7. Radiological Dose Assessment

Nicholas A. Bertoldo • Gretchen M. Gallegos

Lawrence Livermore National Laboratory assesses potential radiological doses to biota, off-site individuals, and the population residing within 80 km of each 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**).

A release of radioactive material to air would be the primary source pathway 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 and to ensure that the doses to the public are kept as low as reasonably achievable (ALARA) .

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 National Emission Standards for Hazardous Air Pollutants (NESHAPs) – Radiological Air. 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 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 dose depends on radionuclide air emission from operations and dose from resuspended radionuclides in soil, whereas the ingestion dose is predicted on assumptions made about the radionuclide concentration in food from the assessment area contributing to the total dose.

In 2009, the radionuclides measured and modeled that contributed to individual and collective doses were tritium and plutonium 239+240 at the Livermore site and 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 in 2009.

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 individual or collective (i.e., population) radiological doses resulting from any radionuclide air emissions. The dispersion parameter file consisting of the meteorological model specific input parameters is prepared from data collected by each LLNL meteorological tower. 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) 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.

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. In order for LLNL to comply with the NESHAPs regulation, the LLNL SW-MEI must not receive an EDE equal to or greater than 100 μSv/y (10 mrem/y) from any radioactive air emission. This hypothetical person is assumed to remain at the SW-MEI 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 predicated on the exposure conditions specified above.

In 2009, 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 2009 Radiological Dose Assessment

This section summarizes the doses to the most exposed public individuals from LLNL operations in 2009, 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.

(1) Calculated for tritium only.

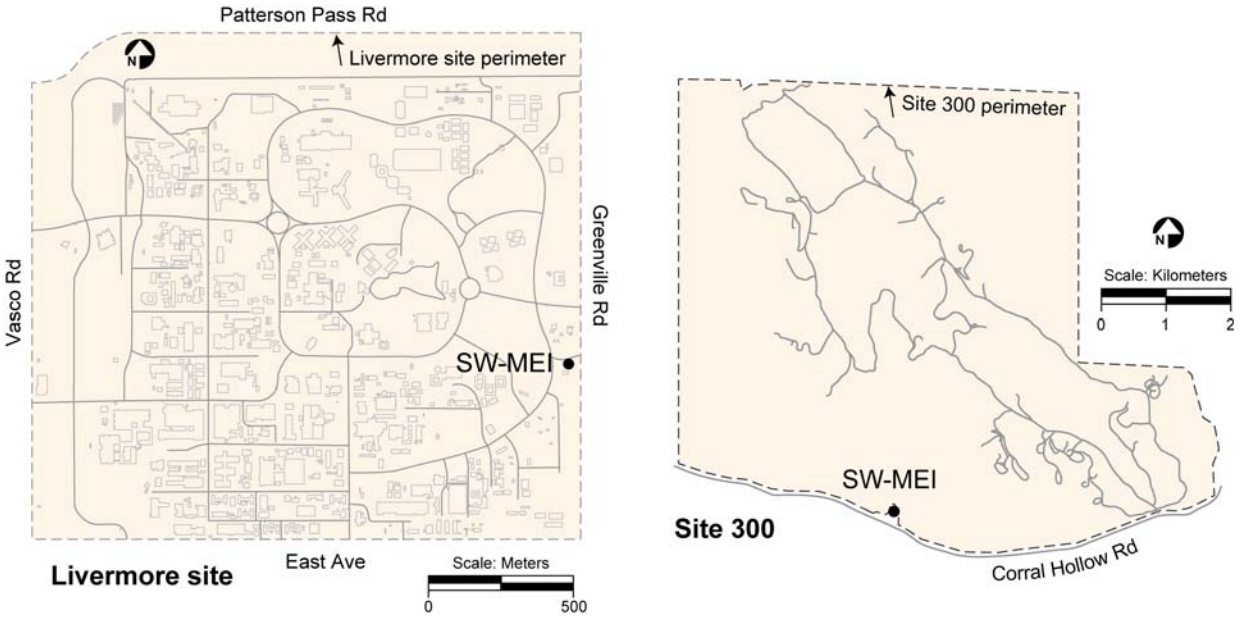

Figure 7-1. Location of the SW-MEI at the Livermore site and Site 300, 2009.

7.3.1 Total Dose to Site-Wide Maximally Exposed Individuals

The total dose to the SW-MEI from Livermore site operations in 2009 was 0.042 μSv/y (0.0042 mrem/y). Of this, the dose attributed to diffuse emissions (area sources) totaled 0.027 μSv (0.0027 mrem) or 64%; the dose due to point sources was 0.015 μSv 0.0015 mrem) or 36% 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.

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 2009. 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 2009 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.

In 2009 at Site 300, there were no outdoor firing table explosive experiments using depleted uranium to produce any emissions. No resuspension of depleted uranium was detected at the SW-MEI location from pre-existing concentrations. Radioactive emissions from Site 300 were solely from the Contained Firing Facility. The calculated dose to the SW-MEI (2.7×10^{-6} μSv/y [2.7×10^{-7} mrem/y]) was due to the isotopes uranium-238, uranium-235, and uranium-234.

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 2009.

Site	Facility (source category)	CAP88-PC dose (μSv/y)[a]	CAP88-PC contribution to total dose
Livermore Site	Tritium Facility stacks (point source)	1.5×10^{-2}	35.7%
	Building 331 WAA, Building 612 Yard (diffuse sources)	1.7×10^{-3}	40%
	Southeast quadrant soil resuspension (diffuse source)	1.0×10^{-2}	23.8%
Site 300	Contained Firing Facility	2.7×10^{-6}	100%

(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 (10 mrem/y).

