9. Livermore Ground Water Protection Management Program

Richard A. Brown
Richard C. Blake
Erich R. Brandstetter

Introduction

LLNL's Ground Water Protection Management Program (GWPMP) is a multifaceted effort to eliminate or minimize adverse impacts of LLNL operations on ground water. U.S. Department of Energy (DOE) Order 5400.1 and the soon-to-be promulgated 10 CFR 834 require all DOE facilities to prepare a GWPMP that describes the site's ground water regime, describes programs to monitor the ground water and monitor and control potential sources of ground water contamination, and describes areas of known contamination and remediation activities. Much of the ground water monitoring and remediation at the Livermore site is carried out under Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) restoration efforts. That monitoring and remediation is fully described in documents issued by the Livermore Site Ground Water Project (see Appendix A) and is summarized in Chapters 2 and 14 of this document. This chapter describes the site's ground water regime, programs to monitor the ground water and to monitor potential sources of ground water contamination, and programs to control potential sources of contamination.

Ground Water Regime

The ground water regime at the Livermore site is described in the following sections.

Livermore Site

Physiographic Setting

The Livermore Valley, which is the most prominent valley within the Diablo Range, is an east-west trending structural and topographic trough bounded on the west by Pleasanton Ridge and on the east by the Altamont Hills. The valley floor is covered by alluvial, lake, and swamp deposits consisting of gravels, sands, silts, and clays with an average thickness of about 100 m. The valley is approximately 25 km long and averages 11 km in width. The valley floor is 220 m at its highest elevation along the eastern margin and gradually dips to 92 m at the southwest corner. The major streams dissecting the Livermore Valley are Arroyo del Valle and Arroyo Mocho, which drain the southern highlands and flow naturally only during the rainy season. Arroyo Mocho now flows the entire year because of water supplied by Zone 7.

Livermore Valley Ground Water Basin

The Livermore Valley Ground Water Basin lies within the Diablo Range, which reaches a maximum elevation of 1160 m above sea level in the tributary watershed. Including the uplands and valley floor, the ground water basin encompasses 17,000 hectares. The prominent streams, all of which are ephemeral, include Arroyo del Valle, Arroyo Las Positas, Arroyo Seco, Arroyo Mocho, Alamo Creek, South San Ramon Creek, and Tassajara Creek. Arroyo del Valle and Arroyo Mocho drain the largest areas and are the largest streams. These streams all flow toward the valley floor and then westward until they converge at Arroyo de la Laguna, which flows southward out of the valley into the Sunol Valley Ground Water Basin.

The Livermore Valley ground water system can be described as a sequence of semiconfined aquifers. Ground water moves downslope from the perimeter (the valley uplands) toward the longitudinal axis of the valley. It then flows in a generally westward direction toward the southwest portion of the basin. From this point, the ground water flows south into the Sunol Valley Ground Water Basin. However, since 1945, heavy draft from the area has eliminated any subsurface outflow from the Livermore Valley Ground Water Basin.

The Livermore Formation, with an average thickness of about 1000 m and an area of approximately 250 km^3, has an available storage capacity significantly greater than that of the overlying alluvium, which averages only about one-tenth the thickness. However, the alluvium is considerably more permeable and is, therefore, the principal water-producing formation for most of the valley (San Francisco RWQCB 1982). The largest quantities of ground water are produced in the central and western portions of the Livermore Valley, where the valley fill is thickest.

The quality of ground water in the Livermore Valley Ground Water Basin is generally a reflection of the surface water that recharges the aquifers. The chemical character ranges from an excellent quality sodium, magnesium, or calcium bicarbonate to a poor quality sodium chloride water. In the eastern part of the valley, the poor quality sodium chloride ground water is indicative of the recharge waters from Altamont Creek, which drains the marine sediments to the east of the valley. High concentrations of naturally occurring dissolved minerals, especially boron, in the eastern part of the valley render the ground water unsuitable for irrigation purposes. Infiltration of wastewater or fertilizers applied to crop lands causes locally elevated levels of nitrates (San Francisco Bay RWQCB 1982). Areas with rapid infiltration rates are limited to the larger stream courses of Arroyo del Valle, Arroyo Mocho, and, to a lesser extent, Arroyo Las Positas.

Surface Drainage

The natural drainage at the Livermore site was altered by construction activities several times up to 1966 (Thorpe et al. 1990) so that the current northwest flow of Arroyo Seco and the north-then-west flow of Arroyo Las Positas do not represent historical flow paths. About 1.6 km to the west of the Livermore site, Arroyo Seco merges with Arroyo Las Positas, which continues to the west to eventually merge with Arroyo Mocho. An abandoned stream channel is visible on air-photo maps of the site east of the present alignment of Arroyo Seco (Carpenter et al. 1984). A Drainage Retention Basin for storm water diversion and flood control was excavated and constructed to the north and west of Building 551 and collects surface water runoff from the site and a portion of the Arroyo Las Positas drainage. This basin was lined in 1990 to prevent infiltration in this area. The gentle 0.5°-to-1° northwest slope of the ground surface (not composed of drainage ways) suggests Holocene deposition by streams flowing northwest from the south and east. Actual ground elevations range from 170 to 200 m above mean sea level.

Hydrogeology

Sediment types at the Livermore site can be grouped into four categories, based on dominant particle size by volume: clay, silt, sand, and gravel. The hydrostratigraphic units of concern at the site are part of the Quaternary alluvial deposits of the upper Livermore member of the Livermore Formation. These strata comprise the upper section of strata at the site and vary from approximately 60 m thick on the eastern part of the site to 120 m thick to the west. Ground water flow is primarily in sand and gravel lenses and channels, bounded by the less permeable clays and silts.

Based on borehole lithologic data, a series of buried sand and gravel-filled stream channels have been identified at the site. The sand and gravel deposits, which are highly permeable, are present in narrow bands at the site and are interpreted as braided stream deposits, similar to strata deposited by the present day Arroyo Mocho. Sand and gravel deposits do not exceed about 30% of the section anywhere at the Livermore site.

The permeable sediments of the Upper Livermore Formation at the Livermore site are vertically separated by the horizontally extensive, low-permeability silt and clay of the Lower Member of the Livermore Formation, which comprise a regional confining layer.

