Chapter 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 kilometers (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. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA).

The release of radioactive material to air is the major source of public radiological exposure form LLNL operations. Therefore, LLNL expends a significant effort monitoring stack air effluent for radiological releases and ambient air for evidence of any radiological impact due to LLNL operations (see **Chapter 4**). In addition, LLNL monitors radioactivity in a variety of media including soil, sediment, vegetation, and wine, and measures environmental gamma

radiation (see **Chapter 6**). LLNL also samples wastewaters, storm water, groundwater, rainfall, and local surface water (see **Chapter 5**). Releases to water systems are not a source of direct exposure to the public because the water is not consumed directly.

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 Title 40 of the *Code of Federal Regulations*, Part 61, (40 CFR Part 61), Subpart H, the National Emission Standards for Hazardous Air Pollutants (NESHAPs). LLNL uses the EPA Clean Air Act Assessment Package-1988 (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 major radionuclides measured by LLNL in 2006 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 Releases of Radioactivity from LLNL Operations

Radiological releases to air are estimated by three principal means: continuous monitoring of stack effluent at selected facilities (described in **Chapter 4**); routine surveillance ambient air monitoring for radioactive particles and gases, both on and off LLNL property (also described in **Chapter 4**); and radioactive material usage inventories. Of these three approaches, stack monitoring provides the most definitive characterization. Beginning in 2003, reliance on usage inventories declined in favor of increased utilization of ambient air monitoring data (see **Section 7.6.1**).

7.2 Radiation Protection Standards

The release of radionuclides from operations at LLNL and the resultant radiological impact to the public are regulated by both DOE and the 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 millisievert per year (1 mSv/y) whole-body effective dose equivalent (EDE), which equals 100 millirem per year (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 F** or Sanchez [2003], Appendix D). These limits pertain to the sum of the EDE from external radiation and the committed 50-year EDE from radioactive materials ingested or inhaled during a particular year that may remain in the body for many years.

The EPA's radiation dose standard for members of the public limits the EDE to 100 μSv/y (10 mrem/y) for air emissions. EPA regulations specify not only the allowed levels but also the approved methods by which airborne emissions and their impacts must be evaluated. With respect to all new or modified projects, NESHAPs compliance obligations define the requirements to install continuous air effluent monitoring. NESHAPs regulations require that any operation with the potential to produce an annual average off-site dose greater than or equal to 1 μSv/y (0.1 mrem/y), taking full credit for emission-abatement devices such as high-efficiency particulate air (HEPA) filters, must obtain EPA approval prior to the startup of operations. This same calculation, but without taking any credit for emission abatement devices, determines whether continuous monitoring of emissions to air from a project is required. These requirements are described in the LLNL *Environment, Safety and Health (ES&H) Manual*, Document 31.2, Radiological Air Quality Compliance.

7.3 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 DOE- and EPA-mandated computer model used by LLNL to compute radiological individual or collective (i.e., population) dose resulting from radionuclide emissions to air.

CAP88-PC uses a modified Gaussian plume equation to estimate the average dispersion of radionuclides released from up to six collocated sources. Input parameters used in the code include radionuclide type, emission rate in curies per year (Ci/y), and stack parameters such as stack height, inside diameter, and exit velocity. 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 in Parks (1992).

Calculated doses include the four principal exposure pathways. Internal exposures are inhalation of air and ingestion of foodstuff and drinking water; drinking water dose is calculated only for tritium. External exposures are irradiation from contaminated ground and immersion in contaminated air. Dose is calculated as a function of radionuclide, pathway, spatial location, and body organ.

CAP88-PC also provides the flexibility to adjust agricultural parameters (e.g., numbers of milk cows per km^2) and the fractions of contaminated foods ingested. For the 2006 evaluation, as for 2004 and 2005, LLNL took advantage of this capability and used updated assumptions for agricultural and food source parameters for CAP88-PC (see Larson et al. 2007). Furthermore, an improved tritium model, NEWTRIT (Peterson and Davis 2002), which uses air concentrations predicted by CAP88-PC to address the dose from releases of

elemental tritium gas (HT) and from the ingestion of organically bound tritium (OBT), was again employed to compare with the tritium model in CAP88-PC.

