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Radiological Dose Assessment

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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 the 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 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 (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. Of these three approaches, stack monitoring provides the most definitive characterization. Beginning in 2003, the extent of reliance on usage inventories declined 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 stack air effluent and 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. These monitoring programs are discussed in previous chapters in this report.

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) (which equals 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 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 and to obtain EPA approval before the startup of new operations. 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 or not continuous monitoring of emissions to air from a project is required. These requirements are spelled out in LLNL's *Environment, Safety, and Health (ES&H) Manual*, Document 31.2, "Radiological 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 (only for tritium), 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

primary 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, CAP88-PC provides the flexibility to use different ingestion pathway parameters; for the 2004 evaluation, LLNL took advantage of this capability and used updated assumptions for agricultural and food source parameters for CAP88-PC (see Harrach et al. 2005). Furthermore, an improved tritium model (NEWTRIT; Peterson and Davis 2002) that uses air concentrations predicted by CAP88-PC to address the dose from HT and the formation of and dose from organically bound tritium was again employed for purposes of comparison to the simple tritium model in CAP88-PC.

Identification of Key Receptors

When assessing probable off-site impacts, LLNL pays particular attention to doses received by three 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 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 who receives the greatest LLNL-induced EDE from all sources at a site. For LLNL to comply with 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 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 that is affected by the same predicted or observed 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 may be received by 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 to locations of key sources on the site.

At the Livermore site, the SW-MEI in 2004 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

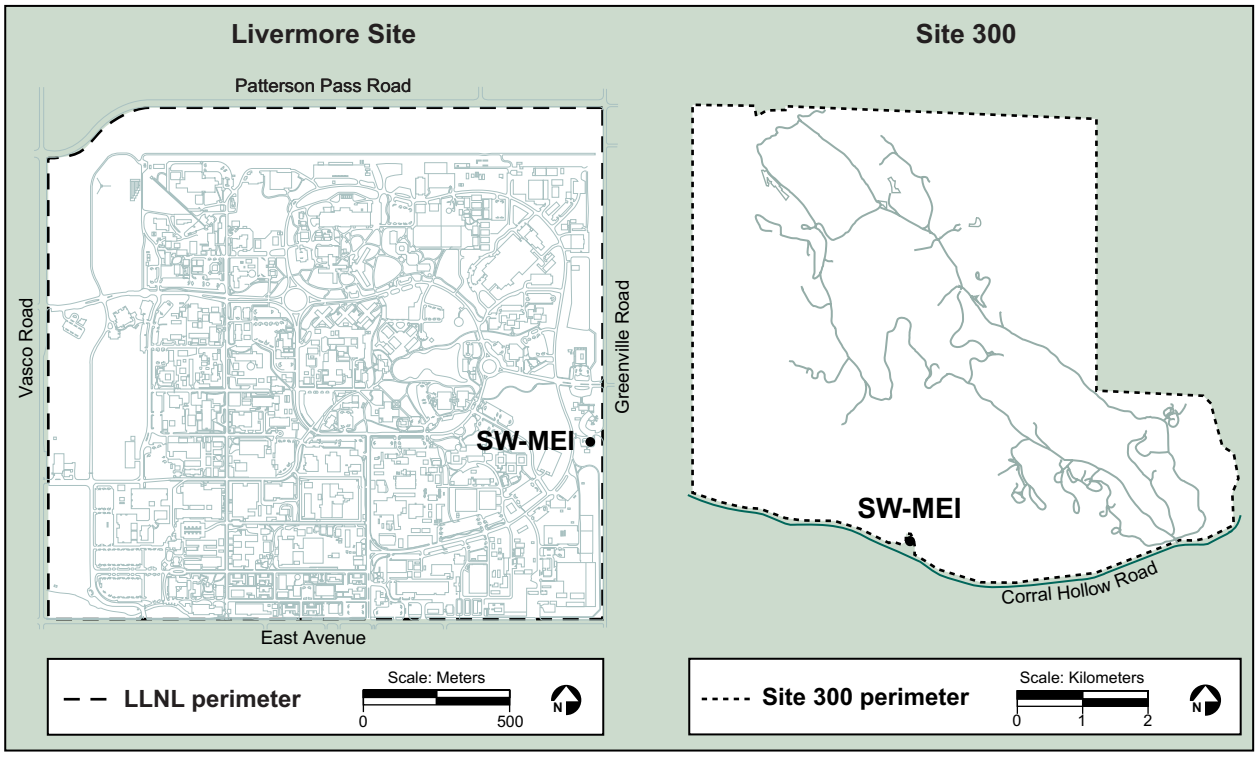

Figure 6-1. Location of the site-wide maximally exposed individual (SW-MEI) at the Livermore site and Site 300, 2004

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).

