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Environmental Monitoring at the Lawrence Livermore National Laboratory

1986 Annual Report

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Forward

This report is prepared for the U.S. Department of Energy by the Guidance and Monitoring Section of the Environmental Protection Department at Lawrence Livermore National Laboratory. It reports the results of the Environmental Quality Verification Group, which is responsible for environmental monitoring. Data are obtained through the combined efforts of the Environmental Protection Department, the Nuclear Chemistry Division, and the Hazards Control Department. In addition to the authors listed, the following personnel made significant contributions to this report:

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- 1 Lawrence Livermore National Laboratory
- 2 Sandia National Laboratory
- 3 South Bay Aqueduct
- 4 Arroyo Seco
- 5 Arroyo Las Positas
- 6 Nearest residential area

- 7 Vasco Road
- 8 East Avenue
- 9 Greenville Road
- 10 Lupin Way
- 11 Interstate 580

Frontispiece. Lawrence Livermore National Laboratory (looking west).

Environmental Monitoring at the Lawrence Livermore National Laboratory 1986 Annual Report

Abstract

This report documents the results of the environmental monitoring program at the Lawrence Livermore National Laboratory (LLNL) for 1986. To evaluate the effect of LLNL operations on the local environment, measurements of direct radiation and a variety of radionuclides and chemical pollutants in ambient air, soil, surface water, groundwater, vegetation, milk, foodstuff, and sewage effluents were made at both the Livermore site and nearby Site 300. This report was prepared to meet the requirements of DOE Order 5484.1. Evaluations are made of LLNL's compliance with all applicable guides, standards, and limits for radiological and nonradiological releases to the environment. The data indicate that no releases in excess of the applicable standards were made during 1986, and that LLNL operations had no adverse environmental impact.

Introduction

The Laboratory and Adjacent Sites

The Lawrence Livermore National Laboratory (LLNL) is located about 64 km (39 mi) east of San Francisco, California, in the Livermore Valley of eastern Alameda County, approximately 5 km (3 mi) east of the city of Livermore. Sandia National Laboratories, Livermore (SNLL) is located adjacent to LLNL's southern boundary. Nearly 5.1 million people live within 80 km of LLNL (see Fig. 1); of these, approximately 50,000 live in Livermore.

The Lawrence Livermore National Laboratory, operated by the University of California for the United States Department of Energy (DOE), was established in 1952 to conduct nuclear weapons and magnetic fusion energy research. Since then, other major programs have been added, including laser fusion and laser isotope separation, biomedical and environmental sciences, and applied energy technology. These programs, in turn, require research in basic scientific disciplines, including chemistry and materials science, computer science and technology, engineering, and physics.

LLNL also carries out a variety of projects for other federal agencies.

Much of LLNL's materials testing and high-explosives diagnostic work is conducted at Site 300, located in the sparsely populated hills of the Diablo Range, 24 km (15 mi) southeast of Livermore. Figure 1 shows the location of LLNL and Site 300 with respect to the surrounding areas.

In 1986, LLNL employed approximately 8,200 people.

Sandia National Laboratories, Livermore, is operated by AT&T Technologies, Inc., under contract to DOE. SNLL's primary mission is research and development associated with nuclear weapons systems engineering and related national security tasks. In addition, it has energy programs involving combustion, fusion, and solar research, and conducts research and development projects for other federal agencies.

In 1986, SNLL employed approximately 1,100 people.

LLNL and SNLL are separate facilities, with different DOE operations headquarters and different local management. Some of the SNLL data are

Figure 1. Estimated population distribution (in thousands) within 80 km of Livermore, by sectors.

included here because the two sites are adjacent and they conduct similar operations. Therefore, it is difficult to separate the source of monitored materials.

The complete report of environmental monitoring data for SNLL is published in 1986 *Environmental Monitoring Report, Sandia National Laboratories, Livermore* (Devlin, 1987).

The Livermore Site

LLNL and SNLL are located in the southeastern portion of the Livermore Valley, which is an east-west oriented topographic and structural depression within the Diablo Range of the California Coast Range Province. The Livermore Valley forms an irregularly shaped lowland area approximately 26 km (16 mi) long, east to west, and averages 11 km (7 mi) wide, north to south. The floor of the valley slopes to the west from an elevation

of approximately 200 m (660 ft) at the eastern end to approximately 90 m (295 ft) at its drainage outlet, located near the southwestern corner.

The climate of the Livermore Valley is characterized by mild, rainy winters and warm, dry summers. The mean annual temperature is 12.5°C (59°F); the normal seasonal temperature range is defined by nighttime winter lows in the vicinity of 0°C (32°F), and summer daytime highs around 38°C (100°F). Annual wind data are given in Fig. 2. Prevailing winds are from the west and southwest from April through September; during the remainder of the year, wind directions are variable. Both rainfall and wind exhibit a strong seasonal pattern. Most of the precipitation occurs between October and April, with very little rainfall during the warmer months of the year. The highest and lowest annual rainfalls on record are 782 mm (30.8 in.) and 138 mm (5.4 in.), with a 115-year average of 369 mm (14.5 in.). Rainfall at LLNL for the 1985–1986 water year (October 1,

Average annual percent frequency of wind direction vs. wind speed (m/s)										Average speed (m/s)	
Direction	0-2	2-3	3-5	5-7	7-9	9-11	11-16	16-20	>20	Total	(m/s)
N	1.3	0.5	0.9	0.6	0.2	0.1	0.0	0.0	0.0	3.6	3.4
NNE	1.1	0.8	1.0	0.2	0.0	0.0	0.0	0.0	0.0	3.1	2.7
NE	1.4	1.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	4.2	2.6
ENE	1.6	0.8	1.3	0.2	0.0	0.0	0.0	0.0	0.0	3.9	2.6
E	3.7	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	4.6	1.4
ESE	6.0	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.7	1.2
SE	3.7	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	4.1	1.3
SSE	2.0	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	2.5	2.0
S	2.0	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	2.6	1.7
SSW	2.3	1.0	0.7	0.3	0.3	0.1	0.0	0.0	0.0	4.7	2.9
SW	3.5	3.8	6.0	2.3	0.5	0.1	0.0	0.0	0.0	16.2	3.5
WSW	4.0	4.4	4.3	0.9	0.1	0.0	0.0	0.0	0.0	13.7	2.9
W	2.7	2.5	4.7	0.8	0.0	0.0	0.0	0.0	0.0	10.7	3.1
WNW	1.5	0.7	1.3	0.5	0.0	0.0	0.0	0.0	0.0	4.0	2.9
NW	1.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.7
NNW	1.3	0.3	0.4	0.3	0.0	0.0	0.0	0.0	0.0	2.3	2.5
Calm	—	—	—	—	—	—	—	—	—	11.0	—
Total	39.4	18.1	23.3	6.4	1.1	0.3	0.0	0.0	0.0	99.7	2.4

Winds are based on 15 minute averages.

No instantaneous winds are available.

Figure 2. Wind rose showing the average annual wind direction and speed during 1986.

1985 through September 30, 1986) was 417 mm (16.42 in.).

Surface drainage is by westward-flowing intermittent streams (arroyos) that merge in the west end of the valley to form the southward flowing Arroyo de la Laguna, a tributary to the Alameda Creek drainage system. Winter flows that are not captured as groundwater recharge flow out of the southwestern corner of the valley and eventually enter San Francisco Bay by way of Alameda Creek. Surface water bodies near the laboratories include: the South Bay Aqueduct, which runs from northeast to southwest, 0.2 km (0.1 mi) to the southeast of LLNL; the treatment tanks and reservoir of the Patterson Pass water treatment facility, about 1.2 km (0.7 mi) east of LLNL; Frick Lake, an area of enclosed drainage 4 km (2.4 mi) north of LLNL, where winter stormflows accumulate in an intermittent pond; and the Springtown pond, an artificial decorative pond maintained in a community recreation area 2.6 km (1.6 mi) northwest of LLNL. Lake Del Valle, a water storage reservoir 8 km (4.9 mi) south of LLNL, provides aquatic recreation (swimming, boating, and fishing), as does the Shadow Cliffs Regional Park Recreation Area, 11 km (6.7 mi) to the west. Lake Isabel, 9 km (4.9 mi) to the southwest, is a fee-for-fishing area. Both Lake Isabel and the Shadow Cliffs facility are excavations produced by gravel quarry operations, which continue to develop additional pits in the same general area. Both LLNL and SNLL normally receive their treated water supply from the Hetch Hetchy Aqueduct (which supplies San Francisco), located 11 km (6.7 mi) southwest of Livermore.

The hydrogeology and groundwater occurrence and movement in the vicinity of the laboratories have been the subjects of several recent and continuing investigations (see the "Groundwater Monitoring" and "Special Assessments" sections of this report). The following description has been summarized from the reports of these investigations (Stone et al., 1982; Stone and Ruggieri, 1983; Carpenter et al., 1984; and Weiss Associates, 1985) and from data supplied by Zone 7, Alameda County Flood Control and Water Conservation District.

The Livermore Valley is bound in the east by the Altamont Hills, where the Miocene-age Neroly and Cierbo Formations and rocks of the Late Cretaceous Great Valley sequence are exposed. Within the valley, lacustrine and fluvial valley fill deposits occur to depths in excess of 1 km. The oldest of these is the Lower Livermore Formation of late Tertiary age, a hard, locally

lithified, predominantly fine-grained sedimentary sequence that is exposed in the hills south of the valley and is encountered beneath the LLNL and SNLL sites at depths ranging from 7 m (23 ft) in the east to 119 m (389 ft) in the west. Above the Lower Livermore Formation are the heterogeneous unconsolidated alluvial sediments of the Pleistocene-age Upper Livermore Formation, which consist of complexly interbedded layers of poorly sorted clay, silt, sand, and gravel. The late Pleistocene and Holocene-age alluvial deposits that form the uppermost sequence of valley sediments are virtually identical to the Upper Livermore Formation.

The Livermore Formation (and overlying alluvial deposits) contains the aquifers of the Livermore Valley groundwater basin, and is an important water-bearing formation. Annually, approximately 14 million cubic meters (11,300 acre-feet) of groundwater are extracted for domestic and agricultural use in the Livermore Valley. Most of this volume is pumped from municipal supply wells in Pleasanton and Livermore. In 1986, groundwater usage represented approximately 35% of total water consumption in the Livermore Valley.

Natural recharge occurs primarily along the fringes of the basin and through the arroyos during periods of winter flow. Zone 7, the agency responsible for groundwater management in the Livermore Valley basin, conducts artificial recharge as needed to maintain groundwater levels. This is done by releasing water from Lake Del Valle or the South Bay Aqueduct into arroyo channels in the eastern portion of the valley. Groundwater flow in the valley generally moves toward the central east-west axis of the valley and then westward through the central basin. Groundwater flow in the basin is generally assumed to be primarily horizontal, although a significant vertical component probably exists in fringe areas and under localized sources of recharge.

Beneath the LLNL site, the depth to water table varies from about 43 m (140 ft) to 8 m (25 ft) according to observations during 1986. Figure 3 shows a contour map of water table elevations (feet above mean sea level) for April, 1986. Although water table elevations vary with seasonal and year-to-year variations in both natural and artificial recharge, the qualitative patterns shown in Fig. 3 are generally maintained. At the eastern edge of the LLNL site, groundwater gradients (change in elevation per unit of horizontal distance) are quite steep, but under most of the site and farther to the west, the contours flatten out to a gradient of approximately 0.003. Groundwater

Figure 3. Approximate ground water surface elevations (feet above mean sea level), LLNL and vicinity, April 1986.

flow under the northern and western portions of the site is generally westward. Under the southeast corner of the site, there is a groundwater divide and a sink to the southeast. This phenomenon was further investigated in 1986. A detailed description of findings to date is provided in Dresen and Nichols (1986). Aquifer tests on monitoring wells in the vicinity of LLNL indicate that the hydraulic conductivity of the permeable sediments ranges from 1 to 16 m/day (Weiss Associates, 1985). This, in combination with the observed water table gradients, yields groundwater velocity estimates of 5–90 m/yr. The range in these values reflects the heterogeneity typical of the more permeable of the alluvial sediments that underlie the area.

On the LLNL site, storm water is channeled through storm sewers designed to accommodate a 10-year flow. Open ditches are used in undeveloped areas of the site. The Arroyo Las Positas flow is channeled north to the northeast corner of the site, and then west along the north perimeter to an outlet at the northwest corner. This outlet, which also constitutes the main pathway for LLNL's surface drainage (storm and irrigation runoff), runs north to the Western Pacific tracks, then west where it joins the Arroyo Seco. The main channel of the Arroyo Seco crosses the center of the SNLL site from the southeast and then the southwest corner of the LLNL site. The LLNL Master Site Plan calls for a small impoundment to be established in the center of the project. On-site water drainage has been re-routed through the basin for this lake.

The combined sewage from LLNL and SNLL is discharged into the city of Livermore's sanitary sewer system and processed at the Livermore Water Reclamation Plant (LWRP). As part of the Livermore-Amador Valley Wastewater Management program, the treated sanitary wastewater is transported out of the valley through a pipeline and discharged into San Francisco Bay. Treated effluent from the LWRP is used for summer irrigation of nearby Livermore city property.

The developed portion of the LLNL site occupies an area of 2.54 km² (1.0 mi²); additional land has recently been acquired for security buffer zones on the west and north sides of the existing site, increasing the total area to 3.28 km² (1.3 mi²). The developed portion of the SNLL site occupies an area of 0.75 km² (0.2 mi²); additional lands are being acquired for security buffer zones on the east and west sides of the SNLL site. There is an existing business park to the southwest of LLNL and one under construction to the north. Al-

though most of the land adjacent to LLNL is presently in agricultural use (grazing and forage crops), much of it has been rezoned for industrial use and development is anticipated in the near term. The nearest residential area is 0.8 km (0.5 mi) from the west perimeter of the developed portion of the LLNL site.

Site 300

Site 300, LLNL's high explosive testing site, is located 24 km (15 mi) east of LLNL in the Altamont Hills of the Diablo Range. The topography of the site is irregular, with a series of steep hills and ridges oriented along a generally northwest/southeast trend separated by intervening ravines. The elevation ranges from approximately 180 m (600 ft) at the southeast corner of the site to approximately 490 m (1600 ft) in the northwestern portion. The climate is generally similar to that at LLNL, but is modified by the higher elevation and greater relief. The temperature range is somewhat more extreme and surface wind patterns are influenced by local topography. Rainfall for the 1986 water year was 325 mm (12.8 in.). For the 20-year period from 1966 through 1986, the average rainfall was 273 mm (10.7 in.), with a maximum of 506 mm (19.9 in.) and a minimum of 121 mm (4.8 in.).

Knowledge of the geology and hydrogeology of Site 300 is based on regional geologic mapping by Dibblee (1980) and Raymond (1969) and has been supplemented by detailed hydrogeologic studies of portions of Site 300 in recent years (Raber and Carpenter, 1983; Carpenter et al., 1983; Carpenter, 1983; Buddemeier, 1985; and Carpenter et al., 1986).

The bedrock underlying most of Site 300 consists chiefly of sedimentary rock of the late Tertiary Neroly formation, which is composed of interbedded sandstones, siltstones, claystones, and conglomerates. This formation is underlain by sandstones and claystones of the older Cierbo formation that outcrops in some places. The bedrock is overlain locally by older alluvial and terrace deposits, and more generally by Quaternary colluvial and valley fill deposits.

Groundwater within Site 300 largely occurs within sandstone and conglomerate beds of the late Tertiary Neroly Formation and probably moves through both pores and fractures. Fractures in claystone beds locally convey water (Raber and Carpenter, 1983; Carpenter et al., 1983; Carpenter, 1983; Buddemeier, 1985; and Carpenter et al., 1986). Preliminary aquifer tests on interbedded

sand-, silt-, and claystones in the northwest portion of the site yielded hydraulic conductivity values ranging from 5×10^{-6} to 3×10^{-3} cm/s (Buddemeier et al., 1987). Groundwater flow is strongly influenced by geologic structures. It tends to follow the plane of the dip of the Neroly aquifers. Folds and faults within the bedrock sequence appear to locally influence groundwater gradients and movement (Raber and Carpenter, 1983). In the southern part of Site 300, groundwater is present in alluvial deposits beneath Corral Hollow (Carpenter et al., 1983). In the northwestern part of Site 300, there is evidence of temporary groundwater flow in alluvial deposits in directions that differ from the underlying Neroly aquifer. These temporary groundwater bodies appeared to have formed during the above normal rainfall years of 1981-1983 (Buddemeier, 1985), and had largely drained by late 1985 as a result of drier conditions from early 1984 through 1985. The water supplies for Site 300 are drawn from production wells located in the southeastern corner of the site adjacent to Corral Hollow. The water supplies are obtained from confined bedrock (or Neroly) aquifers; shallow water-bearing zones are not used for supply purposes.

Figure 4 presents a generalized groundwater map based upon data from the significant water-bearing zones present beneath those portions of Site 300 for which data are available. The map also includes the locations of fault systems that appear to have hydrologic significance. An area underlain by a localized, perched groundwater body detected during site-specific studies in the southeastern part of Site 300 is also shown, as is the site of an anomalous, perched spring located in the southern part of Site 300 (Carpenter et al., 1983 and 1986). Other perched springs and isolated groundwater bodies may exist.

The water level map shown in Fig. 4 is based upon elevations measured in several geohydrologic units that do not strictly correlate with one another, although they appear to be in communication at some locations. In the northwestern portion of Site 300, water surface elevations shown are for a shallow perched water table aquifer (Raber and Carpenter, 1983; Carpenter et al., 1983; Carpenter, 1983; Buddemeier, 1985; and Carpenter et al., 1986). In portions of this area, boreholes drilled to a depth of nearly 300 feet beneath the perched aquifer have failed to encounter any deeper water-yielding zones (Raber and Carpenter, 1983). Northeast of the Elk Ravine Fault, data depicted is for a semi-confined aquifer that is the uppermost of a sequence of aquifers with differing

heads and geochemical properties (Raber and Carpenter, 1983). Beneath the southeastern portion of Site 300, both a water table aquifer and a deeper confined aquifer are present. Contours shown are based upon data points obtained from the water-table aquifer.

Sewage from the Site 300 administrative area in the southeast corner of the site is discharged to a lined pond for digestion and evaporation. Other facilities at Site 300 are served by septic tanks.

Site 300 occupies an area of 28.3 km² (10.9 mi²). The Carnegie State Vehicular Recreation Area is located south of the western portion of Site 300. Adjacent to Site 300 to the east is a high-explosives test facility operated by Physics International; a similar facility operated by SRI International is located approximately 1 km (0.6 mi) south of Site 300. An increasing number of power-generating windmills are being installed northwest of the Site. The remainder of the land around Site 300 is in agricultural use, primarily as grazing land for cattle and sheep. The nearest residential area is the city of Tracy (population 25,000), located 10 km (6 mi) to the northeast.

Environmental Monitoring

The Environmental Quality Verification Group (EQVG) at LLNL conducts an environmental surveillance program to verify the effectiveness of control measures and to assess the potential impacts to the environment and members of the public resulting from LLNL and SNLL operations. Potential hazardous emissions include tritium, uranium, plutonium, metals, solvents, and common laboratory chemicals. Because of its proximity to LLNL and the extensive environmental monitoring program at LLNL, SNLL does not duplicate the LLNL program. This report, therefore, assesses the combined environmental impact of both laboratories.

Strict effluent-control programs that emphasize controlling effluents at the source have been in effect at LLNL and SNLL since operations began. The Environmental Quality Verification Group evaluates the effectiveness of these measures, documents whether effluents from LLNL, Site 300, and SNLL operations are within applicable standards, and estimates the impact of these operations on the environment. Sensitive monitoring equipment is used that can detect radioactive and nonradioactive pollutants at environmental background levels. The program includes the collection and analysis of air, soil, water, sewer

Figure 4. Topography and ground water surface elevations, Site 300.

effluent, vegetation, foodstuffs, and milk samples. Also, environmental radiation levels are measured at numerous locations in the vicinity of LLNL using gamma and neutron dosimeters.

Each spring, LLNL reports the results of environmental monitoring for the previous year, noting significant changes in either the scope of the program or the levels of effluents. This report is prepared in compliance with the DOE Order

No. 5484.1, *Environmental Protection, Safety, and Health Protection Information Reporting Requirements* (U.S. Department of Energy, 1981).

Appendix A is a tabulation of 1986 environmental monitoring data. Graphics have been used in the body of the report to aid in interpretation. Radioactivity values are tabulated with the associated counting uncertainties at the 2σ (95% confidence) level. Radioactivity values at or below the

minimum detection limit of these measurements are indicated in the tables by the use of the "less than or equal to" symbol ($\leq$). See Appendix E for a discussion of the statistical methods used to present this data. In the case of radioactivity measurements, an attempt has been made to assess the potential impact on people from the observed environmental levels of artificially produced radionuclides. This assessment is made by calculating the radiation doses delivered to people and

comparing these with the much larger radiation dose received locally from natural sources. These doses are also compared with radiation protection standards (Appendix C). This assessment is made for the LLNL effluents only. The dose assessment and other detailed environmental information for SNLL is contained in 1986 *Environmental Monitoring Report*, Sandia National Laboratories, Livermore (Devlin, 1987).

Summary

Air Monitoring

Gross radioactivity measurements are not required by regulations or DOE guidance, but are used by LLNL to monitor possible build-up of radionuclides in the environment and to monitor for possible releases of radionuclides not covered by specific analyses (see "Methods" section and Appendix G for specific analyses). The annual averages for gross activity discussed below exclude data collected during May, which showed unusually high levels because of the incident at the Chernobyl nuclear power station in the USSR. See Appendix H for further discussion of the effects of the Chernobyl incident.

In 1986, the annual average airborne gross beta activity in Livermore Valley air samples was 4.7×10^{-14} $\mu\text{Ci/mL}$, not statistically higher than 1985. The average gross alpha activity, 0.6×10^{-15} $\mu\text{Ci/mL}$, shows no significant change from 1985 data. Although isotope ratio measurements indicate the presence of depleted uranium (used in high explosive tests) in air filters at Site 300, the average airborne ^{238}U concentration at the Site was lower than that attributable to natural uranium at the LLNL perimeter. This indicates that LLNL emissions are within the range of natural variations. The ^{238}U concentrations observed were well below the standards set by DOE. The annual average beryllium concentrations at both the LLNL perimeter and Site 300 were less than 1% of the local air pollution standard. The beryllium concentrations are of the same magnitude as the natural beryllium in typical airborne dust. The total tritium released to the atmosphere by LLNL in 1986 was 1254 Ci. Approximately 774 Ci was in the form of tritiated water (HTO). An additional 760 Ci of HTO were released by SNLL. The total quantity of ^{14}N - ^{15}O released in 1986 was 113 Ci. The maximum off-site dose attributable to these

airborne radioactive emissions was 0.06 mrem, which is far less than the EPA limit of 25 mrem/yr.

Soil Monitoring

The concentrations of ^{239}Pu in the soil of the Livermore Valley are similar to those observed in previous years. The highest value of 26.4×10^{-9} $\mu\text{Ci/g}$ (0.22% of the standard), was found east of the LLNL perimeter. Elevated soil radionuclide concentrations in this area are attributed to pre-existing wind-deposited contamination from solar evaporation pits formerly located near LLNL's southeast boundary. The use of these pits was discontinued many years ago. The proposed EPA soil standard for unrestricted use is 12×10^{-6} $\mu\text{Ci/g}$ (12×10^3 pCi/kg). The remaining areas reflect world-wide fallout and naturally occurring concentrations of nuclides.

The soil samples collected at Site 300 show that greater than background concentrations of ^{238}U are limited to isolated regions near the firing tables. The highest value of 156 $\mu\text{g/g}$ is typical of previous years' data.

During 1986, a number of special assessments were in progress that involved the analyses of soil samples. These assessments are being done to investigate the contamination, if any, at Site 300 (landfills and an environmental test facility) and at LLNL (a gasoline tank leak, a landfill, and potential groundwater contamination sources). The soil samples were analyzed for various contaminants (metals, gasoline, chlorinated hydrocarbons, radioactivity, etc.) as appropriate for the specific assessment. A summary of each of these investigations is presented in the "Special Monitoring Assessments" section of this report.

Water Monitoring

Water samples collected in the Livermore Valley and at Site 300 exhibit gross beta and tritium activities within the ranges previously observed in these areas. Four water samples from Site 300 showed an above-average level of gross alpha activity (27, 23, 19, and $10 \times 10^{-9} \mu\text{Ci/mL}$). This activity has been found to be naturally occurring uranium at concentrations well within those specified in *DOE Derived Concentration Guides of August 15, 1986* and below the health advisory level recommended by the State Department of Health Services (DOHS). Some groundwater monitoring wells near a landfill at Site 300 show sharply elevated concentrations of tritiated water. The highest value measured was $2.6 \times 10^{-4} \mu\text{Ci/mL}$; this value is above the DOHS drinking water standard, but was found in an aquifer that is not used for potable water supplies. Traces of halogenated hydrocarbons were detected in wells down-gradient of this area and in the groundwater down-gradient from another landfill at Site 300. These sites are under active investigation.

During 1986, a number of special assessments were in progress that involved the analyses of groundwater samples for various contaminants as appropriate for the specific assessment (see the "Special Monitoring Assessments" section of this report).

The amount of tritiated water (HTO) discharged into the sanitary sewer system in 1986 was 2.0 Ci. The discharge of ^{239}Pu was 15.2 μCi , which was about 317% more than the amount released during the previous year but well within the allowable range.

Tritium analyses were also made on well-water samples collected from monitoring wells near the LWRP. These analyses, begun in 1977, were made to determine the extent to which low levels of tritium in the LWRP effluent may be migrating into groundwater. As was found during earlier surveys, the highest tritium values ($7.8 \times 10^{-7} \mu\text{Ci/mL}$) were detected in test wells down-gradient from the LWRP near Arroyo Las Positas. Since the LWRP effluent is no longer discharged to the arroyo, the primary means of tritium movement to nearby groundwater has been eliminated and the concentrations observed are decreasing. Tritium concentrations observed in local water supply wells in 1986 were generally the same as previous years' measurements and reflect background levels of tritium.

Vegetation and Foodstuff Monitoring

Tritium levels found in the Livermore Valley and Site 300 vegetation were generally comparable to those observed in 1985. Vegetation collected from a landfill area at Site 300 contained substantially higher levels of tritium ($2.14 \times 10^{-4} \mu\text{Ci/mL}$ of recovered water maximum) than other areas. This phenomenon was also recorded in 1985. This area is under investigation for soil and groundwater tritium contamination as is described in the "Special Monitoring Assessments" section.

As a means of evaluating the possible impact of LLNL effluents on locally grown foodstuff, the tritium content of Livermore Valley wines was compared with values from other California and European wines. The tritium levels in Valley wines are within the range found to be present in both European wines and surface waters throughout the world, but are somewhat higher than those in other California wines. Honey produced in the Livermore Valley contained tritium levels comparable to those found in honey from neighboring areas. Milk samples from goats pastured within 5 km of LLNL showed no impact attributable to LLNL activities.

Doses

The 1986 average external gamma-radiation dose of the LLNL perimeter ("fence-post dose") and off-site locations were 61 mrem, and 62 mrem, respectively. This shows no difference between the average perimeter dose and the average off-site dose (which is considered to represent background). These doses are consistent with the 1985 results.

The annual average neutron dose at the LLNL perimeter was 2 mrem. The neutron dose near the south perimeter showed slightly elevated levels for the first and third quarters of 1986 (14.0 and 12.5 mrem, respectively). This was caused by the operation of a 14 MeV neutron generator in Building 212 during these times.

The maximum potential inhalation/submersion dose (from airborne emissions), at the LLNL boundary and to the nearest resident, were 0.16 mrem and 0.07 mrem, respectively. The calculated committed (50 year) effective dose equivalent to the maximally exposed member of the public from all sources and pathways during 1986 was 0.25 mrem. (The DOE radiation protection limit is

Figure 5. LLNL perimeter air-sampling locations.

Figure 6. Site 300 on-site air-sampling locations.

Figure 7. Livermore Valley air-sampling locations.

Figure 8. Livermore Valley soil-sampling locations.

Figure 9. Site 300 soil-sampling locations.

The effluent is continuously monitored at the out-fall for pH, selected metals, and radioactivity. In addition, samples of LLNL sewage effluent are collected quarterly and analyzed for the parameters specified on LWRP's National Pollutant Discharge Elimination System permit. Discharge limits imposed by the City of Livermore are shown in Appendix F. A representative fraction of the total waste stream is collected by a flow proportional sampler and composited over a 24-hour period. Sewage samples are collected daily from LLNL and LWRP. These samples are analyzed daily for gross alpha and gross beta activity and combined to form a monthly composite for ^3H , ^{137}Cs , and ^{239}Pu analyses.

Since February, 1980, the Livermore sewage treatment plant has been connected to a pipeline

constructed as part of the Livermore-Amador Valley Wastewater Management program to transport wastewater out of the valley for discharge into the San Francisco Bay. Although some treated LWRP effluent is still used for irrigation of municipal property during summer months, sewage is no longer discharged into Arroyo Seco. This has eliminated the primary means of tritium migration to local and downstream groundwater.

Water Monitoring

This section describes the ongoing monitoring program for surface and domestic water in the vicinity of LLNL and at Site 300. Expanded water quality monitoring efforts are described in the

"Groundwater Monitoring" section, and special investigations relating to groundwater quality are presented in the "Special Monitoring Assessments" section.

