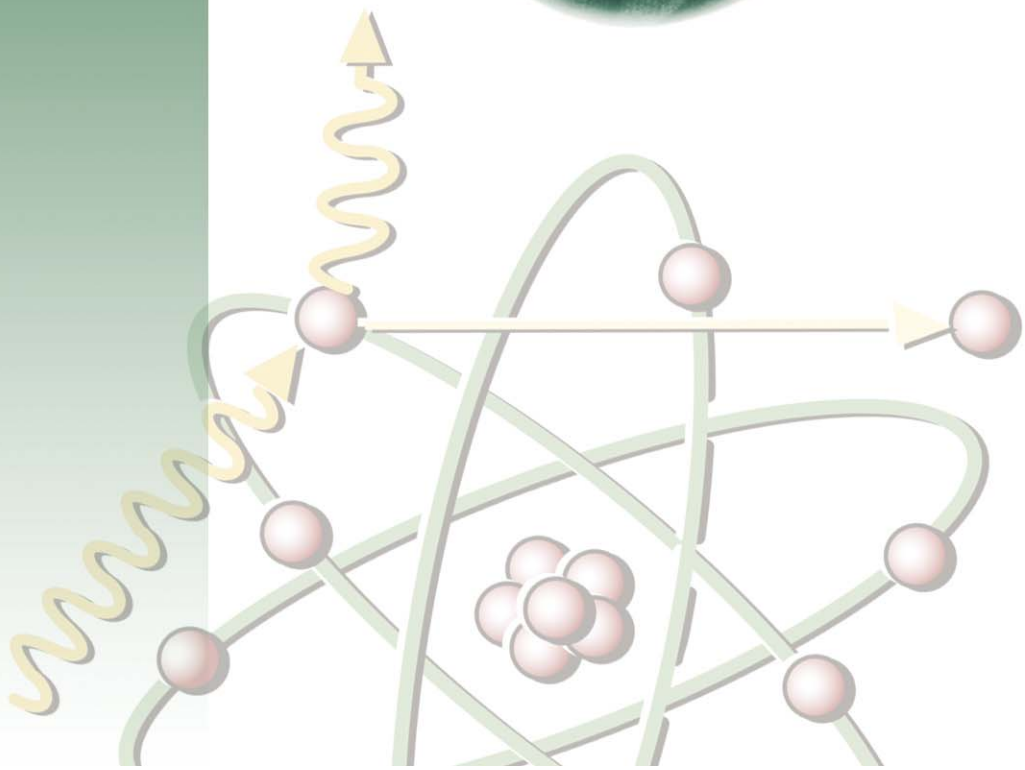
6 Radiological Dose Assessment

Robert J. Harrach
Gretchen M. Gallegos
S. Ring Peterson



INTRODUCTION

LLNL assesses potential radiological doses to the public and biota from its operations, in order to demonstrate compliance with regulatory standards that protect the public and environment. This chapter describes the releases of radioactivity, pathways of exposure, applicable standards, assessment methods and key data and concepts. It summarizes the radiological dose determinations, identifying trends over time and placing them in perspective with natural background and other sources of radiation exposure.

Releases of Radioactivity from LLNL Operations

Releases of radioactive material to air, for example in the form of air effluent dispersed from stacks, are by far the major source of public radiological exposures from LLNL operations. In contrast, releases to groundwater, surface water, and sanitary sewer water are not sources of direct public exposures because these waters are not directly consumed or used by the public. Consequently, measurements and modeling of radiological releases to air determine LLNL's dose to the public.

Data on radiological releases to air are gathered by three principal means: continuous monitoring of stack effluent at selected facilities at the Livermore site (described in Chapter 3); routine surveillance ambient air monitoring for radioactive particles and gases, both on and off LLNL property (also described in Chapter 3); and radioactive material usage inventories. The inventory process is described in LLNL's National Emission Standards for Hazardous Air Pollutants (NESHAPs) annual reports, showing LLNL's compliance with NESHAPs (Harrach et al. 2004). Of these three approaches, stack monitoring provides the most definitive characterization. The extent of reliance on usage inventories declined in 2003, in favor of increased utilization of ambient air monitoring data (see the "Compliance Demonstration for Minor Sources" section below).