The depth to ground water ranges from over 40 m (130 feet) in the southeast corner of the site to 10 m (33 feet) in the northwest and 12 m (40 feet) in the northeast corners (Thorpe et al. 1990). Ground water levels respond to climate and resource use. Decreases in ground water use from the 1960s to 1985 caused the water table to rise. Heavy rains caused rises in 1986, 1993, 1994, and, 1995, and droughts caused declines in 1987 through 1991.

Ground water recharge at the Livermore site primarily consists of controlled releases from the South Bay Aqueduct and direct rainfall. Recharge enters primarily through the arroyos and, until its lining in 1990, the Drainage Retention Basin.

Ground water flow at the Livermore site is generally westward with a southerly component. The gradient is steepest near the northeast (about 0.15 m/m) and southeast corners of the site and decreases to about 0.002 m/m west of the site. The downward vertical gradient at the Livermore site ranges from 0.25 m/m on the east side to 0.3 m/m on the west side.

The site hydrogeology is discussed in detail in the *CERCLA Remedial Investigation Report for the LLNL Livermore Site* (Thorpe et al. 1990) and other reports of the ongoing Ground Water Project (see also Chapter 2).

Subsurface Migration Off Site

The conceptual model presented in the CERCLA Remedial Investigation Report for the LLNL Livermore Site (Thorpe et al. 1990) suggests that ground water generally flows towards two destinations from the Livermore site forming a gap. Ground water from the north half flows west and northwest and eventually discharges to Arroyo Las Positas near First Street in Livermore, about 2 km northwest of the Livermore site. Ground water from the southern half flows generally westward toward the gap between the Mocho I and Mocho II subbasins, about 2 km west of the Livermore site. Ground water velocities at the Livermore site average about 15 to 20 m (49 to 66 feet) per year. In the area of the gap, the magnitude and direction of ground water flow is uncertain; investigations are underway to determine if ground water from the Livermore site (Mocho I subbasin) migrates westward into the Mocho II subbasin, where several City of Livermore water supply wells are located.

Ground Water Monitoring

Distinct ground water monitoring programs are in place at the Livermore site and in the surrounding area; their purposes constitute their primary differences. One is to determine impacts from current and ongoing activities (surveillance monitoring); another is to determine if there is contamination from past practices and to remediate it (CERCLA-related monitoring). The CERCLA-related monitoring is summarized in Chapters 2 and 14 of this document and results are presented in detail elsewhere

Surveillance Ground Water Monitoring

Surveillance Monitoring of On-Site LLNL Monitor Wells

LLNL designed a ground water surveillance monitoring network that was implemented in 1995 to determine impacts to the ground water from current and ongoing activities.

Rationale and Design Criteria

DOE Order 5400.1 states that "Groundwater that is or could be affected by DOE activities shall be monitored to determine and document the effects of operations on groundwater quality and quantity and to demonstrate compliance with DOE requirements and applicable federal, state, and local laws and regulations... A groundwater monitoring plan shall be developed as a specific element of all environmental plans... Ground water monitoring programs shall be conducted on site and in the vicinity of DOE facilities to:

(1) Obtain data for the purpose of determining baseline conditions of groundwater quality and quantity;

(2) Demonstrate compliance with and implementation of all applicable regulations and DOE Orders;

(3) Provide data to permit the early detection of groundwater pollution or contamination;

(4) Provide a reporting mechanism for detected groundwater pollution or contamination;

(5) Identify existing and potential groundwater contamination sources and to maintain surveillance of these sources;

(6) Provide data upon which decisions can be made concerning land disposal practices and the management and protection of groundwater resources.

Site-specific characteristics shall determine monitoring needs. Where appropriate, monitoring programs shall be designed and implemented in accordance with 40 CFR Part 264, Subpart F, or 40 CFR Part 265, Subpart F. Monitoring for radionuclides shall be in accordance with DOE orders in the 5400 series dealing with radiation protection of the public and the environment." Title 40 of the Code of Federal Regulations (CFR) specifies the substantive requirements of the Resource Conservation and Recovery Act (RCRA); Subpart F addresses ground water monitoring requirements for existing RCRA facilities.

Surveillance ground water monitoring results are presented in a later section of this chapter.

Ground Water Remediation

The CERCLA ground water remediation efforts are summarized in Chapters 2 and 14 of this document and are presented in detail elsewhere in CERCLA documents.

Areas of Special Concern

Several areas of special concern for ground water protection have been identified at LLNL.

The objectives of the GWPMP include monitoring the impact of current operations and eliminating or minimizing adverse impacts from ongoing operations on ground water. The basic approach is to be able to detect contaminants before they can enter the ground water. To do this, areas have been identified that are contaminated or potentially contaminated with hazardous and / or radioactive waste, focusing on four areas:

- Geologic areas with rapid communication between surface water and ground water.
- Current processes and operations that could contaminate these high-risk areas.
- Current and planned Best Management Practices (BMPs) that minimize this risk.
- Current and new monitoring to provide early warning of potential ground water contamination.

With these considerations, five areas have been identified as being at risk for ground water contamination:

- The arroyos (Arroyo Las Positas and Arroyo Seco) that cross the site.
- The storm drain system.
- Soil around underground storage tanks.
- Soil around the sanitary sewer.
- The ground water beneath the hazardous waste management (HWM) buildings, B514 and B612 that may be subject to spills.

Source Control Strategies

Soil and Sediment Surveillance Monitoring

Soil monitoring in the arroyos and storm water network was one of the items targeted in the GWPMP surveillance monitoring because "..recharge of natural runoff through the stream beds of arroyos accounts for the majority (about 42%) of resupply to the Livermore Valley ground water basin..." (Webster-Scholten 1990). Infiltrating rain water may carry with it any dissolved constituents that may be present. Programs already exist that address the sanitary sewer system, the building drains, and underground storage tanks (see Chapter 2).

LLNL has developed background levels for total metals in soils and sediments and de minimis (or designated) concentration levels for soluble metals and organics based on Jon Marshack's staff report, *The Designated Level Methodology for Waste Classification and Clean-up Level Determination* (Marshack 1991). This designated level methodology determines what soluble levels of contaminants would not adversely impact ground water beyond its beneficial uses by application of a simple attenuation factor and specific water quality objectives. The attenuation factor agreed upon with the San Francisco Bay Regional Water Quality Control Board (RWQCB) is 100 except for certain metals; the attenuation factor is 1000 for copper, lead and zinc. Any constituents with soluble concentrations above these de minimis levels may adversely impact the ground water beneath. We are in the process of negotiating the appropriate water quality objectives with the San Francisco Bay RWQCB.