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 2004 Radiological Dose Assessment

This section summarizes the doses to the most-exposed public individuals from LLNL operations in 2004, 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 2004 was 0.079 µSv/y (0.0079 mrem/y). Of this, the dose attributed to diffuse emissions totaled 0.058 µSv (0.0058 mrem) or 73%; the dose due to point sources was 0.021 µSv (0.0021 mrem) or 27% 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 0.076 µSv (0.0076 mrem) to 0.065 µSv (0.0065 mrem).

The total dose to the Site 300 SW-MEI from operations in 2004 was 0.26 µSv (0.026 mrem). Point source emissions from firing table explosives experiments accounted for 97% of this total, while 0.0086 µSv (0.00086 mrem), or about 3%, 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 2004. 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 inventory-based modeling to account for dose contributions from the numerous minor sources. This procedure was implemented for the second time in assessing 2004 operations (see also *LLNL NESHAPs 2004 Annual Report* [Harrach et al. 2005]).

Dominant radionuclides at the two sites were the same as in recent years. Tritium accounted for about 96% 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 and the predominant radionuclide contributing to dose. For individual

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 2004

Facility (source category)	CAP88-PC dose (μSv/y)	CAP88-PC percentage contribution to total dose
Livermore site		
Building 331 stacks (point source)	0.014[a]	18
DWTF stack (point source)	0.0069[a]	9
Building 612 Yard (diffuse source)	0.053[a]	67
Site 300		
Building 851 Firing Table (point source)	0.25	97
Soil resuspension (diffuse source)	0.0086	3

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 and DWTF stack are reduced to 89% of the values shown, and that for the Building 331 stacks are reduced to 68% of the value shown.

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. 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 15 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 higher than actually would be experienced by any member of the public.

Doses from Unplanned Releases

There were no unplanned atmospheric releases of radionuclides at the Livermore site or Site 300 in 2004.

Collective Dose

Collective dose, or population dose, for both LLNL sites was 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, 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 2004

Year	Total dose	Point source dose	Diffuse source dose
Livermore site			
2004	0.079[a]	0.021[a]	0.058
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			
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	—[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.

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

The CAP88-PC result for potential collective dose attributed to 2004 Livermore site operations was 0.010 person-Sv (1.0 person-rem); the corresponding collective EDE from Site 300 operations was 0.0385 person-Sv (3.85 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 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 6-3**. It can be seen in **Table 6-3** that the individuals who make up about 98% of the population receive less than 0.01 µSv/y (1 µrem/y).

Table 6-3. Collective dose broken down by level of individual doses, 2004

Individual dose range (µSv/y)	Collective dose (person-Sv/y)	Individual dose range (mrem/y)	Collective dose (person-rem/y)	Percent total collective dose
Livermore site[a]				
0.01 to 0.1	0.0000271	0.001 to 0.01	0.00271	0.272%
0.001 to 0.01	0.000346	0.0001 to 0.001	0.0346	3.46%
0.0001 to 0.001	0.00934	0.00001 to 0.0001	0.934	93.4%
0.00001 to 0.0001	0.000283	0.000001 to 0.00001	0.0283	2.84%
Total	0.01	Total	1.0	100%
Site 300[b]				
0.01 to 0.1	0.000753	0.001 to 0.01	0.0753	1.96%
0.001 to 0.01	0.0139	0.0001 to 0.001	1.39	36.2%
0.0001 to 0.001	0.0238	0.00001 to 0.0001	2.38	61.8%
0.00001 to 0.0001	0	0.000001 to 0.00001	0	0%
Total	0.0385	Total	3.85	100%

a Dose from tritium

b Dose from Building 851 Firing Table

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 other sources. Collective doses from LLNL operations in 2004 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 2004 are nearly 9,000 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, 2004

Location/source	Individual dose[a]		Collective dose[b]	
	(μSv)	(mrem)	(person-Sv)	(person-rem)
Livermore site sources				
Atmospheric emissions	0.079	0.0079	0.010	1.0
Site 300 sources				
Atmospheric emissions	0.26	0.026	0.0385	3.85
Other sources[c]				
Natural radioactivity[d,e]				
Cosmic radiation	300	30	2,130	213,000
Terrestrial radiation	300	30	2,130	213,000
Internal (food consumption)	400	40	2,840	284,000
Radon	2,000	200	14,200	1,420,000
Medical radiation (diagnostic procedures)[e]	530	53	3,760	376,000
Weapons test fallout[e]	10	1.0	71	7,100
Nuclear fuel cycle	4	0.4	28	2,800

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. The Livermore site population estimate of 7.1 million people was used to calculate the collective doses for "Other sources".

