined from the monitoring data (see discussion in Section 2, Emissions Data).

[c]Stack emissions have been combined as permitted by the EPA/DOE Memorandum of Understanding.

[d]Tritium HT and HTO emissions from the stack are continuously monitored.

[e]Air emissions are continuously sampled at the post-HEPA-filter atmospheric discharge points, although potential emissions are low enough that stack monitoring is not required per the NESHAPs 40 CFR 61 regulations

[f]Gamma Emissions are continuously monitored at the stack

[g]Radioiodines are continuously monitored at the stack

[h]The unabated EDE shown is only for the tritium source term

[i]Continuous monitoring for radioactive particulate is in place at surveillance locations

[j]Continuous monitoring for tritium is in place at surveillance locations

ATTACHMENT 2: METEOROLOGICAL DATA

CAP88-PC requires meteorological data in the form of joint-frequency distributions of wind direction and wind speed organized by stability category. The first line of the file contains three hexadecimal file marks that are ignored by CAP88-PC. The second line is the average wind speed and is not used by CAP88-PC. The third line contains the wind frequency totals (in format 6.4, i.e., 6 places per value, 4 after the decimal place) beginning at the direction, N, and cycling counterclockwise through the wind directions. The following 8 lines contain the reciprocal average (or harmonic average) wind speed (in format 5.3) for each class of wind direction and stability. Each row is a stability class, A through G, and each “column” is the wind direction, again beginning at N and cycling counterclockwise. The next 8 lines are the arithmetic average wind speeds, in the same format as the reciprocal average. The final 16 lines are the frequencies of stability class, with the columns being the stability class and the rows the wind direction, beginning with N and cycling counterclockwise. The wind file for the Livermore Site was created from 2017 data collected from the Livermore Site meteorological tower at the 10-m level; the wind file for Site 300 was created from 2017 data collected from the Site 300 meteorological tower at the 10-m level.

A.2.1 LIVERMORE SITE TOWER

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2.17382
0.04800.03570.04480.05530.03940.03110.05540.06500.03750.01780.01890.03170.09810.13380.17820.1093
1.0001.7321.0001.0001.0001.5921.9402.1341.9011.7961.8051.8862.0242.0841.9702.002
1.4021.0291.0371.1800.8291.4582.3012.7042.2251.9531.5732.0572.7282.5472.5721.711
1.8111.4070.9841.3771.1541.2132.5752.9232.1941.4871.6181.9893.0312.7173.0042.285
1.7301.2300.8420.9081.0180.9851.6452.2072.1221.0480.9491.7512.4642.5653.1112.827
1.3820.9460.8420.7830.6890.8421.1191.0140.9711.0850.9741.4221.8151.8131.7891.701
0.9460.6950.6230.5820.5810.6150.6760.7170.7260.6800.7480.7801.0461.1111.1681.124
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1.0001.7321.0001.0001.0001.6322.0402.2622.0171.8291.8551.9652.1572.2092.0902.063
1.7081.0291.0631.1800.8311.5062.5192.9982.7352.2851.8282.4713.0202.8633.0052.228
2.3082.4821.0381.4291.4511.3192.8303.2853.2991.9982.0272.5693.4113.2833.4773.100
2.6152.1381.1381.1251.3381.1402.0503.6224.0421.4801.0952.2862.9733.1753.5603.705
1.6361.2761.0590.9540.8391.0241.5291.4241.3671.5401.2631.7742.0172.0622.1102.011
1.1140.8000.6900.6300.6340.7090.7960.8190.8180.7290.8460.9361.2071.2961.3191.300
0.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.000
   0.0000   0.0048   0.0407   0.1340   0.2488   0.5718   0.0000
   0.0032   0.0032   0.0193   0.0579   0.1511   0.7653   0.0000
   0.0000   0.0077   0.0103   0.0256   0.1000   0.8564   0.0000
   0.0000   0.0021   0.0062   0.0415   0.0996   0.8506   0.0000
   0.0000   0.0058   0.0175   0.0525   0.1108   0.8134   0.0000
   0.0074   0.0295   0.0517   0.1033   0.1513   0.6568   0.0000
   0.0166   0.1573   0.3064   0.1511   0.1118   0.2567   0.0000
   0.0159   0.1855   0.4205   0.1890   0.0618   0.1272   0.0000
   0.0306   0.1865   0.2171   0.3180   0.0948   0.1529   0.0000
   0.0581   0.1806   0.2000   0.2387   0.1032   0.2194   0.0000
   0.1030   0.2909   0.2364   0.1030   0.0848   0.1818   0.0000
   0.0870   0.2246   0.3080   0.1703   0.0725   0.1377   0.0000
   0.0573   0.2690   0.3064   0.1953   0.0901   0.0819   0.0000
   0.0617   0.2453   0.2161   0.2547   0.1158   0.1063   0.0000
   0.0090   0.0708   0.1681   0.4231   0.1700   0.1590   0.0000
   0.0032   0.0168   0.0714   0.2899   0.2395   0.3792   0.0000
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A.2.2 SITE 300 TOWER