In 1996, shallow vadose zones in the arroyos will be sampled at three influent locations (ALPE, ASS2, and GRNE) and the two effluent locations (ASW and WPDC) corresponding to storm water sampling locations. In addition, sediment samples will be collected from settling basins upstream of the Drainage Retention Basin. Samples are to be collected and analyzed for both total and soluble metals (using California's Waste Extraction Test) and for leachable organics (using EPA's Toxicity Characteristic Leaching Potential test); samples may also be analyzed for leachable organic compounds. Furthermore, storm drain system sampling locations will be selected based on available historical information (Gallegos 1994). For a description of methods and a discussion of 1995 arroyo sediment sampling radiological results, see Chapter 10.

LLNL has designed a surveillance monitoring program to detect possible releases from the mixed-waste storage areas, Buildings 514 and 612, in the southeastern portion of LLNL (**Figure 9-1**). Monitoring of the vadose zone is not feasible in this area because most of the area is paved. Therefore, existing ground water wells were chosen for surveillance monitoring. This program consists of four upgradient and four downgradient monitoring wells and was implemented in 1995; these wells were chosen to monitor the uppermost aquifers within that area. The four wells upgradient of the mixed-waste storage areas include monitoring wells W-017 and W-117 screened in Hydrostratigraphic Unit number 6 (HSU-6), and monitoring wells W-107 and W-268 screened in HSU-5. The monitoring wells downgradient of Building 514 and Building 612 are W-217, W-270, W-359, and W-622; all of these wells are screened within HSU-5. Although no such requirements have been imposed upon the LLNL site, the siting of these wells would satisfy any RCRA monitoring or any California Code of Regulations Title 22 monitoring requirements.

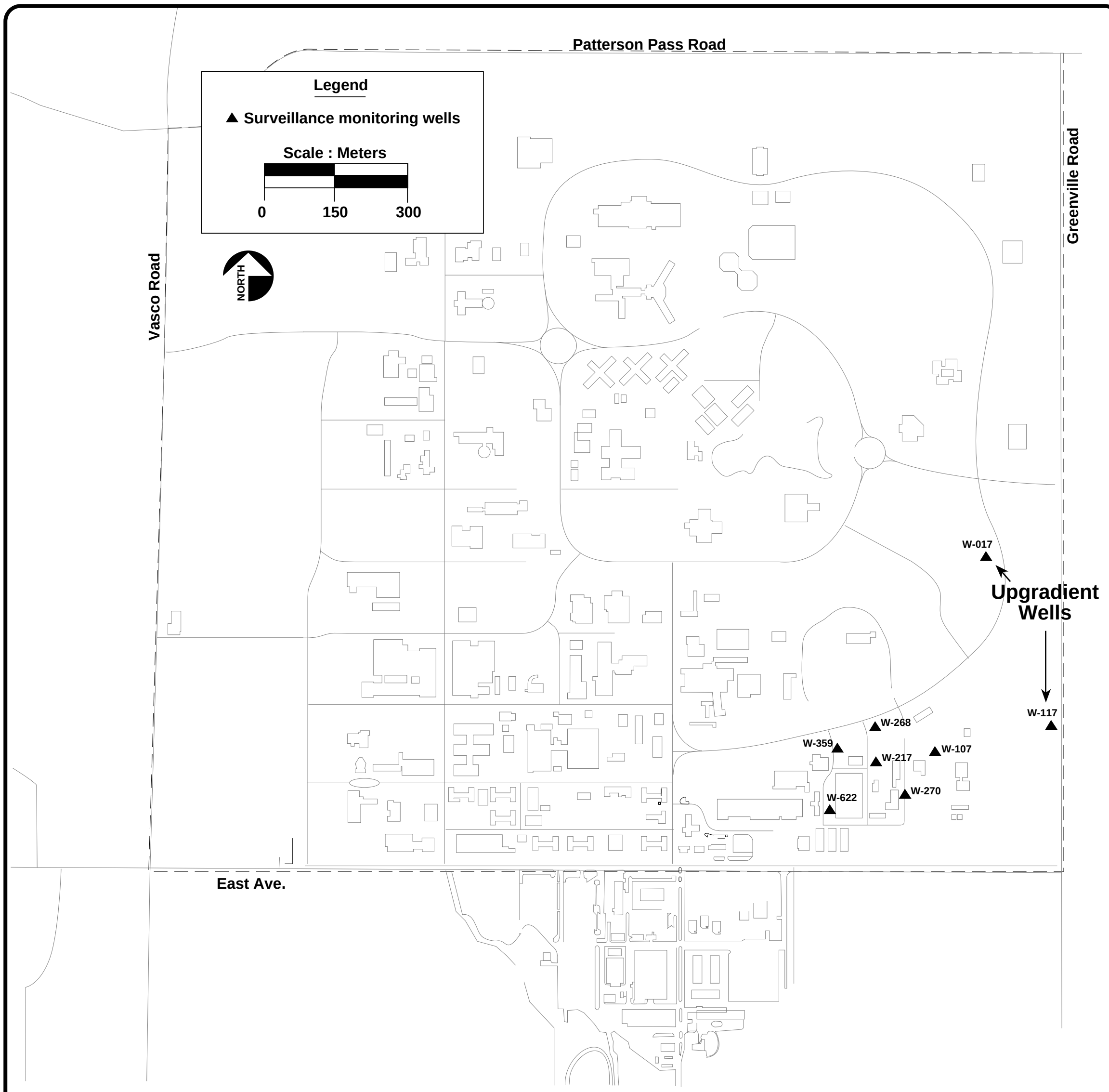

Figure 9-1. Surveillance monitoring wells in the southeastern portion of the Livermore site.

Surveillance Monitoring of On-Site LLNL Wells

Table 9-1 shows the analytes and the quarterly monitoring schedule that was chosen for these eight wells. This quarterly monitoring satisfies requirements delineated in 40 CFR Subpart F for ground water monitoring, although it is not required as a permit condition.