Despite the emphasis on radiological releases to air and monitoring of the ambient air, it should be noted that LLNL's extensive environmental monitoring program, in place since the early 1970s, encompasses a variety of media. In addition to ambient and effluent air monitoring and the three categories of water monitoring already mentioned, LLNL samples rain water, soil, vegetation, and wine, and measures environmental (gamma) radiation. The monitoring program also includes a wide range of potential contaminants; it is not limited to radioactive ones.

Radiation Protection Standards

The release of radionuclides from operations at LLNL and the resultant radiological impact to the public are regulated by both the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA).

The primary DOE radiation standards for protection of the public are 1 millisievert per year (1 mSv/y) or 100 millirem per year (100 mrem/y) whole-body effective dose equivalent (EDE) for prolonged exposure of a maximally exposed individual in an uncontrolled area and 5 mSv/y (500 mrem/y) EDE for occasional exposure of this individual. (EDEs and other technical terms are discussed in *Supplementary Topics on Radiological Dose* [available on report CD] and defined in the glossary of this report.) 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 air emissions limits the EDE to members of the public to 100 μSv/y (10 mrem/y). 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 and to obtain EPA approval before the startup of new operations. NESHAPs regulations require that any operation with the potential to produce an annual-averaged 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 or not continuous monitoring of emissions to air from this project is required. These requirements are spelled out in LLNL's online *Environment, Safety, and Health (ES&H) Manual*, Document 31.1, "Air Quality Compliance."

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. The computer codes used at LLNL to model air releases and their impacts feature idealized, Gaussian-shaped plumes and can be run on personal computers. The CAP88-PC code incorporates dosimetric and health effects data and equations that are mandated by EPA to be used in compliance assessments (Parks 1992). The code evaluates the four principal pathways of exposure from air releases—internal exposures from inhalation of air and ingestion of foodstuff and drinking water, and external exposures through irradiation from contaminated ground and immersion in contaminated air. CAP88-PC accommodates site-specific input data files to characterize meteorological conditions and population distributions for both individual and collective dose evaluations, and the code is relatively easy to use and understand. For these reasons, CAP88-PC has been the "workhorse"

modeling tool for LLNL's regulatory compliance assessments since its availability in March 1992, particularly as applied to chronic releases of radioactivity to air occurring in the course of routine operations. In addition, an LLNL-modified version of CAP88-PC that contains an improved tritium model (NEWTRIT) has been used the past several years for purposes of comparison (Peterson and Davis 2002).

Identification of Key Receptors

When assessing probable off-site impacts, LLNL pays particular attention to doses received by three hypothetical receptors. First is the dose to the site-wide maximally exposed individual (SW-MEI; defined below) member of the public. Second is the dose to the maximally exposed individual (MEI) member of the public from a given source point. Third 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 (where members of the public reside or abide) who receives the greatest LLNL-induced EDE from all sources at a site. For LLNL to comply with the NESHAPs regulations, the LLNL SW-MEI cannot receive an EDE as great 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 this location 24 hours per day, 365 days per year, continuously breathing air having the radionuclide concentration, and consuming a specified fraction of food and drinking water that is affected by the 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 to any member of the public. The location of the SW-MEI can change from one year to the next; it is sensitive to the frequency distribution of wind speeds and directions, as well as locations of key sources on the site.

At the Livermore site, the SW-MEI in 2003 was located at the UNCLE Credit Union, about 10 m outside the controlled eastern perimeter of the site. This location lies 957 m from the Tritium Facility (Building 331), in an east-northeast direction (the typical prevailing wind direction). At Site 300, the SW-MEI occupied a position on the south-central boundary of the site bordering the Carnegie State Vehicular Recreation Area, approximately 3170 m south-southeast of the firing table at Building 851. These SW-MEI locations are depicted in **Figure 6-1**.