Livermore Valley water sampling locations are shown in Fig. 10. Locations 11, 16, 23, 24, 26, and 29 are surface water sources (ponds, creeks, aqueducts, or reservoirs). Location 20 is the rain-fall collection site for LLNL. The other six locations are domestic water supply wells.

Site 300 water samples (Fig. 11) were collected from on-site wells (locations 1-6 and 22), off-site wells (locations 23 and 24), and two off-site creeks (locations 7 and 14). Location 20 is Site 300 rain water, and location 21 is a spring-fed pond near Bunker 812.

The water samples from both the Livermore Valley and Site 300 are analyzed for gross alpha, gross beta, and tritium activity. Because of the low tritium levels typically found, it is necessary to distill and enrich the samples before liquid-scintillation counting.

As noted previously, treated effluent from the LWRP is used to irrigate nearby municipal property. This effluent contains low levels of tritium that come from normal LLNL operational releases to the sanitary sewer system. As part of a study begun in 1977, tritium measurements are now made annually on well-water samples collected from neighboring wells to determine the extent of tritium migration into the groundwater. Many of the wells are in the immediate vicinity of the

Figure 10. Livermore Valley water-sampling locations.

Figure 11. Site 300 water-sampling locations.

LWRP; however, additional samples were also collected from areas at some distance. Locations sampled during 1986 are indicated in Fig. 12.

Beginning in 1975, LLNL's environmental surveillance program was expanded to include surface runoff monitoring. The program has evolved over the years; it was originally designed to detect the pesticides used at LLNL, which include herbicides, fungicides, and insecticides in samples collected from the drainage ditch at the northwest corner of the Laboratory following the first major storm. Additional sampling points were subsequently added and samples analyzed for metals, general water quality parameters, and other priority pollutants, in addition to pesticides.

As presently designed, the runoff monitoring program calls for the sampling of six locations (Fig. 13) during the period of active surface water flow following the first major storm system of the

water year (October 1 to September 30). Station 1 is the influent to the east side of the Laboratory that feeds the Arroyo Las Positas flow; station 2 is from the on-site "lake"; and station 3 is the effluent into the redirected Arroyo Las Positas channel at the northwest site boundary. Station 4 is in the Arroyo Seco channel influent to the SNLL site; station 5 is the effluent to the Arroyo Seco channel of a culvert collecting surface drainage from the southeast area of LLNL; and station 6 is the Arroyo Seco channel effluent at the western boundary of the LLNL buffer zone (Vasco Road). Results from stations 1, 2, 3, and 5 were reported in the 1985 annual report, and a further partial sampling was done at stations 1, 2, 3, and 4 following a storm in the spring of 1986. These are the only data reported for 1986 since no storms creating sufficient runoff for sampling occurred during the fall of 1986.

Figure 12. Livermore Valley ground water-sampling locations (numbers identify specific wells sampled).

Figure 13. Stormwater runoff sampling locations.

Vegetation and Foodstuff Monitoring

Native vegetation samples are collected quarterly at locations in the Livermore Valley (Fig. 14) and at Site 300 (Fig. 15). These samples are freeze-dried and the tritium activity in the recovered water is determined by liquid-scintillation counting.

Wine samples obtained in 1986 were catalytically oxidized to carbon dioxide and water, and the tritium content of the recovered water was measured by gas proportional counting.

Samples of honey produced from a variety of flower sources both in and outside the Livermore Valley were analyzed for tritium content. Following the oxidation of the samples in a Parr oxygen bomb, the tritium content of the water produced was determined by gas proportional counting.

Milk Monitoring

During 1986, goat-milk samples were obtained from three farms within about 5 km of LLNL. Cow's milk was also sampled when avail-

able from one of the farms. A portion of each sample was freeze dried and the water analyzed for tritium activity by liquid-scintillation counting. Another portion was preserved with formalin, and a one-liter aliquot was gamma counted in a Marinelli beaker on a Ge(Li) system.

Environmental Radiation Monitoring

Quarterly, environmental radiation is measured at 22 LLNL perimeter locations (Fig. 16) and at 55 off-site locations (Fig. 17). These measurements are obtained with thermoluminescence dosimeters (TLD) using a previously published procedure (Lindeken et al., 1975). Based on past measurements (Lindeken et al., 1973) environmental terrestrial exposure rates in the Livermore Valley vary from 30 to 60 mR/y. Cosmic radiation, calculated from the local elevation and geomagnetic latitude according to the data of Lowder and Beck (1966), is approximately 35 mR/y.

Figure 14. Livermore Valley vegetation-sampling locations.

Figure 15. Site 300 vegetation-sampling locations.

Environmental neutron dose rate measurements using ^{235}U track-etch detectors are also made at eight locations on the LLNL site perimeter. A detailed description of the detector and the spark-counting procedure has been published (Fisher, 1976). Neutron-monitoring locations are shown in Fig. 16.

Noise Monitoring

As noted elsewhere, LLNL's high-explosive diagnostic work is conducted at Site 300. Because the Site is remote, these experiments can be performed with minimal off-site impact from annoying noises or damaging overpressures. On the basis of meteorological measurements made twice each day, a limit is set on the weight of high explosives that can be detonated without impact in populated areas. To monitor these limits, four microbarograph sensors are maintained in or near

the city of Tracy because the Tracy area is in the direction of the prevailing winds.

Groundwater Monitoring

Groundwater monitoring is conducted under two programs at LLNL. One program is designed to meet regulatory commitments established for specific site investigations, such as the Livermore Ground Water Project and the Site 300 TCE Investigation. These efforts and others are described in the "Special Monitoring Assessments" section of this report. The other program includes groundwater quality monitoring for drinking water parameters and routine compliance monitoring around landfill and surface waste impoundment units as required by the California Regional Water Quality Control Board (CRWQCB), Central Valley Region and the U.S. Environmental Protection Agency (EPA). This latter program is described below.

Figure 16. LLNL perimeter locations for gamma and neutron dosimeters.

Figure 17. LLNL off-site locations for gamma dosimeters.

In the vicinity of Site 300 landfills, groundwater monitoring is regulated by CRWQCB, DOHS, and EPA. There are two active landfill monitoring programs. At Pit 1, groundwater samples from eight monitoring wells are analyzed quarterly for drinking water parameters, groundwater quality parameters, and indicators of groundwater contamination as specified in 40 CFR 265.92. At Pit 7, eight monitoring wells are sampled quarterly for purgeable halocarbons, lead, beryllium, gross alpha, gross beta, and tritium. The placement of these Pit 7 wells also provides monitoring coverage for inactive landfills 3, 4, and 5.

The CRWQCB Waste Discharge Order No. 80-134 requires the monitoring of the six inactive landfills. Groundwater from wells installed to monitor Pits 2, 3, 4, 5, and 8 is analyzed quarterly for gross alpha, gross beta, tritium, and beryllium.

Pit 6 is monitored for drinking water parameters, groundwater quality parameters, and indicators of groundwater contamination as specified in 40 CFR 265.92 because records indicate that capacitors (suspected to be contaminated with PCB), beryllium, mercury, miscellaneous chemicals, and other potentially hazardous wastes were buried in this pit between 1964 and 1973.

In 1985, the CRWQCB (Central Valley Region) issued new groundwater monitoring requirements as part of Waste Discharge Order No. 85-188 for LLNL's two new Class II surface impoundments. These impoundments contain treated non-hazardous high-explosives (HE) process wastewater and photo rinse water. Samples from four wells are analyzed quarterly for pH, TOX, TOC, specific conductance, several explosives compounds (HMX, RDX, nitrate, nitrite),

and metallic elements. Water from one lysimeter is analyzed quarterly (when available) for HE compounds.

As part of the Special Assessments Studies at Site 300, a monitoring network installed in the southeastern area of the Site is sampled quarterly for volatile organic compounds (VOCs) by EPA Method 601. The number of monitoring wells in this network increased from 2 to 14 during 1986. Installation of additional monitoring wells was in progress at year's end.

Off-site monitoring of groundwater at Site 300 is conducted at the Carnegie Motorcycle Park, and in one of two wells near Castle Rock Fire Station. Samples from these wells are collected quarterly and analyzed for gross alpha, gross beta, and tritium.

Site 300 has eight wells that may be used for the production of drinking water. Samples from these wells are periodically analyzed for compliance with state drinking water quality regulations.

As described in the "Special Monitoring Assessments" section of this report, numerous wells were installed as part of the LLNL Ground Water Project. As new wells were installed, water samples were collected and analyzed for the primary drinking water standards listed in the California Title 22, Chapter 15 regulations and for organic compounds identified by the EPA 624/625 method. Well locations are shown in Fig. 18.

Results

Air Monitoring

Airborne Radioactivity. Tables A-1 and A-2 in Appendix A show airborne gross alpha and gross beta activities for the LLNL perimeter and Livermore Valley samples, and Tables A-3 and A-4 show corresponding activities for Site 300. Analysis for gross alpha and gross beta activity is not required by federal, state, or local regulations; nor is it required by the DOE. LLNL collects this data in order to assure that releases of radionuclides other than those specifically analyzed for (see below) will be detected; and also to identify trends in the LLNL environs. The values reported are similar to those observed in 1985 with the exception of the unusually high activities observed in May as a result of the accident at the Chernobyl nuclear power plant (USSR). See Appendix H for further details on this phenomenon. Gross alpha and gross beta values show no statistically significant

differences between Site 300, LLNL perimeter, and Livermore Valley samples. Most of the gross alpha determinations were at or near the detection limit of the method. Most of the observed alpha and beta activity results from the naturally occurring radioisotopes of U and Th and their decay products (except for the month of May, as noted above).

Tables A-5 and A-6 list the activities of selected gamma-emitting radionuclides that normally contribute to the gross beta activity in Livermore and Site 300 samples. Elevated activities observed in May and June are the result of fallout from the Chernobyl accident. Other gamma-emitting nuclides detected in May and June as a result of this event are presented in Appendix H. Of the nuclides tabulated, ^7Be and ^{40}K are naturally occurring and ^{106}Ru , ^{125}Sb , ^{137}Cs , and ^{144}Ce are fission products. The primary source of the ^{137}Cs is normally long-term global fallout and fallout resuspension; its measurement provides an index of fallout deposition that can be used to evaluate the sources of nuclides such as ^{239}Pu , which could originate either from fallout or from LLNL operations. Other fission products are normally detectable only after such events as atmospheric nuclear tests by other nations or accidental releases such as the Chernobyl accident. In addition to providing baseline data on global fallout, analysis of these fission products also serves to monitor the containment of the small inventories of mixed fission products and radio-chemical tracers used at LLNL.

Table A-7 shows the concentration of plutonium on air filter samples collected in Tracy and the Livermore Valley. Tables A-8 and A-9 show the concentrations of airborne ^{239}Pu , ^{235}U , and ^{238}U in the LLNL perimeter and Site 300 air samples. Location 1 at the southeast corner of the site showed slightly higher concentrations of plutonium in air than the other sample locations. The highest monthly samples were collected during October. Their concentrations (maximum of $1.57 \times 10^{-5} \text{ pCi/m}^3$) represent 0.08% of the DOE derived concentration guide value. No other significant differences between locations or samples were noted and the overall levels determined were essentially the same as those reported in 1985. Substantial quantities of depleted uranium (^{238}U) are used at Site 300; in years previous to 1985, higher concentrations of this nuclide were observed at the Site than at the LLNL perimeter. Although the Site 300 $^{235}\text{U}/^{238}\text{U}$ ratios for 1985 indicate the presence of some depleted uranium in the samples, the average concentrations measured

were not significantly different from those observed at the Livermore site perimeter. The uranium concentrations observed are similar to 1985 values. The isotope ratios indicate that this uranium is mostly natural rather than depleted. Therefore, it is probably not the result of Site 300 operations. These higher values are well below the derived concentration guides (DCG) in *DOE Derived Concentration Guides of August 15, 1986*.

Table A-10 shows average biweekly HTO concentrations observed at each sampling location; the overall annual average concentration is $167.1 \times 10^{-12} \mu\text{Ci/mL}$. The highest biweekly concentration occurred in December and was observed at location 14. This concentration, $4480 \times 10^{-12} \mu\text{Ci/mL}$, is 2.2% of the DOE standard. Location 15 showed the highest annual average concentration, $244 \times 10^{-12} \mu\text{Ci/mL}$. The values observed were generally similar to those reported in 1985 with the exception of slightly high values observed at nine locations in September and October and significantly higher values seen at five locations at the end of December. A review of the emissions and operations records at LLNL and SNLL had not revealed any unusual releases associated with the December values by the time this report was written. Efforts to identify the origin of these elevated values are continuing even though they are well below DOE guidelines.

Beryllium in Air. Tables A-11 and A-12 show average monthly concentrations of airborne beryllium for the LLNL perimeter and Site 300 (including the city of Tracy) sampling locations, respectively. The concentrations, which average less than 1% of the ambient concentration limit established by the Bay Area Air Quality Management District (BAAQMD) and the San Joaquin County Air Pollution Control District (SJCAPCD), can be accounted for by resuspension of surface soil containing natural occurring beryllium. Local soils contain approximately 1 ppm of beryllium, and Livermore's air typically contains 10-100 μg of particulates per cubic meter. By using a value of 50 $\mu\text{g}/\text{m}^3$ for an average dust load and 1 ppm for beryllium content of this dust, an air borne beryllium concentration of $5.0 \times 10^{-5} \mu\text{g}/\text{m}^3$ can be calculated. In view of the range of natural variation to be expected in these background values, this value is in excellent agreement with the data in Tables A-11 and A-12. The monthly airborne beryllium concentrations for LLNL and Site 300 are plotted in Figs. 19 and 20.

Soil Monitoring

Table A-13 presents data on the concentrations of ^{239}Pu , ^{40}K , ^{232}Th , ^{137}Cs , and ^{238}U in soil at

the Livermore Valley sampling locations. The ratios for including the naturally occurring nuclides (^{40}K , ^{232}Th , and ^{238}U) and the long-lived fission product (^{137}Cs) has been presented previously in the discussion of airborne radioactivity. The concentrations and distributions observed are within the ranges reported in previous years.

Table A-14 shows the ^{239}Pu , ^{137}Cs , and ^{238}U activities in the Site 300 samples. Since high-explosive tests at Site 300 often involve the use of depleted uranium, one of the purposes of the annual soil samples is to determine how these tests perturb the uranium content of the soil. Uranium measurements were made by gamma spectrometry. As in the past, the analyses indicated that perturbation is essentially limited to areas adjacent to the firing bunkers (Griggs and Buddemeier, 1986; Gudiksen et al., 1973). With the exception of variations in the elevated ^{238}U concentrations near the bunkers, there were negligible changes from activities observed in previous samples collected in the same locations.

Sewage Monitoring

Radioactivity in Sewage. Table A-15 compares the monthly composite activity levels of tritium (HTO), ^{137}Cs , and ^{239}Pu in the LLNL effluent with those in the effluent from the LWRP. The LWRP effluent activity levels are not significantly different from those observed in 1985. LLNL effluent generally showed a return to near 1984 levels after a measureable increase in 1985. The exceptions are the ^{137}Cs and ^{239}Pu values for December, 1986. The ^{137}Cs value of $1.03 \times 10^{-9} \mu\text{Ci/mL}$ is approximately 0.03% of the derived concentration guide. The ^{239}Pu value of $0.3 \times 10^{-9} \mu\text{Ci/mL}$ is approximately 0.01% of the derived concentration guide. As a result, the ^{137}Cs annual average is approximately 45% higher than the 1985 value and the ^{239}Pu annual average is approximately 210% higher. The source of the elevated values appears to be the release of a retention tank on December 21. The analysis of the tank contents prior to release showed values well within release limits. The analytical methods used for the sewage effluent are of such sensitivity that even levels below the release limits were easily detectable. All measured values are well below standards in *DOE Derived Concentration Guides of August 15, 1986* for discharge into the sanitary sewer system.

Nonradioactive Pollutants in Sewage. The monthly average metal concentrations in the LLNL sanitary sewer discharge are listed in Table A-16. The results of quarterly monitoring for metals and other physical and chemical characteristics

Figure 19. Concentration of beryllium on air filters at the LLNL perimeter for 1986.

Figure 20. Concentration of beryllium on air filters at Site 300 and Tracy for 1986.

of the sanitary sewer effluent are provided in Table A-17. These tables present the average concentration of various of various parameters and reflect LLNL's usual compliance with the city ordinance (Appendix F). LLNL also has an alarm system that collects sewer effluent samples automatically if preset warning levels are exceeded. Two such excursions occurred in 1986.

On September 11, twenty-five pounds of Tide laundry detergent was discharged into the sanitary sewer after being used to clean a chiller/heat exchanger. The discharge of the detergent resulted in a maximum pH excursion of 10.9. The LWRP was notified and detected elevated pH levels in their influent but did not experience any disruption of treatment capability.

On September 18, high concentrations of nickel and chromium accidentally entered the sanitary sewer. The LWRP was notified and diverted the flow into a retention basin for appropriate disposal. The alarm system and timely response by LLNL personnel prevented major damage at the LWRP. Additional information on this incident is available in the January 8, 1987, "Investigation Re-

port on the release of Nickel and Chromium to the Livermore Sanitary Sewer System, September 18, 1986" prepared by the Guidance and Monitoring Section of the Environmental Protection Department.

Corrective actions were taken promptly after both of the above excursions to prevent future incidents.

Water Monitoring

Radioactivity in Water. Tables A-18 and A-19 show the gross alpha activities in Livermore, Valley and Site 300 samples. Gross beta activities for Livermore and Site 300 samples are shown in Tables A-20 and A-21. Gross alpha and beta activities in these surface and domestic water samples collected in 1986 were below EPA and State of California standards for drinking water (U.S. Environmental Protection Agency, 1977). Location 4, a well near the Site 300 entrance, showed an elevated gross alpha concentration of 27×10^{-9} µCi/mL during the first quarter and 23×10^{-9} µCi/mL during the second quarter. Location 3, another well near the entrance to Site 300, showed a

value of $10.0 \times 10^{-4} \mu\text{Ci/mL}$ during the fourth quarter. Location 21, an on-site creek, showed an elevated gross alpha level of $19 \times 10^{-4} \mu\text{Ci/mL}$ during the second quarter. Similar observations in the past have been traced to the natural uranium content of the groundwater. The DOHS recommends an action level of $10 \times 10^{-4} \mu\text{Ci/mL}$ and a health advisory level of $40 \times 10^{-4} \mu\text{Ci/mL}$ for natural uranium in drinking water. In the State of California limit for gross alpha activity, uranium is specifically excluded from the total. The uranium concentrations were well within those specified in *DOE Derived Concentration Guides of August 15, 1986* ($6 \times 10^{-7} \mu\text{Ci/mL}$) and below the health advisory level recommended by DOHS.

Stormwater samples were collected at four locations (influent to LLNL, influent to SNLL, effluent to the Arroyo Las Positas, and LLNL "lake") during a major rain early in March. The samples were analyzed for gross alpha, gross beta, and tritiated water.

Table A-22 contains the data for radioactivity in stormwater runoff. All gross alpha concentrations were below the detection limit. Gross beta concentrations did not differ significantly between the LLNL influent and effluent. The only sample containing tritiated water above the detection limit was the LLNL "lake" with a concentration of $17.5 \times 10^{-7} \mu\text{Ci/mL}$. This is a small fraction of the derived concentration guide limit.

Tables A-23 and A-24 show the tritium data for the Livermore and Site 300 samples, respectively. The samples have concentrations that are well below recommended concentration guide values. The highest concentration of tritium in water, $53.0 \times 10^2 \text{ pCi/L}$, occurred in the Livermore Valley rain (location 20), which was collected during September. This represents 0.3% of the DOE derived concentration guide and 26% of the permissible concentration specified by the State of California for drinking water.

Water samples from monitoring wells near a landfill at Site 300 (Table A-25) show much higher concentrations of tritiated water ($2.6 \times 10^5 \text{ pCi/L}$). These samples are discussed in the "Special Monitoring Assessments" section of this report. Tables A-23 and A-24 also include an estimate of the annual dose that may be delivered to an adult who consumes water containing the listed tritium concentrations. These doses, which are all less than 0.1 mrem, are based on a water consumption of 2 liters/day and the dose-conversion factors contained in ICRP 30 (International Commission on Radiological Protection, 1980) and in Appendix D.

The tritium data for wells in the vicinity of the LWRP and for production wells used by local water-supply agencies are shown in Table A-26. The highest tritium values appear in wells down-gradient of the LWRP. Tritium activities in the production wells were at normal background levels, and all samples were well below the limits for water adopted by the State of California (Title 22, Chapter 15). The tritium levels in these wells are similar to those observed in the 1985 samples.

In accordance with the California Regional Water Quality Control Board (CRWQCB), Central Valley Region, Waste Discharge Order No. 80-184, surface water has to be collected at active landfills (Pits 1 and 7) during the rainy season, and analyzed for gross alpha, gross beta, tritium, and beryllium. No samples were collected this year since no runoff was generated from the landfill sites.

Pollutants in Storm Runoff. Most potential pollutants were not present at detectable levels. Of those species with measurable concentrations, none exceeded the permissible concentrations set in State of California Title 22, Chapter 15, regulations for public water supplies. Since the runoff is not used for (and does not directly enter any water used for) public supplies, these standards are cited for comparison only. The data are shown in Table A-27.

Vegetation and Foodstuff Monitoring

Table A-28 shows the tritium data for vegetation collected in the Livermore Valley. The effective dose equivalents shown in this table were derived using the dose-conversion factors in ICRP 30 (International Commission on Radiological Protection, 1980) and the dose-pathway model from NRC Reg. Guide 1.109 (U.S. Nuclear Regulatory Commission, 1977). Conservatively assuming that an adult's diet includes vegetables with the highest observed average tritium concentration and meat and milk derived from livestock fed on grasses with the same concentration, the maximum potential dose is approximately $8 \times 10^{-2} \text{ mrem/y}$.

Table A-29 shows the 1986 tritium data for Site 300 vegetation. Locations 6 and 13 are adjacent to areas that contain tritium-containing debris from a firing table. As a result of the seasonal rains, the tritium is present in the soil and groundwater in the area where these samples are routinely collected. The highest observed concentration (location 6) was $2.1 \times 10^{-4} \mu\text{Ci/mL}$. The calculated annual average dose from vegetation at this location is 1.9 mrem, using the conservative

pathway modeling assumptions. This tritium is further described in the "Special Monitoring Assessments" section of this report.

The data in Table A-30 represent the analyses of wine samples purchased in 1986. A comparison of the wines purchased this year showed that the tritium levels of Livermore Valley wines were somewhat greater than those of California wines produced from grapes grown outside the Valley, but less than those of the European wines sampled.

The data in Table A-31 show that the tritium content of Livermore Valley honey samples is not significantly different from that of honey from neighboring areas.

Milk Monitoring

The activities of ^{137}Cs , ^{40}K , ^{131}I , and ^3H in the samples are shown in Table A-32; no other nuclides were present at detectable levels. The highest concentration of tritium in milk was 6.8×10^2 pCi/L. During the period immediately following the Chernobyl accident, milk sampling frequency was increased. During this time, ^{131}I was detected in the milk at very low levels, as indicated in the table. The levels of ^{131}I present in milk had diminished to the detection limit by the week of June 3. Appendix H contains further information on the impact of the Chernobyl accident. Also shown are the calculated annual whole-body or critical-organ radiation doses that could be received from consuming this milk. These calculations are based on a milk intake of 310 liters/y and on the models previously referenced. The dose resulting from ^3H (Table A-32) was calculated using dose factors from ICRP 30 (International Commission on Radiological Protection, 1980).

Environmental Radiation Monitoring

Table A-33 shows the quarterly and annual gamma radiation dose-equivalents for the perimeter locations and Table A-34 presents the data for the off-site locations. These are obtained by applying a correction factor to the measured TLD dose (rads) to yield dose-equivalents in tissue (mrem). When a TLD packet (changed quarterly) is missing, the annual dose is calculated as four times the average quarterly dose determined from the available data. The average annual dose-equivalent of 61 mrem at the perimeter does not differ significantly from the 62 mrem off-site average. The off-site value (without the unusually high 104 mrem value discussed below) is considered the best available estimate of local background radiation. Table A-35 presents the data for the perimeter neutron dosimeters. The highest an-

nual dose occurs at Location 3, which has historically had the highest neutron dose rate because of its proximity to the 14 MeV neutron generator in Building 212. This year's value of 29.5 mrem is 1985 significantly higher than the 1985 value (but lower than the 1984 value) due to operation of the 14 MeV neutron generator in Building 212.

Figure 21 presents the 1986 annual frequency distribution of environmental gamma dose rates observed at the 55 off-site locations. The dosimeter that recorded the highest dose (104 mrem) was near an off-site (non-LLNL) industrial plant where radiography is performed. With the exception of this location dose data are normally distributed. If the off-site average is recalculated without the 104 mrem value, an average dose of 61 mrem is obtained.

Noise Monitoring

There were no complaints of overpressures attributed to LLNL operations at Site 300 during 1986.

Groundwater Monitoring

The water quality data for the off-site monitoring wells (LLNL site) will be published in early 1987. Several new wells were added during 1986 (see Fig. 18). As new wells were installed, water samples were collected and analyzed for the primary drinking water listed in the California Title 22, Chapter 15 regulations and for organic compounds identified by the EPA Method 624/625. The analytical results for groundwater collected downgradient from the Livermore site indicate that primary drinking water standards were not exceeded except for chromium in a few wells. State action levels for various VOCs were exceeded in some well water samples. The wells installed in 1986 served to further define the extent of the VOCs in groundwater, but did not reveal any previously unknown contamination. The groundwater investigation is discussed further in the "Special Assessments" section of this report.

Data for the groundwater monitoring wells at Site 300 (Fig. 22) are presented in Table A-25. The presence of several trace organics at well K1-1 in the Pit 1 area during the first quarter of 1986 was shown to be caused by the sampling equipment. These constituents no longer appeared after the well pumps were changed. Xylene appeared sporadically in the Pit 1 wells (including an upgradient well during the third quarter) except for the fourth quarter samples. The possibility of this being an artifact of the sampling or analysis is being investigated. The TCE, DCE, and tritium

Figure 21. Annual off-site gamma radiation background for 1986.

Figure 22. Landfills and monitoring wells at Site 300.

concentrations at the Pit 7 wells are similar to those reported last year. The investigations of TCE and tritium at Site 300 are further discussed in the "Special Assessments" section of this report.

Monitoring well and lysimeter data from the vicinity of the High Explosives Surface Impoundment are presented in Table A-25. Monitoring well 817-1 continues to show levels of HE compounds at or near the detection limit. In addition to the HE process water, this impoundment now receives photographic rinse solutions so phenols have been added to the analytical regime. The detection of TOX in all wells at the impoundment during the third quarter and wells 2, 3, and 4 during the fourth quarter may be the result of a sam-

pling or laboratory artifact. This possibility will continue to be investigated in 1987. The monitoring data at Pit 6 showed values similar to those reported previously. The value for TOC at well K6-4 was slightly above the detection limit for the first time in the third quarter analysis, but returned to below the detection limit during the fourth quarter. The fourth quarter value for TOX at well K6-1 was above the detection limit of the first time. Samples from this well will be watched for further recurrence of TOX contamination.

Water quality data for the production wells, both used and unused, at Site 300 are presented in Table A-36. All parameters were within the state and federal limits for public water supplies.

Environmental Impact of LLNL Operations

Radioactive Airborne Effluents

In 1986, a total of 1254 Ci of tritium was released to the atmosphere (see Table A-37) from Building 212 (14-MeV neutron generator), Building 331 (Tritium Facility), Building 292 (Rotating Target Neutron Source), and Building 624 (Incinerator). Approximately 774 of the 1254 Ci was released as HTO, and is the quantity used to calculate doses since the contribution from HT to the dose is insignificant. Approximately 760 Ci of HTO was released by SNLL; this quantity is not included in dose calculations for LLNL operations. One hundred eighty curies of the short-lived radionuclides, ^{13}N - ^{15}O , were released from Building 194 (electron-positron linear accelerator). An additional 45 Ci of ^{13}N - ^{15}O were released from the Advanced Test Accelerator (ATA) at Site 300.

Comparative releases of radioactive effluents at Livermore during the 6-year period from 1981 through 1986 are shown in Table A-37.

Potential radiation doses to the public were calculated from radionuclide concentrations in environmental media (determined by sampling) and emissions of radioactive materials to the atmosphere. The radiological dose assessment included each of the significant environmental transport and exposure pathways: inhalation/submersion from the air pathway, ingestion of locally grown foods, and ingestion of drinking water.

The Department of Energy recently required all contractors to calculate air pathway doses using the Environmental Protection Agency's Clean Air Act Code (CAAC), which contains the AIRDOS-EPA and RADRISK models. The results

of this calculation are presented in Table A-38a. Since the CAAC was obtained only a short time before the writing of this report, we were unable to use detailed exposure data for the LLNL sites in the CAAC. A variety of assumptions and approximations were necessary in order to complete the calculations. Since the doses presented in Table A-38a are thus considered to be estimates, we also computed doses using our previous Continuous-Point-Source (CPS) code. The results of this calculation are presented in Table A-38b. In future years the CAAC will be tailored to the LLNL sites.

The annual average external dose at the LLNL boundary (i.e. the fence-post dose) was 61 mrem (Tables A-33, and A-35). This does not differ significantly from the off-site annual average dose of 62 mrem (Table A-34). The off-site annual average dose without the unusually high value discussed above is 61 mrem.

The inhalation/submersion doses at the following locations were calculated:

- a) The site boundary: 0.16 mrem.
- b) The nearest resident: 0.07 mrem.
- c) The maximum off-site exposure: 0.16 mrem.