Table 9-1. Analyte list for surveillance monitoring wells, 1995.[a]

Analytes	EPA methods
Beryllium	210.2
Chromium (VI)	218.4
Metals by GFAA[b]	204.2, 206.2, 213.2, 239.2, 270.2, 279.2
Metals by ICP[c]	200.7
General minerals	150.1, 160.1, 200.7, 300.0, 310.2
Total cyanide	335.2
Ethylene dibromide	504
Volatile organic compounds (VOCs)	601
Semivolatiles, including PAHs[d]	625
Pesticides and herbicides	608/615
Radiological parameters	Various HASL-300 Series methods

a Surveillance monitoring wells were sampled and analyzed on a quarterly basis. This schedule was followed for 1995.

b Graphite furnace atomic absorption spectroscopy.

c Inductively coupled plasma emission spectroscopy.

d Polynuclear aromatic hydrocarbons.

Table 9-2 demonstrates the Water Quality Objectives (WQOs) that are being met by the reporting limits used for the organic analytes in this monitoring network; **Table 9-3** gives the detection limits by analyte for each of the organic analytes listed, except for ethylene dibromide. **Table 9-4** gives the WQOs for the inorganic analytes; **Table 9-5** gives the WQOs, including DOE guidelines, for radionuclides in water.

Table 9-2. Water quality objectives for organic compounds.

Analytes	EPA method	Detection limits[a] (µg/L)	CA or Federal MCLs[b] (µg/L)	One-in-a-million cancer risk[b] (µg/L)	Sampling schedule
VOCs	601	0.5	0.5+	0.015+	Quarterly
Ethylene dibromide	504	0.01	0.05	0.0004–0.055	Quarterly
Chlorinated pesticides	608	0.03–10	0.01+	0.002+	Quarterly
Chlorinated herbicides	615	0.03–10	7+	NA	Quarterly
Semivolatiles	625	10–50	0.2+	0.002+	Quarterly

[a] Detection limit of 10 µg/L for benzo(a)pyrene, the known carcinogenic polynuclear aromatic compound.

[b] + = or greater (e.g., MCLs for most VOCs are greater than 0.5 µg/L).

Surveillance Monitoring Results

This section presents the surveillance monitoring results for the eight LLNL on-site monitoring wells and for the 21 downgradient wells monitored annually for tritium, at various distances from LLNL.

Livermore Site

All surveillance monitoring analytical results are presented in Volume 2, Chapter 9 of this document. These first-year monitoring efforts are used to establish baseline conditions for future monitoring, as well as to establish if any radioactive materials in the ground water are present at levels of concern to public health or to the environment. These monitoring results are separated into the four upgradient wells and the four downgradient wells.

The volatile organic compounds (VOCs) that were detected are the same ones that are now being remediated under CERCLA, according to the *Record of Decision for Lawrence Livermore National Laboratory Site* (ROD) (Ziagos 1992) that was agreed upon for the Livermore site. Details of this cleanup effort are discussed in the CERCLA documents including the *LLNL Ground Water Project 1995 Annual Report* (Hoffman et al. 1996). Complete data tables of these detections are found in Volume 2, Chapter 9. No ethylene dibromide, chlorinated herbicides, or chlorinated pesticides were detected in this surveillance monitoring.

Table 9-3. List of ground water analyses showing EPA method, organic constituent, and typical reporting limit (a statistically determined concentration limit, above which detection is certain).

Constituent	Reporting limit (µg/L)
EPA Method 601	
1,1,1-Trichloroethane	0.5
1,1,2,2-Tetrachloroethane	0.5
1,1,2-Trichloroethane	0.5
1,1-Dichloroethane	0.5
1,1-Dichloroethene	0.5
1,2-Dichlorobenzene	0.5
1,2-Dichloroethane	0.5
1,2-Dichloroethene (total)	0.5
1,2-Dichloropropane	0.5
1,3-Dichlorobenzene	0.5
1,4-Dichlorobenzene	0.5
2-Chloroethylvinylether	0.5
Bromodichloromethane	0.5
Bromoform	0.5
Bromomethane	0.5
Carbon tetrachloride	0.5
Chlorobenzene	0.5
Chloroethane	0.5
Chloroform	0.5
Chloromethane	0.5
cis-1,3-Dichloropropene	0.5
Dibromochloromethane	0.5
Dichlorodifluoromethane	0.5
Freon-113	0.5
Methylene chloride	0.5
Tetrachloroethene	0.5
trans-1,3-Dichloropropene	0.5
Trichloroethene	0.5
Trichlorofluoromethane	0.5
Vinyl chloride	0.5
1,2-Dichlorobenzene	0.5

Constituent	Reporting limit (µg/L)
EPA Method 602	
1,3-Dichlorobenzene	0.3
1,4-Dichlorobenzene	0.3
Benzene	0.4
Chlorobenzene	0.3
Ethylbenzene	0.3
m- and p-Xylene isomers	0.4
o-Xylene	0.4
Toluene	0.3
Total xylene isomers	0.4
EPA Method 608	
Aldrin	0.05
BHC, alpha isomer	0.05
BHC, beta isomer	0.05
BHC, delta isomer	0.05
BHC, gamma isomer (Lindane)	0.05
Chlordane	0.5
Dieldrin	0.1
Endosulfan I	0.05
Endosulfan II	0.1
Endosulfan sulfate	0.1
Endrin	0.1
Endrin aldehyde	0.1
Heptachlor	0.05
Heptachlor epoxide	0.05
Methoxychlor	0.5
4,4’-DDD	0.1
4,4’-DDE	0.1
4,4’-DDT	0.1
Toxaphene	1

Table 9-3. List of ground water analyses showing EPA method, organic constituent, and typical reporting limit (a statistically determined concentration limit, above which detection is certain) (continued).