7.4 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[(a)] 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 2006, the SW-MEI at the Livermore site was located at the UNCLE Credit Union, about 10 meters (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**.

7.5 Results of 2006 Radiological Dose Assessment

This section summarizes the doses to the most exposed public individuals from LLNL operations in 2006, 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.

(a) Calculated for tritium only.

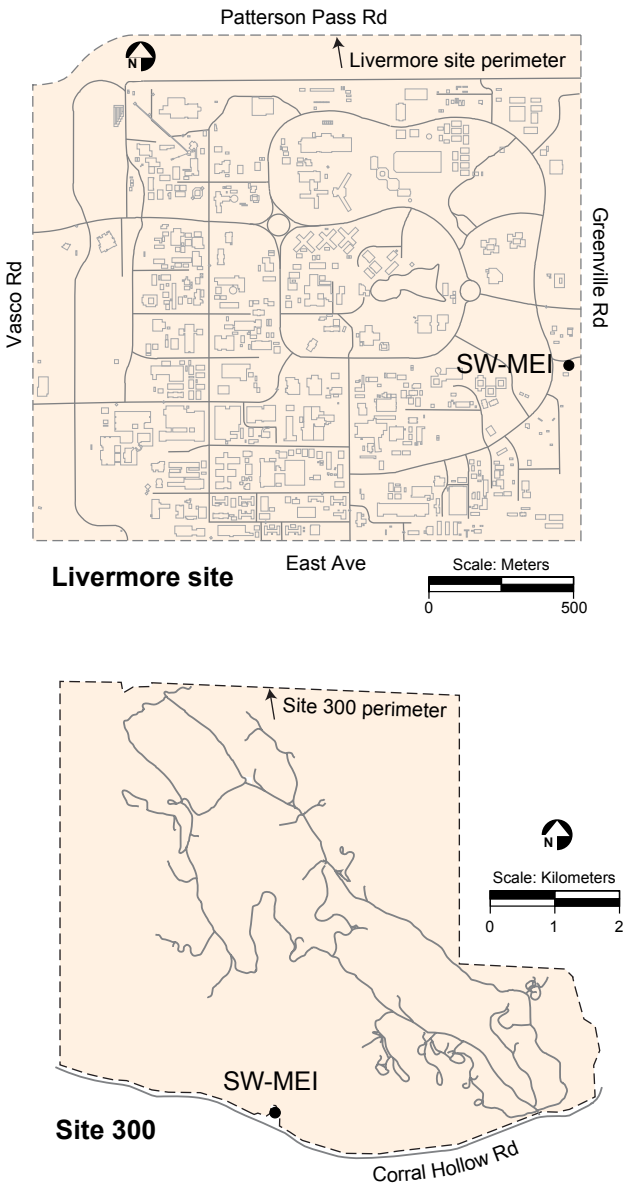

Figure 7-1. Location of the site-wide maximally exposed individual (SW-MEI) at the Livermore site and Site 300, 2006.

7.5.1 Total Dose to Site-Wide Maximally Exposed Individuals

The total dose to the SW-MEI from Livermore site operations in 2006 was 0.045 µSv/y (0.0045 mrem/y). Of this, the dose attributed to diffuse emissions (area sources) totaled 0.029 µSv (0.0029 mrem) or 64%; the dose due to point sources was 0.016 µSv (0.0016 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. Using NEWTRIT rather than CAP88-PC to calculate the dose for tritium emissions reduced the tritium component of the total dose from 0.040 µSv (0.0040 mrem) to 0.030 µSv (0.0030 mrem).