The maximally exposed individual is a hypothetical member of the public who receives the maximum probable radiation dose from all potential exposure pathways. The effective dose equivalent to the hypothetical maximally exposed member of the public was 0.25 mrem (Table A-38c).

The collective population dose to all individuals residing within an 80 km radius of LLNL was 0.29 person-rem. This dose is based on a population of 5.1×10^6 within 80 km of LLNL. Using 100 mrem/y as a typical average from natural

sources, the comparable natural radiation dose is 5.1×10^5 person-rem. By comparison, the dose from LLNL operations is negligible.

Appendix D contains definitions of the above doses and the mathematical equations used to calculate them.

Radioactive Liquid Effluents

Low-level radioactive wastewater is treated to reduce radioactivity to levels as low as reasonably achievable and well within applicable health and safety standards. The treated effluent is then discharged into Livermore's sanitary sewer system. During 1986, 1.5×10^{-5} Ci ^{239}Pu and 2.0 Ci HTO were released into the sewer. Table A-37 summarizes the past six years of airborne and liquid effluent releases. The 1986 data are within the range of previously reported releases. Table A-15 shows that the 1986 average annual concentration of these radionuclides in LLNL sewage represents 1.7×10^{-4} and 0.17% of the DOE standards for ^{239}Pu and HTO, respectively.

Groundwater Quality

The tritium and TCE in groundwater at Site 300 is not considered to have any adverse impact because they have not migrated off-site, and nei-

ther the contaminated aquifer nor any hydrologically connected downgradient aquifers are not used for potable water supplies.

The solvent in groundwater near the southwest edge of the LLNL property and the gasoline contamination in the vicinity of Building 403 are not considered to have any major adverse impacts since they are not in portions of aquifers that are used for potable water supplies. Corrective action for this contamination is being investigated.

Nonradioactive Liquid Effluents

The quantities of regulated materials discharged to the sanitary sewer were well within the limits set by the city of Livermore (Appendix D) and the LWRP's discharge limits set by the CRWQCB, San Francisco Bay Region, with the exception of the pH and chromium excursions noted in the "Results" section of this report.

The stormwater runoff showed no detectable level of specified identifiable chlorinated hydrocarbons and only a few other pollutants at detectable levels. The influent enters LLNL at the east perimeter, flows into the lake, and the effluent exits LLNL primarily at the northwest corner with a lesser outflow at the southwest corner. The analytical data are displayed in Table A-27.

Changes to the Environmental Monitoring Program

During 1986, the LLNL environmental monitoring program instituted the following changes. These changes are permanent in nature and, therefore, differ from the deviations from the sampling program discussed in the following section.

- In November of 1986, a new milk sampling station (designated station 11) was added after we were informed of the presence of a goat at that location.
- In December of 1986, milk sampling station 10 was discontinued because the cow at that location had been sold.
- In June of 1986, an air sampling station was added at Site 300 and designated as station 7.
- In early 1986, a decision was made to increase the number of stormwater runoff sampling stations from four to six. As a trial run of this system, stormwater samples were collected during a spring rainfall (the normal sampling schedule only calls for sampling the first runoff of the year, usually in the fall). Only four samples were collected during this trial, three at the old locations and one

at a new location. Rainfall was not sufficient to generate runoff during the fall, so the normal runoff sample was not available for collection.

- Several new groundwater monitoring wells were added at the LLNL site as described in the "Special Monitoring Assessments" section of this report.
- The following changes were made to the groundwater monitoring regime at Site-300:
 - new pumps were installed at the wells K7-1, K7-3, K7-6, and K1-1.
 - pumps were removed from the following wells, which are now sampled by bailing: NC7-25, NC7-47, and K1-6.
 - the sampling procedures and equipment used were substantially changed during 1986. These changes were made to increase the accuracy and reproducibility of the samples and are documented in internal procedures.
- Two soil sampling locations were added at Site 300 (1066 and 1074). These are located in drainage channels where suspended particulate material may be expected to accumulate.

Deviations from the Sampling Program

Appendix B lists those regularly scheduled samples for which data is not reported because of either inability to collect the sample, or loss during analysis. Table B-1 lists air particulate deviations, air tritium deviations, groundwater deviations, vegetation deviations, milk deviations, environmental radiation monitoring deviations, and deviations from the quality assurance sampling regime.

In addition to the deviations from the routine sampling program as described above, the following changes were made to the sampling program immediately after the accident at the Chernobyl

nuclear power plant in the USSR. These changes were made to allow us to better characterize the perturbations in the normal environment caused by this incident.

1. Two additional air samplers were deployed near LLNL. The filters from these samplers were changed three times per week.

2. Milk sampling was increased from once per month to once per week. A more detailed discussion of the changes to the sampling program caused by the Chernobyl accident, and the results of this special monitoring are presented in Appendix H.

Quality Assurance

During 1986, LLNL participated in the EPA's Environmental Radioactivity Laboratory Intercomparison Studies Program. Table A-39 shows the comparison of analyses by LLNL with the known values and the averages of all participants. The plus or minus values are calculated for 1 σ .

Table A-40 shows the comparison of analyses by LLNL with the known and experimentally determined values for intercomparison of samples provided by the DOE Environmental Measurements Laboratory (EML). All intercomparison results are considered satisfactory.

A part of the LLNL Quality Assurance program is accomplished through replicate sampling (Table A-41). Duplicate air samples for particulates are collected weekly on a schedule of alternate months at one of the six perimeter locations taken in sequence. Duplicate air samples that collect tritiated water (HTO) on silica gel are taken biweekly at one of the perimeter locations during the intervening months. This duplicate sampling was not accomplished from January to September for particulates or from January to April for tritium because of problems of equipment availability. Following the acquisition of new equipment, duplicate samples were taken monthly for particulates and biweekly for HTO for the remainder of the year. (See the "Deviations from the Sampling Program" section.) Duplicate samples of sewer effluent from LLNL and the LWRP are collected each week and analyzed for gross alpha, beta, and HTO.

To test the reproducibility of the sampling and analytical procedures, the ratios of the dupli-

cates are presented in Table A-41. These ratios are considered completely acceptable in view of the fact that they include analytical, sampling, and natural environmental variations.

LLNL participated in the Eighth International Environmental Dosimeter Intercomparison, sponsored by DOE-EML during the 1985-1986 winter season. The objective of this study was to evaluate the performance of laboratories measuring environmental radiation levels using thermoluminescent dosimeters and to allow comparison with other laboratories. The study consisted of two field exposures at separate outdoor locations and one laboratory irradiation by a ^{137}Cs source. Two dosimeters were used at each exposure site along with two storage and transit controls. Following exposure, all dosimeters were returned to LLNL for exposure determination.

The EML estimated exposure at field site #1, field site #2, and the laboratory irradiation were 29.7, 10.4, and 17.2 mR respectively. The LLNL measured exposures were 29.7 ± 4.8 and 34.3 ± 3.3 mR at field site #1 (0% and 15.5% difference); 9.9 ± 1.8 and 11.8 ± 4.2 mR at field site #2 (4.8% and 13.5% difference); and 17.0 ± 3.7 and 13.7 ± 2.2 mR for the laboratory irradiation (1.2% and 20.3% difference). With the exception of one laboratory exposure, these results are well within acceptable error ranges (ANSI N545-1975).

In order to meet the forthcoming requirements of DOE *Derived Concentration Guides of August 15, 1986*, the Environmental Quality Verification Group plans to write and implement a comprehensive Quality Assurance Plan covering

all aspects of environmental monitoring at LLNL. Implementation should be complete by the end of 1987. The plan will be discussed in the 1987 Environmental Monitoring Annual Report.

Special Monitoring Assessments

The following is a brief description of the special assessments that were initiated or were in progress in 1986 and are being discussed with state, federal, or local environmental agencies. Included is a summary of each project, the status of the assessment, and any remedial action as of December 31, 1986. References are cited that give the detailed status of special assessments for which additional reports have been published.

LLNL Ground Water Project

The 1985 Environmental Monitoring Annual Report (Griggs and Buddemeier, 1986) briefly summarized the soil and groundwater investigative work performed during the period from the early 1980s through 1985. The schedule of tasks in CRWQCB, San Francisco Bay Region, Waste Discharge Order No. 85-134 documents the current reporting requirements and priorities of the project. In 1986, 53 additional monitoring wells were installed at or near the Livermore site in our continuing groundwater investigation in order to provide additional baseline hydrogeologic data, evaluate the extent of volatile organic compounds (VOCs) in groundwater, to evaluate potential sources for VOCs, and to enable us to begin to evaluate remedial action alternatives. Fourteen additional wells and one borehole were installed in the vicinity of the Building 403 gasoline leak to evaluate the extent of gasoline constituents in soil and groundwater to enable us to begin to evaluate remedial action alternatives.

Recent record search efforts in the National Archives have yielded conclusive evidence that World War II Naval Air Stations such as Livermore were directed to use various VOCs consistent with those found in the groundwater near the LLNL site (Graham, 1986).

In addition to the various reports cited below, monthly progress reports have been submitted to the regulatory agencies (Hoffman et al., 1986a-d; Dresen et al., 1986b-h).

The status of the project in each of the areas called out in Waste Discharge Order No. 85-134 is briefly discussed below:

The sampling and analytical procedures are described in Appendix G. Blank samples are routinely analyzed.

Area West of LLNL

The VOCs west of the southwest corner of LLNL form a plume 3600 ft long by 1700 ft wide by 200 ft deep consisting of two subplumes.

The larger of the two subplumes is dominated by tetrachloroethylene (PCE) at concentrations up to 1100 ppb. This plume, based on our hydrogeologic work and records search, is presumed to have resulted from past discharges to the storm sewer system in the southern portion of the LLNL property; the lined storm sewer discharges water into an unlined portion of Arroyo Seco at the southwest corner of LLNL. Our data indicate that the VOCs have migrated westward and downward in overlapping, northwest dipping alluvial sediments. Near the apparent source of the VOC plume, VOCs are not present below a depth of about 90 ft. Near the leading edge of the plume, VOCs are not present below a depth of about 200 ft (Dresen and Hoffman, 1986).

The smaller subplume is dominated by trichloroethylene (TCE) at concentrations up to 580 ppb. Its source is unconfirmed at this time but may be a sump near Building 141. This plume does not appear to extend below a depth of 125 ft nor more than about 600 ft horizontally to the west or north.

In addition to the report defining the extent of VOCs in the area west of LLNL (Dresen and Hoffman, 1986), the program identified private wells west of the Livermore site that may be conduits for inter-aquifer cross-connection and recommended closure options for those wells known or suspected to be inter-aquifer conduits for VOC-containing water (Dresen and McConachie, 1986).

A report evaluating remedial action alternatives for the area west of LLNL is currently in preparation.

Southeast LLNL and Vicinity

Groundwater chemistry and site history indicate that there are three main sources of VOCs, dominated by TCE (in concentrations up to 2 ppm) with different ratios of other VOCs, which "fingerprint" the sources in this area (McConachie and Hoffman, 1986; Dresen and Nichols, 1986).

In the Building 518 area, VOCs extend no more than about 200 ft to 550 ft to the west, north-west, northeast, and southeast and 900 ft to the southwest, and to depths of less than 165 ft.

In the Building 612 Yard/Building 514 area VOCs have not migrated very far; however, further plume definition is underway in order to be able to address potential remedial action alternatives.

In the northern part of the southeast area of LLNL, VOCs probably originate from one or more sources in the Taxi Strip/Old Salvage Yard areas. Further plume definition will take place as part of the investigation of the extent of VOCs in the Taxi Strip/Old Salvage Yard areas.

Additional work planned for this area includes long term (24 to 48 hour) pump or hydraulic tests and the preparation of a report evaluating remedial action alternatives.

Gasoline in Soil and Groundwater

An estimated 65,000 liters of gasoline leaked from four underground storage tanks located near LLNL's southern boundary prior to March, 1979. This site has now been included in Waste Discharge Order No. 85-134, issued by the CRWQCB, San Francisco Bay Region. In response to this order, LLNL has conducted an investigation that established boundaries delineating the extent of gasoline constituents in the underlying groundwater plume and in the unsaturated and saturated soil formations. The results of these investigations are contained in Dresen et al., (1986) and in the *LLNL Ground Water Project, Monthly Progress Report* (Hoffman et al., 1986a-d; Dresen et al., 1986b-h). Current steps being taken in response to the Waste Discharge Order address the requirement to develop plans for the remediation of the affected soil and groundwater.

East Traffic Circle Landfill and Taxi Strip/Old Salvage Yard Areas and the Rest of the Site

Work is currently underway to determine the extent of VOCs in groundwater in these areas. VOCs dominated by TCE in concentrations up to 1.3 ppm are present in groundwater in the East Traffic Circle Landfill area. TCE and PCE are present in groundwater in the Taxi Strip/Old Salvage Yard area in concentrations up to 5.8 and 1.3 ppm, respectively. Other VOCs appear in lower concentrations. Following the determination and documentation of the extent of VOCs, the next phases of work for each of these areas will be the hydraulic testing of appropriate wells and the evaluation of remedial action alternatives.

EG&G Aerial Survey

At the request of the DOE Office of Nuclear Safety, EG&G (Las Vegas, Nevada) conducted radiation-survey overflights above LLNL property and adjacent areas in April, 1986. The purpose of the survey is twofold: 1) to document at a given point in time the location of areas where gamma radioactivity is detectable, and 2) to aid in evaluating the magnitude and spatial extent of contamination from radioactive materials released to the environment (past, present, and future). A similar aerial survey was conducted at LLNL and adjacent areas in August, 1975.

The EG&G aerial survey final report has not been completed as of the writing of this report. LLNL will include survey results in the next annual report.

TCE at Site 300

Trichloroethylene (TCE) is used as a heat-exchange fluid in the environmental testing facilities and is also provided for shop use. At Site 300, pump and valve leaks, system overflows, and past housekeeping practices have resulted in TCE spills. This material has been found in soil, rock, and/or water at five locations at Site 300. Initially, in 1983, 23 exploratory and soil-sampling holes were drilled and 5 groundwater monitoring wells were completed to assess TCE distributions. Two feet of significantly contaminated soil nearest the surface was removed from portions of the Building 834 and 854 complexes, aerated, and replaced. The spill areas were covered with PVC sheeting to prevent infiltration and retard further percolation to groundwater (Carpenter et al., 1983). Equipment at the Building 834 and 854 complexes has been improved to prevent future spills at these facilities.

In 1985, following consultation with State of California regulatory agencies, a second phase of studies was initiated. This work included the drilling of 5 additional soil sampling holes at 2 locations within Site 300 and the installation of 11 monitoring wells and piezometers at 3 locations. Soil and water samples were analyzed for TCE and other volatile organics. This work led to the identification of soil contamination at one additional location. Results of these investigations were reported to the CRWQCB, Central Valley Region, during 1986 (Carpenter et al., 1986).

In an effort to completely define the distribution of TCE and other VOCs at Site 300, additional

field studies were undertaken during the latter portion of 1986. As a result of this work, 11 additional monitoring wells were drilled and several special-purpose borings were completed. Work is scheduled to continue into 1987.

Underground Tank Testing

LLNL has developed and implemented a testing program to determine the integrity of its underground tank systems and to meet the requirements of Waste Discharge Order No. 85-134 and Title 23, Chapter 3, subchapter 16 of the California Administrative Code.

Beginning in July of 1985, tank systems have been tested in accordance with the performance standards of the National Fire Protection Association Code 329: "Precision Test."

Between July, 1985, and July, 1986, 81 tanks were tested, 61 were found to be leak tight, 9 were shown to have leaks, and 11 yielded inconclusive results. Schedules are being developed for periodic testing of tanks and for remedial actions.

The Underground Tank Testing Program is discussed in detail in Henry et al., (1986).

Tritium in Groundwater at Site 300

During 1983 and 1984, increases in tritium concentrations were observed in monitoring wells downgradient from experimental and waste disposal areas in the West Firing Area of Site 300. In 1984, concentrations in excess of the state limit for drinking water (20,000 pCi/L or 2×10^{-5} μ Ci/mL) were observed in wells K7-1, K7-3, and K2-1 (see Fig. 22). The CRWQCB, Central Valley Region, was notified and an investigation was initiated. Two extensive reports on the progress of this investigation have been prepared (Buddemeier, 1985; Buddemeier et al., 1987). The information that follows is summarized from those reports. Table A-25 summarizes the analytical findings resulting from the Site 300 monitoring well program.

Pits 3 and 5 (inactive landfills in the Pit 7 complex) have been identified as the sources of one combined plume of tritium in groundwater. An extensive drilling program has established bounds on the maximum extent of this plume and installed monitoring wells downgradient of the contaminated areas. The contaminated groundwater in the landfill area is limited to a shallow perched aquifer that is not a present or potential source of potable water supply. Groundwater

flow is to the east and northeast, with maximum velocities of a few tens of meters per year; this rate and direction of flow poses no near-term threat to any on- or off-site water supplies. The highest concentration of tritium observed is approximately 1×10^6 pCi/L (or one microcurie). Concentrations of TCE that are detectable but below the state action level have also been observed in a few wells immediately adjacent to Pit 5.

A second plume of tritiated water appears to originate in the vicinity of Building 850, a high-explosive firing area south of the Pit 7 complex. The concentrations and near-field hydrogeology of this plume are similar to the landfill plume; however, some tritium appears to have migrated into the East Firing Area, probably by streambed transport from the Building 850 area. The investigation has shown that groundwater tritium found near Pit 2 is not a result of local tritium in the East Firing Area landfills, but is traceable to the 850 plume.

The present phase of the continuing investigation is directed toward improving our estimates of groundwater flow and tritium migration and determining the extent of tritium dispersal into East Firing Area groundwater. Results are routinely reported to the CRWQCB (Central Valley Region) and DOHS. Further actions will be determined after review and consultation with these agencies.

Burn Pit Operation

Site 300 operates a burn pit area near Building 829 to burn high-explosives waste and paper potentially contaminated with high explosives. The facility is regulated by the Environmental Protection Agency and Department of Health Services and is operated in accordance with 40 CFR 265.382.

The burn pit area includes three trenches situated in a line running from west to east, and one furnace ("iron horse"). The most westerly trench is equipped with a cage and is used to burn paper waste that may be contaminated with HE. The center trench was used in the past to burn pieces of HE. The easterly trench is equipped with a steel pan and is currently used for burning pieces of HE up to 1 kg in size. The furnace is used to burn wet HE fines collected from the HE process water clarifier systems.

Necessary permits are being worked on with the appropriate regulatory agencies to move the

HE burn facility from Building 829 to Building 845 to provide better operational and safety controls.

High Explosives (HE) Wastewater Lagoon, Site 300

For many years, process water at Site 300's high explosives formulation, pressing, and machining facilities has been directed through clarifiers and weirs to remove particulate HE. The wastewater was discharged into unlined lagoons.

The unlined lagoons have been removed from service and replaced with two Class II double-lined surface impoundments (evaporation ponds). The new impoundments have a synthetic liner, underlain by a leachate collection system, and a clay secondary liner.

The industrial wastewater discharged to the lagoons has been tested in past years. The results indicated that effluents are not hazardous, based upon DOHS Title 22 WET tests and EPA toxicity tests. Fish toxicity tests were also run. While wastewater was found to be non-hazardous, the sludge results were inconclusive.

In 1985, duplicate fish toxicity tests were run on effluents from three points in the system: the effluent as it exited the facility, the concrete box where sludge collects, and the influent to the pond. Survival rates of 100% of the *Pimephales promelas* (fathead minnow) were noted, indicating that the wastestream is nonhazardous.

In late 1984, four monitoring wells were installed in the vicinity of the impoundments (as required by Title 23, Chapter 3, Subchapter 15 of the California Administrative Code) in order to detect any groundwater quality changes arising from future operation of the new surface impoundments. During development of baseline data and subsequent routine quarterly monitoring, the presence of small quantities of a high explosives compound, RDX, was detected in groundwater samples obtained from the upgradient well, 817-1, in the network (see Fig. 22). As a result of this finding and because of the need to close the unlined wastewater lagoons in the HE Processing Area, an investigation was begun during 1986.

Two additional monitoring wells were drilled during 1986 (Fig. 22). No HE compounds were detected in water samples obtained from these wells. Soil samples were obtained from boreholes at 12 locations within the 806/807 lagoon complex and analyzed for HE compounds. Low levels of the high explosives HMX and RDX were detected at most locations, but TNT was detected in trace concentrations in only one sample. The maximum depth of HE penetration in soil and rock was 70 ft. The results of the investigation of the 806/807 area were reported to the CRWQCB (Crow et al., 1986).

During 1986, soil samples were obtained from boreholes made in four other lagoon areas and at a wash-down facility. These samples were being analyzed at year's end.

Permits and Environmental Assessments

During 1986, LLNL held several environmental permits, orders, and notices that were issued for operations at Site 300 and the Livermore site. A short description of these follows:

Air Permits

In 1986, LLNL was issued 166 permits to operate equipment at Livermore and Site 300. The permits allow the operation of 99 hot water/steam boilers, 26 degreasers, 11 machine shop operations, 7 diesel fuel storage tanks, 5 paint spray booths, 2 gasoline pump islands, 1 gasoline storage facility (with tanks), and 15 miscellaneous items. Livermore site permits expire July 1, 1987; Site 300 permits expire January 31, 1988. At the appropriate time LLNL will renew source permits.

Livermore Site air pollution sources are regulated by the Bay Area Air Quality Management District. The San Joaquin County Air Pollution Control District regulates Site 300 sources.

Groundwater Investigation

As described in the "Special Assessments" section of this report, LLNL is currently involved in a comprehensive groundwater investigation in the vicinity of the Livermore site. This investigation has been ongoing since September, 1984. Waste Discharge Requirements were adopted by the California Regional Water Quality Control Board, San Francisco Bay Region, on November 20, 1985 (see Waste Discharge Order No. 85-134 listed below).

Liquid Waste Discharge

Waste Discharge Order No. 85-188 was issued in 1985 to regulate the surface impoundment (for nonhazardous process wastewater), sewage evaporation pond, and septic tank systems at Site 300.

Waste Discharge Order No. 82-105 covers cooling tower blowdown discharges at Site 300.

Waste Discharge Order No. 85-134 directs the groundwater contamination investigation.

Waste Discharge Order No. 86-95 covers the discharge of pumped groundwater.

Solid Waste Landfills

Eight landfills are addressed in Waste Discharge Order No. 80-184 issued by the CRWQCB, Central Valley Region. These landfills are also covered by DOHS Interim Status Document No. CA2890090002. Diversion ditches, groundwater monitoring wells, and lysimeters have been installed to meet the specified requirements. As described in the "Groundwater Monitoring" section, the landfills are circled by wells to detect changes in groundwater quality. Some tritium in groundwater has been detected in the Pit 7 area and is attributed to adjacent inactive landfills, Pits 3 and 5. A discussion of the tritium investigation results can be found in the "Special Monitoring Assessments" section.

Other Hazardous Waste Operations

Both Site 300 and the Livermore Site have Interim Status Documents (ISDs) issued by the State Department of Health Services (DOHS) for storage, treatment, and disposal of hazardous wastes. Facilities are being upgraded, and the design for a new storage and treatment facility is approximately 50% complete.

The "Part B" application for the Livermore site existing incinerator is currently under review by the Environmental Protection Agency (EPA) and the DOHS. A trial burn is planned pending EPA and DOHS approval. The Operations Plan for the existing storage and treatment facility at the Livermore site has been reviewed by the DOHS and a draft permit submitted for public notice. One public hearing has been held on the draft permit, and another is scheduled for early 1987.

The "Part B" application for the landfills at Site 300 designated as Pit 1 and Pit 7 is currently under review by the EPA and the DOHS.

Environmental Impact Report for Contract Renewal

The University of California is considering renewal of its contract with DOE for the operation and management of LLNL. A decision to continue management and operation of LLNL constitutes a "project" under the California Environmental Quality Act (CEQA). Prior to making a decision on renewal, the University is addressing the environmental impacts associated with continuing LLNL activities. The University is assessing these impacts through the Environmental Impact Report (EIR) review process. A draft EIR was published on December 22, 1986 (University of California, 1986).

Environmental Assessment for the Environmental Compliance and Cleanup Project

The Environmental Assessment for the Environmental Compliance and Cleanup Project (Hieb, 1987) was published in February, 1987. This document is prepared annually in accordance with DOE Order 1021.2 (10CFR Chapter X), which defers to guidelines mandated by the National Environmental Policy Act (NEPA). The document describes the environment that may be affected by tasks proposed by LLNL in the Environmental Compliance and Cleanup (ECC) Project, and potential beneficial and adverse effects that may be attributed to each task or sub-task. DOE reviews this document to determine whether NEPA documentation is required. The Environmental Compliance and Cleanup Project proposed by LLNL consists of seven major tasks:

- Groundwater contamination cleanup
- Soil contamination cleanup
- Landfill construction and cleanup
- Liquid waste discharge and corrective action
- Underground tanks and piping systems corrective action and cleanup
- PCB electrical equipment removal and disposal, and
- Nuclear reactor decommissioning.

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Appendix A. Tables

Table A-1a. Gross alpha activity on air filters—LLNL perimeter and Livermore Valley.

Month	Perimeter Locations ^a					
	1	2	12 [10 ¹⁵ $\mu\text{Ci/mL} \pm 2\sigma$ (%)] ^b	13	14	15
Jan.	≤ 0.4	≤ 0.3	≤ 0.4	≤ 0.5	≤ 0.4	≤ 0.4
Feb.	≤ 0.5	≤ 0.3	≤ 0.4	≤ 0.5	≤ 0.4	≤ 0.2
Mar.	≤ 0.4	≤ 0.3	≤ 0.4	≤ 0.4	≤ 0.4	≤ 0.2
Apr.	≤ 0.4	≤ 0.3	0.3 ± 0	≤ 0.4	≤ 0.4	0.3 ± 36
May	0.6 ± 58	≤ 0.3	0.6 ± 107	≤ 0.5	0.5 ± 38	0.4 ± 96
June	≤ 0.4	≤ 0.3	0.4 ± 48	≤ 0.5	≤ 0.4	0.4 ± 41
July	0.5 ± 40	0.3 ± 0	0.4 ± 65	0.6 ± 92	≤ 0.5	0.4 ± 50
Aug.	≤ 0.6	0.3 ± 33	0.3 ± 33	0.4 ± 29	≤ 0.4	0.4 ± 64
Sept.	≤ 0.5	0.3 ± 76	0.4 ± 82	0.6 ± 57	≤ 0.4	0.5 ± 52
Oct.	1.0 ± 37	0.7 ± 44	0.8 ± 18	1.0 ± 34	0.9 ± 40	1.0 ± 31
Nov.	1.0 ± 31	0.7 ± 42	0.7 ± 22	0.9 ± 47	0.7 ± 23	0.7 ± 17
Dec.	0.6 ± 14	0.6 ± 14	0.9 ± 27	0.8 ± 24	0.6 ± 27	0.7 ± 37
Annual Average ^c	0.6 ± 3	0.4 ± 43	0.5 ± 40	0.6 ± 34	0.5 ± 32	0.5 ± 49

^a See Fig. 5.

^b Standard deviation of monthly average.

^c The overall annual average for perimeter locations is $0.5 \times 10^{15} \mu\text{Ci/mL}$.

Table A-1b. Gross alpha activity on air filters—LLNL perimeter and Livermore Valley.

Month	Valley Locations ^a										
	3	4	5	6	7	8	9	10	11	16	17
	[10 ⁻¹⁵ $\mu\text{Ci/mL} \pm 2\sigma$ (%)] ^b										
Jan.	≤ 0.3	≤ 0.4	0.6 ± 96	0.7 ± 68	0.6 ± 69	≤ 0.4	0.8 ± 29	≤ 0.2	0.7 ± 132	0.4 ± 87	≤ 0.4
Feb.	≤ 0.3	≤ 0.4	0.6 ± 64	0.6 ± 42	0.6 ± 58	≤ 0.4	0.7 ± 44	≤ 0.2	0.6 ± 51	≤ 0.3	0.6 ± 24
Mar.	≤ 0.3	≤ 0.4	0.6 ± 69	0.6 ± 57	≤ 0.4	≤ 0.5	0.5 ± 38	≤ 0.2	0.5 ± 20	≤ 0.3	≤ 0.4
Apr.	≤ 0.3	≤ 0.4	0.6 ± 45	0.7 ± 62	0.5 ± 22	≤ 0.5	0.7 ± 36	≤ 0.2	0.5 ± 67	≤ 0.4	≤ 0.4
May	≤ 0.5	0.5 ± 60	0.6 ± 74	0.7 ± 76	0.6 ± 64	≤ 0.4	0.6 ± 72	0.4 ± 25	0.6 ± 43	≤ 0.4	≤ 0.4
June	≤ 0.4	≤ 0.4	0.8 ± 43	0.6 ± 64	0.6 ± 57	≤ 0.4	0.7 ± 62	≤ 0.2	0.6 ± 69	≤ 0.5	≤ 0.4
July	0.4 ± 45	≤ 0.4	0.5 ± 40	0.7 ± 104	0.6 ± 69	≤ 0.4	0.6 ± 122	≤ 0.3	0.6 ± 72	≤ 0.4	≤ 0.4
Aug.	≤ 0.4	0.5 ± 33	0.7 ± 36	0.8 ± 32	0.6 ± 57	≤ 0.4	0.6 ± 54	≤ 0.3	0.5 ± 33	≤ 0.5	≤ 0.4
Sept.	≤ 0.4	0.6 ± 33	0.8 ± 45	0.7 ± 58	0.7 ± 61	≤ 0.4	0.7 ± 23	≤ 0.2	0.7 ± 28	0.5 ± 0	≤ 0.4
Oct.	0.6 ± 0	0.6 ± 22	1.1 ± 8	1.3 ± 23	1.0 ± 17	0.6 ± 38	1.5 ± 10	0.6 ± 44	1.2 ± 13	0.5 ± 17	0.6 ± 35
Nov.	0.7 ± 16	0.4 ± 12	0.9 ± 24	1.0 ± 18	0.7 ± 20	0.8 ± 31	1.1 ± 20	0.3 ± 20	0.8 ± 30	0.5 ± 8	0.5 ± 10
Dec.	0.8 ± 20	0.5 ± 21	1.4 ± 15	1.4 ± 15	1.1 ± 18	0.7 ± 14	1.6 ± 4	0.6 ± 45	1.3 ± 23	0.7 ± 18	0.7 ± 30
Annual Average ^c	0.4 ± 37	0.5 ± 17	0.8 ± 34	0.8 ± 33	0.7 ± 30	0.5 ± 28	0.8 ± 43	0.3 ± 49	0.7 ± 37	0.4 ± 24	0.5 ± 23

^a See Fig. 7.