7.3.2 Doses from Unplanned Releases

There were no unplanned atmospheric releases of radionuclides at the Livermore site or Site 300 in 2009.

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 7.22 million residents included for the Livermore site collective dose determination and 6.7 million for Site 300. The populations were derived using ORNL LandScan 2007 data and ESRI ARCMAP software.

The CAP88-PC result for potential collective dose attributed to 2009 Livermore site operations was 0.002 person-Sv (0.2 person-rem); the corresponding collective dose from Site 300 operations was 5.11×10^{-7} person-Sv (5.11×10^{-5} person-rem).

Because LLNL is surrounded by a significant population residing within an 80-km radius, even a very small dose when multiplied by a large population number will result in a collective dose that overemphasizes the operational dose to the public at specific distances from the source. For this reason, the International Commission on Radiological Protection (ICRP) recommended that regulatory limits not be set in term of a collective dose (ICRP 2005). As in LLNL's case, when individual doses range greatly over large distances, the dose distribution are more appropriately characterized by subdividing the individual dose into several ranges whereby the population size, mean individual dose, collective dose, and associated uncertainties are representative of each range. (For further information, see NCRP [1995]).

Table 7-2. Doses calculated for the SW-MEI for the Livermore site and Site 300, 1990 to 2009.

Site	Year	Annual Dose (μSv)[a]	Site	Year	Annual Dose (μSv)[a]
Livermore site	2009	0.042	Site 300	2009	2.7×10^{-6}
	2008	0.013		2008	4.4×10^{-7}
	2007	0.031		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 7-3** compares them to average doses received in the United States from exposure to natural background radiation and other sources. The collective dose is high even though the individual dose is very small. This is due to the high population density in the 80-km radius. Moreover, the overall contribution of dose from LLNL operations in 2009 is overshadowed by natural radiation.

Table 7-3. Comparison of radiation doses from LLNL sources to average doses from background (natural and man-made) radiation, 2009.

Location/source	Category	Individual dose[a] (μSv)[c]	Collective dose[b] (person-Sv)[d]
LLNL			
Livermore site sources	Atmospheric emissions	0.042	0.002
Site 300 sources	Atmospheric emissions	2.7×10^{-6}	5.1×10^{-7}
Other sources[e] (background)	Natural radioactivity[f,g]		
	Cosmic radiation	300	2,170
	Terrestrial radiation	300	2,170
	Internal (food and water consumption)	400	2,888
	Radon	2,000	14,440
	Medical radiation (diagnostic procedures)[f]	530	3,827
	Weapons test fallout[f]	10	72
	Nuclear fuel cycle	4	29

(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 7.22 million people for the Livermore site and 6.7 million for Site 300), calculated with respect to distance and direction from each site. The Livermore site population estimate of 7.22 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

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 location 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 and is represented by location PSTL.

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 7-4**. 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 7-4. Mean concentrations of radionuclides of concern at the location of the SW-MEI in 2009.

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	5.9×10^{-2}(a)	1.1×10^{-3}
Livermore SW-MEI	Plutonium-239	7.4×10^{-5}	1.9×10^{-8}	1.44×10^{-8}(b)	1.9×10^{-4}
Site 300 SW-MEI	Uranium-238	3.1×10^{-4}	1.1×10^{-9}	7.4×10^{-7}(c)	2.4×10^{-3}

Note: 1 Bq = 2.7×10^{-11} Ci

(a) The measured tritium value includes contributions from all minor sources (including the Building 612 Yard and the Building 331 Outside Yard), Tritium Facility, and DWTF; it is not possible to differentiate the contributions of the Tritium Facility and DWTF from those of the minor sources.

(b) The mean measured concentration is less than the detection limit.

(c) The ratio for the mean uranium-235 and uranium-238 concentrations for 2008 is 0.00725, which is equal to the ratio of these isotopes for naturally occurring uranium. This value for uranium-238 is from naturally occurring uranium resuspended in the soil.

7.4.1 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 2009, 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 2009 LLNL assessment, the maximum concentration of each radionuclide measured in soils and surface waters was used in the dose screening calculations. This approach resulted in an assessment that is extremely conservative, given that the maximum concentrations in the media are distributed over a very large area. Specifically, it accounts for the exposure at both the Livermore site and Site 300 and no plant or animal would likely be exposed to both. 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 (e.g., 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 2009, the sum of the fractions for the aquatic system was 0.0714, and the sum for the terrestrial system was 0.0243 with a total of 0.0957 for the combined fraction. The predominant contribution is due to uranium in the Site 300 soil.

7.5 Environmental Impact

The annual radiological doses from all emissions at the Livermore site and Site 300 in 2008 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 2009 were:

- Livermore site: 0.042 μSv (0.0042 mrem)—36% from point-source emissions; 64% from diffuse-source emissions.
- Site 300: 2.7×10^{-6} μSv (2.7×10^{-7} mrem)—100% from the point source emissions.

As noted earlier, the major radionuclides accounting for the doses were tritium and plutonium at the Livermore site and the three isotopes of 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 2009 was estimated to be 0.002 person-Sv (0.2 person-rem) for the Livermore site and 5.1×10^{-7} person-Sv (5.1×10^{-5} person-rem) for Site 300. These doses include potentially exposed populations of 7.22 million people for the Livermore site and 6.7 million people for Site 300 living within 80 km of 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 2009 were insignificant compared to both the federal standard and the dose received from natural background sources. The collective doses from LLNL operations in 2009 reflect the large population within the 80-km range of the Livermore site and Site 300.

Potential doses to aquatic and terrestrial biota from LLNL operations were assessed using RESRAD-BIOTA and found to be well below DOE screening dose limits due to the extremely low levels of the radionuclides of concern present in the soil and water samples that represent the source of exposure for the biota.

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 2009.