7. Radiological Dose Assessment

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Lawrence Livermore National Laboratory assesses potential radiological doses to biota, off-site individuals, and the population residing within 80 km of either of the two LLNL sites, the Livermore site and Site 300. These potential doses are calculated to determine the impact of LLNL operations, if any, on the general public and the environment, and to demonstrate compliance with regulatory standards set by the U.S. DOE and the U.S. EPA. For protection of the public, DOE has set the limit for prolonged exposure of a maximally exposed individual in an uncontrolled area at 1 mSv/y whole-body effective dose equivalent (EDE), which equals 100 mrem/y EDE. For occasional exposure, the limit is 5 mSv/y (500 mrem/y) EDE. EDEs and other technical terms are defined in the glossary and discussed in "Supplementary Topics on Radiological Dose" (see **Appendix D** or Sanchez [2003], Appendix D).

The release of radioactive material to air is the major source of public radiological exposure from LLNL operations. Therefore, LLNL expends a significant effort monitoring stack air effluent for radiological releases and ambient air for radiological impact due to LLNL operations.

Measurements of radiological releases to air and modeling the dispersion of the released radionuclides are used to determine LLNL's dose to the public. Because LLNL is a DOE facility, it is subject to the requirements of 40 CFR Part 61, Subpart H of the NESHAPs. The EPA's radiation dose standard for members of the public limits the EDE to 100 μSv/y (10 mrem/y) for air emissions. LLNL uses the EPA CAP88-PC computer model to help demonstrate site compliance with NESHAPs regulations. CAP88-PC is used to evaluate the four principal exposure pathways: ingestion, inhalation, air immersion, and irradiation by contaminated ground surface. The relative significance of inhalation and ingestion depends on the assumptions made about the origin of food consumed and the predominant radionuclide contributing to dose.

The major radionuclides measured by LLNL in 2007 that contributed to individual and collective dose were tritium at the Livermore site and three uranium isotopes (uranium-234, uranium-235, and uranium-238) at Site 300. All radionuclides measured at the Livermore site and Site 300 were used to assess dose to biota.

This chapter summarizes detailed radiological dose determinations and identifies trends over time while placing them in perspective with natural background and other sources of radiation exposure.

7.1 Air Dispersion and Dose Models

Computational models are needed to describe the transport and dispersion in air of contaminants and the doses to exposed persons via all pathways. CAP88-PC is the EPA-mandated computer model used by LLNL to compute radiological individual or collective (i.e., population) dose

resulting from radionuclide emissions to air. A site-specific wind parameter file is prepared annually from meteorological data collected by LLNL. The mathematical models and equations used in CAP88-PC are described by Parks (1992).

7.2 Identification of Key Receptors

Dose is assessed for two types of receptors. First is the dose to the site-wide maximally exposed individual (SW-MEI; defined below) member of the public. Second is the collective or "population" dose received by people residing within 80 km of either of the two LLNL sites.

The SW-MEI is defined as the hypothetical member of the public at a single, publicly accessible location who receives the greatest LLNL-induced EDE from all sources at a site. For LLNL to comply with NESHAPs regulations, the LLNL SW-MEI must not receive an EDE equal to or greater than 100 μSv/y (10 mrem/y) from releases of radioactive material to air. Public facilities that could be the location of the SW-MEI include schools, churches, businesses, and residences. This hypothetical person is assumed to remain at one location 24 hours per day, 365 days per year, continuously breathing air having the predicted or observed radionuclide concentration, and consuming a specified fraction of food and drinking water(1) that is affected by the same predicted or observed air concentration caused by releases of radioactivity from the site. Thus, the SW-MEI dose is not received by any actual individual and is a conservative estimate of the highest possible dose that might be received by any member of the public.

In 2007, the SW-MEI at the Livermore site was located at the UNCLE Credit Union, about 10 m outside the site's controlled eastern perimeter, and 957 m east-northeast of the Tritium Facility. The SW-MEI at Site 300 was located on the site's south-central perimeter, which borders the Carnegie State Vehicular Recreation Area. The location was 3170 m south–southeast of the firing table at Building 851. The two SW−MEI locations are shown in **Figure 7-1**.

7.3 Results of 2007 Radiological Dose Assessment

This section summarizes the doses to the most exposed public individuals from LLNL operations in 2007, shows the temporal trends compared with previous years, presents the potential doses to the populations residing within 80 km of either the Livermore site or Site 300, and places the potential doses from LLNL operations in perspective with doses from other sources.