^b Standard deviation of monthly average.

^c The overall annual average for valley locations is $0.6 \times 10^{-15} \mu\text{Ci/mL}$.

Table A-2a. Gross beta activity on air filters—LLNL perimeter and Livermore Valley.

Month	Perimeter Locations ^a					
	1	2	12 [10 ⁻¹⁴ μ Ci/mL $\pm$ 2 σ (%)] ^b	13	14	15
Jan.	0.8 $\pm$ 151	1.2 $\pm$ 87	1.3 $\pm$ 98	1.6 $\pm$ 121	1.5 $\pm$ 107	1.4 $\pm$ 104
Feb.	0.9 $\pm$ 114	0.9 $\pm$ 80	0.9 $\pm$ 79	0.8 $\pm$ 97	0.8 $\pm$ 102	0.9 $\pm$ 104
Mar.	1.0 $\pm$ 161	1.0 $\pm$ 125	1.2 $\pm$ 90	1.1 $\pm$ 118	1.0 $\pm$ 142	1.0 $\pm$ 112
Apr.	1.0 $\pm$ 49	1.1 $\pm$ 71	1.0 $\pm$ 89	1.3 $\pm$ 56	1.0 $\pm$ 75	1.0 $\pm$ 61
May	32.1 $\pm$ 182 ^c	25.2 $\pm$ 180 ^c	25.2 $\pm$ 168 ^c	47.5 $\pm$ 128 ^c	34.5 $\pm$ 178 ^c	28.1 $\pm$ 182 ^c
June	2.6 $\pm$ 108	2.6 $\pm$ 128	2.9 $\pm$ 175	2.6 $\pm$ 95	2.8 $\pm$ 106	2.5 $\pm$ 114
July	0.8 $\pm$ 42	0.8 $\pm$ 40	0.8 $\pm$ 21	1.1 $\pm$ 32	0.9 $\pm$ 31	0.9 $\pm$ 18
Aug.	0.8 $\pm$ 68	0.9 $\pm$ 31	0.8 $\pm$ 48	1.1 $\pm$ 47	1.0 $\pm$ 65	1.0 $\pm$ 45
Sept.	0.9 $\pm$ 47	1.0 $\pm$ 41	1.0 $\pm$ 50	1.2 $\pm$ 16	1.1 $\pm$ 21	1.0 $\pm$ 26
Oct.	2.5 $\pm$ 14	2.2 $\pm$ 20	2.2 $\pm$ 14	2.7 $\pm$ 21	2.5 $\pm$ 22	2.5 $\pm$ 30
Nov.	1.0 $\pm$ 13	1.5 $\pm$ 42	1.4 $\pm$ 42	2.0 $\pm$ 61	1.6 $\pm$ 42	1.5 $\pm$ 50
Dec.	3.0 $\pm$ 25	2.6 $\pm$ 18	2.8 $\pm$ 27	3.0 $\pm$ 30	3.3 $\pm$ 32	3.2 $\pm$ 25
Annual Average ^d	4.0 $\pm$ 225	3.4 $\pm$ 202	3.4 $\pm$ 199	5.5 $\pm$ 241	4.3 $\pm$ 220	3.8 $\pm$ 206

^a See Fig. 5.

^b Standard deviation of monthly average.

^c Elevated levels attributed to Chernobyl.

^d The overall annual average for perimeter locations is 4.1×10^{-14} μ Ci/mL.

Table A-2b. Gross beta activity on air filters—LLNL perimeter and Livermore Valley.

Month	Valley Locations ^a										
	3	4	5	6	7	8	9	10	11	16	17
	[10 ⁻¹⁴ μ Ci/mL $\pm$ 2 σ (%)] ^b										
Jan.	1.5 $\pm$ 128	2.2 $\pm$ 20	2.6 $\pm$ 50	3.5 $\pm$ 58	2.2 $\pm$ 37	1.4 $\pm$ 136	3.0 $\pm$ 53	1.4 $\pm$ 104	3.2 $\pm$ 80	1.4 $\pm$ 115	1.1 $\pm$ 118
Feb.	1.1 $\pm$ 26	1.2 $\pm$ 25	2.2 $\pm$ 20	2.8 $\pm$ 29	2.2 $\pm$ 12	1.1 $\pm$ 100	2.4 $\pm$ 37	0.9 $\pm$ 97	2.0 $\pm$ 26	1.1 $\pm$ 101	1.0 $\pm$ 74
Mar.	1.0 $\pm$ 134	1.2 $\pm$ 126	2.3 $\pm$ 26	2.8 $\pm$ 49	2.3 $\pm$ 34	1.0 $\pm$ 124	2.8 $\pm$ 43	0.9 $\pm$ 148	2.6 $\pm$ 32	1.0 $\pm$ 156	0.7 $\pm$ 116
Apr.	1.1 $\pm$ 80	1.2 $\pm$ 62	2.3 $\pm$ 9	2.9 $\pm$ 28	2.4 $\pm$ 16	1.2 $\pm$ 83	3.0 $\pm$ 25	0.9 $\pm$ 61	2.6 $\pm$ 23	1.2 $\pm$ 30	0.9 $\pm$ 45
May	28.0 $\pm$ 259 ^c	40.4 $\pm$ 184 ^c	23.8 $\pm$ 166 ^c	40.1 $\pm$ 175 ^c	21.7 $\pm$ 163 ^c	31.7 $\pm$ 185 ^c	32.3 $\pm$ 166 ^c	31.6 $\pm$ 195 ^c	27.8 $\pm$ 182 ^c	29.1 $\pm$ 208 ^c	24.3 $\pm$ 183 ^c
June	2.4 $\pm$ 102	3.0 $\pm$ 111	3.6 $\pm$ 38	4.5 $\pm$ 63	3.7 $\pm$ 46	2.6 $\pm$ 108	4.3 $\pm$ 66	2.6 $\pm$ 108	3.8 $\pm$ 33	3.0 $\pm$ 114	2.2 $\pm$ 122
July	0.8 $\pm$ 33	1.0 $\pm$ 31	4.7 $\pm$ 84	5.2 $\pm$ 85	4.6 $\pm$ 83	0.8 $\pm$ 21	4.6 $\pm$ 82	0.8 $\pm$ 36	5.2 $\pm$ 86	0.7 $\pm$ 65	0.8 $\pm$ 56
Aug.	0.8 $\pm$ 54	1.1 $\pm$ 58	2.3 $\pm$ 19	3.0 $\pm$ 12	2.5 $\pm$ 14	0.8 $\pm$ 59	2.4 $\pm$ 17	0.9 $\pm$ 48	2.9 $\pm$ 20	0.8 $\pm$ 54	0.8 $\pm$ 44
Sept.	0.9 $\pm$ 44	1.1 $\pm$ 18	2.6 $\pm$ 12	3.0 $\pm$ 22	2.6 $\pm$ 11	1.0 $\pm$ 62	2.9 $\pm$ 32	1.0 $\pm$ 45	3.0 $\pm$ 13	1.1 $\pm$ 9	0.8 $\pm$ 7
Oct.	2.0 $\pm$ 0	2.0 $\pm$ 14	3.7 $\pm$ 10	4.2 $\pm$ 9	3.2 $\pm$ 6	2.7 $\pm$ 18	4.7 $\pm$ 7	2.8 $\pm$ 39	4.3 $\pm$ 6	2.0 $\pm$ 22	1.8 $\pm$ 28
Nov.	2.1 $\pm$ 50	1.2 $\pm$ 37	3.1 $\pm$ 22	3.6 $\pm$ 30	2.7 $\pm$ 18	1.8 $\pm$ 56	4.2 $\pm$ 40	1.5 $\pm$ 50	3.4 $\pm$ 17	1.4 $\pm$ 33	1.2 $\pm$ 48
Dec.	3.4 $\pm$ 28	2.8 $\pm$ 40	3.7 $\pm$ 19	5.7 $\pm$ 22	3.6 $\pm$ 13	3.8 $\pm$ 24	6.1 $\pm$ 23	3.0 $\pm$ 35	4.2 $\pm$ 15	2.8 $\pm$ 30	2.7 $\pm$ 44
Annual Average ^d	3.8 $\pm$ 204	4.9 $\pm$ 230	4.7 $\pm$ 128	6.8 $\pm$ 156	4.5 $\pm$ 122	4.2 $\pm$ 210	6.1 $\pm$ 138	4.0 $\pm$ 217	5.4 $\pm$ 131	3.8 $\pm$ 210	3.2 $\pm$ 209

^a See Fig. 7.^b Standard deviation of monthly average.^c Elevated levels attributed to Chernobyl.^d The annual average for valley locations is 4.7×10^{-14} μ Ci/mL.

Table A-3. Gross alpha activity on air filters—Site 300.

Month	Location ^a									
	1	2	3	4	5	6	7	8	9	10
	[$10^{-15} \mu\text{Ci/mL} \pm 2\sigma (\%)$] ^b									
Jan.	0.2 ± 0	≤0.2	≤0.3	0.2 ± 0	≤0.4	0.4 ± 0	ND ^c	≤0.4	≤0.2	≤0.2
Feb.	≤0.2	≤0.2	≤0.6	0.2 ± 0	≤0.2	≤0.5	ND	≤0.3	≤0.2	≤0.1
Mar.	0.2 ± 41	≤0.2	≤0.3	0.3 ± 156	0.3 ± 94	≤0.4	ND	≤0.3	≤0.2	≤0.3
Apr.	0.2 ± 74	0.2 ± 41	≤0.3	0.2 ± 44	0.3 ± 69	≤0.4	ND	≤0.3	≤0.2	≤0.3
May	0.4 ± 106	0.4 ± 109	≤0.4	0.4 ± 122	≤0.3	0.5 ± 95	ND	0.5 ± 53	0.4 ± 92	≤0.4
June	0.3 ± 42	0.3 ± 81	0.3 ± 31	0.3 ± 52	0.3 ± 68	0.5 ± 50	0.4 ± 41	0.4 ± 44	0.3 ± 103	≤0.3
July	0.4 ± 74	0.2 ± 0	≤0.4	0.3 ± 0	0.4 ± 51	0.4 ± 0	≤0.6	0.4 ± 24	0.4 ± 74	≤0.4
Aug.	0.4 ± 80	0.5 ± 93	≤0.4	0.3 ± 54	≤0.4	0.6 ± 26	0.6 ± 47	0.4 ± 27	0.3 ± 94	0.5 ± 40
Sept.	0.2 ± 46	0.2 ± 0	≤0.2	0.3 ± 60	0.5 ± 142	≤0.5	0.5 ± 94	0.3 ± 47	0.3 ± 103	0.3 ± 68
Oct.	0.6 ± 72	0.4 ± 0	0.4 ± 57	≤0.3	0.5 ± 113	1.0 ± 57	0.6 ± 66	0.4 ± 71	0.5 ± 72	0.6 ± 72
Nov.	0.4 ± 21	0.4 ± 30	0.4 ± 24	0.4 ± 30	0.7 ± 31	1.1 ± 19	0.8 ± 12	0.6 ± 39	0.5 ± 28	0.8 ± 29
Dec.	0.5 ± 9	0.4 ± 18	0.4 ± 15	0.6 ± 17	0.6 ± 31	0.8 ± 31	0.7 ± 42	0.6 ± 44	0.5 ± 33	0.7 ± 36
Annual Average ^d	0.3 ± 41	0.3 ± 38	0.4 ± 27	0.3 ± 35	0.4 ± 35	0.6 ± 41	0.6 ± 22	0.4 ± 26	0.3 ± 37	0.4 ± 50

^a See Fig. 6. Location 6 is in Tracy.

^b Standard deviation of monthly average.

^c Station not in operation before June. See "Changes to the Environmental Monitoring Program" section.

^d The overall annual average for Site 300 is $5.4 \times 10^{-15} \mu\text{Ci/mL}$.

Table A-4. Gross beta activity on air filters—Site 300.

Month	Location ^a									
	1	2	3	4	5	6	7	8	9	10
	[10^{-13} $\mu\text{Ci/mL} \pm 2\sigma$ (%)] ^b									
Jan.	1.3 $\pm$ 81	1.4 $\pm$ 73	1.0 $\pm$ 79	1.4 $\pm$ 95	1.0 $\pm$ 105	2.1 $\pm$ 59	ND ^d	0.4 $\pm$ 135	1.2 $\pm$ 80	0.9 $\pm$ 65
Feb.	0.9 $\pm$ 131	0.9 $\pm$ 160	0.8 $\pm$ 175	1.6 $\pm$ 0	1.2 $\pm$ 164	1.0 $\pm$ 77	ND ^d	0.7 $\pm$ 56	0.9 $\pm$ 104	1.2 $\pm$ 0
Mar.	1.3 $\pm$ 106	1.1 $\pm$ 100	0.9 $\pm$ 117	1.4 $\pm$ 66	1.2 $\pm$ 101	1.5 $\pm$ 113	ND ^d	1.0 $\pm$ 144	1.2 $\pm$ 105	1.3 $\pm$ 78
Apr.	1.1 $\pm$ 44	0.9 $\pm$ 41	0.9 $\pm$ 45	0.9 $\pm$ 26	1.2 $\pm$ 24	1.2 $\pm$ 28	ND ^d	1.0 $\pm$ 119	1.0 $\pm$ 10	1.0 $\pm$ 10
May	36.0 $\pm$ 197 ^c	34.2 $\pm$ 171 ^c	31.1 $\pm$ 164 ^c	35.2 $\pm$ 180 ^c	20.5 $\pm$ 183 ^c	40.4 $\pm$ 186 ^c	ND ^d	38.3 $\pm$ 176 ^c	34.2 $\pm$ 172 ^c	21.9 $\pm$ 189 ^c
June	2.9 $\pm$ 171	3.2 $\pm$ 128	2.5 $\pm$ 131	3.0 $\pm$ 127	2.9 $\pm$ 112	2.8 $\pm$ 118	2.6 $\pm$ 130	3.1 $\pm$ 149	3.0 $\pm$ 152	3.1 $\pm$ 118
July	1.4 $\pm$ 26	1.2 $\pm$ 22	1.0 $\pm$ 20	1.0 $\pm$ 29	1.1 $\pm$ 18	1.1 $\pm$ 0	1.2 $\pm$ 119	0.8 $\pm$ 72	1.2 $\pm$ 21	1.0 $\pm$ 86
Aug.	2.0 $\pm$ 60	1.6 $\pm$ 53	1.4 $\pm$ 49	1.4 $\pm$ 35	0.8 $\pm$ 199	1.8 $\pm$ 47	2.0 $\pm$ 33	1.4 $\pm$ 81	1.6 $\pm$ 42	1.5 $\pm$ 46
Sept.	1.5 $\pm$ 38	1.1 $\pm$ 36	1.0 $\pm$ 32	1.3 $\pm$ 37	1.4 $\pm$ 55	1.2 $\pm$ 9	1.6 $\pm$ 42	1.2 $\pm$ 38	1.3 $\pm$ 41	1.3 $\pm$ 29
Oct.	2.4 $\pm$ 41	2.3 $\pm$ 62	1.7 $\pm$ 81	1.3 $\pm$ 127	2.1 $\pm$ 85	3.0 $\pm$ 38	2.1 $\pm$ 76	2.0 $\pm$ 75	2.4 $\pm$ 43	2.3 $\pm$ 61
Nov.	2.0 $\pm$ 40	1.5 $\pm$ 46	1.4 $\pm$ 50	1.3 $\pm$ 62	1.9 $\pm$ 45	2.0 $\pm$ 47	1.6 $\pm$ 35	1.4 $\pm$ 35	1.7 $\pm$ 53	1.8 $\pm$ 42
Dec.	3.5 $\pm$ 21	2.9 $\pm$ 18	2.6 $\pm$ 23	3.2 $\pm$ 29	3.5 $\pm$ 30	4.2 $\pm$ 30	3.0 $\pm$ 23	2.9 $\pm$ 28	2.9 $\pm$ 18	3.0 $\pm$ 23
Annual Average ^e	4.7 $\pm$ 211	4.4 $\pm$ 216	3.9 $\pm$ 223	4.4 $\pm$ 220	3.2 $\pm$ 170	5.2 $\pm$ 214	2.0 $\pm$ 31	4.5 $\pm$ 236	4.4 $\pm$ 215	3.4 $\pm$ 175

^a See Fig. 6. Location 6 is in Tracy.^b Standard deviation of monthly average.^c Elevated levels attributed to Chernobyl.^d No data. Station not in operation before June.^e The overall annual average for Site 300 is 4.0×10^{-14} $\mu\text{Ci/mL}$.

Table A-5. Gamma activity on air filters—LLNL perimeter.^a

Month	⁷ Be [10 ⁻¹³ μ Ci/mL $\pm$ 2 σ (%)]	⁴⁰ K	¹⁰⁶ Ru	¹²⁵ Sb	¹³⁷ Cs	¹⁴⁴ Ce
			[10 ⁻¹⁶ μ Ci/mL $\pm$ 2 σ (%)]			
Jan.	0.96 $\pm$ 4	2.63 $\pm$ 48	ND	ND	0.09 $\pm$ 78	ND
Feb.	0.62 $\pm$ 2	ND	ND	ND	ND	ND
Mar.	1.21 $\pm$ 3	ND	ND	ND	0.16 $\pm$ 46	ND
Apr.	1.39 $\pm$ 2	ND ^c	ND	ND	0.24 $\pm$ 38	ND
May	1.58 $\pm$ 2	ND	391 $\pm$ 3 ^b	37.6 $\pm$ 9 ^b	1184 $\pm$ 2 ^b	23.9 $\pm$ 48 ^b
June	0.98 $\pm$ 2	ND	35.9 $\pm$ 12 ^b	1.9 $\pm$ 19 ^b	35.9 $\pm$ 2 ^b	ND
July	0.76 $\pm$ 2	5.90 $\pm$ 36	ND	ND	0.80 $\pm$ 14 ^b	ND
Aug.	0.85 $\pm$ 2	180 $\pm$ 8	ND	ND	0.48 $\pm$ 38	ND
Sept.	1.14 $\pm$ 2	4.70 $\pm$ 48	ND	ND	0.32 $\pm$ 24	ND
Oct.	14.8 $\pm$ 2	79.5 $\pm$ 38	ND	ND	3.60 $\pm$ 40	ND
Nov.	0.62 $\pm$ 2	6.89 $\pm$ 48	ND	ND	0.14 $\pm$ 82	ND
Dec.	1.22 $\pm$ 2	ND	ND	ND	0.20 $\pm$ 52	ND
Annual average	1.23 ^d	46.6	0.22	0.10	0.67	$\leq$ 0.55
% SDM	396	154	0	0	168	0
DCG (μ Ci/mL)	5 $\times$ 10 ⁻⁸	9 $\times$ 10 ⁻¹⁰	3 $\times$ 10 ⁻¹¹	1 $\times$ 10 ⁻⁹	4 $\times$ 10 ⁻¹⁰	3 $\times$ 10 ⁻¹¹
% DCG	2 $\times$ 10 ⁻⁴	5 $\times$ 10 ⁻⁴	7 $\times$ 10 ⁻⁵	1 $\times$ 10 ⁻⁶	2 $\times$ 10 ⁻⁵	—

^a Not including nuclides attributed to the Chernobyl incident. See Appendix H.

^b Elevated levels attributed to Chernobyl. See Appendix H. Not included in annual average.

^c ND = Not detected.

^d Data not normally distributed. Log transformation used. See Appendix D.

Table A-6. Gamma activity on air filters—Site 300.^a

Month	⁷ Be [10 ⁻¹³ μCi/mL · 2σ (%)]	⁴⁰ K	¹⁰⁶ Ru	¹²⁵ Sb	¹³⁷ Cs	¹⁴⁴ Ce
Jan.	0.77 ± 1	ND	ND	ND	0.07 ± 70	ND
Feb.	0.84 ± 2	ND	ND	ND	0.08 ± 62	ND
Mar.	1.16 ± 2	ND	ND	ND	0.11 ± 36	ND
Apr.	1.44 ± 3	ND ^c	ND	ND	0.15 ± 34	ND
May	1.82 ± 2	ND	367 ± 3.6 ^b	34.1 ± 9 ^b	1044 ± 1 ^b	22.5 ± 18 ^b
June	1.32 ± 3	4.03 ± 30	35.2 ± 4 ^b	1.56 ± 20 ^b	29.4 ± 2 ^b	1.72 ± 40 ^b
July	1.41 ± 2	4.37 ± 30	1.00	ND	0.69 ± 8 ^b	ND
Aug.	1.70 ± 2	2.98 ± 50	ND	ND	0.36 ± 20	ND
Sept.	1.30 ± 2	2.08 ± 46	ND	ND	0.23 ± 20	ND
Oct.	1.31 ± 2	3.42 ± 44	ND	ND	0.29 ± 16	ND
Nov.	0.72 ± 2	ND	ND	ND	0.11 ± 40	ND
Dec.	1.31 ± 2	2.66 ± 58	ND	ND	0.34 ± 14	ND
Annual average	1.21 ^d	2.50 ^e	0.67 ^e	0.13 ^e	0.19 ^d	0.33 ^e
% SDM	111	46 ^f	96 ^f	8 ^f	1116	2 ^f
DCG (μCi/mL)	5 · 10 ⁻⁸	9 · 10 ⁻¹⁰	3 · 10 ⁻¹¹	1 · 10 ⁻⁹	4 · 10 ⁻¹⁰	3 · 10 ⁻¹¹
% DC	2 · 10 ⁻⁴	3 · 10 ⁻⁵	—	—	5 · 10 ⁻⁶	—

^a Not including additional nuclides attributed to the Chernobyl incident. See Appendix H.^b Elevated levels attributed to Chernobyl. See Appendix H.^c ND = Not detected.^d Data not normally distributed. Log transformation used. See Appendix D.^e Median value. See Appendix D.^f Median absolute deviation. See Appendix D.Table A-7. ²³⁹Pu on air filters—Valley locations.

Month	Location ^a						
	3	4	8	10	16	17	6
	[10 ⁻¹⁷ μCi/mL ± 2σ (%)]						
Jan.	0.03 ± 69	0.06 ± 74	≤0.03	≤0.02	0.03 ± 70	≤0.04	≤0.02
Feb.	0.01 ± 96	0.03 ± 80	0.02 ± 90	≤0.008	0.03 ± 55	≤0.02	0.02 ± 90
Mar.	0.03 ± 64	ND ^b	0.02 ± 99	≤0.01	0.03 ± 67	≤0.006	≤0.03
Apr.	0.02 ± 62	0.02 ± 73	≤0.02	0.02 ± 80	0.04 ± 76	0.01 ± 82	≤0.02
May	0.05 ± 74	0.10 ± 44	0.09 ± 46	0.08 ± 33	0.16 ± 37	0.09 ± 43	0.06 ± 34
June	≤0.03	0.05 ± 60	0.05 ± 65	≤0.03	0.10 ± 57	0.02 ± 88	≤0.04
July	≤0.04	0.06 ± 71	≤0.02	0.03 ± 82	0.04 ± 80	≤0.05	≤0.07
Aug.	≤0.004	0.06 ± 71	0.02 ± 93	≤0.02	0.03 ± 100	≤0.02	≤0.06
Sept.	0.02 ± 75	0.04 ± 86	0.02 ± 90	≤0.02	0.20 ± 35	0.02 ± 84	≤0.05
Oct.	≤0.08	0.03 ± 85	≤0.003	0.03 ± 90	0.19 ± 38	≤0.04	0.02 ± 97
Nov.	0.03 ± 72	0.01 ± 60	0.03 ± 56	0.01 ± 78	0.04 ± 54	0.01 ± 93	0.02 ± 64
Dec.	0.02 ± 99	0.02 ± 67	0.02 ± 88	≤0.008	0.06 ± 48	≤0.04	≤0.05
Annual average	0.03 ^c	0.04	0.06 ^c	0.04 ^c	0.06 ^d	0.05 ^d	0.04 ^d
% SDM ^e	33	59	42	62	43	70	50
% DCG ^f	2 × 10 ⁻³	2 × 10 ⁻³	3 × 10 ⁻³	2 × 10 ⁻³	3 × 10 ⁻³	2 × 10 ⁻³	2 × 10 ⁻³

^a See Fig. 7. Location 6 is in city of Tracy.^b ND = Not detected.^c Median value and median absolute deviation.^d Data not normally distributed. Log transformation used. See Appendix D.^e Values are at or near the detection limit, so % SDM reflects precision of the analytical method rather than environmental ²³⁹Pu distributions.^f DCG = 2 × 10⁻¹⁴ μCi/mL or 2 × 10⁻² pCi/m³.

Table A-8. Plutonium and uranium on air filters--LLNL perimeter.

Month	Location ^a	²³⁹ Pu ^b	²³⁵ U	²³⁸ U	²³⁵ U/ ²³⁸ U
		[10 ⁻¹⁷ μ Ci/mL $\pm$ 2 σ (%)]	[10 ⁻⁷ μ g/m ³]	[10 ⁻⁵ μ g/m ³]	(10 ⁻³)
Jan.	1	0.10 $\pm$ 49	1.95	2.84	6.9
	2	0.05 $\pm$ 61	2.80	3.92	7.2
	12	0.08 $\pm$ 56	3.81	5.40	7.1
	13	0.06 $\pm$ 76	ND	ND	—
	14	0.06 $\pm$ 60	1.96	2.72	7.3
	15	0.03 $\pm$ 82	2.01	2.84	7.1
Feb.	1	0.23 $\pm$ 28	2.59	3.76	6.9
	2	0.05 $\pm$ 45	2.28	3.27	7.1
	12	0.07 $\pm$ 43	3.14	4.51	7.0
	13	$\leq$ 0.01	0.69	1.00	7.0
	14	0.06 $\pm$ 46	1.85	2.62	7.1
	15	0.04 $\pm$ 53	1.62	2.29	7.2
Mar.	1	0.25 $\pm$ 34	3.66	5.43	6.7
	2	$\leq$ 0.01	2.91	3.96	7.3
	12	0.23 $\pm$ 33	4.73	6.77	7.0
	13	ND ^c	3.98	5.66	7.0
	14	0.05 $\pm$ 52	2.82	3.78	7.5
	15	0.02 $\pm$ 70	ND	ND	—
Apr.	1	0.66 $\pm$ 13	5.61	8.25	6.9
	2	0.03 $\pm$ 50	3.35	4.73	7.2
	12	0.10 $\pm$ 27	4.13	6.04	6.9
	13	0.05 $\pm$ 61	4.77	6.69	7.2
	14	0.11 $\pm$ 27	3.50	4.92	7.2
	15	0.05 $\pm$ 40	5.34	7.53	7.2
May	1	0.64 $\pm$ 18	6.43	9.20	7.0
	2	0.54 $\pm$ 36	37.20 ^d	48.00 ^d	7.8
	12	0.18 $\pm$ 21	6.20	8.40	7.4
	13	0.12 $\pm$ 39	7.33	10.20	7.2
	14	0.10 $\pm$ 36	5.07	7.14	7.1
	15	0.09 $\pm$ 32	12.6	17.6	7.2
June	1	0.26 $\pm$ 42	6.48	9.24	7.1
	2	0.01 $\pm$ 100	3.37	4.72	7.2
	12	0.10 $\pm$ 53	6.75	9.68	7.1
	13	0.04 $\pm$ 61	6.79	9.51	7.4
	14	0.10 $\pm$ 42	5.34	7.35	7.4
	15	0.09 $\pm$ 49	8.87	12.60	7.2
July	1	0.46 $\pm$ 24	6.83	9.51	7.3
	2	0.03 $\pm$ 76	3.79	5.33	7.2
	12	0.07 $\pm$ 62	5.92	7.88	7.6
	13	0.11 $\pm$ 60	11.90	16.70	7.2
	14	0.17 $\pm$ 46	5.82	8.20	7.2
	15	0.06 $\pm$ 60	8.17	11.60	7.2
Aug.	1	0.31 $\pm$ 28	4.40	6.25	7.1
	2	0.04 $\pm$ 70	2.58	3.66	7.1
	12	0.12 $\pm$ 35	ND	ND	—
	13	0.05 $\pm$ 75	ND	ND	—

Table A-8. (Continued).