Constituent	Reporting limit (μg/L)
EPA Method 615	
2,4,5-T	0.5
2,4,5-TP (Silvex)	0.2
2,4-D	1
2,4-Dichlorophenoxy acetic acid	2
Dalapon	2
Dicamba	1
Dichloroprop	2
Dinoseb	1
MCPA	250
MCPP	250
EPA Method 625	
1,2,4-Trichlorobenzene	10
1,2-Dichlorobenzene	10
1,3-Dichlorobenzene	10
1,4-Dichlorobenzene	10
2,4,5-Trichlorophenol	10
2,4,6-Trichlorophenol	10
2,4-Dichlorophenol	10
2,4-Dimethylphenol	10
2,4-Dinitrophenol	50
2,4-Dinitrotoluene	10
2,6-Dinitrotoluene	10
2-Chloronaphthalene	10
2-Chlorophenol	10
2-Methylphenol	10
2-Methyl-4,6-dinitrophenol	50
2-Methylnaphthalene	10
2-Nitroaniline	50
2-Nitrophenol	10

Constituent	Reporting limit (μg/L)
EPA Method 625 (continued)	
3,3'-Dichlorobenzidine	20
3-Nitroaniline	50
4-Bromophenylphenylether	10
4-Chloro-3-methylphenol	20
4-Chloroaniline	20
4-Chlorophenylphenylether	10
4-Nitroaniline	50
4-Nitrophenol	50
Acenaphthene	10
Acenaphthylene	10
Anthracene	10
Benzo(a)anthracene	10
Benzo(a)pyrene	10
Benzo(b)fluoranthene	10
Benzo(g,h,i)perylene	10
Benzo(k)fluoranthene	10
Benzoic acid	50
Benzyl alcohol	20
Bis(2-chloroethoxy)methane	10
Bis(2-chloroisopropyl)ether	10
Bis(2-ethylhexyl)phthalate	10
Butylbenzylphthalate	10
Chrysene	10
Di-n-butylphthalate	10
Di-n-octylphthalate	10
Dibenzo(a,h)anthracene	10
Dibenzofuran	10
Diethylphthalate	10
Dimethylphthalate	10
Fluoranthene	10
Fluorene	10
Hexachlorobenzene	10

Table 9-3. List of ground water analyses showing EPA Method, organic constituent, and typical reporting limit (a statistically determined concentration limit, above which detection is certain) (concluded).

Constituent	Reporting limit (μg/L)
Hexachlorobutadiene	10
Hexachlorocyclopentadiene	10
Hexachloroethane	10
Indeno(1,2,3-c,d)pyrene	10
Isophorone	10
m- and p-Cresol	10
N-Nitrosodi-n-propylamine	10
N-Nitrosodiphenylamine	10
Naphthalene	10
Nitrobenzene	10
Pentachlorophenol	50
Phenanthrene	10
Phenol	10
Pyrene	10

Summary **Tables 9-6** and **9-7** present the summary analytical results for inorganics data for the upgradient wells and the downgradient wells, respectively. Note that the General Indicator Parameters of specific conductance and total dissolved solids are higher in the downgradient wells, especially well W-217, than in the upgradient or background wells. Likewise, particular elements and anions such as barium, chlorides, and nitrates are higher in the downgradient wells as a whole, and Well W-217 in particular, than in the background wells. In March 1995, the nitrates in Well W-217 were analyzed at 46 mg/L, which very slightly exceeds the drinking water MCL of 45 mg/L, but concentrations of nitrates in that well dropped down below the MCL for the remainder of the year. Trends of concentrations of chlorides and nitrates in ground water will be tracked in future years and attempts will be made to discover if a continuing on-site source of these anions exists.

Tables 9-8 and **9-9** present the corresponding summary analytical results for the radiological data. The only obvious trend from the summary data is that activities of tritium are somewhat higher in the downgradient wells, although still found in activities of less than 5% of the drinking water MCL (740 Bq/L, or 20,000 pCi/L) for tritium. Activities for uranium are somewhat higher in the background wells than in the downgradient wells.

This surveillance monitoring program will be reevaluated on an ongoing basis to identify areas of potential concern that may warrant further monitoring (see Chapter 11 and the *Environmental Monitoring Plan*, Tate et al. 1995, for further details).

Table 9-4. Water quality objectives for inorganic compounds.

Inorganic:	EPA method	Reporting limits (mg/L)	CA or Federal MCL[a] (mg/L)	SFRWQCB[b] basin plan WQOs[c] (mg/L)	EPA health advisory (mg/L)
Aluminum	200.7	0.2	1	5/20	NA
Antimony	204.2	0.005-0.01	0.006	0.006	0.003
Arsenic	206.2	0.002	0.05	0.05	0.00002
Barium	200.7	0.025	1	1	2
Beryllium	210.2	0.0005	0.004	0.004	0.000008
Boron	200.7	0.1	NA	0.5/2	0.6
Cadmium	213.2	0.0005	0.005	0.005	0.005
Chloride	325.3	5	250[d]	250	NA
Chromium(VI)	218.4, 218.5	0.01	0.05	0.05	0.1
Copper	200.7, 220.2	0.001-0.05	1[d]	1	NA
Cyanide	335.2	0.02	0.2	0.2	0.2
Fluoride	340.2	0.05	1.4-2.4	0.8/1.7	NA
Iron	200.7	0.1	0.3[d]	0.3	NA
Lead	239.2	0.002	0.015[e]	5/10	NA
Manganese	200.7	0.03	0.05[e]	0.05	NA
Mercury	245.1	0.0002	0.002	0.002	0.002
Molybdenum	246.1	0.05	NA	0.01/0.05	0.035
Nickel	249.2	0.005	0.1	0.1	0.1
Nitrate, as NO_3	353.2	0.5	45	45	45
Nitrite, as N	300.0	0.5	1	1	1
pH (units)	9040	0.1	6.5-8.5[d]	6.5	NA
Selenium	270.2	0.002	0.05	0.05	NA
Silver	272.2	0.01	0.1	0.05	0.1
Specific conductance (µmhos/cm)	120.1	200	900[d]	900	NA
Sulfate	375.4	1	250[d]	250	NA
Total dissolved solids (TDS)	160.1	1	500[d]	500	NA
Thallium	279.2	0.001-0.005	0.002	0.002	0.0004
Vanadium	200.7	0.025	NA	0.1/1	NA
Zinc	200.7	0.01	5[d]	5.0	2

a Maximum contaminant level, as listed in U.S. Environmental Protection Agency (USEPA) Region IX *Drinking Water Standards and Health Advisories Table*, dated December 1995.

b San Francisco Bay Regional Water Quality Control Board.

c Water quality objectives.

d USEPA Secondary MCL.

e USEPA action level for lead.

Table 9-5. Water quality objectives for radioactive compounds.