7.3.1 Total Dose to Site-Wide Maximally Exposed Individuals

The total dose to the SW-MEI from Livermore site operations in 2007 was 0.031 μSv/y (0.0031 mrem/y). Of this, the dose attributed to diffuse emissions (area sources) totaled 0.018 μSv (0.0018 mrem) or 58%; the dose due to point sources was 0.013 μSv 0.0013 mrem) or 42% of the total. The point source dose includes Tritium Facility elemental tritium gas (HT) emissions modeled as tritiated water (HTO), as directed by EPA Region IX.

(1) Calculated for tritium only.

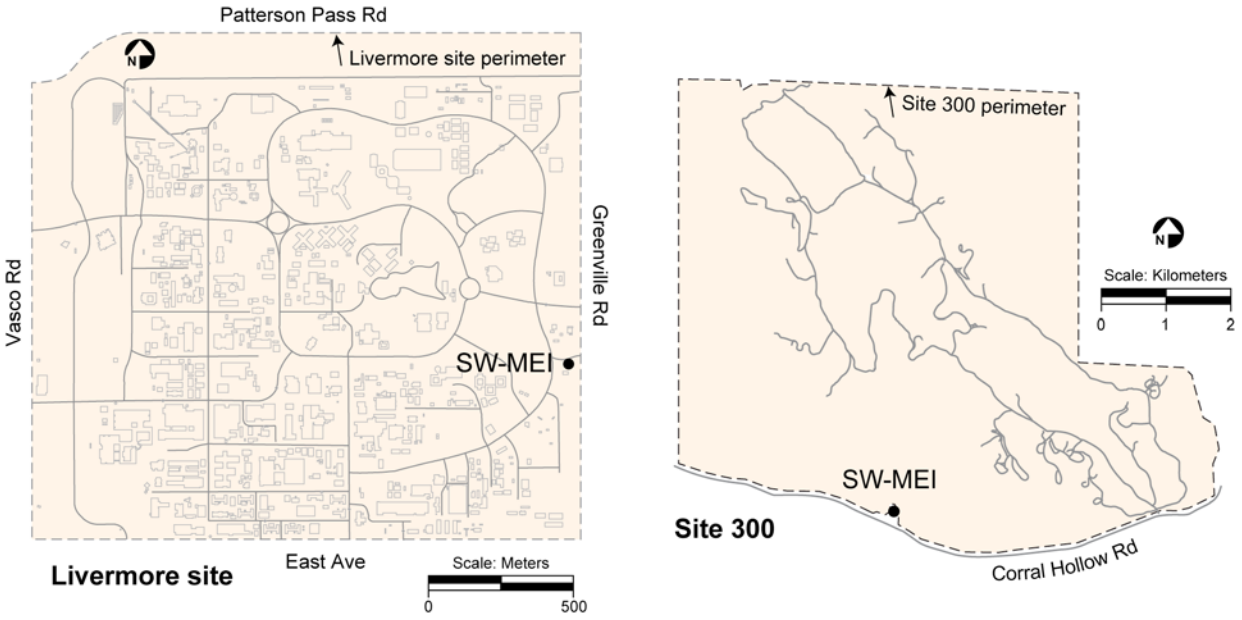

Figure 7-1. Location of the SW-MEI at the Livermore site and Site 300, 2007.

The total dose to the Site 300 SW-MEI from operations in 2007 was 0.035 µSv (0.0035 mrem). Point source emissions from firing table explosives experiments totaled 0.031 µSv (0.0031 mrem) accounting for 90% of the dose, while 0.004 µSv (0.0004 mrem), or about 10%, was contributed by diffuse emission sources.

Table 7-1 shows the facilities or sources that accounted for nearly 100% of the dose to the SW-MEI for the Livermore site and Site 300 in 2007. Although LLNL has nearly 150 sources with the potential to release radioactive material to air according to NESHAPs prescriptions, most are very minor. Nearly the entire radiological dose to the public in 2007 from LLNL operations came from no more than six sources. LLNL uses, with permission from EPA, surveillance monitoring in place of inventory-based modeling to account for dose contributions from the numerous minor sources.

Dominant radionuclides at the two sites were the same as in recent years. Tritium accounted for about 86% of the Livermore site's calculated dose. At Site 300, practically the entire calculated dose was due to the isotopes uranium-238, uranium-235, and uranium-234 from depleted uranium. Regarding pathways of exposure, for individual doses calculated for tritium, the ingestion dose accounts for slightly more than the inhalation dose, approximately 53% and 47%, respectively. For uranium, the inhalation pathway dominates: 97% by the inhalation pathway versus 3% via ingestion. Air immersion and ground irradiation pathways are negligible for both tritium and uranium.