Month	Location ^a	²³⁹ Pu ^b [10 ⁻¹⁷ μCi/mL · 2σ (%)]	²³⁵ U [10 ⁻⁷ μg/m ³]	²³⁸ U [10 ⁻⁵ μg/m ³]	²³⁵ U/ ²³⁸ U (10 ⁻³)
	14	0.16 · 34	ND	ND	—
	15	0.06 · 42	ND	ND	—
Sept.	1	0.32 · 25	5.50	7.82	7.1
	2	· 0.03	3.32	4.61	7.3
	12	0.10 · 40	6.27	9.33	6.8
	13	· 0.05	10.20	14.30	7.2
	14	0.20 · 28	4.12	5.91	7.1
	15	0.03 · 55	6.85	9.69	7.2
Oct.	1	1.57 · 13	9.85	14.10	7.1
	2	0.04 · 70	4.76	6.75	7.2
	12	0.86 · 41	7.67	10.80	7.2
	13	0.04 · 83	12.00	16.70	7.3
	14	— ^c	4.87	6.87	7.2
	15	0.12 · 45	47.90 ^d	68.10 ^d	7.1
Nov.	1	1.03 · 17	6.38	9.13	7.1
	2	· 0.02	5.85	8.54	6.9
	12	0.10 · 37	7.51	10.90	7.0
	13	0.13 · 60	13.10	18.50	7.2
	14	0.13 · 33	6.33	8.96	7.2
	15	· 0.02	7.74	11.00	7.1
Dec.	1	0.5 · 22	5.16	7.35	7.1
	2	· 0.03	4.10	5.85	7.1
	12	· 0.04	4.40	6.29	7.1
	13	0.02 · 80	7.19	10.10	7.2
	14	0.02 · 75	3.22	4.54	7.2
	15	0.03 · 56	4.16	6.01	7.0

Annual averages

Location	²³⁹ Pu			²³⁵ U			²³⁸ U		
	10 ⁻¹⁷ μCi/mL	% SDM	% DCG ^e	10 ⁻⁷ μg/m ³	% SDM	% DCG ^f	10 ⁻⁵ μg/m ³	% SDM	% DCG ^g
1	0.41 ^h	82	2 · 10 ⁻²	5.40	39	1 × 10 ⁻³	7.74	38	3 × 10 ⁻²
2	0.28 ⁱ	88	1 · 10 ⁻²	3.30	22	7 × 10 ⁻⁴	5.03	31	2 × 10 ⁻²
				(4.18)	(51)	(9 × 10 ⁻⁴)	(8.61)	(145)	(3 × 10 ⁻²)
12	0.13 ^h	36	6 · 10 ⁻³	5.30 ^h	18	1 × 10 ⁻³	7.82	28	3 × 10 ⁻²
13	0.07	58	4 × 10 ⁻³	6.24 ^h	48	1 × 10 ⁻³	8.78 ^h	40	3 × 10 ⁻²
14	0.09 ^h	28	4 × 10 ⁻³	4.08	37	9 × 10 ⁻⁴	5.73	38	2 × 10 ⁻²
15	0.05	19	2 × 10 ⁻³	5.34 ^h	41	1 × 10 ⁻⁴	7.56	34	2 × 10 ⁻²
				(6.64) ^h	(50)	(1)	(9.42)	(42)	(3)

^a See Fig. 5.^b In all tables, activity listed as ²³⁹Pu includes activity due to ²⁴⁰Pu isotope.^c No data.^d Outlier. Values with outlier included are in parentheses.^e DCG = 2 × 10⁻¹⁴ μCi/ml for ²³⁹Pu activity in air or 2 × 10⁻² pCi/m³.^f DCG = 1 × 10⁻¹³ μCi/ml (= 0.047 μg/m³) for ²³⁵U activity in air.^g DCG = 1 × 10⁻¹³ μCi/ml (= 0.3 μg/m³) for ²³⁸U activity in air.^h Log transformation used. See Appendix D.ⁱ Median value ± median absolute deviation.

Table A-9. Plutonium, cesium, and uranium on air filters—Site 300.

Month	²³⁹ Pu	¹³⁷ Cs	²³⁹ Pu/ ¹³⁷ Cs	²³⁵ U	²³⁸ U	²³⁵ U/ ²³⁸ U
	[10 ⁻¹⁸ μCi/mL ± 2σ (%)]	[10 ⁻¹⁶ μCi/mL ± 2σ (%)]	(10 ⁻²)	[10 ⁻⁷ μg/m ³]	[10 ⁻⁵ μg/m ³]	(10 ⁻¹)
Jan.	18.5 ± 13	0.07 ± 70	26.4	1.0	1.6	6.1
Feb.	4.2 ± 17	0.08 ± 62	5.2	1.0	1.7	5.6
Mar.	2.9 ± 18	0.11 ± 36	2.6	1.3	2.0	6.6
Apr.	8.8 ± 11	0.15 ± 34	5.9	2.3	4.8	4.7
May	15.7 ± 9	1044 ± 1.4 ^d	0.0015	3.1	4.6	6.7
June	10.6 ± 19	29.4 ± 1.6 ^d	0.04	3.9	6.0	6.6
July	ND ^b	0.69 ± 8	—	4.7	6.9	6.9
Aug.	2.8 ± 21	0.36 ± 20	0.8	4.3	6.5	6.7
Sept.	5.0 ± 15	0.23 ± 20	2.2	2.2	3.4	6.5
Oct.	7.4 ± 23	0.29 ± 16	2.6	4.6	6.7	6.9
Nov.	4.6 ± 23	0.11 ± 40	4.2	3.8	5.9	6.5
Dec.	6.7 ± 21	0.34 ± 14	2.0	2.4	3.6	6.7
Annual average	6.6 ^c	0.19 ^c		2.9	4.5	
% SDM	33	25		48	44	
DCG (μCi/mL)	2 × 10 ⁻¹⁴	4 × 10 ⁻¹⁰		4.7 × 10 ⁻² μg/m ³	0.3 μg/m ³	
% DCG	3 × 10 ⁻³	5 × 10 ⁻⁶		6 × 10 ⁻⁴	2 × 10 ⁻²	

^d Elevated value attributed to Chernobyl. See Appendix H.^b No data. See "Deviations from the Sampling Program" section.^c Data not normally distributed. Log transformation used. See Appendix D.

Table A-10a. Tritium in air.

Month	Perimeter Locations ^a					
	1	2	12 [10 ¹¹ μ Ci/mL $\pm$ 2 σ (%)]	13 [10 ¹¹ μ Ci/mL $\pm$ 2 σ (%)]	14	15
Jan.	ND	6.7 $\pm$ 2	ND	4.7 $\pm$ 2	2.3 $\pm$ 4	3.2 $\pm$ 3
	3.2 $\pm$ 4	5.5 $\pm$ 3	5.8 $\pm$ 3	8.6 $\pm$ 2	3.6 $\pm$ 4	4.3 $\pm$ 3
	6.0 $\pm$ 3	6.6 $\pm$ 2	7.2 $\pm$ 2	6.6 $\pm$ 2	4.7 $\pm$ 3	4.6 $\pm$ 3
Feb.	2.7 $\pm$ 4	3.7 $\pm$ 4	5.9 $\pm$ 2	4.2 $\pm$ 4	2.9 $\pm$ 4	2.3 $\pm$ 5
	ND	4.0 $\pm$ 4	3.0 $\pm$ 5	2.4 $\pm$ 6	2.9 $\pm$ 5	ND
Mar.	ND	2.4 $\pm$ 5	3.2 $\pm$ 4	ND	2.5 $\pm$ 6	2.6 $\pm$ 6
	ND	2.3 $\pm$ 4	5.4 $\pm$ 2	4.1 $\pm$ 4	1.6 $\pm$ 6	1.3 $\pm$ 7
Apr.	2.7 $\pm$ 5	2.1 $\pm$ 5	3.4 $\pm$ 4	4.2 $\pm$ 5	2.4 $\pm$ 5	2.6 $\pm$ 6
	3.9 $\pm$ 4	1.3 $\pm$ 7	3.1 $\pm$ 4	2.3 $\pm$ 8	6.9 $\pm$ 3	1.8 $\pm$ 6
				0.9 $\pm$ 10		
May	2.4 $\pm$ 4	1.9 $\pm$ 7	2.0 $\pm$ 5	0.9 $\pm$ 11	2.2 $\pm$ 5	3.1 $\pm$ 4
	1.7 $\pm$ 5	1.4 $\pm$ 5	2.2 $\pm$ 4	2.1 $\pm$ 5	3.0 $\pm$ 4	4.8 $\pm$ 4 ^h
						2.6 $\pm$ 7
June						2.7 $\pm$ 4 ^h
	2.5 $\pm$ 5	0.1 $\pm$ 70	1.2 $\pm$ 9	0.08 $\pm$ 100 ^c	2.5 $\pm$ 5	1.5 $\pm$ 7
	2.5 $\pm$ 4	1.0 $\pm$ 11	1.5 $\pm$ 7	1.3 $\pm$ 8	3.2 $\pm$ 5	1.7 $\pm$ 6
July	2.8 $\pm$ 4				2.4 $\pm$ 4	
	2.0 $\pm$ 4	0.9 $\pm$ 11	1.6 $\pm$ 6	ND	2.4 $\pm$ 4	1.4 $\pm$ 7
	1.6 $\pm$ 7	0.6 $\pm$ 16	3.6 $\pm$ 6	0.2 $\pm$ 46	3.4 $\pm$ 4	3.0 $\pm$ 4
Aug.	5.4 $\pm$ 3	0.4 $\pm$ 25 ^h	0.7 $\pm$ 14	ND	ND	5.5 $\pm$ 3
		1.3 $\pm$ 8	2.6 $\pm$ 4			
		1.0 $\pm$ 11 ^h				
Sept.	1.6 $\pm$ 7	0.5 $\pm$ 21 ^h	0.6 $\pm$ 15	0.2 $\pm$ 41	2.0 $\pm$ 5	1.4 $\pm$ 6
	2.4 $\pm$ 5	ND	0.8 $\pm$ 11	0.2 $\pm$ 29	ND	1.7 $\pm$ 6
				0.4 $\pm$ 24 ^h		ND
Oct.	62.2 $\pm$ 1 ^c	43.0 $\pm$ 1 ^c	1.4 $\pm$ 7	0.6 $\pm$ 13	ND	2.0 $\pm$ 5
	12.2 $\pm$ 2 ^c	34.6 $\pm$ 1 ^c	8.5 $\pm$ 2	18.5 $\pm$ 1 ^c	5.2 $\pm$ 3	ND
		ND				2.7 $\pm$ 4
Nov.						12.4 $\pm$ 2 ^{c,h}
	1.5 $\pm$ 5	ND	7.8 $\pm$ 2	2.3 $\pm$ 4	1.3 $\pm$ 6	1.0 $\pm$ 7
	5.5 $\pm$ 2	4.1 $\pm$ 3	6.6 $\pm$ 2	5.7 $\pm$ 3	1.4 $\pm$ 6	10.9 $\pm$ 2 ^c
Nov.			7.0 $\pm$ 2		6.5 $\pm$ 2	
	2.0 $\pm$ 4	2.7 $\pm$ 4	4.1 $\pm$ 3	6.6 $\pm$ 2	1.7 $\pm$ 5	1.8 $\pm$ 5
	2.5 $\pm$ 5	5.9 $\pm$ 2	3.0 $\pm$ 3	4.1 $\pm$ 3 ^h	1.7 $\pm$ 5	2.2 $\pm$ 4
Nov.				6.6 $\pm$ 2		9.1 $\pm$ 2 ^c
				7.1 $\pm$ 2 ^h		

Table A-10a. Continued.

Month	Perimeter Locations ^a					
	1	2	12 [10 ⁻¹¹ μ Ci/mL $\pm$ 2 σ (%)]	13	14	15
Dec.	3.0 $\pm$ 3 1.4 $\pm$ 6 ND	3.4 $\pm$ 3 5.7 $\pm$ 4 1.9 $\pm$ 5	3.8 $\pm$ 3 5.2 $\pm$ 2 ND	3.2 $\pm$ 3 5.6 $\pm$ 2 320.0 $\pm$ 1 ^c	1.9 $\pm$ 4 1.2 $\pm$ 6 448.0 $\pm$ 1 ^c	3.4 $\pm$ 3 1.0 $\pm$ 7 1.0 $\pm$ 9 ^h 367.0 $\pm$ 1 ^c 315.0 $\pm$ 1 ^{c,h}
Annual average ^e	2.8 (5.8) ^g	1.8 (5.4) ^g	3.0 ⁱ	2.1 (15.1) ^g	2.9 (19.9) ^g	2.2 (24.4) ^g
% SDM	46 (215)	165 (184)	70	160 (396)	52 (439)	60 (342)
% DCG ^d	1.4 $\times$ 10 ⁻²	9 $\times$ 10 ⁻³	1.5 $\times$ 10 ⁻²	1.0 $\times$ 10 ⁻²	1.4 $\times$ 10 ⁻²	1.1 $\times$ 10 ⁻²
Effective dose equivalent (mrem)	2 $\times$ 10 ⁻²	1 $\times$ 10 ⁻²	2 $\times$ 10 ⁻²	2 $\times$ 10 ⁻²	2 $\times$ 10 ⁻²	2 $\times$ 10 ⁻²

^a See Fig. 5.^b No data. See "Deviations from the Monitoring Program" section.^c Outliers^d DCG = 2 $\times$ 10⁻⁷ μ Ci/mL, or 2 $\times$ 10⁻⁵ pCi/m³.^e LLNL perimeter overall annual average = 2.5 $\pm$ 20 (12.3 $\pm$ 72)ⁱ.^f Data not distributed normally. Log transformation used. See Appendix D.^g Values with outliers included are in parentheses.^h QA samples.

Table A-10b. Tritium in air.

Month	Valley Locations ^a					
	S-1	S-2	V04	V07	V09	V17
	[10 ⁻¹¹ $\mu\text{Ci/mL} \pm 2\sigma$ (%)]					
Jan.	2.8 $\pm$ 4 3.6 $\pm$ 3 5.4 $\pm$ 3	2.6 $\pm$ 4 3.4 $\pm$ 4 10.1 $\pm$ 2 ^e	2.3 $\pm$ 4 2.2 $\pm$ 5 ND	ND ^d 1.2 $\pm$ 8 ND	ND ND 2.4 $\pm$ 5	1.8 $\pm$ 5 2.5 $\pm$ 5 2.5 $\pm$ 5
Feb.	1.7 $\pm$ 6 ND	1.3 $\pm$ 8 2.9 $\pm$ 5	1.4 $\pm$ 6 1.5 $\pm$ 9	1.5 $\pm$ 6 ND	ND 0.7 $\pm$ 26	1.5 $\pm$ 7 1.4 $\pm$ 9
Mar.	ND 1.4 $\pm$ 7	1.7 $\pm$ 8 1.3 $\pm$ 7	ND 1.1 $\pm$ 9	1.2 $\pm$ 11 0.9 $\pm$ 10	ND 0.4 $\pm$ 23	0.9 $\pm$ 13 0.6 $\pm$ 15
Apr.	1.4 $\pm$ 8 1.5 $\pm$ 6	1.7 $\pm$ 7 0.8 $\pm$ 11	1.0 $\pm$ 10 0.8 $\pm$ 11	0.6 $\pm$ 16 0.6 $\pm$ 12	ND 0.2 $\pm$ 35	0.7 $\pm$ 17 0.8 $\pm$ 14
May	1.5 $\pm$ 7 2.2 $\pm$ 6	0.8 $\pm$ 12 1.1 $\pm$ 7	1.2 $\pm$ 7 1.1 $\pm$ 7	0.9 $\pm$ 9 0.7 $\pm$ 13	0.5 $\pm$ 15 0.2 $\pm$ 29	0.8 $\pm$ 13 ND
June	1.3 $\pm$ 8 0.8 $\pm$ 12	0.5 $\pm$ 18 0.5 $\pm$ 18	1.7 $\pm$ 6 0.9 $\pm$ 11	0.6 $\pm$ 16 0.4 $\pm$ 27	0.5 $\pm$ 23 0.1 $\pm$ 86	0.6 $\pm$ 17 0.6 $\pm$ 17
July	1.6 $\pm$ 6 0.9 $\pm$ 12 3.3 $\pm$ 4	0.9 $\pm$ 10 0.4 $\pm$ 26 ND	1.5 $\pm$ 7 1.6 $\pm$ 7 2.4 $\pm$ 5	0.7 $\pm$ 12 0.4 $\pm$ 23 1.0 $\pm$ 11	0.3 $\pm$ 26 0.09 $\pm$ 100 0.4 $\pm$ 24	0.8 $\pm$ 12 0.2 $\pm$ 42 0.5 $\pm$ 21
Aug.	1.5 $\pm$ 7 0.9 $\pm$ 9	0.4 $\pm$ 21 ND	ND ND	0.6 $\pm$ 18 0.5 $\pm$ 16	0.3 $\pm$ 37 0.8 $\pm$ 14	0.08 $\pm$ 100 ^e 0.2 $\pm$ 39
Sept.	1.0 $\pm$ 8 10.6 $\pm$ 2 ^e	10.4 $\pm$ 2 ^e 1.0 $\pm$ 9	1.5 $\pm$ 6 ND	22.6 $\pm$ 1 ^e 0.8 $\pm$ 11	0.5 $\pm$ 20 0.8 $\pm$ 13	8.3 $\pm$ 2 ^e 0.5 $\pm$ 17
Oct.	10.3 $\pm$ 2 ^e 5.4 $\pm$ 3	5.2 $\pm$ 2 ND	0.6 $\pm$ 11 1.4 $\pm$ 7	15.3 $\pm$ 1 ^e 1.5 $\pm$ 7	24.1 $\pm$ 1 ^e 2.2 $\pm$ 5	7.8 $\pm$ 1 ^e 2.7 $\pm$ 4
Nov.	2.3 $\pm$ 4 1.2 $\pm$ 7	ND ND	2.4 $\pm$ 5 3.8 $\pm$ 3	1.9 $\pm$ 4 1.6 $\pm$ 5	1.5 $\pm$ 5 0.8 $\pm$ 9	0.8 $\pm$ 7 1.8 $\pm$ 4
Dec.	1.9 $\pm$ 4 1.6 $\pm$ 5 1.0 $\pm$ 9	ND 1.3 $\pm$ 6 51.6 $\pm$ 1 ^e	1.8 $\pm$ 5 0.5 $\pm$ 14 0.6 $\pm$ 12	3.5 $\pm$ 3 0.3 $\pm$ 25 274.0 $\pm$ 1 ^e	3.1 $\pm$ 3 0.4 $\pm$ 14 0.4 $\pm$ 19	1.3 $\pm$ 6 ND 0.8 $\pm$ 13
Annual average ^b	2.0 (2.7) ^f	1.5 ^f (4.8) ^f	1.3 ^g	0.8 ^h (13.9) ^h	0.8 ^f (1.8) ^f	0.9 ^h (1.6) ^h
% SDM	65 (96)	83 (233)	171	368 (400)	100 (278)	579 (128)
% DCG ^c	1.0 $\times$ 10 ⁻²	8 $\times$ 10 ⁻³	6 $\times$ 10 ⁻³	4 $\times$ 10 ⁻³	4 $\times$ 10 ⁻³	4 $\times$ 10 ⁻³
Effective dose equivalent (mrem)	2 $\times$ 10 ⁻²	1 $\times$ 10 ⁻²	1 $\times$ 10 ⁻²	6 $\times$ 10 ⁻³	6 $\times$ 10 ⁻³	7 $\times$ 10 ⁻³

^a See Fig. 7.^b Livermore Valley overall annual average = 1.2 $\pm$ 39 (4.4 $\pm$ 111)^f.^c DCG = 2 $\times$ 10⁻⁷ $\mu\text{Ci/mL}$.^d No data. See "Deviations from the Monitoring Program" section.^e Outliers^f Values with outliers included are in parentheses.^g Data not distributed normally. Used log transformation. See Appendix D.

Table A-11. Beryllium on air filters—LLNL perimeter.

Month	Location ^a					
	1	2	12 (10 ^c $\mu\text{g}/\text{m}^3$)	13	14	15
Jan.	1.9	10.0	9.1	5.9	27.0 ^b	29.0 ^b
Feb.	1.9	2.0	3.3	0.3	0.9	2.0
Mar.	3.3	7.6	3.7	3.8	2.0	4.9
Apr.	4.3	3.6	2.5	4.9	1.7	2.0
May	6.3	6.3	4.5	0.8	3.6	6.1
June	6.4	5.7	6.2	8.0	5.0	3.0
July	11.3	7.0	5.4	5.4	11.0	13.4
Aug.	6.5	5.0	4.5	9.4	4.4	4.3
Sept.	2.5	3.6	1.2	5.7	5.7	1.2
Oct.	5.6	5.0	5.4	8.2	3.9	6.4
Nov.	3.3	3.2	2.7	3.2	2.7	3.8
Dec.	3.0	2.8	4.3	8.4	3.4	3.2
Annual average ^c	4.7	5.2	4.4	3.9	3.3 ^d (4.0) ^b	3.7 ^d (4.3) ^b
% SDM	58	45	46	76	56 (64)	50 (55)
% CG ^e	0.5	0.4	0.4	0.4	0.3 (0.4)	0.4 (0.4)

^a See Fig. 5.^b Outlier. Values with outliers included are shown in parentheses.^c LLNL perimeter overall annual average = 4.4 ± 11 .^d Log transformation used. See Appendix D.^e Ambient concentration guide set by the Bay Area Air Quality Management District is $0.01 \mu\text{g}/\text{m}^3$.

Table A-12. Beryllium on air filters—Site 300.

Month	Location ^a									
	1	2	3	4	5 (10 ^c $\mu\text{g}/\text{m}^3$)	6 ^b	7	8	9	10
Jan.	0.5	0.7	0.7	2.5	1.0	4.9	— ^c	0.5	1.9	0.6
Feb.	0.4	0.2	0.6	0.4	0.5	1.7	— ^c	0.3	0.2	0.2
Mar.	1.0	4.4	4.6	0.8	2.1	3.4	— ^c	2.1	0.3	0.6
Apr.	2.0	1.0	1.4	1.6	2.6	3.4	— ^c	1.3	1.1	1.9
May	3.4	2.6	3.2	4.1	1.4	9.3	11.8	5.0	1.4	3.4
June	2.3	1.6	1.7	4.0	3.3	7.8	1.8	1.6	1.7	5.3
July	5.7	6.0	5.2	6.0	8.7	5.9	7.1	7.0	5.6	6.6
Aug.	2.3	1.9	1.6	2.5	2.0	4.8	4.4	2.5	1.4	3.3
Sept.	1.8	1.2	1.2	2.0	2.3	2.4	4.6	1.6	0.6	2.4
Oct.	3.5	2.7	2.4	2.4	3.4	7.8	6.4	2.7	2.4	3.6
Nov.	1.1	1.1	0.3	1.2	1.4	0.3	0.7	1.0	0.8	1.8
Dec.	0.7	1.1	0.5	1.6	2.7	2.4	3.8	1.1	1.0	0.9
Average ^d	2.1	2.0	2.0	2.4	2.1 ^f	3.4 ^f	5.1	2.4	1.6	2.7
% SDM	75	82	82	66	97	76	68	83	88	72
% CG ^e	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.2	0.2	0.3

^a See Fig. 6.^b Location 6 is in city of Tracy.^c No data available. See "Changes to the Monitoring Program" section.^d Site 300 overall annual average = $2.6 \pm 39\%$.^e Ambient concentration guide set by the Bay Area Air Quality Management District is $0.01 \mu\text{g}/\text{m}^3$.^f Log transformation used. See Appendix D.

Table A-13. Various radionuclides in soil—Livermore Valley (sampling depth = 0–5 cm).

Location ^a	²³⁹ Pu [10 ⁻⁹ μCi/dry g ± 2σ (%)]	⁴⁰ K [10 ⁻⁶ μCi/dry g ± 2σ (%)]	¹³⁷ Cs [10 ⁻⁶ μCi/dry g ± 2σ (%)]	²³² Th [μg/dry g ± 2σ (%)]	²³⁸ U [μg/dry g ± 2σ (%)]
1042 ^b	18.0 ± 5	8.6 ± 4	0.17 ± 17	4.7	3.0 ± 22
1043 ^b	26.4 ± 5	14.4 ± 3	0.24 ± 5	6.7	2.7 ± 48
1044	11.8 ± 5	9.2 ± 5	0.38 ± 4	5.1	2.9 ± 19
1045	7.6 ± 5	13.1 ± 3	0.25 ± 5	ND ^d	2.0 ± 52
1046	0.8 ± 14	13.2 ± 4	0.02 ± 46	6.8	4.6 ± 11
1047	2.2 ± 11	13.0 ± 5	0.08 ± 10	5.6	2.1 ± 42
1048	4.0 ± 8	14.9 ± 4	0.20 ± 6	ND	5.4 ± 10
1049	2.2 ± 10	17.8 ± 6	0.10 ± 8	ND	5.9 ± 12
1050	3.0 ± 9	11.8 ± 4	0.09 ± 11	5.7	2.6 ± 46
1051	3.2 ± 8	11.8 ± 4	0.18 ± 6	ND	3.7 ± 18
1052	6.2 ± 7	9.0 ± 4	0.32 ± 4	ND	2.5 ± 50
1053	0.7 ± 16	11.9 ± 8	≤0.02	3.9	2.0 ± 60
1054	3.2 ± 9	12.9 ± 4	0.15 ± 8	ND	5.7 ± 12
1055 ^c	1.6 ± 12	10.7 ± 6	0.07 ± 12	ND	3.2 ± 48
1056 ^c	0.9 ± 15	10.1 ± 4	0.05 ± 20	ND	3.7 ± 26
1057	4.2 ± 8	13.6 ± 4	0.20 ± 6	ND	3.4 ± 20
1058	7.3 ± 6	14.8 ± 4	0.30 ± 5	7.3	5.9 ± 10
1059	3.6 ± 7	10.3 ± 4	0.16 ± 8	ND	2.1 ± 54
1060	3.7 ± 8	13.0 ± 3	0.25 ± 4	6.7	4.6 ± 9
1061	0.7 ± 14	12.8 ± 2	0.06 ± 18	ND	4.4 ± 12
1062	0.9 ± 18	11.1 ± 4	0.06 ± 18	9.0	5.0 ± 12
1063	2.7 ± 7	8.0 ± 4	0.14 ± 4	ND	2.5 ± 30
1064	3.2 ± 11	7.3 ± 4	0.15 ± 6	ND	4.4 ± 10

^a See Fig. 8 for sample locations.^b Samples 1042 and 1043 are duplicates.^c Samples 1055 and 1056 are duplicates.^d ND = Not detected.

Table A-14. Plutonium, cesium and uranium in soil—Site 300 (sampling depth = 0–5 cm).

Location ^a	²³⁹ Pu [10 ⁻⁹ μCi/dry g ± 2σ (%)]	¹³⁷ Cs [10 ⁻⁶ μCi/dry g ± 2σ (%)]	²³⁸ U [μg/dry g ± 2σ (%)]
1065	0.01 ± 17	0.05 ± 16	6.3 ± 40
1066	0.8 ± 17	0.04 ± 18	12.2 ± 6
1067	7.3 ± 7	0.31 ± 4	2.5 ± 48
1068	4.0 ± 9	0.20 ± 4	14.1 ± 4
1069	2.4 ± 11	0.13 ± 8	6.5 ± 10
1070	7.0 ± 6	0.34 ± 4	4.0 ± 70
1071 ^b	3.8 ± 8	0.26 ± 4	156.3 ± 4
1072 ^b	4.2 ± 10	0.24 ± 6	115.5 ± 6
1073	8.4 ± 7	0.35 ± 4	3.4 ± 44
1074	0.6 ± 13	0.04 ± 24	8.7 ± 42
1075	2.4 ± 9	0.11 ± 8	≤3.6
1076	0.5 ± 16	0.03 ± 26	4.6 ± 10
1077	0.5 ± 18	0.02 ± 30	2.3 ± 52
1078	6.4 ± 8	0.36 ± 4	2.5 ± 38

^a See Fig. 9 for location of samples.^b Samples 1071 and 1072 are duplicates.

Table A-15. Various radionuclides in effluents—LLNL and Livermore River Reclamation Plant (LWRP).