The total dose to the Site 300 SW-MEI from operations in 2006 was 0.16 µSv (0.016 mrem). Point source emissions from firing table explosives experiments totaled 0.14 µSv (0.014 mrem) accounting for 87.5% of the dose, while 0.020 µSv (0.0020 mrem), or about 12.5%, 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 2006. 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 each year from LLNL operations comes from no more than six sources. In April 2003, EPA granted LLNL permission to use surveillance monitoring in place of inventory-based modeling to account for dose contributions from the numerous minor sources. This procedure was implemented for the fourth time in assessing 2006 operations (see Larson et al. 2007).

Dominant radionuclides at the two sites were the same as in recent years. Tritium accounted for about 89% of the Livermore site's calculated dose. At Site 300, practically the

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 2006.

Site	Facility (source category)	CAP88-PC dose (μSv/y)[a]	CAP88-PC contribution to total dose
Livermore site	Tritium Facility stacks (point source)	0.016[b]	36%
	Building 612 yard (diffuse source)	0.013[(b)]	29%
	Tritium Facility outside (diffuse source)	0.011[(b)]	25%
	Southeast quadrant soil resuspension (diffuse source)	0.0046	10%
Site 300	Soil resuspension (diffuse source)	0.020	12.5%
	Building 851 firing table (point source)	0.14	87.5%

(a) 1 μSv = 0.1 mrem

(b) When LLNL's NEWTRIT model is used in place of CAP88-PC's default tritium model, the dose for the Tritium Facility's stacks is reduced to approximately 57% of the value shown, and doses for the Building 612 yard and Tritium Facility outside are reduced to 89% of the values shown.

entire calculated dose was due to the isotopes uranium-238, uranium-235, and uranium-234 from depleted uranium. Regarding pathways of exposure, 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. 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.

The trends in dose to the SW-MEI from emissions at the Livermore site and Site 300 over the last 17 years are shown in **Table 7-2**. The general pattern, particularly over the last decade, shows year-to-year fluctuations around a low dose level, staying at or below about 1% of the federal standard. The SW-MEI dose estimates are intentionally conservative, predicting potential doses that are higher than actually would be experienced by any member of the public.

7.5.2 Doses from Unplanned Releases

In June 2006 at the Livermore site, a solid titanium tritide source was transferred from one building to another for potential use as a check source. Subsequently, after routine radiation swipes identified tritium contamination in both buildings, it was determined that this legacy source had leaked tritiated particulate matter. During the transfer, the source was wrapped, but tritium contamination was inadvertently spread to the environment via personnel contact with the particulate matter. Contamination that measured above the DOE's release limit for tritium contamination was remediated. The bioassays performed for the personnel who

Table 7-2. Doses calculated for the site-wide maximally exposed individual (SW-MEI) for the Livermore site and Site 300, 1990 to 2006.

		Dose (μSv/y)[a]		
Site	Year	Total	Point source	Diffuse source
Livermore site	2006	0.045[b]	0.016[b]	0.029
	2005	0.065[b]	0.027[b]	0.038
	2004	0.079[b]	0.021[b]	0.058
	2003	0.44[b]	0.24[b]	0.20
	2002	0.23[b]	0.10[b]	0.13
	2001	0.17[b]	0.057[b]	0.11
	2000	0.38[b]	0.17[b]	0.21
	1999	1.2[b]	0.94[b]	0.28
	1998	0.55[b]	0.31[b]	0.24
	1997	0.97	0.78	0.19
	1996	0.93	0.48	0.45
	1995	0.41	0.19	0.22
	1994	0.65	0.42	0.23
	1993	0.66	0.40	0.26
	1992	0.79	0.69	0.10
	1991	2.34	2.34	—[c]
	1990	2.40	2.40	—[c]
Site 300	2006	0.16	0.14	0.020
	2005	0.18	0.088	0.094
	2004	0.26	0.25	0.0086
	2003	0.17	0.17	0.0034
	2002	0.21	0.18	0.033
	2001	0.54	0.50	0.037
	2000	0.19	0.15	0.037
	1999	0.35	0.34	0.012
	1998	0.24	0.19	0.053
	1997	0.20	0.11	0.088
	1996	0.33	0.33	0.0045
	1995	0.23	0.20	0.03
	1994	0.81	0.49	0.32
	1993	0.37	0.11	0.26
	1992	0.21	0.21	—[d]
	1991	0.44	0.44	—[d]
	1990	0.57	0.57	—[d]