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5.51415
0.03710.05240.02920.01400.01070.01660.02290.03300.07530.12140.08890.06180.07300.16420.15750.0418
2.7021.0003.0983.1391.0002.8572.3542.3672.4292.5963.2971.0003.9751.0001.0001.000
2.0792.8282.2761.8461.8442.1062.2522.2812.8183.1783.8613.0312.7383.4633.7412.500
2.9912.4892.2871.9331.9872.1072.1062.2142.9563.4023.3993.8134.4875.3025.1843.299
3.8723.8594.7602.6761.6981.2261.2661.7103.9745.0704.3554.1695.5247.3008.3764.699
2.1792.1332.0161.6801.3411.4181.1981.6161.4041.8822.0712.0402.0832.6232.0132.185
1.3401.2421.0611.0780.9951.0711.0460.9901.0821.2811.2761.1791.1801.2791.1401.297
0.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.000
2.8201.0003.0983.1391.0002.9302.5072.5682.4792.8333.2971.0003.9751.0001.0001.000
2.4172.9602.4142.0391.9662.4512.5432.5743.2453.6494.1403.4133.1414.1724.3992.744
3.5092.8922.6542.2282.4582.4102.3602.5083.5184.1474.1124.4615.1086.2436.3974.218
4.7374.9657.4904.5062.1581.3621.4942.3276.0976.8465.3234.8986.5568.35710.046.107
2.4302.3142.1091.8271.5391.5401.4371.8711.5582.1302.3152.3152.6063.2052.4722.475
1.4511.4061.1931.1561.0791.1661.1491.0791.2561.3861.4251.3431.3341.4641.3051.418
0.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.0000.000
```

0.0062	0.0154	0.0586	0.4846	0.2654	0.1698	0.0000
0.0000	0.0219	0.0678	0.5624	0.2363	0.1116	0.0000
0.0039	0.0118	0.1137	0.5451	0.1686	0.1569	0.0000
0.0082	0.0574	0.1803	0.2951	0.0984	0.3607	0.0000
0.0000	0.0645	0.2796	0.2581	0.1720	0.2258	0.0000
0.0138	0.2828	0.3172	0.0966	0.1172	0.1724	0.0000
0.0150	0.4450	0.2950	0.0700	0.0700	0.1050	0.0000
0.0278	0.3750	0.3472	0.1042	0.0451	0.1007	0.0000
0.0107	0.3440	0.3623	0.2100	0.0304	0.0426	0.0000
0.0019	0.1152	0.2927	0.4769	0.0661	0.0472	0.0000
0.0013	0.0387	0.1561	0.5652	0.1368	0.1019	0.0000
0.0000	0.0315	0.1206	0.5826	0.1503	0.1150	0.0000
0.0016	0.0126	0.1036	0.6954	0.1162	0.0706	0.0000
0.0000	0.0098	0.0635	0.8422	0.0615	0.0230	0.0000
0.0000	0.0102	0.0313	0.8654	0.0626	0.0306	0.0000
0.0000	0.0055	0.0740	0.5479	0.2521	0.1205	0.0000

ATTACHMENT 3: POPULATION DATA

The source of the geographic population distribution data used for this report is Oak Ridge National Laboratory (ORNL) LandScan™ 2010 data and ESRI ARCMAP software. The data are placed into an annular grid that is created from sixteen 22.5-degree sectors centered on the cardinal wind directions and five distances spaced at 16 km to a total 80-km radius. In deriving the population for each site, the ORNL data set is input into ESRI ARCMAP with the 80-km grid for the Livermore Site centered at 37.686 N latitude, -121.7045 W longitude (near the center of the site) and Site 300 centered at the 52-m meteorological tower located at 37.675 N latitude, -121.541 W longitude. The first line of the input file is informational. Distances are shown in the second row. Population data begin in the third row starting with direction, N. There are 20 spaces reserved for each direction no matter how many are used; i.e., the next direction, NNW, starts approximately half-way through the fifth row, 21 values after the first value.

A.3.1 LIVERMORE SITE