Table 7-1. List of facilities or sources whose combined emissions accounted for nearly 100% of the SW-MEI doses for the Livermore site and Site 300 in 2007.

Site	Facility (source category)	CAP88-PC dose (µSv/y)[a]	CAP88-PC contribution to total dose
Livermore site	Tritium Facility stacks (point source)	0.013	42%
	Building 612 yard (diffuse source)	0.010	32%
	Southeast quadrant soil resuspension (diffuse source)	0.0040	13%
	Tritium Facility outside (diffuse source)	0.0040	13%
Site 300	Building 851 firing table (point source)	0.031	90%
	Soil resuspension (diffuse source)	0.0035	10%

(a) 1 µSv = 0.1 mrem

The doses to the SW-MEI from emissions at the Livermore site and Site 300 since NESHAPs reporting began are shown in **Table 7-2**. These SW−MEI dose estimates are conservative, predicting potential doses that are higher than actually would be experienced by any member of the public, and are all less than 10% of the federal standard of 100 µSv/y.

7.3.2 Doses from Unplanned Releases

There were no unplanned atmospheric releases of radionuclides at the Livermore site or Site 300 in 2007.

7.3.3 Collective Dose

Collective dose for both LLNL sites was calculated using CAP88-PC for a radius of 80 km from the site centers. Population centers affected by LLNL emissions within the 80-km radius include the nearby communities of Livermore and Tracy; the more distant metropolitan areas of Oakland, San Francisco, and San Jose; and the San Joaquin Valley communities of Modesto and Stockton. Within the 80-km radius specified by DOE, there are 7.1 million residents included for the Livermore site collective dose determination and 6.2 million for Site 300. The source of the geographic population distribution data used for this report is Dobson et al. (2000).

The CAP88-PC result for potential collective dose attributed to 2007 Livermore site operations was 0.0050 person-Sv (0.50 person-rem); the corresponding collective dose from Site 300 operations was 0.0028 person-Sv (0.28 person-rem).

Although collective doses from LLNL operations are tiny compared with doses from natural background radiation, they may be high compared with other DOE facilities due to large populations within 80 km of the LLNL sites. However, a large dose to a small number of people is not equivalent to a small dose to many people, even though the collective dose may be the same. Given that the population centers potentially affected by LLNL operations are distant from both the Livermore site and Site 300, the collective doses from LLNL operations are better described by breaking them down into categories of dose received by individuals in the

population affected. The breakdown (or disaggregation) of collective dose by the level of the individual dose is shown in **Table 7-3**.

Table 7-2. Doses calculated for the SW-MEI for the Livermore site and Site 300, 1990 to 2007.

Site	Year	Total Dose (μSv/y)[a]	Site	Year	Total Dose (μSv/y)[a]
Livermore site	2007	0.031	Site 300	2007	0.035
	2006	0.045		2006	0.16
	2005	0.065		2005	0.18
	2004	0.079		2004	0.26
	2003	0.44		2003	0.17
	2002	0.23		2002	0.21
	2001	0.17		2001	0.54
	2000	0.38		2000	0.19
	1999	1.2		1999	0.35
	1998	0.55		1998	0.24
	1997	0.97		1997	0.20
	1996	0.93		1996	0.33
	1995	0.41		1995	0.23
	1994	0.65		1994	0.81
	1993	0.66		1993	0.37
	1992	0.79		1992	0.21
	1991	2.34		1991	0.44
	1990	2.40		1990	0.57

(a) 1 μSv = 0.1 mrem

7.3.4 Doses to the Public Placed in Perspective

As a frame of reference to gauge the size of the LLNL doses, **Table 7-4** compares them to average doses received in the United States from exposure to natural background radiation and other sources. These values vary with location. Collective doses from LLNL operations in 2007 are more than 100,000 times smaller than ones from natural background radiation. The estimated maximum potential doses to individual members of the public from operations at either of the two LLNL sites in 2007 are more than 10,000 times smaller than ones received from background radiation in the natural environment.

Table 7-3. Collective dose broken down by level of individual doses, 2007.

Site	Individual dose range (μSv/y)[a]		Collective dose (person-Sv/y)[b]	Percent total collective dose
Livermore site	0.01 to 0.1		0.000016	<1
	0.001 to 0.01		0.00029	6
	0.0001 to 0.001		0.0047	94
		Total	0.0050[c]	100
Site 300[d]	0.01 to 0.1		0.000055	2
	0.001 to 0.01		0.00097	35
	0.0001 to 0.001		0.00175	63
		Total	0.0028	100

(a) 1 μSv = 0.1 mrem

(b) 1 person-Sv = 100 person-rem

(c) Collective dose output from CAP88-PC for each sector and each distance from the source is in two significant figures. When dose is calculated by summing outputs for each sector and distance, as is done for the disaggregation of collective dose, the total collective dose may be slightly different from the total calculated directly by CAP88-PC.