Month	HTO ^a		¹³⁷ Cs		²³⁹ Pu		²³⁸ Pu ^c
	[10 ⁻⁶ μ Ci/mL $\pm$ 2 σ (%)]		[10 ⁻¹¹ μ Ci/mL $\pm$ 2 σ (%)]		[10 ⁻¹² μ Ci/mL $\pm$ 2 σ (%)]		[10 ⁻⁸ μ Ci/g $\pm$ 2 σ (1%)]
	LLNL	LWRP	LLNL	LWRP	LLNL	LWRP	LWRP Sludge
Jan.	2.0 $\pm$ 36	0.5 $\pm$ 88	5.9 $\pm$ 42	$\leq$ 1.0	9.88 $\pm$ 13	0.21 $\pm$ 66	
Feb.	2.8 $\pm$ 43	0.4 $\pm$ 89	8.1 $\pm$ 30	$\leq$ 0.8	3.98 $\pm$ 15	0.28 $\pm$ 56	
Mar.	1.0 $\pm$ 52	0.4 $\pm$ 90	$\leq$ 4.6	$\leq$ 1.2	3.05 $\pm$ 19	0.14 $\pm$ 89	2.46 $\pm$ 6
Apr.	5.4 $\pm$ 46	0.6 $\pm$ 76	$\leq$ 1.6	$\leq$ 1.8	0.12 $\pm$ 86 ^b	$\leq$ 0.28	
May	3.4 $\pm$ 44	0.8 $\pm$ 71	9.2 $\pm$ 26	$\leq$ 1.4	2.99 $\pm$ 44	$\leq$ 0.30	
June	1.7 $\pm$ 45	0.4 $\pm$ 83	17.0 $\pm$ 28	$\leq$ 1.6	18.83 $\pm$ 7 ^b	0.25 $\pm$ 56	4.89 $\pm$ 7
July	3.1 $\pm$ 34	0.6 $\pm$ 78	14.0 $\pm$ 38	3.3 $\pm$ 76	3.21 $\pm$ 20	0.16 $\pm$ 77	
Aug.	3.2 $\pm$ 34	0.5 $\pm$ 77	10.2 $\pm$ 32	$\leq$ 1.2	7.16 $\pm$ 16	0.19 $\pm$ 80	
Sept.	1.6 $\pm$ 62	0.5 $\pm$ 77	6.8 $\pm$ 40	$\leq$ 1.3	6.61 $\pm$ 13	0.18 $\pm$ 73	4.41 $\pm$ 5
Oct.	8.9 $\pm$ 34	0.6 $\pm$ 47	6.6 $\pm$ 32	3.5 $\pm$ 74	5.59 $\pm$ 16	$\leq$ 0.22	
Nov.	5.2 $\pm$ 5	0.6 $\pm$ 6	4.6 $\pm$ 42	$\leq$ 1.3	3.11 $\pm$ 17	0.15 $\pm$ 88	
Dec.	2.8 $\pm$ 5	0.5 $\pm$ 198	103 $\pm$ 6 ^b	7.9 $\pm$ 44	295 $\pm$ 5 ^b	2.00 $\pm$ 28 ^b	8.59 $\pm$ 6
Annual average	3.4	0.5 ^f	8.0 (16.0) ^d	4.4 ^c	5.06 (29.96) ^c	0.20 (0.40) ^c	5.09
% SDM	6.4	32	55 (174) ^c	2.2	48 (279) ^c	25 (152)	50
DIC G (μ Ci/mL)	2 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	3 $\times$ 10 ⁻⁶	3 $\times$ 10 ⁻⁶	3 $\times$ 10 ⁻⁶	3 $\times$ 10 ⁻⁶	None
% DCG	0.17	2 $\times$ 10 ⁻²	2.7 $\times$ 10 ⁻³	1.5 $\times$ 10 ⁻³	1.7 $\times$ 10 ⁻⁴	6.7 $\times$ 10 ⁻⁶	—
			(5.3 $\times$ 10 ⁻³) ^c		(1.0 $\times$ 10 ⁻³) ^c	(1.3 $\times$ 10 ⁻⁵) ^c	

^a Monthly average value.^b Outlier.^c Value with outliers included is presented in parentheses.^d Median value $\pm$ median absolute deviation.^e Quarterly data.^f Log transformation used. See Appendix D.

Table A-16. Various elements in LLNL liquid effluent.

Month	Cd	Cr	Cu	Fe	Pb	Ni	Ag	Zn	Al	Be
(mg/liter)										
Jan.	0.0014	0.043	0.230	1.10	0.033	0.025	0.005	0.31	0.56	0.0002
Feb.	0.0019	0.053	0.089	1.50	0.014	0.015	0.006	0.18	0.05	0.0002
Mar.	0.0020	0.040	0.080	1.00	0.013	0.015	0.005	0.18	0.48	0.0002
Apr.	0.0100	0.050	0.090	0.86	0.010	0.08	0.010	0.18	0.37	0.0010
May ^a	0.0030	0.058	0.078	0.68	0.015	0.015	0.003	0.21	0.23	0.0002
June ^a	0.0020	0.020	0.070	0.52	0.012	0.014	0.007	0.24	0.12	0.0002
July ^a	0.0018	0.035	0.120	0.47	0.014	0.016	0.009	0.18	0.16	0.0006
Aug.	0.0022	0.070	0.200	0.73	0.015	0.015	0.110 ^b	0.16	0.24	0.0004
Sept.	0.0020	0.090	0.110	1.30	0.015	0.053	0.001	0.25	0.26	0.0003
Oct.	0.0040	0.072	0.140	0.75	0.017	0.011	0.073 ^b	0.20	0.42	≤ 0.03
Nov.	0.0020	0.043	0.065	0.94	0.077	0.012	0.002	0.12	0.24	≤ 0.03
Dec.	0.0021	0.042	0.100	0.75	0.010	0.020	0.008	0.23	0.21	0.0008
Average	0.0024 ^c	0.051	0.105 ^c	0.69 ^c	0.014 ^c	0.018	0.006 (0.020) ^d	0.20	23.5 ^c	0.0003 ^c
% SDM	9	37	17	29	87	67	54 (173) ^d	24	21	53

^a From May 21 to July 14, 1986, the Livermore Site received its water from Zone 7 instead of the normal Hetch Hetchy water.

^b Outliers.

^c Data not distributed normally. Log transformation used. See Appendix D.

^d Values with outliers included.

Table A-17. Physical and chemical examinations of LLNL liquid effluents.

	Jan.-Mar.	Apr.-June	July-Sept. ^c	Oct.-Dec.	Average	% SDM
	(mg/liter)					
BOD	80	100	20	116	79	53
COD	131	203	28	195	139	58
Oil and grease	15	6	≤ 5	16	12	45
Phenolics	≤ 0.05	0.18	0.13	0.09	0.13	34
Settleable solids (mL/liter/h)	5.0	2.2	≤ 0.1	1.2	2.1	99
TICH ^a	ND ^b	ND	ND	ND	—	—
Total dissolved solids	207	269	370	180	256	33
Total organic carbon	63	66	11	63	51	52
Total solids	306	300	380	1000	329	14
Total suspended solids	45	19	16	29	27	48
Volatile solids (% total solids)	4.6	25	20	74	31	97
Ammonia nitrogen (as N)	26	38	11	47	31	51
Chloride	35	35	70	3	36	76
Cyanide	≤ 0.02	≤ 0.02	≤ 0.02	≤ 0.02	≤ 0.02	0
Nitrate nitrogen (as N)	≤ 0.10	≤ 0.10	≤ 0.17	≤ 0.10	≤ 0.12	30
Nitrite nitrogen (as NO ₂)	≤ 0.03	12	0.10	0.03	4.04	170
Sulfate	61	88	98	62	77	24
Total alkalinity (as CaCO ₃)	134	126	144	150	138	8
Total Kjeldahl nitrogen (as N)	36	38	15	36	31	35
Total phosphorous (as P)	4.1	4.1	5.0	14	6.8	71
Arsenic	≤ 0.007	0.004	0.001	≤ 0.001	≤ 0.003	88
Boron	0.40	0.52	0.40	0.37	0.42	16
Calcium	11	14	23	6.2	14	52
Chromium	0.02	0.05	0.02	0.067	0.04	59
Copper	0.04	0.07	0.07	0.09	0.07	30
Magnesium	1.3	1.5	11	1.4	3.8	126
Mercury	0.0009	0.0011	0.0005	0.0013	0.0010	36
Nickel	≤ 0.05	≤ 0.05	≤ 0.05	≤ 0.008	≤ 0.04	53
Potassium	21	16	9.8	18	16	29
Selenium	0.007	≤ 0.001	≤ 0.001	0.001	0.004	106
Sodium	67	39	81	30	54	44
Sodium (as % cations)	70	30	53	24	44	48
Zinc	0.08	0.16	0.16	0.16	0.14	28

^a Total identifiable chlorinated hydrocarbons.^b None detected.^c Maintenance at the Mocho pumping station during this quarter caused the Livermore site to receive its water from Zone 7 instead of the normal Hetch Hetchy water. Consequently, the liquid effluent data for this quarter reflect the change in water supply.

The following compounds would have been reported had they appeared at or above their respective detection limits as indicated below:

Organochlorine pesticides	μg/L		
Aldrin	0.05	DDD (mixed isomers)	0.05
Chlordane	0.3	Heptachlor	0.05
Endrin	0.1	Heptachlor Epoxide	0.05
Dieldrin	0.05	Methoxychlor	0.2
BHC (mixed isomers)	0.05		
DDT (mixed isomers)	0.1	Polychlorinated biphenyls	
DDE (mixed isomers)	0.05	Aroclors 1016-1262	0.3

Table A-18. Gross alpha activity in water—Livermore Valley.

Location ^a	Number of samples	Maximum	Minimum	Average	% SDM
		[10 ⁻⁹ μ Ci/mL $\pm$ 2 σ (%)]			
11	4	≤ 3.1	≤ 3.1	≤ 3.1	0
15	4	≤ 3.1	≤ 3.1	≤ 3.1	0
16	4	≤ 6.2	≤ 3.1	≤ 4.6	35
19	4	≤ 3.1	≤ 3.1	≤ 3.1	0
20	4	≤ 3.1	≤ 3.1	≤ 3.1	0
23	4	≤ 3.1	≤ 3.1	≤ 3.1	0
24	4	≤ 3.1	≤ 3.1	≤ 3.1	0
26	4	≤ 3.1	≤ 3.1	≤ 3.1	0
29	4	≤ 3.1	≤ 3.1	≤ 3.1	0
31	4	≤ 3.1	≤ 3.1	≤ 3.1	0
34	4	≤ 3.1	≤ 3.1	≤ 3.1	0
37	4	≤ 3.1	≤ 3.1	≤ 3.1	0

^a See Fig. 10 for sample locations.

Table A-19. Gross alpha activity in water—Site 300.

Location ^a	Number of samples	Maximum	Minimum	Average	% SDM
		[10 ⁻⁴ μ Ci/mL $\pm$ 2 σ (%)]			
3	3	10.0 $\pm$ 69	$\leq$ 3.1	4.8	72
4	3	27.0 $\pm$ 3.7	23.0 $\pm$ 42	24.7	8
5	3	$\leq$ 3.1	$\leq$ 3.1	$\leq$ 3.1	0
6	4	$\leq$ 3.1	$\leq$ 3.1	$\leq$ 3.1	0
7	2	$\leq$ 3.1	$\leq$ 3.1	$\leq$ 3.1	0
14	4	$\leq$ 3.1	$\leq$ 3.1	$\leq$ 3.1	0
21	4	19 $\pm$ 45	$\leq$ 3.1	9.3	77
22	2	$\leq$ 3.1	$\leq$ 3.1	$\leq$ 3.1	0
23	4	$\leq$ 3.1	$\leq$ 3.1	$\leq$ 3.1	0

^a See Fig. 11 for sample locations.

Table A-20. Gross beta activity in water—Livermore Valley.

Location ^a	Number of samples	Maximum	Minimum	Average	% SDM
		[10 ⁻⁹ μCi/mL ± 2σ (%)]			
11	4	≤10.0	≤10.0	≤10.0	0
15	4	≤10.0	≤10.0	≤10.0	0
16	4	≤10.0	≤10.0	≤10.0	0
19	4	≤10.0	≤10.0	≤10.0	0
20	4	≤10.0	≤10.0	≤10.0	0
23	4	≤10.0	≤10.0	≤10.0	0
24	4	≤10.0	≤10.0	≤10.0	0
26	4	≤10.0	≤10.0	≤10.0	0
29	4	≤10.0	≤10.0	≤10.0	0
31	4	≤10.0	≤10.0	≤10.0	0
33	4	≤10.0	≤10.0	≤10.0	0
37	4	≤10.0	≤10.0	≤10.0	0

^a See Fig. 10 for sample locations.

Table A-21. Gross beta activity in water—Site 300.

Location ^a	Number of samples	Maximum	Minimum	Average	% SDM
		[10 ⁻⁹ μCi/mL ± 2σ (%)]			
3	2	≤ 10.0	≤ 10.0	≤ 10.0	0
4	3	15 ± 65	14 ± 63	14	4.9
5	2	≤ 10.0	≤ 10.0	≤ 10.0	0
6	4	13.0 ± 67	≤ 10.0	11.5	18.4
7	2	≤ 10.0	≤ 10.0	≤ 10.0	0
14	4	≤ 10.0	≤ 10.0	≤ 10.0	0
21	4	36.0 ± 30	≤ 11.0	23.8	53.0
22	2	≤ 10.0	≤ 10.0	≤ 10.0	0
23	4	14.0 ± 62	≤ 10.0	11.2	16.8

^a See Fig. 11 for sample locations.

Table A-22. Radionuclides in stormwater runoff.

	Gross Alpha 10^{-9} $\mu\text{Ci/mL}$	Gross Beta 10^{-8} $\mu\text{Ci/mL} \pm 2\sigma$ (%)	Tritium 10^{-7} $\mu\text{Ci/mL} \pm 2\sigma$ (%)
Influent ^a LLNL	≤ 6.7	2.7 ± 62	≤ 4.2
Influent SNLL	≤ 7.7	3.4 ± 52	≤ 3.0
NW Effluent	≤ 6.7	3.2 ± 54	≤ 7.5
LLNL Lake	≤ 6.7	≤ 2.0	17.5 ± 31

^a See Fig. 13.

Table A-23. Tritium (HTO) in water—Livermore Valley.

	Location ^a							
	11 ^d	15 ^e	16 ^d	19 ^f	20 ^f	23 ^d	24 ^d	26 ^d
	[10 ⁻⁷ μ Ci/mL $\pm$ 2 σ (%)]							
First quarter	1.1 $\pm$ 7	0.6 $\pm$ 11	3.3 $\pm$ 4	0.7 $\pm$ 10 0.7 $\pm$ 10	31.1 $\pm$ 2 5.3 $\pm$ 3 12.3 $\pm$ 2	0.6 $\pm$ 10	1.0 $\pm$ 8	1.9 $\pm$ 5
Second quarter	0.4 $\pm$ 13	0.7 $\pm$ 10	2.4 $\pm$ 4	0.5 $\pm$ 11	8.7 $\pm$ 3	0.4 $\pm$ 15 0.4 $\pm$ 14	1.1 $\pm$ 7	1.4 $\pm$ 6
Third quarter	0.4 $\pm$ 17	0.3 $\pm$ 18	1.1 $\pm$ 7	0.5 $\pm$ 14	53.0 $\pm$ 3	0.3 $\pm$ 21	0.4 $\pm$ 17	1.4 $\pm$ 6 1.4 $\pm$ 6
Fourth quarter	0.7 $\pm$ 12	0.4 $\pm$ 19	1.7 $\pm$ 6	0.4 $\pm$ 20	40.4 $\pm$ 2	0.5 $\pm$ 18	0.4 $\pm$ 19	1.5 $\pm$ 7
Annual Average	0.6	0.5	2.1	0.6	25.3	0.4	0.7	1.5
% SDM	51	36	44	24	76	26	52	14
% DCG ^b	3 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	1 $\times$ 10 ⁻²	3 $\times$ 10 ⁻³	1 $\times$ 10 ⁻¹	2 $\times$ 10 ⁻³	4 $\times$ 10 ⁻³	8 $\times$ 10 ⁻³
Effective Dose Equivalent (mrem)	3 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	1 $\times$ 10 ⁻²	3 $\times$ 10 ⁻³	1 $\times$ 10 ⁻¹	2 $\times$ 10 ⁻³	3 $\times$ 10 ⁻³	7 $\times$ 10 ⁻³

Table A-23. (Continued).

	Location ^a						
	29 ^d	30 ^g	31 ⁱ	33 ^e	34 ^e	37 ^f	43 ^h
	[10 ⁻⁷ μ Ci/mL $\pm$ 2 σ (%)]						
First quarter	0.5 $\pm$ 15	0.5 $\pm$ 14	0.3 $\pm$ 21	ND ^c	0.5 $\pm$ 13	0.6 $\pm$ 10	1.9 $\pm$ 5
Second quarter	0.4 $\pm$ 16	0.4 $\pm$ 18	0.4 $\pm$ 16	ND	1.0 $\pm$ 7	0.4 $\pm$ 17	0.5 $\pm$ 12
Third quarter	0.3 $\pm$ 19	0.3 $\pm$ 19	0.3 $\pm$ 23	ND	0.4 $\pm$ 13	0.3 $\pm$ 18	2.1 $\pm$ 5 3.2 $\pm$ 4 3.9 $\pm$ 4
Fourth quarter	0.6 $\pm$ 10 0.5 $\pm$ 13	0.4 $\pm$ 17	0.4 $\pm$ 17	ND	0.6 $\pm$ 10	0.6 $\pm$ 10	5.4 $\pm$ 3 5.4 $\pm$ 3 6.7 $\pm$ 3
Average	0.5	0.4	0.4	—	0.6	0.5	2.8
% SDM	25	20	16	—	42	32	60
% DCG ^b	2 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	—	3 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	1 $\times$ 10 ⁻²
Effective Dose Equivalent (mrem)	2 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	—	3 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	1 $\times$ 10 ⁻³

^a See Fig. 10 for sample locations.^b CG = 2 $\times$ 10⁻³ μ Ci/mL.^c No data. See "Deviations from the Sampling Program" section.^d Surface water.^e Well water.^f Rain water.^g Tap water-LLNL.^h LLNL swimming pool.ⁱ Tap water-Livermore locations.

Table A-24. Tritium (HTO) in water—Site 300.

	Location ^a												
	1 ^e	2 ^e	3 ^e	4 ^e	5 ^e	6 ^e	7 ^e	14 ^d	20 ^f	21 ^d	22 ^e	23 ^e	24 ^e
	[10 ⁻² $\mu\text{Ci/mL} \pm 2\sigma$ (%)]												
First quarter	8.2 $\pm$ 3	0.7 $\pm$ 10	0.4 $\pm$ 18	0.2 $\pm$ 37	0.5 $\pm$ 14	0.06 $\pm$ 85 0.2 $\pm$ 35	0.4 $\pm$ 16	0.7 $\pm$ 10	1.6 $\pm$ 6 0.3 $\pm$ 20	0.1 $\pm$ 40	0.4 $\pm$ 100	0.3 $\pm$ 27	0.1 $\pm$ 45
Second quarter	8.4 $\pm$ 3	0.4 $\pm$ 16	0.08 $\pm$ 100	0.03 $\pm$ 100	0.04 $\pm$ 91	0.1 $\pm$ 36	0.08 $\pm$ 61	0.5 $\pm$ 13	0.3 $\pm$ 18 0.7 $\pm$ 10	0.2 $\pm$ 33 0.2 $\pm$ 34	0.2 $\pm$ 100	0.05 $\pm$ 92	0.02 $\pm$ 100
Third quarter	6.7 $\pm$ 29 9.7 $\pm$ 3 9.7 $\pm$ 3	0.6 $\pm$ 11	0.2 $\pm$ 24	0.3 $\pm$ 19	0.1 $\pm$ 36	0.06 $\pm$ 100 0.09 $\pm$ 56	ND ^c	0.5 $\pm$ 14	0.4 $\pm$ 40	0.2 $\pm$ 34	0.002 $\pm$ 100	0.06 $\pm$ 76	0.1 $\pm$ 41
Fourth quarter	10.7 $\pm$ 3	0.7 $\pm$ 10	0.4 $\pm$ 16 0.4 $\pm$ 14	0.3 $\pm$ 15	0.4 $\pm$ 14	0.2 $\pm$ 24	ND	0.6 $\pm$ 11	0.5 $\pm$ 13	0.2 $\pm$ 24	0.1 $\pm$ 100	0.2 $\pm$ 34	0.1 $\pm$ 58
Average	8.9	0.6	0.3	0.2	0.3	0.1	0.2	0.6	0.6	0.2	0.2	0.2	0.08
σ_{SDM}	16	24	50	61	86	55	94	17	78	25	97	78	50
σ_{DCG}^b	4 $\times$ 10 ⁻²	3 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	1 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	5 $\times$ 10 ⁻⁴	1 $\times$ 10 ⁻³	3 $\times$ 10 ⁻³	3 $\times$ 10 ⁻³	1 $\times$ 10 ⁻³	1 $\times$ 10 ⁻³	1 $\times$ 10 ⁻³	4 $\times$ 10 ⁻⁴
Effective Dose Equivalent (mrem)	4 $\times$ 10 ⁻²	3 $\times$ 10 ⁻³	1 $\times$ 10 ⁻³	9 $\times$ 10 ⁻⁴	1 $\times$ 10 ⁻³	5 $\times$ 10 ⁻⁴	9 $\times$ 10 ⁻⁴	3 $\times$ 10 ⁻³	3 $\times$ 10 ⁻³	9 $\times$ 10 ⁻⁴	9 $\times$ 10 ⁻⁴	9 $\times$ 10 ⁻⁴	4 $\times$ 10 ⁻⁴

^a See Fig. 11.^b DCG = 2 $\times$ 10⁻³ $\mu\text{Ci/mL}$.^c No data. See "Deviations from the Monitoring Program" section.^d Surface water^e Well water^f Rain water

Table A-25a. Water quality parameters for Site 300 monitoring wells.

Parameters Analyzed			
Physical (Pits 1,7,6, HE) Detection Limit (mg/L)		Title 22 Organics (Pits 1,6) Detection Limit (µg/L)	
Arsenic		2,4,5-TP (silvex)	0.1
Barium	0.1	2,4-D	0.5
Cadmium	0.01	Endrin	0.1
Chromium	0.02	Lindane	0.05
Lead	0.001	Methoxychlor	0.3
Mercury	0.0001	Toxaphene	1.0
Selenium	0.001	Purgable priority, pollutants	
Silver	0.01	1,1,1-trichloroethane	1.0
Iron	0.03	Acrolein	10
Manganese	0.01	Acrylonitrile	10
Sodium		Chloroform	1.0
Beryllium	0.01	Other	1.0
Nickel	0.05	Xylene	
Vanadium	0.2		
Filterable residue (TDS)		B/N,A Ext. Priority Pollutants (pit 1,6) Detection Limit (µg/L)	
Non-filterable		2,4-Dinitrophenol	25
residue (TSS)	1.0	2-Methyl-4,6-Dizotrophenol	50
Low level phenolics	0.01	3,3'-Dichlorobenzidene	40
Total kjeldahl nitrogen	0.35	4-Nitrophenol	100
Ammonia nitrogen (as N)	0.1	Bis(2-ethylhexyl) phthalate	40
Nitrate (as N)	0.03	Benzidene	50
Nitrate (as NO ₃)		Dibutylphthalate	25
Flouride		Dimethylphthalate	40
Chloride		N-Nitrosodi-N-Propylamine	80
Sulfate		Other	1
Carbonate	1.0	Phenol	
Thallium	0.1		
Zinc	0.07	C3-benzene isomers	
Molybdenum	0.1	Ethylhexanol	
Antimony	0.1	Hexahydroazepineone	
Cobalt	0.05	Methylhydroxypentanone	
Copper	0.02		
Conductivity µmhos/cm			
Phenolics	0.05		
EPA Method 601 (Pit 7) Detection Limit (µg/L)		Other Organics (Pits 1,6, HE) Detection Limit (mg/L)	
1,1,2,2-Trichloroethane	0.5	TOC	4
1,1,2-Trichloroethane	0.5	TOX	0.05
1,1-Dichloroethane	0.5	Explosives	30
1,1-Dichloroethene	0.5		
1,2-Dichlorobenzene	0.5		
1,2-Dichloroethane	0.5	Radiological (Pits 1,6,7, HE) Detection Limit (pCi/L)	
Trans-1,2-Dichloroethene	0.5	Gross Alpha	5.0
1,2-Dichloropropane	0.5	Gross Beta	4.0
1,3-Dichlorobenzene	0.5	Tritium	1000
1,4-Dichlorobenzene	0.5	²³⁸ U	0.1
2-Chloroethylvinyl ether	0.5	²³⁵ U	0.1
Bromodichloromethane	0.5	²³⁴ U	0.1
Bromomethane	0.5	²³⁸ Ra	0.1
Bromoform	0.5		
Chlorobenzene	0.5		
Carbon Tetrachloride	0.5		
Chloroethane	0.5		
Chloroform	0.5		
Chloromethane	0.5		
Dibromochloromethane	0.5		
Dichlorofluoromethane	0.5		
Methylene Chloride	0.5		

Table A-25a. Continued.

Parameters Analyzed	
EPA Method 601 (Pit 7) Detection Limit (µg/L) (continued)	
Tetrachloroethene	0.5
1,1,1 Trichloroethane	0.5
Trichloroethylene	0.5
Trichlorofluoromethane	0.5
Vinyl Chloride	0.5
Cis-1,3-Dichloropropene	0.5
Trans-1,3-Dichloropropene	0.5

Table A-25b. Pit 1 wells.

Positively detected parameters	Well							
	K1-1	K1-2	K1-3	K1-4	K1-5	K1-7	K1-8	K1-9
<u>Physical (mg/L)</u>								
Arsenic	0.010	0.012	0.010	0.011	0.012	0.010	0.012	0.012
Lead	0.017	0.002	0.01	0.002	0.001	0.004	0.002	0.002
Iron	0.017	0.03	0.03	0.03	0.24	0.07	0.14	0.11
Sodium	34	36	34	39	38	41	39	38
Filterable residue (TDS)	370	365	344	367	342	372	349	344
Non-filterable residue (TSS)	156	7	1	<1	8	17	43	9
Total kjeldahl nitrogen	0.17	<0.18	<0.19	<0.11	0.14	0.26	0.18	0.16
Nitrite (as NO ₂)	9.8	6.6	7.3	4.3	9.1	10.1	9.2	9.0
Nitrate (as N)	0.03	0.20	0.04	0.13	0.20	0.03	0.06	0.08
Fluoride	0.36	0.32	0.27	0.36	0.46	0.43	0.48	0.44
Chloride	40	40	35	37	39	45	38	39
Sulfate	39	50	37	57	40	36	40	41
Phenolics	0.07	0.07	<0.05	<0.05	0.06	0.26	<0.05	0.25
Selenium	0.003	0.003	0.002	0.002	0.001	0.002	<0.001	0.001
Chromium	<0.02	<0.02	<0.02	<0.02	<0.02	0.03	0.02	<0.02
Mercury	0.0023	0.0003	0.0001	0.0003	0.0006	<0.0001	<0.0001	0.0005
Conductivity µmho/cm	534	522	483	515	496	540	500	501
<u>Other organics (mg/L)</u>								
TOC	6	<4	1	<5	3	6	3	4
TOX	<0.05	<0.05	<0.05	<0.05	<0.31	0.24	<0.05	<0.05
<u>Title 22 organics</u>								
Xylene (µg/L)	5	<1	<1	<1	<1	<1	<1	9
<u>B/N/A ext. priority pollutants (µg/L)</u>								
Phenol	18	—	—	—	5	7	3	4
C-3 benzene	40	—	—	—	—	—	—	—
Ethylhexanol	10	—	—	—	—	—	—	—
Hexahydroazepineone	10	—	—	—	—	—	—	—
Methylhydroxypentanone	—	—	—	—	6	5	—	—
<u>Radiological (pCi/L)</u>								
Gross alpha	4	<5	<5	<5	<5	<5	<5	<5
Gross beta	5	9	4	4	5	5	5	4
²³⁸ U	0.8	0.7	0.5	0.8	0.6	0.7	<0.6	0.6
²³⁴ U	1.9	1.3	1.1	1.4	1.1	1.4	<1.0	1.2
²³⁸ Pu	0.4	<0.1	<0.1	10.9	0.2	0.2	<0.1	1.3
³ H	≤1000	≤1000	≤1000	≤1000	≤1000	≤1000	≤1000	≤1000

Table A-25c. Pit 7 wells.

Positively detected parameters	Well							
	K7-1	K7-3	K7-5	K7-6	NC7-1	NC7-25	NC7-26	NC7-47
<u>Physical (mg/L)</u>								
Lead	0.060	0.004	< 0.001	< 0.005	0.074	0.008	0.170	< 0.001
<u>EPA method 601 (µg/L)</u>								
1,1 Dichloroethene	2.4	1.9	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Trichloroethylene	3.6	5.6	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
1,1,1-Trichloroethane	1.4	1.1	< 0.05	2.6	< 0.05	< 0.05	< 0.05	< 0.05
<u>Radiological (pCi/L)</u>								
Gross alpha	< 5	< 5	< 5	< 5	—	9	< 5	< 5
Gross beta	10	6	7	4	—	12	< 4	6
Tritium	27,000	109,000	< 1000	< 1000	6000	245,000	4000	< 1000

Table A-25d. Pit 6 wells.

Positively detected parameters	Well					
	K6-1	K6-3	K6-4	EP6-7	EP6-8	EP6-9
<u>Physical (mg/L)</u>						
Arsenic	0.062	0.016	0.014	0.015	0.012	0.010
Chloride	91	95	97	93	98	126
Filterable residue (TDS)	644	717	656	716	728	740
Flouride	0.36	0.42	0.38	0.42	0.34	0.37
Iron	0.07	0.04	< 0.03	< 0.03	< 0.03	< 0.03
Manganese	0.08	0.07	< 0.01	0.13	0.02	< 0.01
Mercury	0.0001	0.0006	< 0.0001	0.0002	0.0001	0.0002
Ammonia nitrogen (as N)	< 0.1	0.20	< 0.1	0.29	< 0.1	< 0.1
Total kjeldahl nitrogen	0.21	0.28	0.12	0.43	0.19	0.19
Nitrate (as N)	0.1	< 0.1	2.4	< 0.1	1.8	1.3
Nitrite (as NO ₂)	0.03	0.06	0.03	0.03	0.03	0.03
Selenium	< 0.001	< 0.001	0.003	< 0.001	0.004	0.002
Sodium	140	123	110	133	137	137
Sulfate	283	235	172	230	191	219
Lead	< 0.001	0.004	0.001	0.007	< 0.001	< 0.001
Phenolics	0.09	< 0.05	< 0.05	< 0.05	0.07	< 0.05
Conductivity µmho/cm	1124	1018	950	1039	980	1089
<u>Other organics (mg/L)</u>						
TOC	< 5	< 5	8	< 5	< 5	< 5
TOX	0.29	0.19	0.14	0.13	0.10	0.20
<u>Radiological (pCi/L)</u>						
Gross alpha	< 5	< 5	6	< 5	< 5	< 5
Gross beta	10	9	11	8	10	11
²³⁸ U	0.4	0.2	0.4	0.2	0.5	0.9
²³⁴ U	0.6	0.3	0.7	0.3	0.6	1.0
²²⁶ Ra	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.2
³ H	≤ 1000	≤ 1000	≤ 1000	≤ 1000	≤ 1000	≤ 1000

Table A-25e. High explosive surface impoundment.