While the SW-MEI location is determined by all sources at a site and coincides with an actual publicly accessible facility, the location of the MEI is any point of unrestricted public access receiving the largest potential dose from a given source and is generally different for each emission point. Such a point typically occurs at the site perimeter, and is often referred to as the maximum "fence line" dose. However, the off-site maximum dose could occur some distance beyond the perimeter (e.g., when a stack is close to the perimeter).

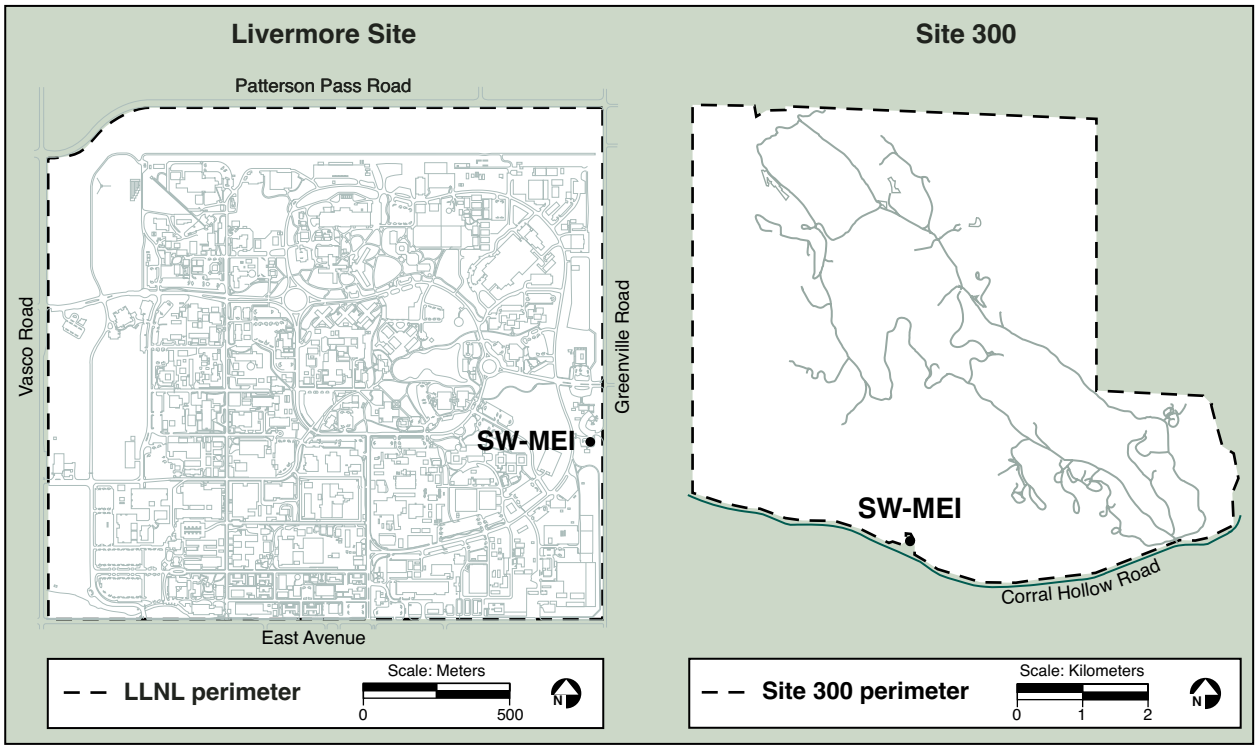


Figure 6-1. Location of the site-wide maximally exposed individual (SW-MEI) at the Livermore site and Site 300, 2003.

All new or modified LLNL projects in which releases of radioactivity to the environment may occur are reviewed for joint compliance with NESHAPs and the National Environmental Policy Act (NEPA). Dose to the MEI is used to evaluate whether continuous monitoring of the emissions from a given project is required, and whether it is necessary to petition the EPA for permission to start up the activity.