Radionuclide	Analytical method	Minimum detectable activity (Bq/L)	CA or Federal MCL (Bq/L)	SFRWQCB basin plan WQOs (Bq/L)	DOE's derived concentration guidelines (DCGs; in Bq/L)	EPA health advisory (Bq/L)
Gross alpha (excluding uranium and radon)	EPA 906	0.04–0.14	0.56	0.56	NA	0.0056
Gross beta	EPA 906	0.09–0.1	1.85	1.85	NA	0.4 µSv (0.04 mrem)/y
^{238}Pu	HASL-300 Series[a]	0.0001	NA	NA	1.11	NA
$^{238, 240}Pu$	HASL-300 Series	0.0001	NA	NA	1.11	NA
^{226}Ra	HASL-300 Series	0.004	0.185[b]	0.185[b]	3.7	0.0074
^{228}Th	HASL-300 Series	0.0004	NA	NA	15	NA
^{232}Th	HASL-300 Series	0.0004	NA	NA	1.85	NA
^{3}H	EMSL-LV-0539-17	1.6–1.8	740	740	74,000	NA
^{234}U	HASL-300 Series	0.0005	0.74[c]	0.74[c]	18.5	0.7 µg/L (total uranium)
^{235}U	HASL-300 Series	0.0005	0.74[c]	0.74[c]	22	0.7 µg/L (total uranium)
^{238}U	HASL-300 Series	0.0005	0.74[c]	0.74[c]	22	0.7 µg/L (total uranium)

a The HASL-300 series contains the procedures used by DOE's Environmental Measurements Laboratory.

b For both radium 226 and radium 228.

c Isotopes of uranium are undifferentiated by the USEPA guidance documents.

Surveillance Monitoring of Off-Site Livermore Valley Wells:

In order to protect downgradient users of ground water, LLNL has been monitoring tritium in wells hydraulically downgradient of LLNL since 1988. Off-site well locations are shown in **Figure 9-2**. Rain and storm water runoff in the Livermore Valley recharges local aquifers. Rain and runoff contain small amounts of tritium from natural sources, from past atmospheric nuclear weapons tests, and from atmospheric emissions from LLNL and SNL/California (see Chapter 4 on Air Monitoring for further discussion on air emissions).

Table 9-6. Analytical results (1995) for general indicators, metals, and minerals for upgradient monitor wells W-017, W-107, W-117, and W-268.

	Median	IQR[(a)]	Minimum	Maximum
General indicators				
pH (units)	7.40	0.5	7.20	9.70
Specific conductance (µmhos/cm)	700	165	49	990
Total dissolved solids (mg/L)	426	108	240	671
Metals and minerals (mg/L)				
Bicarbonate alkalinity (as $CaCO_3$)	165	30	10	340
Total alkalinity (as $CaCO_3$)	165	30	110	360
Barium	0.200	0.03	0.120	0.520
Boron	0.240	0.165	0.100	0.610
Calcium	48	32.2	8.2	82
Chloride	115	65	76	190
Chromium (VI)	0.012	0.004	0.010	0.032
Fluoride	0.46	0.092	0.27	0.54
Total hardness (as $CaCO_3$)	55	135	86	410
Magnesium	29	16	16	49
Nitrate (as NO_3)	11.0	5.2	0.5	16.0
Potassium	1.6	0.8	1.1	2.9
Sodium	66	8	57	76
Sulfate	26.5	21.8	6.0	54

[a] Interquartile range.

Tritium measurements of water samples collected during the summer of 1995 from 21 wells in the Livermore Valley are given in **Table 9-10**. Tritium in all well samples was very low compared to the 740 Bq/L (20,000 pCi/L) MCL established by the State of California. As in previous years, the highest tritium activity measured was from Well 11B1, located about 10 km west of LLNL. The activity in that well in 1995 was 11.4 Bq/L (309 pCi/L), a decrease of 65% from its measurement of 33.0 Bq/L (893 pCi/L) in 1988.

Table 9-7. Analytical results (1995) for general indicators, metals, and minerals for downgradient monitor wells W-217, W-270, W-359, and W-622.

	Median	IQR[(a)]	Minimum	Maximum
General indicator				
pH (units)	7.40	0.20	7.20	8.30
Specific conductance (µmhos/cm)	690	255	500	1100
Total dissolved solids (mg/L)	495	242	360	1100
Metals and minerals (mg/L)				
Bicarbonate alk (as $CaCO_3$)	140	32	61	190
Total alkalinity (as $CaCO_3$)	140	32	61	190
Barium	0.255	0.23	0.160	0.720
Boron	0.240	0.17	0.100	0.400
Calcium	57	13.2	48	130
Chloride	115	58	75	350
Chromium, hexavalent	0.010	0.003	0.008	0.031
Fluoride	0.29	0.068	0.22	0.38
Total hardness (as $CaCO_3$)	240	85	200	510
Magnesium	25	11	16	45
Nitrate (as NO_3)	17.0	6.8	12.0	46.0
Potassium	2.4	0..5	1.7	2.9
Sodium	56	28	35	100
Sulfate	22.5	51.8	5.2	160

a Interquartile range.

Table 9-8. Radiological results (1995) for upgradient monitor wells W-017, W-107, W-117, and W-268.

	MCL	Median	IQR[(a)]	Minimum	Maximum
General radioactivity (Bq/L)					
Gross alpha	0.56	–0.0075	0.060	–0.068	0.119
Gross beta	1.85	0.122	0.133	0.051	0.370
Radioisotopes (Bq/L)					
^{226}Ra	0.185	0.029	0.045	0.002	0.11
^{3}H	740	2.54	0.413	1.59	3.00
^{234}U	0.74	0.032	0.027	0.013	0.121
^{235}U	0.74	0.0013	0.0017	0.0002	0.0038
^{238}U	0.74	0.021	0.019	0.007	0.077

a Interquartile range.

Table 9-9. Radiological results (1995) for downgradient monitor wells W-217, W-270, W-359, and W-622, 1995.

	MCL	Median	IQR[(a)]	Minimum	Maximum
General radioactivity (Bq/L)					
Gross alpha	0.56	–0.016	0.071	–0.074	0.081
Gross beta	1.85	0.100	0.108	–0.002	0.199
Radioisotopes (Bq/L)					
^{226}Ra	0.185	0.0201	0.037	0.001	0.055
^{3}H	740	13.4	10.5	1.63	28.8
^{234}U	0.74	0.022	0.013	0.012	0.060
^{235}U	0.74	0.0008	0.0001	0.0002	0.0017
^{238}U	0.74	0.013	0.008	0.008	0.036

a Interquartile range.