Positively detected parameters	817-1	817-2	817-3	817-4	Lower lagoon lysimeter
Physical (mg/L)					
Selenium	0.031	0.043	0.012	0.075	^a
Arsenic	0.062	0.044	0.040	0.040	^a
Nitrate (as N)	18	19	19	21	^a
Zinc	0.06	0.10	0.02	0.13	^a
Antimony	< 0.1	< 0.1	0.3	< 0.1	^a
Copper	0.03	0.02	0.04	0.05	^a
Mercury	0.0204	< 0.0001	< 0.0001	< 0.0001	^a
Molybdenum	0.1	0.1	< 0.1	< 0.1	^a
Nitrite (as NO ₂)	0.18	0.12	0.10	0.15	^a
Silver	< 0.01	0.01	< 0.01	< 0.01	^a
Conductivity μ mho/cm	1471	2641	2220	2092	^a
Other organics (mg/L)					
TOC	4	5	2	4	^a
TOX	0.26	0.28	0.29	0.23	^a
Explosives	41	< 30	< 30	< 30	20

^a Analysis not required.

Table A-26. Tritium (HTO) in groundwater—Livermore Valley.

Well Identification ^a	[10^{-7} μ Ci/mL $\pm$ 2 σ (%)] Activity	% DCG ^b
3S1E-1P2	3.6 $\pm$ 4	2 $\times$ 10 ⁻²
3S1E-1R2	0.7 $\pm$ 10	4 $\times$ 10 ⁻³
3S1E-2R1	2.3 $\pm$ 5	1 $\times$ 10 ⁻²
3S1E-9M3	1.3 $\pm$ 7	6 $\times$ 10 ⁻³
3S1E-11B1	7.8 $\pm$ 3	4 $\times$ 10 ⁻²
3S1E-12A2	1.3 $\pm$ 6	6 $\times$ 10 ⁻³
3S1E-12G1	3.3 $\pm$ 4	2 $\times$ 10 ⁻²
3S1E-12D2	5.7 $\pm$ 3	3 $\times$ 10 ⁻²
3S1E-16L7	0.4 $\pm$ 15	2 $\times$ 10 ⁻³
3S1E-17D2	0.5 $\pm$ 14	2 $\times$ 10 ⁻³
3S1E-18A5	0.3 $\pm$ 21	2 $\times$ 10 ⁻³
3S2E-7C2	1.5 $\pm$ 6	8 $\times$ 10 ⁻³
3S2E-9Q1	0.4 $\pm$ 15	2 $\times$ 10 ⁻³
3S2E-15H7	0.3 $\pm$ 19	2 $\times$ 10 ⁻³

^a See Fig. 12 for sample locations.

^b DCG = 2 $\times$ 10⁻³ μ Ci/mL.

Table A-27. LLNL nonradioactive liquid effluent—stormwater runoff.

Analyses (mg/L)	Influent LLNL	Influent SNLL	Effluent NW	Lake
Arsenic	< 0.001	< 0.001	< 0.001	< 0.001
Barium	< 0.1	< 0.1	< 0.1	< 0.1
Beryllium	< 0.01	< 0.01	< 0.01	< 0.01
Cadmium	< 0.01	< 0.01	< 0.01	< 0.01
Chromium	< 0.02	< 0.02	< 0.02	< 0.02
Lead	< 0.001	< 0.001	< 0.001	< 0.001
Mercury	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Selenium	< 0.001	< 0.001	< 0.001	< 0.001
Silver	< 0.01	< 0.01	< 0.01	< 0.01
Nitrate (as N)	0.10	1.2	1.4	0.68
Fluoride	0.19	0.24	0.26	< 0.1
Chemical Oxygen Demand	85	110	88	31
Total Organic Carbon (TOC)	31	18	21	6
Oil and Grease	8	13	9	< 5
Title 22 Organics				
2,4-D (µg/L)	11	< 0.5	3.2	< 0.5
Purgeable Priority Pollutants				
Chloroform (µg/L)	< 1	5	< 1	< 1
Trichlorofluoromethane (µg/L)	3	3	3	3

The following compounds would have been reported had they appeared at or above their detection limits, indicated below:

Title 22 Organics (µg/L)	Purgeable Priority Pollutants (µg/L)
2,4,5-TP (SILVEX)	< 0.1
Endrin	< 0.1
Lindane	< 0.05
Methoxychlor	< 0.5
Toxaphene	< 1
Polychlorinated Biphenyls (µg/L)	B/N,A Ext. Priority Pollutants (µg/L)
Aroclor 1016	< 0.3
Aroclor 1221	< 0.3
Aroclor 1232	< 0.3
Aroclor 1242	< 0.3
Aroclor 1248	< 0.3
Aroclor 1254	< 0.3
Aroclor 1260	< 0.3
Aroclor 1262	< 0.3
Total PCBs	< 2.4
	2,4-Dinitrophenol
	2-Methyl-4,6-dinitrophenol
	3,3'-Dichlorobenzidine
	4-Nitrophenol
	Bis(2-ethylhexyl)phthalate
	Benzidine
	Dibutylphthalate
	Dimethylphthalate
	N-Nitrosodi-n-propylamine
	N-Nitrosodimethylamine

Table A-28. Tritium (HTO) in vegetation—Livermore Valley.

	Location ^a							
	4	15	20	23	29	31	32	33
	[10 ⁻⁷ μ Ci/mL ^b $\pm$ 2 σ (%)]							
First quarter	1.4 $\pm$ 76	11.8 $\pm$ 10	13.4 $\pm$ 9	59.8 $\pm$ 3 70.5 $\pm$ 2	18.1 $\pm$ 7	7.9 $\pm$ 15	2.6 $\pm$ 43	1.4 $\pm$ 76
Second quarter	2.7 $\pm$ 41	9.5 $\pm$ 12	2.6 $\pm$ 42	48.1 $\pm$ 3	7.4 $\pm$ 15	6.2 $\pm$ 18	3.5 $\pm$ 32 2.8 $\pm$ 39	1.1 $\pm$ 100
Third quarter	2.6 $\pm$ 41	10.8 $\pm$ 11	8.4 $\pm$ 14 8.9 $\pm$ 13	15.8 $\pm$ 11	7.2 $\pm$ 16	5.3 $\pm$ 21	2.1 $\pm$ 53	1.4 $\pm$ 77
Fourth quarter	1.9 $\pm$ 6 ^a	10.0 $\pm$ 14	16.4 $\pm$ 7	16.8 $\pm$ 7	29.5 $\pm$ 5 28.7 $\pm$ 5	6.5 $\pm$ 16	5.7 $\pm$ 18	1.7 $\pm$ 58
Average	2.2	10.5	9.9	42.2	18.2	6.5	3.4	1.4
% SDM	28	10	53	59	60	17	42	17
Effective Dose Equivalent (mrem) ^c	4 $\times$ 10 ⁻³	2 $\times$ 10 ⁻²	2 $\times$ 10 ⁻²	8 $\times$ 10 ⁻²	3 $\times$ 10 ⁻²	1 $\times$ 10 ⁻²	6 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³

^a See Fig. 14 for sampling locations.

^b Of moisture content.

^c This dose represents the total effective dose equivalent from the forage-cow-milk pathway.

Table A-29. Tritium (HTO) in vegetation—Site 300.

	Location ^a					
	1	2	3	6	12	13
	[10 ⁻⁷ μ Ci/mL $\pm$ 2 σ (%)]					
First quarter	$\leq$ 2.2	$\leq$ 2.2 $\leq$ 2.2	$\leq$ 2.2	420 $\pm$ 1	2.5 $\pm$ 44	5.3 $\pm$ 21
Second quarter	$\leq$ 2.2	1.3 $\pm$ 83	$\leq$ 2.2	613 $\pm$ 1 2140 $\pm$ 0.5	$\leq$ 2.0	29.8 $\pm$ 5
Third quarter	$\leq$ 2.2 1.3 $\pm$ 85	$\leq$ 2.0	1.5 $\pm$ 74	ND ^b	1.3 $\pm$ 85	108 $\pm$ 2
Fourth quarter	$\leq$ 2.4	$\leq$ 2.4	$\leq$ 2.4 1.3 $\pm$ 95	ND	$\leq$ 2.4	17.3 $\pm$ 9
Average	1.2 ^c	1.2 ^c	1.3 ^c	1058	1.8 ^c	40.1
% SDM	8 ^d	8 ^d	8 ^d	89	36 ^d	116
Effective Dose Equivalent (mrem) ^e	2 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	2 $\times$ 10 ⁻³	1.9	3 $\times$ 10 ⁻³	7 $\times$ 10 ⁻²

^a See Fig. 15 for sampling locations.

^b ND = No data. See "Deviations from the Sampling Program" section.

^c Median Value.

^d Median absolute deviation.

^e This dose represents the total effective dose equivalent from the forage-cow-milk pathway.

Table A-30. Tritium (HTO) in wine.

Sample	Location		
	Livermore	Other California [10 ⁻⁷ μ Ci/mL $\pm$ 2 σ (%)]	European
1	1.84 $\pm$ 9	0.25 $\pm$ 76	8.43 $\pm$ 4
2	2.29 $\pm$ 10	0.28 $\pm$ 50	1.22 $\pm$ 12
3	2.63 $\pm$ 10	0.38 $\pm$ 46	1.41 $\pm$ 14
4	2.01 $\pm$ 11		2.02 $\pm$ 11
5	2.15 $\pm$ 11		
Average	2.18	0.30	3.27
% SDM	14	22	106

Table A-31. Tritium (HTO) in Honey.

Sample	Location	
	Livermore	California [10 ⁻⁷ μ Ci/mL (in water recovered) $\pm$ 2 σ (%)]
1	2.17 $\pm$ 11	2.67 $\pm$ 9
2	1.60 $\pm$ 14	1.26 $\pm$ 16
Average	1.88	1.96
% SDM	21	51

Table A-32a. ^3H in milk—Livermore Valley.

	Location				
	5 ^a	7 ^a	8 ^a [$10^{-7} \mu\text{Ci/mL} \pm 2\sigma$ (%a)]	10 ^b	11 ^a
Jan.	ND ^c	4.0 ± 27	5.1 ± 22	6.8 ± 17	
Feb.	ND	± 2.2	1.4 ± 80	1.7 ± 66	
Mar.	ND	± 2.2	± 2.2	2.3 ± 47	
Apr.	3.2 ± 33	± 2.0	1.1 ± 96	± 2.0	
May	2.2 ± 47	± 2.0	1.1 ± 92	± 2.0	
	1.9 ± 57	± 2.0	± 2.0	± 2.0	
	2.3 ± 41	± 1.8	± 1.8	1.4 ± 66	
	2.3 ± 46	1.5 ± 70	2.3 ± 46	± 2.0	
June	2.3 ± 47	1.3 ± 82	1.2 ± 84	1.4 ± 76	
July	1.2 ± 86	1.1 ± 97	1.7 ± 63	± 2.0	
Aug.	± 2.2	± 2.2	± 2.2	1.7 ± 67	
Sept.	1.6 ± 62	5.0 ± 20	± 1.8	ND	
Oct.	ND	1.2 ± 82	2.6 ± 42	± 3.0	
Nov.	ND	ND	ND	1.0 ± 98	3.5 ± 28
Dec.	ND	ND	ND	ND	ND
Average	2.0	3.0 ^d	3.0 ^d	3.9 ^d	—
% SDM	32	1.8 ^e	1.8 ^e	2.2 ^e	—
Effective Dose Equivalent (mrem)	4×10^{-3}	6×10^{-3}	6×10^{-3}	8×10^{-3}	7×10^{-3}

^a Goat's milk.^b Cow's milk.^c No data. See "Deviations from the Sampling Program" section.^d Median value, see Appendix D.^e Median absolute deviation. See Appendix D.Table A-32b. ^{40}K in milk—Livermore Valley.

	Location				
	5 ^a	7 ^a	8 ^a [$10^{-6} \mu\text{Ci/mL}$]	10 ^b	11 ^a
Jan.	— ^c	1.51 ± 3	1.51 ± 3	1.57 ± 3	
Feb.	—	1.57 ± 2	1.77 ± 3	1.66 ± 3	
Mar.	—	1.58 ± 3	1.67 ± 3	1.45 ± 2	
Apr.	1.66 ± 4	1.50 ± 8	1.7 ± 8	1.45 ± 2	
May	0.7 ± 12	1.9 ± 12	2.1 ± 2	1.5 ± 8	
June	0.9 ± 8	1.6 ± 4	1.8 ± 3	1.4 ± 4	
July	1.8 ± 3	1.7 ± 3	1.7 ± 3	1.5 ± 3	
Aug.	1.8 ± 2	1.9 ± 2	1.8 ± 2	1.3 ± 4	
Sept.	1.8 ± 2	1.8 ± 2	1.8 ± 2	—	
Oct.	—	1.8 ± 2	1.6 ± 4	1.4 ± 1	
Nov.	—	—	—	1.3 ± 2	1.7 ± 2
Dec.	—	—	—	—	—

^a Goat's milk.^b Cow's milk.^c No sample. See "Deviations from the Monitoring Program" section.

Table A-32c. ^{137}Cs in milk—Livermore Valley.

	Location				
	5 ^a	7 ^a	8 ^a [10 ⁻⁹ $\mu\text{Ci/mL}$]	10 ^b	11 ^a
Jan.	— ^c	~ 3.0	~ 1.2	2.62 ± 58	
Feb.	—	~ 1.2	~ 2.9	~ 3.8	
Mar.	—	~ 1.9	~ 1.3	0.68 ± 84	
Apr.	ND ^d	ND	ND	~ 2.0	
May	ND	ND	0.79 ± 82	~ 0.6	
June	~ 0.2	~ 0.2	ND	2.52 ± 72	
July	4.05 ± 26	2.36 ± 40	~ 3.5	ND	
Aug.	3.56 ± 48	1.57 ± 92	~ 1.6	2.41 ± 70	
Sept.	~ 4.0	~ 0.0	0.88 ± 84	—	
Oct.	—	~ 3.2	3.06 ± 44	2.85 ± 56	
Nov.	—	—	—	3.03 ± 54	2.86 ± 28
Dec.	—	—	—	—	—

^a Goat's milk.^b Cow's milk.^c No sample. See "Deviations from the Monitoring Program" section.^d Not detected.Table A-32d. ^{131}I in milk—Livermore Valley.^a

	Location			
	5	7 [10 ⁻⁹ $\mu\text{Ci/mL}$]	8	10
Jan.	ND ^b	ND	ND	ND
Feb.	ND	ND	ND	ND
Mar.	ND	ND	ND	ND
Apr.	ND	ND	ND	ND
May	~ 12.0	6.0 ± 72	ND	3.0 ± 64
June	ND	ND	ND	ND
July	ND	ND	ND	ND
Aug.	ND	ND	ND	ND
Sept.	ND	ND	ND	ND
Oct.	ND	ND	ND	ND
Nov.	ND	ND	ND	ND
Dec.	ND	ND	ND	ND

^a Attributable to Chernobyl. See Appendix H.^b ND = Not detected.

Table A-33. Environmental radiation measurements (TLD)—LLNL perimeter.

Location ^a	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Annual
		(mrem)			
1	20	14	16	18	68
2	16	12	13	16	57
3	20	14	16	20	70
4	21	13	16	19	69
5	21	14	15	19	69
6	20	14	13	18	65
7	19	13	13	18	63
8	17	14	14	16	61
9	18	13	15	17	63
10	16	12	12	15	55
11	15	13	14	14	56
12	19	— ^c	14	13	61 ^b
13	19	13	14	17	63
42	17	12	13	16	58
47	18	12	11	16	57
48	17	12	12	16	57
49	17	12	12	17	58
50	16	11	13	16	56
52	17	13	12	17	59
53	18	12	12	16	58
54	18	13	12	16	59
56	18	12	12	16	58
Average	18	13	13	17	61

^a See Fig. 16.^b The annual dose is calculated by using a second quarter total determined by averaging the doses recorded for the available quarters.^c No data available, dosimeter was missing at collection time.

Table A-34. Environmental radiation measurements (TLD)—Livermore Valley.

Location ^a	Jan.-Mar.	Apr.-June (mrem)	July-Sept.	Oct.-Dec.	Annual
14	19	10	11	13	53
15	20	13	13	19	65
16	19	14	14	18	65
17	41	19	— ^b	18	104 ^c
18	19	14	15	17	65
19	15	12	12	15	54
20	16	11	11	16	54
21	17	11	13	15	56
22	19	14	15	18	66
23	17	13	12	18	60
24	18	14	15	20	67
25	21	14	16	20	71
26	19	13	13	18	63
27	18	12	12	20	62
28	22	15	15	20	72
29	20	13	15	18	66
30	18	13	14	18	63
31	— ^b	13	16	19	64 ^c
32	19	12	12	17	60
33	20	14	15	17	66
34	— ^b	13	31	17	81 ^c
35	17	12	15	18	62
36	19	13	15	20	67
37	17	12	13	— ^b	56 ^c
38	18	13	15	— ^b	61 ^c
39	20	14	15	— ^b	65 ^c
40	19	13	15	— ^b	63 ^c
41	20	12	— ^b	19	68 ^c
43	19	13	14	18	64
44	20	13	— ^b	18	68 ^c
45	17	12	11	— ^b	53 ^c
46	18	11	13	16	58
51	17	11	12	17	57
55	20	12	15	— ^b	63 ^c
57	20	12	14	18	64
58	17	13	11	16	57
59	19	13	15	17	64
60	19	13	12	18	62
61	14	12	10	14	50
62	— ^b	11	12	16	52 ^c
63	18	11	13	17	59
64	20	12	14	17	63
65	19	12	14	16	61
66	19	13	15	18	65
67	18	13	14	18	63
68	17	13	15	19	64
69	16	13	13	15	57
70	18	12	12	19	61
71	19	13	— ^b	— ^b	64 ^c
72	22	14	15	21	72
73	18	— ^b	13	— ^b	62 ^c
74	15	— ^b	11	15	55 ^c
75	13	11	11	15	50
76	12	9	— ^b	10	41 ^c
77	17	9	12	14	52
Average	19	12	14	17	62

^a See Fig. 17.^b No data available; dosimeters missing.^c The annual dose is calculated by averaging the doses recorded for the available quarters.

Table A-35. Environmental neutron monitoring—LLNL perimeter.

	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	
Location ^a	(mrem)				Total
1	0.9	0.7	1.2	1.1	3.9
2	1.1	1.3	1.3	1.3	5.0
3	14.0	1.4	12.5	1.6	29.5
4	1.1	0.8	1.2	0.9	5.0
5	2.1	0.8	1.5	1.3	7.1
6	1.3	0.9	1.6	1.2	5.0
7	0.9	0.9	1.3	1.2	4.3
8	1.4	1.2	1.1	1.5	5.2
Average	2.8	1.0	2.7	1.3	8.1

^a See Fig. 16.

Table A-36. Water quality parameters for Site 300 production wells.

Positively detected parameters	Well						
	1	3	4	6	7	18	19
<u>Physical (mg/L)</u>							
Lead	0.032	0.012	0.001	0.001	0.001	0.003	0.002
Flouride	0.36	0.26	0.39	0.71	0.34	0.26	0.44
Arsenic	0.007	0.002	0.001	0.046	0.004	0.001	0.001
Nitrate (as NO ₃)	7.6	0.44	0.44	3.5	0.44	0.44	< 0.44
Chloride	58	48	74	168	94	71	79
Sulfate	65	110	130	150	170	130	130
Bicarbonate (as HCO ₃)	188	204	234	230	260	242	188
Carbonate (as CO ₃)	0.6	14	12	19	9	12	43
Sodium	41	99	140	230	190	160	200
Potassium	2.9	4.9	3.7	4.3	3.8	5.8	2.2
Calcium (EDTA titration)	56	35	26	8	21	19	8
Magnesium	20	15	6	1.5	5	2	0.1
Hydroxide alk (as CaCO ₃)	1.0	1.0	1.0	1.0	1.0	1.0	< 1.0
Carbonate alk (as CaCO ₃)	1.0	24	20	32	15	20	72
Bicarb alk (as CaCO ₃)	154	168	192	190	210	198	154
Ca hardness (as CaCO ₃)	138	87	65	20	52	47	20
Mg hardness (as CaCO ₃)	82	62	25	6.2	21	8.2	0.5
Total hardness	220	149	90	26	73	55	205
Iron	0.64	0.41	0.23	0.03	0.03	0.05	0.03
Manganese	0.01	0.01	0.05	0.01	0.03	0.01	< 0.01
Copper	0.02	0.02	0.02	0.02	< 0.02	< 0.02	< 0.02
Zinc	0.55	3.2	0.08	0.01	0.02	0.01	< 0.01
Filterable residue (TDS)	425	460	610	800	700	630	670
Conductance μ mhos/cm	640	710	880	1290	1050	940	1000
pH (units)	7.8	8.2	8.0	8.3	8.0	8.1	8.7
<u>Purgeable priority pollutants (μg/L)</u>							
Trichloroethylene	< 1	< 1	1	6	15	—	—

The following compounds would have been reported had they appeared at or above their detection limits, indicated below:

<u>Title 22 organics (μg/L)</u>		<u>Purgeable priority pollutants (μg/L)</u>	
2,4,5-TP (silvex)	0.1	Acrolein	10
2,4-D	0.5	Acrylonitrile	10
Endrin	0.1	Other Purgeable priority pollutants	1
Lindane	0.05		
Methoxychlor	0.3	<u>Physical and chemical parameters (μg/L)</u>	
Toxaphene	1	Cadmium	0.01
Surfactants	0.02	Mercury	0.0001
		Chromium	0.02
<u>Trihalomethanes (μg/L)</u>		<u>Pesticides (μg/L)</u>	
Bromodichloromethane	0.5	Propoxur	2
Bromoform	1	Bromacil	1
Chloroform	0.5	Carbaryl	1
Dibromochloromethane	0.5	Warfarin	1
		Fumarin	1
		Amitrole	10
		Roundup	10

Table A-37. Radioactive effluent releases from LLNL from 1982 through 1986.

Year	Airborne effluents (Ci)		Liquid effluents (Ci)	
	^3H	^{13}N - ^{15}O	HTO	^{239}Pu
1981	2620	344	6	9.2×10^{-5}
1982	2014	584	1.6	4.3×10^{-6}
1983	3245	855	1.7	6.7×10^{-6}
1984	7354	51	1.7	3.2×10^{-6}
1985	2204	520	3.6	4.8×10^{-6}
1986	1254	113	2.0	1.5×10^{-5}

Table A-38a. Radiation dose from the air pathway, all facilities during 1986 (CAAC method).^a

Nuclide	Facility	Curies	Dose at site boundary (mrem) ^b	Dose to nearest resident (mrem) ^b	Dose at maximum off-site exposure (mrem) ^b
$^3\text{H}^b$	Tritium facility	1128	0.03	0.03	0.03
	Insulating core accelerator	15	0.0	0.0	0.0
	Rotating target neutron source	106	0.007	0.004	0.007
	Incinerator	5.1	0.002	0.002	0.002
^{13}N - ^{15}O	Linear accelerator	90	0.02	0.01	0.02
	ATA ^c (Site 300)	23	0.005	0.008	0.005
Total			0.064	0.054	0.064
Percent of Federal Emission Standard ^c			0.26	0.22	0.26

^a These doses were calculated pursuant to the National Emissions Standards for Hazardous Air Pollutants (Clean Air Act) 40 CFR 61, Subpart H.

^b These doses are dose equivalents calculated using the ICRP 2 method (i.e., whole body/critical organ concept). These calculations were performed using the EPA approved Clean Air Act Code, which contains the AIRDOS-EPA and RADRISK models for calculating atmospheric transport, exposure and dose. Site-specific meteorological data was used except for atmospheric stability, which was obtained from Oakland Airport for the period 1960-1964.

^c The federal emission standards for radionuclides (contained in 40 CFR 61, Subpart H) limit doses to the public to 25 mrem/year to the whole body and 75 mrem/year to any critical organ.

Table A-38b. Estimated radiation dose to the public from LLNL airborne effluents during 1986 (CPS method).

Facility	Nuclide/ emission (curies)	Dose at site boundary ^{a,b} (mrem)	Dose to nearest resident ^{a,b} (mrem)	Dose at maximum off-site exposure (mrem) ^{a,b}	Collective dose (80-km radius of LLNL) ^a (person-rem)
Tritium facility	³ H, 1128	0.04	0.03	0.04	0.25
Insulating core accelerator	³ H, 15	0	0	0	0
Rotating target neutron source	³ H, 106	0.03	0.02	0.03	0.04
Incinerator	³ H, 5.1	0	0	0	0
Linear accelerator	¹³ N- ¹⁵ O, 180	0.09	0.02	0.09	0
ATA ^c (Site 300)	¹³ N- ¹⁵ O, 45	0	0	0	0
Total		0.16	0.07	0.16	0.29

^a This dose represents the 50-year committed effective dose equivalent resulting from an exposure to LLNL operations during 1986. Dose calculations were made using the Continuous-Point-Source computer code.

^b Doses are based on the 774.7 Ci of HTO released by LLNL. The dose due to the 480.4 Ci of HT released by LLNL does not add significantly to the total. SNLL emitted about 760 Ci of HTO which are not included in these calculations.

^c Advanced test accelerator.

Table A-38c. Summary of radiological dose assessment for 1986.

Effective Dose Equivalent to the Maximally Exposed Individual in the Public						
Nuclide	Pathways			Total		Percent of DOE primary radiation protection standard for the public ^b
	Inhalation/ submersion ^a (mrem)	Ingestion— foodstuff (mrem)	Ingestion— water (mrem)	(mrem)	(mSv)	
³ H	0.07	0.08	0.01	0.16	1.6×10^{-3}	0.2%
¹³ N- ¹⁵ O	0.09	0	0	0.09	9×10^{-4}	0.1%
			Total ^c	0.25 mrem	$(2.5 \times 10^{-3} \text{ mSv})$	0.3%

^a The inhalation/submersion dose was derived using the Continuous-Point-Source code and represents committed effective dose equivalents.

^b The primary DOE radiation standard for protection of the public (all sources and all pathways) is 100 mrem/year.

^c This dose is the maximum potential dose to a member of the public from all sources and all exposure pathways.

Table A-39. Quality-assurance analyses for the participation in the U.S. EPA Environmental Radioactivity Laboratory Intercomparison studies.

Analyses	Media	Value reported (pCi/L $\pm$ 1 σ)		
		LLNL	Known	Grand average of all Laboratories
Gross alpha	Water	9.00 $\pm$ 1.00	8.00 $\pm$ 5.00	7.35 $\pm$ 2.13
		4.00 $\pm$ 1.00	3.00 $\pm$ 5.00	3.59 $\pm$ 1.38
		13.00 $\pm$ 1.00	20.00 $\pm$ 5.00	17.33 $\pm$ 5.09
Gross beta	Water	17.33 $\pm$ 0.58	15.00 $\pm$ 5.00	14.75 $\pm$ 2.83
		7.33 $\pm$ 0.58	7.00 $\pm$ 5.00	7.20 $\pm$ 1.83
		25.67 $\pm$ 0.58	20.00 $\pm$ 5.00	20.44 $\pm$ 3.21
Gross alpha	Air	16.00 $\pm$ 1.00	15.00 $\pm$ 5.00	15.74 $\pm$ 2.89
		25.00 $\pm$ 3.00	22.00 $\pm$ 5.00	21.53 $\pm$ 4.27
Gross beta	Air	62.67 $\pm$ 2.31	47.00 $\pm$ 5.00	51.36 $\pm$ 6.18
		82.00 $\pm$ 3.60	66.00 $\pm$ 5.00	70.59 $\pm$ 8.07
Tritium	Water	3252 $\pm$ 23 (3063 $\pm$ 78) ^a	3125 $\pm$ 360	3052 $\pm$ 347
		5157 $\pm$ 18 (5280 $\pm$ 70)	5227 $\pm$ 523	5105 $\pm$ 340
		5684 $\pm$ 3 (5883 $\pm$ 180)	5973 $\pm$ 597	5693 $\pm$ 406

^a Data in parentheses are provided by the Nuclear Chemistry Division. All other LLNL data is provided by the Hazards Control Department.

Table A-40. Quality-assurance analyses for LLNL's participation in the DOE Environmental Measurements Laboratory (EML) Quality Assessment Program.^{a,b}

Analyses	Media	LLNL Value	EML value	LLNL/EML ratio
⁷ Be	Air	5650	1980	2.85
¹³⁷ Cs		602	221	2.72
²³⁹ Pu		2.64	2.39	1.10
U		1.27	1.15	1.10
⁴⁰ K	Soil	18.46	20.40	0.90
¹³⁷ Cs		0.937	0.810	1.16
²³⁹ Pu		0.008	0.010	0.82
³ H	Water	22.0	21.8	1.01
¹³⁷ Cs		2.33	2.43	0.96

^a The following values are relative; the exponents are not included and, therefore, do not indicate actual concentrations.

^b All data provided by LLNL's Nuclear Chemistry Division.

Table A-41. Quality Assurance—Replicate Sampling.