Results of 2003 Radiological Dose Assessment

This section summarizes the doses to the most-exposed public individuals from LLNL operations in 2003, shows the temporal trends by comparison to 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.

Total Dose to Site-Wide Maximally Exposed Individuals

The total dose to the SW-MEI from Livermore site operations in 2003 was 0.44 µSv/y (0.044 mrem/y). Of this, the dose attributed to diffuse emissions totaled 0.20 µSv (0.020 mrem) or 45%; the dose due to point sources was 0.24 µSv (0.024 mrem) or 55% 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 to calculate the dose for tritium emissions reduced the tritium component of the total dose from 0.41 µSv (0.041 mrem) to 0.30 µSv (0.030 mrem).

The total dose to the Site 300 SW-MEI from operations in 2003 was 0.17 µSv (0.017 mrem). Point source emissions from firing table explosives experiments accounted for 98% of this total, while 0.0034 µSv (0.00034 mrem), or about 2%, was contributed by diffuse sources.

Table 6-1 shows the facilities or sources that accounted for more than 90% of the doses to the SW-MEI for the Livermore site and Site 300 in 2003. Although LLNL has nearly 150 sources with potential for releasing 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 a dozen sources. In April 2003, EPA granted LLNL permission to use surveillance monitoring in place of

Table 6-1. List of facilities or sources whose combined emissions accounted for more than 90% of the SW-MEI doses for the Livermore site and Site 300 in 2003

Facility (source category)	CAP88-PC dose (µSv/y)	CAP88-PC percentage contribution to total dose
Livermore site		
Building 331 stacks (point source)	0.22[a]	50
Building 612 Yard (diffuse source)	0.13[a]	30
Building 331 outside (diffuse source)	0.059[a]	13
Building 612, R102 (point source)	0.014	3.2
Site 300		
Building 851 Firing Table (point source)	0.17	98
Soil resuspension (diffuse source)	0.0034	2

a When LLNL's NEWTRIT model is used in CAP88-PC in place of CAP88-PC's default tritium model, the doses for Building 612 yard, Building 331 stacks, and Building 331 outside are reduced to 75% of the values shown, and that for the Building 331 stacks are reduced to 73% of the value shown.

inventory-based modeling to account for dose contributions from the numerous minor sources; see attachment in last year's *NESHAPs Annual Report* (Harrach et al. 2003). This procedure was implemented for the first time in assessing 2003 operations, as reported here and in this year's *NESHAPs Annual Report* (Harrach et al. 2004).

Dominant radionuclides at the two sites were the same as in recent years. Tritium accounted for about 93% 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 in depleted uranium. Regarding pathways of exposure, the relative significance of inhalation and ingestion depends on the assumptions made about the origin of food consumed. The assumption when assessing individual LLNL doses that milk is imported while the remainder of the food is produced locally results in ingestion dose exceeding inhalation dose in the case of tritium, approximately 80% to 20%, respectively. For uranium, these numbers are nearly reversed: 17% by the ingestion pathway versus 83% via inhalation. LLNL doses from air immersion and ground irradiation 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 14 years are shown in **Table 6-2**. 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 generally higher than actually would be experienced by any member of the public.

Table 6-3 shows the Site 300 SW-MEI dose values attributed to firing table experiments for 1990 through 2003; the table also shows the total amounts of depleted uranium and the total quantity of high explosives used each year in the experiments. (Only explosives experiments that included depleted uranium are considered here; most have none.)

Doses from Unplanned Releases

There were no unplanned atmospheric releases of radionuclides at the Livermore site or Site 300 in 2003.

Population Doses

Population doses, or collective EDEs, for both LLNL sites were calculated out to a distance of 80 km in all directions from the site centers using CAP88-PC. As noted earlier, CAP88-PC evaluates the four principal exposure pathways: ingestion through food and water consumption, inhalation, air immersion, and irradiation by contaminated ground surface.