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 to EPA, 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 by EPA in April 2003. This report marks the second year that LLNL is 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 0.0047 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 2004

Location	Nuclide	EPA concentration standard (Ci/m^3)	Detection limit (approximate) (Ci/m^3)	Mean measured concentration (Ci/m^3)	Measured concentration as a fraction of the standard
Livermore SW-MEI	Tritium	1.5×10^{-9}	1×10^{-12}	1.3×10^{-12}(a)	8.7×10^{-4}
Livermore SW-MEI	Plutonium-239	2.0×10^{-15}	5×10^{-19}	1.3×10^{-19}(b)	6.5×10^{-5}
Site 300 SW-MEI	Uranium -238	8.3×10^{-15}	3×10^{-20}	3.9×10^{-17}(c)	4.7×10^{-3}

a The tritium value includes contribution of emissions from the Tritium Facility, Building 612 Yard, DWTF, and Building 331 Waste Accumulation Area.

b 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 2004 is 0.0068, which is only slightly less than 0.00726, the ratio of these isotopes for naturally occurring uranium. This indicates that approximately 90% 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 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 the LLNL assessment, the maximum concentration of each radionuclide measured in soils, sediments, and surface waters during 2004, no matter whether measured on the Livermore site, in the Livermore Valley, or at Site 300, 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 plant or 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 2004 that would contribute to a dose to biota were americium-241, cesium-137, tritium, plutonium-239 (also as a surrogate for gross alpha), 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 0.573, and the sum for the terrestrial system was 0.046. Both the aquatic and terrestrial systems passed the screening test in spite of these improbable assumptions. However, for the aquatic system, results are more than double those in 2001, 2002, and 2003. This is primarily due to use in the screening model of surrogates (gross alpha and gross beta) in runoff instead of concentrations of radionuclides in surface water to which biota are likely to have been exposed. The sum of the fractions for the terrestrial system is similar to previous years.

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 collected 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 the same fraction as in 2003 and less than 25% of the fraction derived from the ultraconservative approach. It is clear that dose to biota from LLNL operations is below levels of regulatory concern.

Modeling Dose from Tritium — Comparison of Approaches

Because 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 2004 of the approaches used at LLNL to model its dose impacts.

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. 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) and drinking water (Chapter 4), as well as doses from inhalation (Chapter 3). Both CAP88-PC and Regulatory Guide 1.109 only account for dose from HTO. More 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). 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 can 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—these assumptions match those that have been used historically for the NRC Regulatory Guide 1.109 calculations rather than those employed for CAP88-PC. 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.

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 1.109 (from mean air, vegetation, and tap water[b] concentrations)	NEWTRIT (from mean air tritium concentrations)
Inhalation and skin absorption	23	7.9	8.6
Food ingestion (vegetables; milk; meat)	73; 45; 27	2.0; 4.9; 2.0	22; 14; 7.1
Drinking water	1.3	< 27[c]	3.7
Food ingestion dose	145	9.0	43
Total dose	169	< 44	55

a Doses from CAP88-PC are based on the sum of the predicted HTO concentrations at VIS for the Tritium Facility stacks (1.63×10^{-2} Bq/m^3), the DWTF stack (5.18×10^{-3} Bq/m^3), the Building 612 Yard (0.059 Bq/m^3), and the Building 331 Waste Accumulation Area (2.48×10^{-3} Bq/m^3).

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

c All tap waters measured for tritium in 2004 were below the limit of detection.

The dose comparison shows about a factor of four difference between the lowest (NRC 1.109) and highest (CAP88-PC) dose predictions, each of which is based on valid assumptions. Differences are primarily due to predicted (0.083 Bq/m^3) versus observed

(0.0374 Bq/m^3) air concentrations and assumptions about intake rates and dose coefficients (see Appendix C of *Environmental Report 2002* [Sanchez et al. 2003]). When predicted air concentrations drive the doses, doses are normally higher than when observed air and vegetation concentrations drive the results. The total dose from CAP88-PC is the highest, as expected, and the NEWTRIT dose is within a factor of three 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 (**Table 6-8**) lowers the annual dose from tritium to as low as about 20% of the lowest dose in **Table 6-7**, even while including tiny potential doses from other dose pathways.

Table 6-8. Doses for the tritium exposure of an individual residing at the location of the VIS air tritium monitor in 2004, based on observed HTO-in-air concentrations and using plausible but conservative assumptions (as indicated)

Source of dose	Annual dose (nSv/y)	Assumption
Inhalation	3.3	Breathes air at VIS 16 hours a day, all year
Ingesting food, including OBT	5.7	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	0.87	Drinks one liter bottle of Livermore Valley wine each week at the mean concentration for 2004
Immersion	0.045	Swims in the LLNL pool 50 hours per year (pool closed in June 2004)
All sources	10[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.

Environmental Impact

The annual radiological dose from all emissions at the Livermore site and Site 300 in 2004 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 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 2004 were:

- Livermore site: 0.079 μSv (0.0079 mrem)—27% from point-source emissions, 73% 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: 0.26 μSv (0.026 mrem)—97% from explosive experiments, which are classified as point-sources, 3% 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 2004 was estimated to be 0.010 person-Sv (1.0 person-rem) for the Livermore site and 0.0385 person-Sv (3.85 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 2004 were below one-half of one percent (0.5%) of the federal standard and were nearly 9,000 times smaller than the dose from background radiation. The population doses from LLNL operations in 2004 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 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 2004.