(a) 1 μSv = 0.1 mrem

(b) The dose includes HT emissions modeled as HTO as directed by EPA Region IX.

(c) Diffuse source doses were not calculated for the Livermore site for 1990 and 1991.

(d) No diffuse emissions were evaluated at Site 300 before 1993.

had handled the source or worked in the rooms impacted by the incident indicated either no tritium intake or none attributable to the incident. Because the greatest potential dose would have been to these personnel, rather than to a member of the public, any potential dose to a member of the public from this incident would have been completely negligible.

At Site 300, there were no unplanned atmospheric releases of radionuclides in 2006.

7.5.3 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 2006 Livermore site operations was 0.0075 person-Sv (0.75 person-rem); the corresponding collective dose from Site 300 operations was 0.033 person-Sv (3.30 person-rem). These values are both within the normal range of variation seen from year to year.

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

Table 7-3. Collective dose broken down by level of individual doses, 2006.

Site	Individual dose range (μSv/y)[a]		Collective dose (person-Sv/y)[b]	Percent total collective dose
Livermore site	0.01 to 0.1		0.000029	0.38%
	0.001 to 0.01		0.00047	6.27%
	0.0001 to 0.001		0.0067	88.8%
	0.00001 to 0.0001		0.00032	4.32%
		Total	0.0075[c]	100%
Site 300[d]	0.01 to 0.1		0.0029	8.8%
	0.001 to 0.01		0.022	67.0%
	0.0001 to 0.001		0.0076	23.0%
	0.00001 to 0.0001		0.00051	1.5%
		Total	0.033	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.

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 in shown **Table 7-3** demonstrates that about 92% of the population receives less than 0.01 μSv/y (1 μrem/y).

7.5.4 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 2006 are about 500,000 times smaller than ones from natural background radiation. The estimated maximum potential doses to individual members of the public from operations at the two LLNL sites (combined) in 2006 are nearly 15,000 times smaller than ones received from background radiation in the natural environment.

Table 7-4. Comparison of radiation doses from LLNL sources to average doses from background (natural and man-made) radiation, 2006.

Location/source	Category	Individual dose[a] (μSv)[c]	Collective dose[b] (person-Sv)[d]
LLNL			
Livermore site sources	Atmospheric emissions	0.045	0.0075
Site 300 sources	Atmospheric emissions	0.16	0.033
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.

7.6 Special Topics on Dose Assessment

7.6.1 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. This 2006 report marks the fourth year that LLNL is demonstrating 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

Table 7-5. Mean concentrations of radionuclides of concern at the location of the SW-MEI in 2006.

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	$0.028^{(a)}$	5.0×10^{-4}
Livermore SW-MEI	Plutonium-239	7.4×10^{-5}	1.9×10^{-8}	$6.6 \times 10^{-9(b)}$	8.9×10^{-5}
Site 300 SW-MEI	Uranium-238	3.1×10^{-4}	1.1×10^{-9}	$4.6 \times 10^{-7(c)}$	1.5×10^{-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.

(b) The mean measured concentration for plutonium is less than the detection limit; only 1 of the 13 values composing the mean was a measured detection.

(c) The ratio for the mean uranium-235 and uranium-238 concentrations for 2006 is 0.0065, which is less than 0.00725, the ratio of these isotopes for naturally occurring uranium. This results in approximately 86% of the resuspension being attributable to naturally occurring uranium and 14% being attributable to depleted uranium.