The overall trend in tritium activity has been decreasing in Livermore Valley ground waters downgradient of LLNL (**Figure 9-3**). The median activities of tritium in these downgradient wells increased from 3.45 Bq/L (93.2 pCi/L) in 1988 to 4.59 Bq/L (124 pCi/L) in 1989. By summer of 1995, the median activity had dropped to 1.77 Bq/L (47.8 pCi/L).

CERCLA Remedial Actions

Livermore Site

An extensive investigation of the remediation options for the contaminated areas discussed above is summarized in the *CERCLA Feasibility Study for Lawrence Livermore National Laboratory Livermore Site* (Isherwood 1990). The *Record of Decision for Lawrence Livermore National Laboratory Livermore Site* (ROD) (Ziagos 1992) documents the remedial options selected for implementation. The selected remedies for ground water contamination involve pumping the ground water for surface treatment by a combination of ultraviolet-light hydrogen peroxide, air stripping, and granulated activated carbon. The selected remedies for contaminants in the unsaturated zone are vacuum-induced venting with surface treatment of the vapors by catalytic oxidation or activated-carbon filtration. The goal of the remedial action is to clean the ground water to the levels specified in the applicable, relevant, and appropriate requirements developed for this project and outlined in the ROD. A description of the remediation efforts during 1995 can be found in Chapters 2 and 14 of this document.

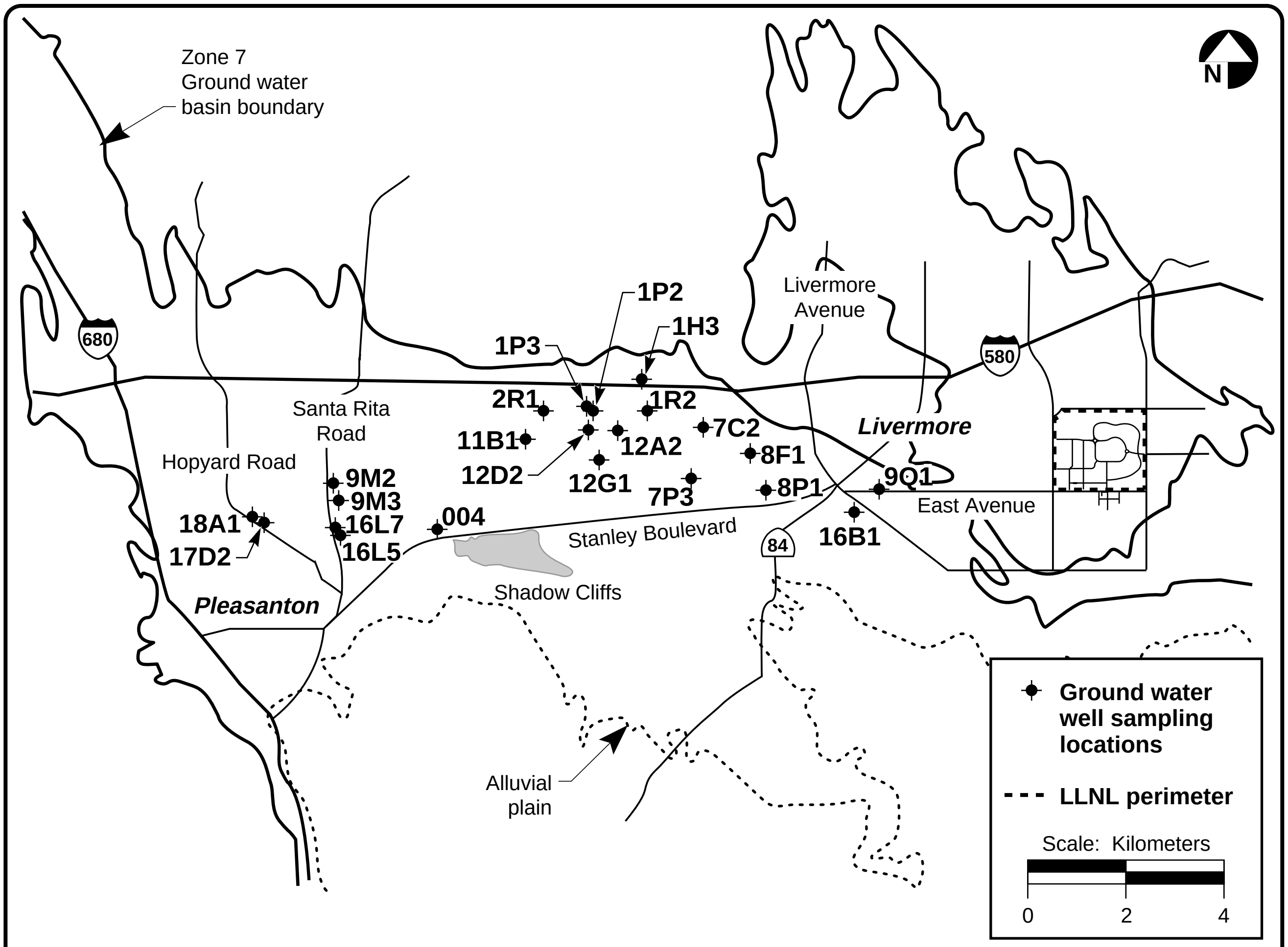

Figure 9-2. Ground water surveillance well sampling locations, Livermore Valley, 1995.

Pollution Prevention Activities

LLNL beneficially reuses excess construction soils on site if they do not pose a potential threat to beneficial uses of ground water supplies as defined by the local California RWQCB. At a CERCLA site such as LLNL, regulatory agencies usually require that the cleanup level for contaminants be background. The background level for synthetic VOCs, which are the primary contaminants at LLNL, is no contamination (zero concentration). As a result, LLNL selected an alternative method to allow reuse of soils with minimal levels of VOCs. The Designated Level Methodology (DLM), developed by Jon Marshack (Marshack 1991) of the Central Valley RWQCB has been approved for use by both the Central Valley and the San Francisco Bay RWQCB.

Table 9-10. Tritium activity in Livermore Valley wells in Bq/L, 1995.