(d) Dose from Building 851 firing table.

Table 7-4. Comparison of radiation doses from LLNL sources to average doses from background (natural and man-made) radiation, 2007.

Location/source	Category	Individual dose[a] (μSv)[c]	Collective dose[b] (person-Sv)[d]
LLNL			
Livermore site sources	Atmospheric emissions	0.031	0.0050
Site 300 sources	Atmospheric emissions	0.035	0.0028
Other sources[e] (background)	Natural radioactivity[f,g]		
	Cosmic radiation	300	2,130
	Terrestrial radiation	300	2,130
	Internal (food and water consumption)	400	2,840
	Radon	2,000	14,200
	Medical radiation (diagnostic procedures)[f]	530	3,760
	Weapons test fallout[f]	10	71
	Nuclear fuel cycle	4	28

(a) For LLNL sources, this dose represents that experienced by the SW-MEI.

(b) The collective dose is the combined dose for all individuals residing within an 80-km radius of LLNL (approximately 7.1 million people for the Livermore site and 6.2 million for Site 300), calculated with respect to distance and direction from each site. The Livermore site population estimate of 7.1 million people was used to calculate the collective doses for "Other sources."

(c) 1 μSv = 0.1 mrem

(d) 1 person-Sv = 100 person-rem

(e) From National Council on Radiation Protection and Measurements (NCRP 1987a,b)

(f) These values vary with location.

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

7.4 Special Topics on Dose Assessment

7.4.1 Compliance Demonstration for Minor Sources

From 1991 through 2002, LLNL demonstrated compliance for minor sources of radiation through a labor-intensive inventory and modeling process. The dose consequences to the public for these sources were 8 to 20 orders of magnitude below the regulatory standard of 100 μSv/y (10 mrem/y) and did not justify the level of effort expended in accounting for them. To better allocate resources, in March 2003 LLNL made a request to EPA, pursuant to the NESHAPs regulations, to use existing ambient air monitoring to demonstrate compliance for minor sources. The request was granted by EPA in April 2003, and LLNL began implementation of the approved process with calendar year 2003 data. LLNL demonstrates NESHAPs compliance for minor sources by comparing measured ambient air concentrations at the location of the SW-MEI to concentration limits set by the EPA in 40 CFR Part 61, Table 2, Appendix E. The radionuclides for which the comparison is made are tritium and plutonium-239+240 for the Livermore site SW-MEI and uranium-238 for the Site 300 SW-MEI. At the Livermore site, the average of the monitoring results for locations VIS and CRED represents the SW-MEI. At Site 300, the minor source that has the potential to have a measurable effect is the resuspension of depleted uranium contaminated soil. Because this is a diffuse source, the average of the results for all monitoring locations at the site is used to represent the SW-MEI.

The standards contained in 40 CFR Part 61, Table 2, Appendix E, and the measured concentrations at the SW-MEI are presented in SI units in **Table 7-5**. As demonstrated by the calculation of the fraction of the standard, LLNL-measured air concentrations for tritium and plutonium-239+240 and uranium-238 are less than one–one-hundredth of the health protective standard for these radionuclides.

Table 7-5. Mean concentrations of radionuclides of concern at the location of the SW-MEI in 2007.

Location	Nuclide	EPA concentration standard (Bq/m^3)	Detection limit (approximate) (Bq/m^3)	Mean measured concentration (Bq/m^3)	Measured concentration as a fraction of the standard
Livermore SW-MEI	Tritium	56	0.037	0.036[(a)]	6.4×10^{-4}
Livermore SW-MEI	Plutonium-239	7.4×10^{-5}	1.9×10^{-8}	5.9×10^{-9}[(b)]	8.0×10^{-5}
Site 300 SW-MEI	Uranium-238	3.1×10^{-4}	1.1×10^{-9}	3.5×10^{-7}[(c)]	1.1×10^{-3}

Note: 1 Bq = 2.7×10^{-11} Ci

(a) The tritium value includes contributions from the Tritium Facility, Building 612 yard, Tritium Facility outside yard, and contributions from other minor sources. The mean measured concentration for tritium is less than the approximate detection limit; nonetheless, 50 of the 56 values composing the mean were measured detections.

(b) The mean measured concentration for plutonium is less than the detection limit; only 3 of the 15 values composing the mean were measured detections. Only values greater than zero are used in the calculation of the mean.