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 Systéme International (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 0.0015 or less than the health protective standard for these radionuclides.

7.6.2 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. In 2004, DOE's Interagency Steering Committee on Radiation Standards (ISCORS) published a user's guide for the RESRAD-BIOTA (U.S. DOE 2004). The code was developed for DOE with support from the EPA, the U.S. Nuclear Regulatory Commission (NRC), and the informal, interagency Ecological Radiological Work Group (ECORAD-WG).

Limits on absorbed dose to biota are 10 milligray per day (mGy/d) (1 rad per day [rad/d]) for aquatic animals and terrestrial plants, and 1 mGy/d (0.1 rad/d) for terrestrial

animals. At LLNL in 2006, radionuclides contributing to dose to biota were americium-241, cesium-137, tritium, plutonium-239 (analyzed as plutonium-239+240 and also as a surrogate for gross alpha), thorium-232, uranium-235, and uranium-238; in addition, gross beta was represented by strontium-90. In the 2006 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. Other assumptions increase the possibility that the estimated dose is conservative. For example, while only gross alpha and gross beta are measured in water, it is assumed that gross alpha is represented by plutonium-239 and gross beta by strontium-90 to ensure maximum dose. 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 much 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 derived concentration limit or Biota Concentration Guide (BCG). Radionuclide concentrations in each medium when entered are then divided by the BCG and a partial fraction for each nuclide and medium is 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 2006, the sum of the fractions for the aquatic system was 0.298, and the sum for the terrestrial system was 0.036. These ultraconservative results for the aquatic system are similar to those for 2003, 2004, and 2005. The sum of the fractions for the terrestrial system is similar to previous years.

A more realistic approach can be made using runoff or release concentrations from Lake Haussmann, combined with sediment from the East Settling Basin (location ESB). Using these concentrations, the sum of the fractions for the aquatic system is 0.093, which is about two thirds of the fractions from the ultraconservative approach. It is clear that dose to biota from LLNL operations is below levels of regulatory concern.

7.6.3 Modeling Dose from Tritium—Comparison of Approaches

Dose predictions can vary due to different modeling approaches and assumptions. Because tritium has been and continues to be the principal radionuclide released to air in Livermore

Table 7-6. Bulk transfer factors used to calculate inhalation and ingestion doses from measured concentrations in air, vegetation, and drinking water.

Exposure pathway	Bulk transfer factors[(a)] times observed mean concentrations
Inhalation and skin absorption	0.21 x concentration in air (Bq/m^3); see **Chapter 4**
Drinking water	0.013 x concentration in drinking water (Bq/L); see **Chapter 5**
Food ingestion	0.0049 x concentration in vegetation (Bq/kg) (see **Chapter 6**); factor obtained by summing contributions of 0.0011 for vegetables, 0.0011 for meat and 0.0027 for milk

(a) See Sanchez et al. (2003), Appendix C, for the derivation of bulk transfer factors.

site operations (from a public dose standpoint), a comparison of potential doses for 2006, calculated from different approaches, is presented.

Since 1986, LLNL has calculated doses from releases of HTO (or total tritium modeled as HTO) to the atmosphere using the regulatory model CAP88-PC (since 1992) or its predecessor, AIRDOS-EPA. This dose is calculated from air concentrations derived after modeling the dispersion of tritium released from the principal tritium-handling facilities on site. In addition, since 1979, using bulk transfer factors (see **Table 7-6**) derived from equations in the NRC Regulatory Guide 1.109 (U.S. NRC 1977), LLNL has calculated potential ingestion doses from measured HTO concentrations in vegetation (see **Chapter 6**) and drinking water (see **Chapter 5**), as well as doses from inhalation (see **Chapter 4**). Both CAP88-PC and Regulatory Guide 1.109 account for dose only from HTO. More conceptually accurate assessments should account for dose from releases of HT and from ingestion of organically bound tritium (OBT); if OBT is ignored, ingestion dose may be underestimated by up to a factor of two (ATSDR 2002). In recent years, another model, NEWTRIT (Peterson and Davis 2002), has been used to estimate inhalation and ingestion doses from releases of both HT and HTO; the ingestion dose accounts for both HTO and OBT. NEWTRIT uses observed or predicted air concentrations as input.