	Bq/L
LWRP[(a)]	
1H3	0.54 ± 0.12
1P2	3.64 ± 0.22
1R2	1.77 ± 0.18
2R1	3.18 ± 0.23
7C2	2.84 ± 0.21
11B1	11.43 ± 0.43
12A2	2.67 ± 0.23
12D2	5.40 ± 0.30
12G1	5.22 ± 0.30
LWRP median	3.18
Livermore	
7P3	<0.1[(b)] ± 0.1
8F1	0.62 ± 0.72
8P1	1.27 ± 0.16
9Q1	0.69 ± 0.12
16B1	1.02 ± 0.16
Livermore median	0.86
Pleasanton	
9M2	2.70 ± 1.20
9M3	3.89 ± 1.30
004	1.39 ± 0.18
16L5	1.03 ± 0.16
16L7	0.77 ± 0.13
17D2	<1.22[(b)] ± 1.22
18A1	3.89 ± 1.34
Pleasanton median	1.39
Overall Statistics	
Median	2.67
Minimum	<0.1
Maximum	11.43
Interquartile range	2.74
Number of samples	19

[a] Livermore Water Reclamation Plant.

[b] Below reporting limit. Not included in statistics.

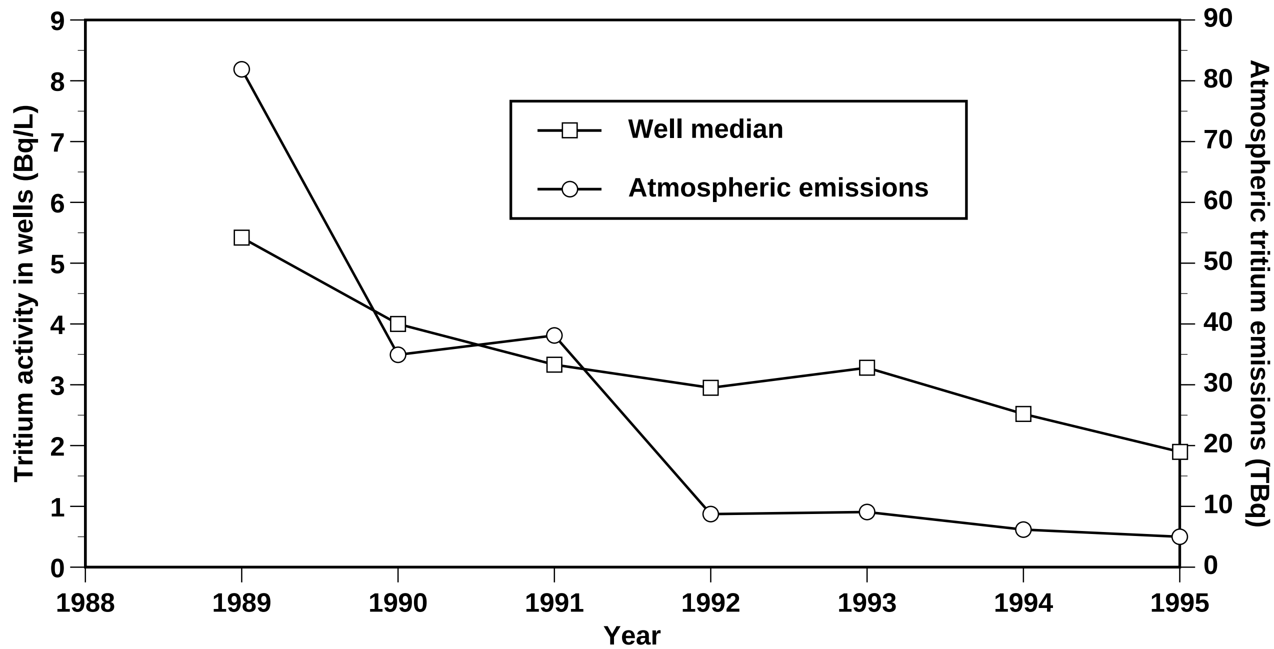

Figure 9-3. Trends of tritium in Livermore Valley wells and atmospheric emissions, 1989 to 1995.

LLNL-developed de minimis concentrations for VOC-contaminated soils based on the DLM (Isherwood 1994) were formally approved by the San Francisco Bay RWQCB for use at the Livermore site. During 1995, we also updated natural background concentrations for trace metals in soils. As an additional constraint, we also developed de minimis concentrations for soluble metals in soils using the DLM (Jackson 1995). Any soils with VOC contamination below de minimis concentrations, and with total metals below background or soluble metals less than de minimis concentrations can now be reused anywhere needed at the Livermore site. This ensures that LLNL construction activities add no unacceptable pollution to the ground water beneath the site and reduce the volume of "clean" soil shipped to landfills.

Environmental Impacts

DOE Order 5400.5 specifically establishes standards and requirements for operations of DOE and their contractors in order to protect "members of the public and the environment against undue risk from radiation." This order states that "It is the policy of DOE to provide a level of protection for persons consuming water from a public drinking water supply operated by the DOE, either directly or through a DOE contractor, that is equivalent to that provided by the public community drinking water standards, maximum contaminant levels (MCLs), of 40 CFR Part 141. These systems shall not cause persons consuming the water to receive an effective dose equivalent greater than 0.04 mSv (4 mrem) in a year. Combined radium-226 and radium-228 activities shall not exceed 0.185 Bq/L (5 pCi/L) and gross alpha activity (including radium-226 but excluding radon and uranium) shall not exceed 0.555 Bq/L (15 pCi/L)."

Of the on-site wells, none of the inorganic data approached the primary drinking water MCLs, with the exception of nitrate. The median nitrate concentration (21.4 mg/L) for the wells downgradient of the HWM facilities was less than one-half of its MCL. Likewise, none of the radiological data approached their respective MCLs. Total uranium came the closest (27%) to its radiological MCL.

Likewise, the maximum tritium activity (11.4 Bq/L) in one of the off-site wells, Well 11B1, was about 1.5% of its MCL.

Summary

It is LLNL's policy to operate in a manner that does not adversely affect the environment. Past material-handling activities and practices have resulted in soil and ground water contamination. LLNL is working closely with local, state, and federal regulatory agencies, with input from the public, to develop and implement efficient, cost-effective ways to remediate the contamination. LLNL is also looking at its current and future operations to prevent possible negative impacts to ground water. Through ongoing plans, LLNL is working to remove sources of concern and to implement protection against accidental impacts.