(c) The ratio for the mean uranium-235 and uranium-238 concentrations for 2007 is 0.0071, which is less than 0.00725, the ratio of these isotopes for naturally occurring uranium. This results in approximately 97% of the resuspension being attributable to naturally occurring uranium and 3% being attributable to depleted uranium.

7.4.2 Estimate of Dose to Biota

Biota (flora and fauna) also need to be protected from potential radiological exposure from LLNL operations since their exposure pathways are unique to their environment (e.g., a ground squirrel may be exposed to dose by burrowing in contaminated soil). Thus, LLNL calculates potential dose to biota from LLNL operations according to *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (U.S. DOE 2002) and by using the RESRAD-BIOTA computer code, a tool for implementing DOE's graded approach to biota dose evaluation.

Limits on absorbed dose to biota are 10 mGy/d (1 rad/d) for aquatic animals and terrestrial plants, and 1 mGy/d (0.1 rad/d) for terrestrial animals. At LLNL in 2007, radionuclides contributing to dose to biota were americium-241, cesium−137, tritium, plutonium-238, plutonium-239, thorium-232, uranium-234, uranium−235, and uranium-238. In the 2007 LLNL assessment, the maximum concentration of each radionuclide measured in soils, sediments, and surface waters was used in the dose screening calculations; the maximum concentration may have occurred on the Livermore site, in the Livermore Valley, or on Site 300. This approach resulted in an assessment that was unrealistically conservative, given that the maximum concentrations in the media are scattered over a very large area, and no plant or animal could possibly be exposed to them all. Furthermore, although biota would most likely live in and near permanent bodies of water (i.e., surface water), measurements of storm water runoff were used for the assessment because higher concentrations of radionuclides are measured in runoff than in surface waters.

In the RESRAD-BIOTA code, each radionuclide in each medium (i.e., soil, sediment, and surface water) is assigned a Biota Concentration Guide (BCG). Radionuclide concentrations in each medium are divided by the BCG, and the resulting fractions for each nuclide and medium are summed. 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 sums of the fractions for the aquatic and terrestrial systems are both less than 1 (i.e., the dose to the biota does not exceed the screening limit), the site has passed the screening analysis and biota are assumed to be protected. In 2007, the sum of the fractions for the aquatic system was 0.032, and the sum for the terrestrial system was 0.043. These results are similar to those for previous years.

7.5 Environmental Impact

The annual radiological doses from all emissions at the Livermore site and Site 300 in 2007 were found to be well below the applicable standards for radiation protection of the public, in particular the NESHAPs standard. This standard limits to 100 μSv/y (10 mrem/y) the EDE to any member of the public arising as a result of releases of radioactive material to air from DOE facilities. Using an EPA-mandated computer model and actual LLNL meteorology appropriate to the two sites, potential doses to the LLNL SW-MEI members of the public from LLNL operations in 2007 were:

- Livermore site: 0.031 μSv (0.0031 mrem)—42% from point-source emissions; 58% from diffuse-source emissions.
- Site 300: 0.035 μSv (0.0035 mrem)—90% from explosive experiments, which are classified as point-sources; 10% from diffuse-source emissions.

As noted earlier, the major radionuclides accounting for the doses were tritium at the Livermore site and the three isotopes of depleted uranium (uranium-234, uranium-235, and uranium-238) at Site 300. The only significant exposure pathway contributing to dose from LLNL operations was release of radioactive material to air, leading to doses by inhalation and ingestion.

The collective EDE attributable to LLNL operations in 2007 was estimated to be 0.0050 person-Sv (0.50 person-rem) for the Livermore site and 0.0028 person-Sv (0.28 person-rem) for Site 300. These doses include potentially exposed populations of 7.1 million people for the Livermore site and 6.2 million people for Site 300 living within a distance of 80 km from the site centers.

The doses to the SW-MEI, which represent the maximum doses that could be received by members of the public resulting from Livermore site and Site 300 operations in 2007, both were less than 1% of the federal standard and were more than 10,000 times smaller than the dose from background radiation. The collective doses from LLNL operations in 2007 were more than 100,000 times smaller than those caused by natural radioactivity in the environment.

Potential doses to aquatic and terrestrial biota from LLNL operations were assessed and found to be well below DOE screening dose limits.

Potential radiological doses from LLNL operations were well below regulatory standards and were very small compared with doses normally received from natural background radiation sources, even though highly conservative assumptions were used in the determination of LLNL doses. The potential maximum doses to the public indicate that LLNL's use of radionuclides had no credible impact on public health during 2007.