Table 6-2. Doses (μSv) calculated for the sitewide maximally exposed individual (SW-MEI) for the Livermore site and Site 300, 1990 to 2003

Year	Total dose	Point source dose	Diffuse source dose
Livermore site			
2003	0.44[a]	0.24[a]	0.20
2002	0.23[a]	0.10[a]	0.13
2001	0.17[a]	0.057[a]	0.11
2000	0.38[a]	0.17[a]	0.21
1999	1.2[a]	0.94[a]	0.28
1998	0.55[a]	0.31[a]	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	—[b]	—[b]
1990	2.40	—[b]	—[b]
Site 300			
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	—[c]
1991	0.44	0.44	—[c]
1990	0.57	0.57	—[c]

a The dose includes HT emissions modeled as HTO as directed by EPA Region IX. EPA Region IX acknowledges that such modeling results in an overestimation of the dose. This methodology is used for purposes of compliance.

b Diffuse source doses were not reported separately from the total dose for the Livermore site for 1990 and 1991.

c No diffuse emissions were evaluated and reported at Site 300 before 1993.

Table 6-3. Annual dose to the SW-MEI from explosives experiments on firing tables at Site 300, 1990 to 2003, related to the total quantity of depleted uranium used in the experiments and the total quantity of high explosives driving the detonations

Year	Annual dose to SW-MEI		Total depleted uranium used in experiments (kg)	Total quantity of high explosive used in depleted uranium experiments (kg)
	*μ*Sv	mrem		
2003	0.17	0.017	62	48
2002	0.18	0.018	45	77
2001	0.50	0.050	187	104
2000	0.15	0.015	43	34
1999	0.34	0.034	216	168
1998	0.19	0.019	230	192
1997	0.11	0.011	163	122
1996	0.33	0.033	272	112
1995	0.20	0.020	165	199
1994	0.49	0.049	230	134
1993	0.11	0.011	99	74
1992	0.21	0.021	151	360
1991	0.44	0.044	221	330
1990	0.57	0.057	340	170

Population centers affected by LLNL emissions include the relatively 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 outer distance specified by DOE, there are 7.1 million residents included for the Livermore site population dose determination, and 6.2 million for Site 300. Population data files (distribution of population with distance and direction) used for the present report were updated for the 2003 modeling effort. These population distributions are based on the LandSpan Global Population 2001 Database (Dobson et al. 2000).

The CAP88-PC result for potential population dose attributed to 2003 Livermore-site operations was 0.016 person-Sv (1.6 person-rem); the corresponding collective EDE from Site 300 operations was 0.032 person-Sv (3.2 person-rem). These values are both within the normal range of variation seen from year to year.

Doses to the Public Placed in Perspective

As a frame of reference to gauge the size of these LLNL doses, **Table 6-4** compares them to average doses received in the United States from exposure to natural background radiation and medical tests. Population doses from LLNL operations in 2003 are about 400,000 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 2003 are nearly 5000 times smaller than ones received from background radiation in the natural environment.

Table 6-4. Comparison of background (natural and man-made) and LLNL radiation doses, 2003

Location/source	Individual dose[a]		Population dose[b]	
	(μSv)	(mrem)	(person-Sv)	(person-rem)
Livermore site sources				
Atmospheric emissions	0.44	0.044	0.016	1.6
Site 300 sources				
Atmospheric emissions	0.17	0.017	0.032	3.2
Other sources[c]				
Natural radioactivity[d,e]				
Cosmic radiation	300	30	1,900	190,000
Terrestrial radiation	300	30	1,900	190,000
Internal (food consumption)	400	40	2,500	250,000
Radon	2,000	200	12,500	1,250,000
Medical radiation (diagnostic procedures)[e]	530	53	3,300	330,000
Weapons test fallout[e]	10	1.0	68	6,800
Nuclear fuel cycle	4	0.4	25	2,500

a For LLNL sources, this dose represents that experienced by the SW-MEI member of the public.

b The population dose is the collective (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.