```
$ LLNL, 2010 LIVERMORE     LAT=  37.686 LON=121.7045 NSEC=16 NRADS= 5
       16.0       32.0       48.0       64.0       80.0
     4603.    50952.    51137.     7792.     1670.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.     8306.     2745.   139294.      316.
   205660.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
     6524.    30164.   303953.   126916.   115478.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.    25489.   107100.   223714.   757007.
   248993.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
    71906.   107349.   333955.   451185.   501855.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.    16937.   157636.   148012.   339533.
    19998.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
     1183.   114211.   412258.   157789.     4542.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.      408.    23676.   752857.   280018.
    49939.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
      184.       14.    55832.    71355.    73855.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.      353.        3.       52.       22.
     1300.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
      227.       52.       26.      427.    14103.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.     1589.      130.     1345.    20868.
    74302.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
      285.    24193.     4631.   192319.   206376.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.      303.    61658.    96564.    21120.
     4351.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
      474.     5142.   117528.   287466.    21648.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.     3720.    11446.     1792.     3562.
    31044.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
```

A.3.2 SITE 300

```
$ LLNL, 2010 LIVERMORE     LAT=37.67502 LON=121.541 NSEC=16 NRADS= 5
       16.0      32.0      48.0      64.0      80.0
     5615.     3457.     1896.     4880.    12496.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.      401.    20707.   124388.     6373.
    75585.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
       26.      145.    64103.   269493.   148777.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.     5032.    18097.   125359.   317499.
   590429.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
    10536.   131506.   209722.   366132.   899386.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.      288.     1351.   265880.   336275.
   168555.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
       50.       22.   437134.   819824.    14140.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.       26.        1.    88891.   201189.
    15024.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
       13.       43.       24.    34136.    66497.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        2.        6.       33.        1.
      424.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
       60.        2.     2680.    10933.     9207.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.      165.      868.    19088.    57566.
    67281.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
     1021.     2270.   139601.   234692.    13111.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.    28653.    45774.    35505.    12505.
     1051.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
    50245.    17601.   165338.     8051.     7348.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.     2686.      715.   199143.    79849.
    31433.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
        0.        0.        0.        0.        0.        0.        0.        0.
```

ATTACHMENT 4: UNITS OF MEASURE AND EQUIVALENTS

Symbols and Units of Measure

Bq	becquerel	mph	mile per hour
GBq	gigabecquerel (10^9 Bq)	mrem	millirem (10^{-3} rem)
ºC	degree centigrade	m/s	meter per second
Ci	curie	mrem/y	millirem per year (10^{-3} rem/y)
cm	centimeter	pCi	picocurie (10^{-12} Ci)
ºF	degree Fahrenheit	pCi/m3	picocurie (10^{-12} Ci) per meter cubed
in.	inch	person-Sv	person-sievert
km	kilometer	Sv	sievert
m	meter	µSv	microsievert
mi	mile	µSv/y	microsievert per year

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)	28.6 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	

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