Hypothetical tritium doses predicted at location VIS, the Livermore site air tritium and vegetation sampling location (see **Chapter 6**, **Figure 6-1**), using the three modeling approaches, are compared in **Table 7-7**. All predictions were made for a hypothetical person living 100% of the time adjacent to the air tritium monitor at location VIS and eating 100% locally grown food. Because the air tritium monitor can sample only for HTO, only HTO releases were used to calculate air tritium concentrations using CAP88-PC.

The dose comparison shows a factor of about 5 between the lowest (NEWTRIT) and highest (CAP88-PC) dose predictions, each of which is based on valid assumptions. Differences are due primarily to predicted (0.0877 becquerel per cubic meter [Bq/m^3]) versus observed (0.0236 Bq/m^3) air concentrations and assumptions about intake rates and dose coefficients (see Sanchez et al. [2003], Appendix C). When predicted air concentrations drive

Table 7-7. Comparison of hypothetical doses at the Livermore site VIS air tritium and vegetation monitoring location calculated from predicted and observed concentrations of HTO in air in 2006.

Exposure pathway	Hypothetical dose (nSv/y)		
	CAP88-PC (from predicted air concentrations)[a]	NRC 1.109 (from mean air, vegetation, and tap water[b] concentrations)	NEWTRIT (from mean air tritium concentrations)
Inhalation and skin absorption	24	5.0	5.4
Food ingestion			
Vegetables	77	2.6	14
Milk	47	6.5	9
Meat	28	2.6	4.5
Total food ingestion dose	152	12	28
Drinking water	1.0	<27[c]	2.3
Total	177	<44	35

(a) Doses from CAP88-PC are based on the sum of the predicted HTO concentrations at VIS for the Tritium Facility stacks (1.52×10^{-2} Bq/m^3), the Building 612 Yard (2.07×10^{-2} Bq/m^3), and the Tritium Facility area source (5.18×10^{-2} Bq/m^3).

(b) Tap water is measured on the Livermore site but not at location VIS.

(c) The mean concentration for tap waters measured for tritium in 2006 was below the limit of detection.

the doses, doses are normally higher than when observed air and vegetation concentrations drive the results. The mean observed tritium concentration in air at location VIS for 2006 is relatively uncertain because 58% of the samples were below the minimum detection limit.

Using assumptions about the fraction of diet that realistically could be contaminated by LLNL tritium rather than assuming, as in **Table 7-7**, that the entire diet is contaminated, reduces the dose by a factor of 4 or more.

7.7 Environmental Impact

The annual radiological doses from all emissions at the Livermore site and Site 300 in 2006 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 2006 were:

- Livermore site: 0.045 μSv (0.0045 mrem)—36% from point-source emissions; 64% from diffuse-source emissions. The point source emissions include gaseous tritium modeled as HTO for compliance purposes, as directed by EPA Region IX.
- Site 300: 0.16 μSv (0.016 mrem)—87.5% from explosive experiments, which are classified as point-sources; 12.5% 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 2006 was estimated to be 0.0075 person-Sv (0.75 person-rem) for the Livermore site and 0.033 person-Sv (3.30 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 2006, were 0.04% and 0.16%, respectively, of the federal standard and were more than 15,000 times smaller than the dose from background radiation. The collective doses from LLNL operations in 2006 were about 500,000 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 determinations of LLNL doses. The maximum credible doses to the public indicate that LLNL's use of radionuclides had no significant impact on public health during 2006.