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

d These values vary with location.

e This dose is an average over the U.S. population.

Special Topics on Dose Assessment

Compliance Demonstration for Minor Sources

Since 1991, LLNL has demonstrated compliance for minor sources 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 10 mrem/y and did not justify the level of effort expended in accounting for them. To better allocate resources, LLNL made a request, pursuant to the NESHAPs regulations, to use existing ambient air monitoring to demonstrate compliance for minor emissions sources. This request was made in March 2003 and granted in April 2003. For this calendar year 2003 compliance report, LLNL is, for the first time, demonstrating NESHAPs compliance for minor sources by comparing measured ambient air concentrations at the location of the SW-MEI to concentrations limits set by the EPA in Table 2, Appendix E of 40 CFR 61. 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 L-VIS and L-CRED represent 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 are used to represent the SW-MEI.

The Table 2, Appendix E of 40 CFR 61 standards and the measured concentrations at the SW-MEI are presented in **Table 6-5**. As demonstrated by the calculation of the fraction of the standard, LLNL measured concentrations for tritium and plutonium-239+240, and uranium-238 in air are 0.003 or less than the health protective standard for these radionuclides.

Estimate of Dose to Biota

Although mankind is protected from excess radiation dose by the methods outlined in this chapter, biota is not necessarily protected because of different exposure pathways (e.g., dose to a ground squirrel burrowing in contaminated soil). Thus LLNL calculates potential dose to biota from LLNL operations using the DOE guidance document, "DOE Standard: A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (U.S. DOE 2002), and the RAD-BCG (Biota Concentration Guides) Calculator (Version 2) in an Excel spreadsheet. 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.

Table 6-5. Mean concentrations of radionuclides of concern at the location of the SW-MEI in 2003

Location	Nuclide	EPA concentration standard (Ci/m^3)	Mean measured concentration (Ci/m^3)	Measured concentration as a fraction of the standard	Detection limit (approximate) (Ci/m^3)
Livermore SW-MEI	Tritium	1.5×10^{-9}	5.0×10^{-12}(a)	3.3×10^{-3}	1×10^{-12}
Livermore SW-MEI	Plutonium-239	2.0×10^{-15}	1.3×10^{-19}(b)	6.5×10^{-5}	5×10^{-19}
Site 300 SW-MEI	Uranium -238	8.3×10^{-15}	7.0×10^{-18}(c)	8.4×10^{-4}	3×10^{-20}

a The tritium value includes contribution of emissions from the Tritium Facility, estimated at 3.8×10^{-12} Ci/m^3.

b Note that the mean measured concentration for plutonium is less than the detection limit; only 3 of the 24 values comprising the mean were measured detections.

c The mean ratio for uranium-235/uranium-238 for 2003 is 0.00708, which is only slightly less than 0.00726, the ratio of these isotopes for naturally occurring uranium. This indicates that approximately 96% of the measured quantities of uranium-238 were caused by resuspension of soil containing naturally occurring uranium.

In the RAD-BCG Calculator, each radionuclide in each medium (soil, sediment, surface water) is assigned a derived concentration limit. For each concentration entered in the spreadsheet, a fraction of the derived concentration limit for that radionuclide is automatically calculated; the fractions are summed for each medium. For aquatic and riparian environments, if a concentration for water is entered, the calculator automatically assigns an expected concentration to the sediment, and vice versa.

For aquatic and riparian animals, the sum of the fractions for water exposure are 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 the biota are assumed to be protected.

In the LLNL assessment, the maximum concentration of each radionuclide measured in soils, sediments, and surface waters during 2003, no matter where measured, was entered into the screening calculation. This approach may result in an assessment that is unrealistically conservative, given that the maximum concentrations in the media are spread over a very large area, and no animal could possibly be exposed to them all. Other assumptions increase the possibility that the estimated dose will be 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 assure 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 they had higher concentrations than surface waters. Finally, when measurements were available for both runoff and sediment, the value that gave the highest fraction of the BCG was used.

Radionuclides measured by LLNL in 2003 that might have been contributed by LLNL operations were americium-241, cesium-137, tritium, plutonium-239, thorium-232, uranium-235, and uranium-238; in addition, gross beta is represented by strontium-90. For LLNL, the sum of the fractions for the aquatic system was 0.19, and the sum for the terrestrial system was 0.032, both well below the screening level. These results are similar to those in 2001 and 2002.

A less artificial assessment of dose to aquatic biota from LLNL operations can be made using surface water concentrations from the Drainage Retention Basin (DRB) combined with sediment concentrations from the East Settling Basin (ESB). Sediment samples are not taken in the DRB, and water is ephemeral at the ESB. Nevertheless, concentrations may be expected to be similar given that water drains through the ESB to the DRB. Using these concentrations in the RAD-BCG Calculator, the sum of the fractions for aquatic exposure is 0.13, which is about two-thirds of the fraction from the ultra-conservative approach. It is clear that dose to biota from LLNL operations are below the level of regulatory concern.

Modeling Dose from Tritium — Comparison of Approaches

Since tritium has been and continues to be the principal radionuclide released to air in Livermore site operations (from a public dose standpoint), a comparison was made in 2003 of the approaches used at LLNL to model its dose impacts.

Since 1986, LLNL has calculated dose 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. The dose calculated with AIRDOS-EPA or CAP88-PC uses source terms that represent the principal tritium sources at the site. As well, since 1979, using bulk transfer factors (**Table 6-6**) derived from equations in the Nuclear Regulatory Commission's (NRC) Regulatory Guide 1.109 (U.S. NRC 1977), LLNL has calculated potential ingestion doses from measured concentrations in vegetation (Chapter 5), as well as doses from inhalation (Chapter 3) and drinking water (Chapter 4). Both CAP88-PC and Regulatory Guide 1.109 only account for dose from HTO. In the last few years, it has been learned that doses that neglect the contribution of organically bound tritium (OBT) may underestimate dose, but by no more than a factor of two and in most cases by a much smaller factor (U.S. Department of Health and Human Services 2001). Recently, 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.

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

Doses in μSv	Bulk transfer factors times observed mean concentrations
Inhalation and skin absorption	0.21 x concentration in air (Bq/m^3) (See Chapter 3)
Drinking water	0.013 x concentration in drinking water (Bq/L) (See Chapter 4)
Food Ingestion	0.0049 x concentration in vegetation (Bq/kg) (See Chapter 5); (factor obtained by summing contributions of 0.0011 for vegetables, 0.0011 for meat and 0.0027 for milk)

Note: The derivation for these bulk transfer factors may be found in Appendix C of *Environmental Report 2002* (Sanchez et al. 2003)

Hypothetical tritium doses predicted at the onsite location of the air tritium monitor, VIS (see Figure 3-1) using the three modeling approaches are compared in **Table 6-7**. All predictions were made for a hypothetical person living 100% of the time adjacent to the air tritium monitor at VIS and eating 100% locally grown food. Assumptions about the quantities of food consumed vary between the models. Because the air tritium monitor can only sample for HTO, no HT was included in the source term for CAP88-PC. Vegetation is also sampled at VIS.

The dose comparison shows about a factor of five difference between the lowest and highest dose predictions, each of which is based on a valid approach. Differences are primarily due to estimated concentrations and assumptions about intake rates and dose

Table 6-7. Comparison of hypothetical annual doses (nSv/y) at the VIS air tritium monitoring location calculated from predicted and observed concentrations of HTO in air

	CAP88-PC (from predicted air concentrations [a]	NRC R.G. 1.109 (from mean air, vegetation, and tap water[b] concentrations)	NEWTRIT (from mean air tritium concentrations)
Inhalation and skin absorption	64	38	42
Food ingestion (vegetables; milk; meat)	200; [130]; 75	7.9; 19; 7.9	110; 68; 34
Drinking water	3.7	< 29[c]	18
Food ingestion dose	270 [400]	35	210
Total dose	340 [470]	< 100	270

a Doses from CAP88-PC are based on the sum of the predicted HTO concentrations at VIS for B331 (0.13 Bq/m^3), the B612 yard (0.070 Bq/m^3), and the B331 Waste Accumulation Area (0.034 Bq/m^3). Numbers in brackets (e.g., dose from milk) are not calculated for reported LLNL doses. See *NESHAPs Report and Guidance for Radiological Dose Assessment*.

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

c All tap waters measured for tritium in 2003 were below the limit of detection.

coefficients (see Appendix C of *Environmental Report 2002* [Sanchez et al. 2003]). The total dose from CAP88-PC is the highest, as expected, and the NEWTRIT dose is well within a factor of two of the CAP88-PC dose. All doses are far below any level of concern.

A more realistic, but still highly conservative, set of assumptions about the lifestyle of the hypothetical member of the public residing at the VIS monitor location lowers the annual dose from tritium (**Table 6-8**) to as low as one-half of the lowest dose in **Table 6-7**, even while including tiny potential doses from other dose pathways.

Environmental Impact

The annual radiological dose from all emissions at the Livermore site and Site 300 in 2003 was 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

Table 6-8. Doses for the tritium exposure of an individual residing at the location of the VIS air tritium monitor in 2003, based on observed HTO-in-air concentrations and using plausible but conservative assumptions (as indicated)

Source of dose	Annual dose (nSv/y)	Assumption
Inhalation	16	Breathes air at VIS 16 hours a day, all year
Ingesting food, including OBT	29	Raises and eats 25% homegrown leafy vegetables, fruit vegetables, fruits and root crops, no homegrown milk, beef, or grain but 12 kg/y homegrown chickens and 20 kg/y homegrown eggs. Assume the feed for the chickens is 50% homegrown; chickens drink water from outdoor pans at 50% air moisture.
Drinking water	[5.9][a]	Drinks 440 L/y of well water at average concentration of California groundwater
Drinking wine, including OBT	0.88	Drinks one liter bottle of Livermore Valley wine each week
Immersion	0.15	Swims in the LLNL pool 100 hours per year
All sources	46[a]	

a Drinking water dose is not included in a realistic estimate of the dose impacts of LLNL releases of tritium to the atmosphere because Livermore drinking water is unaffected by LLNL operations. Nevertheless, inclusion of a drinking water dose demonstrates that the dose attributable to LLNL is not much different than background, especially given that all doses shown include background.

radioactive material to air from DOE facilities. Using EPA-mandated computer models and actual LLNL meteorology appropriate to the two sites, the potential doses to the LLNL SW-MEI members of the public from operations in 2003 were:

- Livermore site: 0.44 μSv (0.044 mrem)—55% from point-source emissions, 45% from diffuse-source emissions. The point source emissions include gaseous tritium modeled as tritiated water vapor for compliance purposes, as directed by EPA Region IX.
- Site 300: 0.17 μSv (0.017 mrem)—98% from explosive experiments, which are classified as point-sources, 2% from diffuse-source emissions.

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

The collective EDE or population dose attributable to LLNL operations in 2003 was estimated to be 0.016 person-Sv (1.6 person-rem) for the Livermore site and 0.032 person-Sv (3.2 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 members of the public resulting from Livermore site and Site 300 operations in 2003 were below one-half of one percent (0.5%) of the federal standard and were nearly 5000 times smaller than the dose from background radiation. The population doses from LLNL operations in 2003 were more than 400,000 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 allowable dose limits.

In conclusion, potential radiological doses from LLNL operations were well below regulatory standards and were very small compared with doses normally received by these populations from natural background radiation sources, even though highly conservative assumptions were used in the determinations of LLNL doses. These maximum credible doses to the public indicate that LLNL's use of radionuclides had no significant impact on public health during 2003.