	Air-LLNL Perimeter ^{a,b}			Sewage-LLNL ^{a,b}			Sewage-LWRP ^{a,b}			Vegetation-LLNL ^a	Vegetation S-300 ^a	Water-LLNL ^a	Water S-300 ^a
	Gross Alpha ^b	Gross Beta ^b	HTO	Gross Alpha	Gross Beta	HTO	Gross Alpha	Gross Beta	HTO	HTO	HTO	HTO	HTO
Jan.	—	—	—	1.35	1.10	1.03	—	1.28	1.78	—	—	1.09	—
Feb.	—	—	—	0.92	1.09	1.02	—	—	1.02	0.85	0.99	—	0.37
Mar.	—	—	—	—	0.87	0.84	—	—	—	—	—	—	—
Apr.	—	—	—	0.88	0.94	0.91	—	—	0.81	1.23	0.29	0.89	0.94
May	—	—	1.00	0.60	0.90	0.91	—	0.89	0.80	—	—	—	—
June	—	—	1.03	1.45	0.85	0.69	—	0.65	—	—	—	—	—
July	—	—	1.61 1.42	1.07	1.19	1.12	—	1.21	0.96	0.94	0.85	1.00	—
Aug.	—	—	0.69	—	0.94	0.93	—	0.88	1.42	—	—	—	—
Sept.	—	—	0.23	0.90	1.02	0.86	—	0.77	1.22	—	—	—	0.99
Oct.	1.30	0.85	1.18 0.94	1.28	1.15	1.04	—	—	0.97	1.03	0.93	—	0.91
Nov.	1.02	0.82	—	—	1.00	1.32	—	1.43	15.4	—	—	—	—
Dec.	0.90	0.88	—	0.95	1.34	0.94	—	0.52	0.76	—	—	—	—

^a Ratio of normal sample/replicate sample. Sample results below the limit of detection were not used to calculate ratios, and are indicated with a dash.

^b Values are average monthly ratios.

^c Data not collected.

Appendix B. Deviations from the Sampling Program

Table B-1. Data for the following routinely scheduled samples were not reported for the listed reasons.

Station	Air monitoring-particulates Date	Reason
3	1-07-86	air sampler malfunction
3	2-18-86	air sampler malfunction
3	5-20-86	air sampler malfunction
4	1-07-86	air sampler malfunction
4	1-21-86	air sampler malfunction
4	2-18-86	air sampler malfunction
4	7-08-86	air sampler malfunction
4	9-23-86	air sampler malfunction
4	9-30-86	air sampler malfunction
6	5-27-86	air sampler malfunction
7	1-14-86	air sampler malfunction
8	2-18-86	air sampler malfunction
9	4-08-86	air sampler malfunction
10	2-18-86	air sampler malfunction
10	9-09-86	air sampler malfunction
10	9-30-86	air sampler malfunction
11	1-21-86	air sampler malfunction
11	2-11-86	air sampler malfunction
13	1-07-86	air sampler malfunction
13	4-08-86	air sampler malfunction
13	5-06-86	air sampler malfunction
13	9-02-86	air sampler malfunction
14	9-09-86	air sampler malfunction
16	4-01-86	air sampler malfunction
16	8-05-86	air sampler malfunction
16	9-23-86	air sampler malfunction
17	2-18-86	air sampler malfunction
17	2-25-86	air sampler malfunction
S300-3	6-03-86	air sampler malfunction
S300-4	1-07-86	air sampler malfunction
S300-4	2-04-86	air sampler malfunction
S300-4	2-18-86	air sampler malfunction
S300-4	2-25-86	air sampler malfunction
S300-4	3-11-86	air sampler malfunction
S300-4	3-18-86	air sampler malfunction
S300-4	4-01-86	air sampler malfunction
S300-5	3-04-86	air sampler malfunction
S300-5	5-13-86	air sampler malfunction
S300-5	8-12-86	air sampler malfunction
S300-6	7-08-86	air sampler malfunction
S300-6	7-22-86	air sampler malfunction
S300-6	7-29-86	air sampler malfunction
S300-6	8-19-86	air sampler malfunction
S300-6	8-27-86	air sampler malfunction
S300-6	9-02-86	air sampler malfunction
S300-6	9-16-86	air sampler malfunction
S300-7	6-03-86	air sampler malfunction

Table B-1. (Continued)

Station	<u>Air monitoring-particulates</u>	
	Date	Reason
S300-7	7-01-86	air sampler malfunction
S300-7	7-15-86	air sampler malfunction
S300-9	4-29-86	air sampler malfunction
S300-10	1-07-86	air sampler malfunction
S300-10	2-04-86	air sampler malfunction
S300-10	2-18-86	air sampler malfunction
S300-10	2-25-86	air sampler malfunction
S300-10	3-11-86	air sampler malfunction
S300-10	3-18-86	air sampler malfunction
S300-10	4-01-86	air sampler malfunction
S300-10	4-08-86	air sampler malfunction
S300-10	5-13-86	air sampler malfunction

Station	<u>Uranium results</u>	
	Date	Reason
12	8-00-86	lost in chemistry
13	8-00-86	lost in chemistry
14	8-00-86	lost in chemistry
15	8-00-86	lost in chemistry

Station	<u>Air monitoring-tritium</u>	
	Date	Reason
1	1-02-86	no flow
1	2-27-86	no flow
1	3-13-86	flask broken
1	3-27-86	no flow
1	12-31-86	no flow
2	8-28-86	no flow
2	9-25-86	no flow
2	10-09-86	no flow
4	1-30-86	no flow
4	3-13-86	no flow
4	8-15-86	flask broken
4	8-28-86	no flow
4	9-25-86	no flow
7	1-02-86	no flow
7	1-30-86	no flow
7	2-27-86	no flow
9	1-02-86	no flow
9	1-16-86	no flow
9	2-13-86	no flow
9	3-13-86	no flow
9	4-10-86	no flow
12	1-02-86	no flow
12	12-31-86	no flow
13	3-13-86	no flow
13	7-03-86	no flow
13	7-31-86	no flow
13	12-04-86	no flow
14	7-31-86	no flow
14	8-28-86	no flow
14	9-12-86	no flow

Table B-1. (Continued)

<u>Air monitoring-tritium</u>		
Station	Date	Reason
15	2-27-86	no flow
15	8-28-86	no flow on duplicate
15	9-12-86	no flow on duplicate
17	5-22-86	no flow
17	12-18-86	no flow
s1	12-27-86	no flow
s1	3-13-86	no flow
s2	7-31-86	no flow
s2	8-28-86	no flow
s2	10-23-86	no flow
s2	11-06-86	no flow
s2	11-20-86	no flow
s2	12-04-86	no flow
<u>Groundwater monitoring</u>		
Station	Date	Reason
33	1-00-86	pump not working
33	4-00-86	pump not working
33	7-00-86	pump not working
33	10-00-86	pump not working
<u>Vegetation monitoring</u>		
Station	Date	Reason
S300-6	7-00-86	area burned
S300-6	10-00-86	area burned
<u>Milk monitoring</u>		
Station	Date	Reason
5	1-00-86	goat not producing
5	2-00-86	goat not producing
5	3-00-86	goat not producing
5	10-00-86	goat not producing
5	11-00-86	goat not producing
5	12-00-86	goat not producing
7	11-00-86	goat not producing
7	12-00-86	goat not producing
8	11-00-86	goat not producing
8	12-00-86	goat not producing
10	9-00-86	cow not producing
10	12-00-86	animal no longer available
<u>Quality assurance replicate sampling</u>		
Station	Date	Reason
perimeter	1-00-86 to 9-00-86	no duplicate air filter taken due to equipment shortage.
perimeter	1-00-86 to 4-00-86	no duplicate tritium due to equipment shortage.

In addition to the deviations from the routine sampling program as listed above, the following changes were made to the sampling program immediately after the accident at the Chernobyl nuclear power plant in the USSR. These changes were made to better characterize the perturbations in the normal environment caused by this incident.

- Two additional air samplers were deployed near LLNL. The filters from these samplers were changed three times per week.

- Milk sampling was increased from once per month to once per week. A more detailed discussion of the changes to the sampling program caused by the Chernobyl accident, and the results of this special monitoring are presented in Appendix H.

Appendix C. Radiation Protection Standards

Operations at the Lawrence Livermore National Laboratory (LLNL) are conducted in accordance with a variety of federal, state, and local standards and permits. Radiation protection standards are established by the Department of Energy (DOE) orders pursuant to the Atomic Energy Act.

The DOE environmental radiation protection standards are provided in *DOE Derived Concentration Guides of August 15, 1986*. Even though this order is in draft form, the standards are in effect. The revised DOE Order incorporates a new system for controlling exposures to the public from operations at DOE facilities. These standards are based on recommendations by the International Commission on Radiological Protection (ICRP) and the National Commission on Radiation Protection and Measurements (NCRP). The primary DOE radiation standards for protection of the public are provided below.

The Derived Concentration Guides (DCGs) for controlling exposures to members of the public. The DCGs are concentrations of radionuclides in water and air that could be continuously consumed or inhaled (365 days/year) and not exceed the DOE primary radiation protection standard to the public (100 mrem/y effective dose equivalent). The DCGs pertinent to this report are listed in Table C-3.

Table C-1. All pathways and all sources.^a

Exposure	Effective dose equivalent ^b	
	(mrem/y)	(mSv/y)
Prolonged exposure	100	1
Occasional exposure	500	5

^a These limits are based on the dose to the maximally exposed individual in an uncontrolled area.

^b The "effective dose equivalent" is defined as the sum of the effective dose equivalent from external radiation and the committed (50-year) effective dose equivalent from ingestion and inhalation during the calendar year.

Table C-2. Air pathway only (limits of 40 CFR 61, Subpart H).^a

Exposure	Dose equivalent	
	(mrem/y)	(mSv/y)
Whole body	25	0.25
Any organ	75	0.75

^a National Emission Standards for Hazardous Air Pollutants (Clean Air Act) 40 CFR 61, Subpart H.

Table C-3. Derived Concentration Guides.

Nuclide	Concentration in air (μCi/mL)	Concentration in water (μCi/mL)
³ H	2 × 10 ⁻⁷	2 × 10 ⁻³
⁷ Re	5 × 10 ⁻⁸	1 × 10 ⁻³
¹³ N	2 × 10 ⁻⁸	—
¹⁵ O	2 × 10 ⁻⁸	—
⁴⁰ K	9 × 10 ⁻¹⁰	7 × 10 ⁻⁶
¹⁰⁶ Ru	3 × 10 ⁻¹¹	6 × 10 ⁻⁶
¹²⁵ Sb	1 × 10 ⁻⁹	6 × 10 ⁻⁵
¹³⁷ Cs	4 × 10 ⁻¹⁰	3 × 10 ⁻⁶
¹⁴⁴ Ce	3 × 10 ⁻¹¹	7 × 10 ⁻⁶
²³⁵ U	1 × 10 ⁻¹³	6 × 10 ⁻⁷
²³⁸ U	1 × 10 ⁻¹³	6 × 10 ⁻⁷
²³⁹ Pu	2 × 10 ⁻¹⁴	3 × 10 ⁻⁶

The State of California (Title 22, Chapter 15) specifies Maximum Contaminant Levels (MCL) for public water supplies as follows:

Gross alpha particle activity (including ^{226}Ra but excluding Ru and U)	—	15 pCi/L or $1.5 \times 10^{-8} \mu\text{Ci/mL}$.
Gross beta particle activity	—	50 pCi/L or $5.0 \times 10^{-8} \mu\text{Ci/mL}$.
Tritium	—	20,000 pCi/L or $2.0 \times 10^{-5} \mu\text{Ci/mL}$.

In the revised DOE orders, no standards have been provided for gross alpha and gross beta activity. Although not a DOE requirement, gross activity measurements have been included in this report for historical continuity.

Appendix D. Methods of Dose Calculations

The radiological impact to the public from operations at the Lawrence Livermore National Laboratory (LLNL) is assessed in accordance with applicable Department of Energy (DOE) orders. Based on releases of radioactivity to the environment and measurements of environmental media, potential doses are calculated at the site boundary, nearest resident, point of maximum exposure in an uncontrolled area and to the population residing within an 80-km radius of the LLNL. The doses in this report may be compared to the radiation protection standards established by the DOE and other regulatory bodies (Appendix C).

For the purposes of this report, doses are reported in terms of "effective dose equivalent," which is defined as the sum of the effective dose equivalent from external radiation and the committed (50-year) effective dose equivalent from ingestion and inhalation during a one-year period. This dose is a measure of the potential health effects from radiation exposure. It also accounts for the radiation dose delivered to the body from intakes of radionuclides with a long effective half life (i.e., radionuclides with long residency in the body). Thus, the "effective dose equivalent" includes the total dose received over a 50-year period following a one-year exposure. The effective dose equivalents in this report were calculated using the dosimetric parameters recommended by the International Commission on Radiological Protection (ICRP) in Publications 26 and 30.

Pursuant to the National Emission Standards for Hazardous Air Pollutants (40 CFR 61, Subpart H), doses from the air pathway are also reported in terms of "dose equivalent." These doses refer to a measure of radiation dose and are calculated based on the whole body/critical organ concept of ICRP Publication Number 2. These doses were derived using the Clean Air Act Code, which contains the Environmental Protection Agency (EPA) approved models (AIRDOS-EPA and RADRISK) for calculating atmospheric transport and exposure. Population exposure was converted to dose using dose conversion factors and weighting factors specified by the EPA.

Radiological Dose Assessment Performed for 1986

Briefly described below are each of the doses used to measure the radiological impact from LLNL during 1986.

1. External "fence-post" dose: The fence-post dose rate is a measure of the maximum external dose at locations of nearest uncontrolled public access. Dose rates from external penetrating radiations (primarily gamma rays and neutrons) are measured using environmental dosimeters (thermoluminescence dosimeters and neutron detectors). The environmental dosimeters measure dose rates from all external radiation sources; including cosmic radiations, naturally occurring radioactivity in the environment, fallout from nuclear weapons testing, and any contribution from LLNL operations. Hence, these doses are not solely attributable to LLNL and in most instances are a measure of regional background. This is determined by comparing the perimeter measurements with those made at off-site (Livermore Valley) locations. Moreover, these measurements are made at points of maximum exposure and assume an occupancy of 24 hours per day, 365 days per year. In actuality, no member of the public resides at these locations for extended periods of time, thus making these conservative estimates.

2. Ingestion dose: Potential doses from ingestion of locally produced foodstuff and surface water are based on actual measurements of radionuclide concentrations in the various media (determined by sampling). Conservative exposure data and current ICRP dosimetric factors are used to estimate doses to the individual. The following radionuclide exposure pathways are assessed by means of field measurements: tritium in water, tritium in milk and tritium in vegetation (which includes the forage-cow-milk pathway).

3. Inhalation/submersion dose: Air pathway doses are calculated for each airborne radioactive discharge to the atmosphere. Inhalation/submersion doses are calculated at the LLNL boundary, nearest resident and point of maximum off-site exposure. The amount of radioactivity released from the LLNL is usually too low to accurately measure radionuclide concentrations in ambient air and determine dose. Therefore, environmental transport and exposure pathway models are used to calculate potential doses resulting from effluent emissions (i.e., measurements made at the stack). These doses are calculated by two methods to comply with both the newly adopted DOE standards (equivalent to current ICRP recommendations) and the National Emission Standards for Hazardous Air Pollutants, 40 CFR 61, Subpart H.

Dose calculations were made using a continuous-point-source computer code based on the Gaussian plume model (Peterson et al., 1976). This code provides ratios of concentration to release rate (X/Q) through sixteen 22.5° compass sectors, and distances from 0.1 to 100 km from potential release points. The average annual X/Q values have been calculated using local meteorological data. These data were obtained from 40-m sensors on the LLNL meteorological tower. From records of these data, wind speed, wind direction, and atmospheric stability estimates were tabulated at 1/4-h intervals over the calendar year. Digitized meteorological data became available at Site 300 in May of 1986, and was used to perform dispersion calculations for the ATA emissions.

Variance in the horizontal wind direction was used to estimate Pasquill-Gifford stability categories based on the method described by D. H. Slade (Slade, 1968). Lateral and vertical standard deviations σ_y and σ_z , are entered in the computer code as functions of these stability categories and the respective distances. Based on the annual effluent data, (release rate Q) and the appropriate X/Q values, the radionuclide concentrations at the site boundary and the nearest resident were calculated. "Nearest resident" refers to the resident receiving the highest dose from each radioactivity release point, not necessarily the resident nearest to the site boundary.

4. Maximally exposed individual dose: This dose represents the maximum credible dose to any member of the public. It includes contributions from all potential exposure pathways and is derived using the most conservative but realistic exposure data and assumptions. This dose is calculated for a "hypothetical" individual who receives the maximum possible exposure. This hypothetical person is assumed to reside at the point of highest ground-level radionuclide air concentration continuously 24 hours per day, 365 days per year. During this occupancy period, a portion of this person's diet consists of locally produced foodstuffs and drinking water containing the highest measured radionuclide concentration. Thus, this is not a dose actually received by any individual and should be viewed as a conservative estimate (i.e., over estimate) of the highest possible dose to any member of the general public.

5. Collective "population" dose: The population dose is the collective dose for all individuals residing within an 80-km radius of the LLNL. The population dose is calculated by summing for each region the average individual dose multiplied by the number of individuals residing in the region. The population dose is referred to as the "collective effective dose equivalent" and is expressed in terms of person-rem.

The effective dose equivalents shown in this report have been calculated using models and methods consistent with Nuclear Regulatory Commission Regulatory Guide 1.109, *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluent*. The dose and dose-rate conversion factor used in these calculations were obtained from the Committed Dose Equivalent Tables for U.S. Department of Energy Population Dose Calculations. These dose conversion factors are consistent with those specified by Publication 30 of the International Commission on Radiological Protection, *Limits of Intakes of Radionuclides by Workers*. Examples of these calculations and assumptions are shown below.

Annual Dose from Potable Water

Assuming that all water sampled is available as drinking water, the annual whole-body dose for tritium has been calculated using the following equation:

$$R_{\text{total body}} = C_w U_w D_w \quad (1)$$

where

C_w = concentration in pCi/L ,

U_w = intake rate, liters/y ,

= 730 liters/y for maximum exposed individual ,

D_w = dose factor, mrem/pCi ,

6.3×10^{-8} mrem/pCi for the whole-body ingestion pathway for an adult, and

$R_{\text{total body}}$ = effective dose equivalent in mrem to the total body from ingestion of 730 liters of potable water with concentration C_w .

Annual Dose from Forage-Cow-Milk Pathway for Tritium in Vegetation

Assuming that all feed for the cattle was pasture grass, the effective dose equivalent per $\mu\text{Ci/mL}$ HTO for the maximum exposed individual has been calculated using the following equation:

$$D_{\text{total body}} = D_{\text{veg}} + D_{\text{meat}} + D_{\text{milk}} \quad (2)$$

$$D_{\text{veg}} (\text{leafy vegetables}) = U_{\text{veg}} \times C_{\text{veg}} \times D_{\text{HTO}} \quad (2a)$$

where

U_{veg} = intake rate, kg/y, 64 kg/y for maximum exposed individual ,

C_{veg} = concentration in $\mu\text{Ci/kg}$ = $10^9 \frac{\mu\text{Ci/kg}}{\mu\text{Ci/mL}} \times C_{\text{veg}} \mu\text{Ci/mL}$ (measured) ,

D_{HTO} = dose factor, mrem/pCi = 6.3×10^{-8} mrem/pCi for ^3H for the adult whole-body ingestion pathway ,

$D_{\text{veg}} (\text{mrem/y}) = 0.40 \times 10^4 C_{\text{veg}} \mu\text{Ci/mL}$ (measured) .

$$D_{\text{meat}} = U_{\text{meat}} \times C_{\text{meat}} \times D_{\text{HTO}} \quad (2b)$$

where

$U_{\text{meat}} = 110 \text{ kg/y}$,

$D_{\text{HTO}} = 6.3 \times 10^{-8} \text{ mrem/pCi}$,

$C_{\text{meat}} = (F_f) (Q_f) (C_{\text{veg}}) \exp(-\lambda_i t_s)$.

F_f = fraction of daily intake of nuclide per kg of animal/fish (pCi/kg in meat per pCi/day ingested by the animal), days/kg ,

Q_f = amount of feed consumed, kg/day ,

C_{veg} = same as above ,

λ_i = radiological decay constant, day^{-1} ,

t_s = time between slaughter to consumption, days .

$$C_{\text{meat}} = \left(1.2 \times 10^{-2} \frac{\text{day}}{\text{kg}}\right) \left(50 \frac{\text{kg}}{\text{day}}\right) \left(C_{\text{veg}} \frac{\mu\text{Ci}}{\text{mL}}\right) \left(10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}}\right) \\ \times \exp[-1.5 \times 10^{-4}(20)] = 0.6 \times 10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}} \times C_{\text{veg}} \frac{\mu\text{Ci}}{\text{mL}} (\text{measured}) \quad ,$$

$D_{\text{meat}} (\text{mrem/y}) = 0.41 \times 10^4 \times C_{\text{veg}} \mu\text{Ci/mL}$ (measured) .

$$D_{\text{milk}} = U_{\text{milk}} \times C_{\text{milk}} \times D_{\text{HTO}} \quad (2c)$$

where

$U_{\text{milk}} = 310 \text{ liters/y}$,

$$D_{HIO} = 6.3 \times 10^{-8} \text{ mrem/pCi} ,$$

$$C_{milk} = F_m Q_f C_{veg} \exp(-\lambda_i t_i) ,$$

F_m = fraction of daily intake of nuclide per liter of milk (pCi/liter in milk per pCi/day ingested by the animal), day/liter ,

Q_f = amount of feed consumed, kg/day ,

C_{veg} = same as above ,

λ_i = radiological decay constant, days⁻¹ ,

t_i = transport time from the feed to milk receptor ,

$$C_{milk} = \left(1.0 \times 10^{-2} \frac{\text{day}}{\text{liter}} \right) \left(50 \frac{\text{kg}}{\text{d}} \right) \left(C_{veg} \frac{\mu\text{Ci}}{\text{mL}} \right) \left(10^6 \frac{\text{pCi/kg}}{\mu\text{Ci/mL}} \right) \\ \times \exp[-1.5 \times 10^{-4} (2)] = 0.5 \times 10^6 \frac{\text{pCi/liter}}{\mu\text{Ci/mL}} \times C_{veg} \frac{\mu\text{Ci}}{\text{mL}} (\text{measured}) .$$

$$D_{milk} (\text{mrem/y}) = 0.97 \times 10^4 \times C_{veg} \mu\text{Ci/mL} (\text{measured}) .$$

$$D_{total} (\text{mrem/y}) = 0.40 \times 10^4 C_{veg} \mu\text{Ci/mL} (\text{measured}) + 0.41 \times 10^4 C_{veg} \mu\text{Ci/mL} (\text{measured}) \\ + 0.97 \times 10^4 C_{veg} \mu\text{Ci/mL} (\text{measured}) = 1.78 \times 10^4 C_{veg} \mu\text{Ci/mL} (\text{measured}) .$$

Inhalation/Submersion Dose

To calculate the air pathway dose at the site boundary, to the nearest resident, and to the point of maximum exposure, a continuous-point-source computer code based on the Gaussian plume model was used.

A. Inhalation Dose (³H)

$$D_{max} = C \times U \times D \quad (3)$$

where

C = radionuclide concentration at the receptor

U = intake rate (the inhalation rate for adult maximally exposed individual is 8,400 m³/y)

D = dose factor ³H: $D = 9.45 \times 10^{-8} \text{ mrem/pCi} .$

(The tritium dose conversion factor was obtained by multiplying the inhalation dose factor $6.3 \times 10^{-8} \text{ mrem/pCi}$, by 1.5 to include absorption through the skin.)

$$C = 3.17 \times 10^4 (\chi/Q)(Q) , \quad (3a)$$

where

χ/Q = diffusion parameter, sec /m³ ,

Q = release rate, Ci/y ,

$$3.17 \times 10^4 = 1 \times 10^{12} \frac{\text{pCi}}{\text{Ci}} / 3.15 \times 10^7 \frac{\text{sec}}{\text{y}} .$$

B. External Immersion Dose (^{13}N and ^{15}O)

$$D_{\text{max}} = C \times \text{DRF} \quad (4)$$

where

$$\text{DRF} = \text{dose-rate factor, } \frac{\text{mrem} \cdot \text{m}^3}{\text{pCi} \cdot \text{y}}$$

(i.e., the DRF is the external dose-equivalent rate per unit radionuclide concentration)

$$\text{for } ^{13}\text{N: DRF} = 5.22 \times 10^{-5} \frac{\text{mrem} \cdot \text{m}^3}{\text{pCi} \cdot \text{y}}$$

$$\text{for } ^{15}\text{O: DRF} = 5.25 \times 10^{-5} \frac{\text{mrem} \cdot \text{m}^3}{\text{pCi} \cdot \text{y}}$$

Annual Population Dose

For population dose, the diffusion factors and population figures for an area within 80 km of LLNL were summed over all directions.

$$\text{Dose (person-mrem)} = 3.17 \times 10^4 \left[\sum_{i=1}^n (\chi/Q)_i P_i \right] Q U D \quad (5)$$

where

$$\left[\sum_{i=1}^n (\chi/Q)_i P_i \right] = \text{Summation of the } (\chi/Q) \text{ for region } i$$

times the population in region i for all regions n , $\frac{\text{person-sec}}{\text{m}^3}$

Q = release rate, Ci/y

U = inhalation rate, average individual (adult)

D = dose factor, mrem/pCi

Appendix E. Statistical Methods

The following statistical methods were applied to the reported data.

1. Lower Limit of Detection (LLD): LLDs are indicated in the tables by the "less than or equal to" ($\leq$) sign. For computation of average values and errors, actual data points (when available) were used in place of LLDs. The LLDs are reported in the tables for the sake of clarity. A result was assumed to be at or below the LLD when the 2σ error was 100% or greater. When available, LLDs calculated by the computational programs were used. When actual data points were available, the data point plus the 2σ error was used in order to give a conservative estimate.
2. Distribution Analysis: For sample sets greater than 10, a distribution analysis was performed using the chi-square method. Where necessary, log transformations were carried out to achieve a normal distribution before statistical parameters were calculated.
3. Reporting: For sample sets containing few LLDs or extreme values (or those for which actual values below the LLD are available), numbers are reported as the arithmetic mean $\pm$ two standard deviations. For sample sets containing many (1/3 or more of the total) LLDs or extreme values (for which actual data points are not available), numbers are reported as the median value $\pm$ the median absolute deviation.

Appendix F. Discharge Limits to the Sanitary Sewer System of the City of Livermore

Sections 18.62, 18.62.2, 18.62.3, 18.62.4, and 18.62.5 of the Code of the City of Livermore (1983) state the discharge limits for Livermore's sanitary sewer system. These limits are as follows:

Section 18.62 General Discharge Prohibitions.

No person shall contribute or cause to be contributed, directly or indirectly, any pollutant or wastewater that will interfere with the operation or performance of the publicly-owned treatment works (POTW). These general prohibitions apply to all such users of the POTW whether or not the user is subject to national categorical pretreatment standards or any other national, state, or local pretreatment standards or requirements. A user may not contribute the following substances to the POTW:

(a) Any liquids, solids, or gases that by reason of their nature or quantity are, or may be, sufficient either alone or by interaction with other substances to cause fire or explosion or be injurious in any other way to the POTW or to the operation of the POTW. At no time shall two successive readings on an explosion hazard meter, at the point of discharge into the system (or at any point in the system) be more than five percent (5%) nor any single reading over ten percent (10%) of the lower explosive limit (LEL) of the meter. Prohibited materials include, but are not limited to, gasoline, kerosene, naphtha, benzene, toluene, xylene, ethers, alcohols, ketones, aldehydes, peroxides, chlorates, perchlorates, bromates, carbides, hydrides, and sulfides and any other substances that the city, the state or the EPA has notified the user is a fire hazard or a hazard to the system.

(b) Solid or viscous substances that may cause obstruction to the flow in a sewer or other interference with the operation of the wastewater treatment facilities such as, but not limited to: grease, garbage with particles greater than one half inch (1/2") in any dimension, animal guts or tissues, paunch manure, bones, hair, hides or fleshings, entrails, whole blood, feathers, ashes, cinders, sand, spent lime, stone or marble dust, metal, glass, straw, shavings, grass clippings, rags, spent grains, spent hops, waste paper, wood, plastics, gas, tar, asphalt residues, residues from refining, or processing of fuel or lubricating oil, mud, or glass grinding or polishing wastes.

Specifically excluded from the sewers are waste products resulting from the handling, storage and sale of fruits and vegetables from other than retail produce establishments, or other foods not intended primarily for immediate consumption.

(c) Any wastewater having a pH less than 6.8 or greater than 8.5, unless a city permit is obtained. Wastewater having any other corrosive property capable of causing damage or hazard to structures, equipment, and/or personnel of the POTW is also prohibited.

(d) Any wastewater containing toxic pollutants in sufficient quantity, either singly or by interaction with other pollutants, to injure or interfere with any wastewater treatment process, constitute a hazard to humans or animals, create a toxic effect in the receiving waters of the POTW, or to exceed the limitation set forth in the categorical pretreatment standard. A toxic pollutant shall include, but not be limited to any pollutant identified pursuant to Section 307(a) of the Act.

(e) Any noxious or malodorous liquids, gases, or solids, which either singly or by interaction with other wastes are sufficient to create a public nuisance or hazard to life or are sufficient to prevent entry into the sewers for maintenance and repair.

(f) Any substance that may cause the POTW's effluent or any other product of the POTW such as residues, sludges, scums, or gases, to be unsuitable for reclamation and reuse or to interfere with the reclamation process. In no case, shall a substance discharged to the POTW cause the POTW to be in noncompliance with sludge use or disposal criteria, guidelines or regulations developed under Section 405 of the Act, any criteria, guidelines, or regulations affecting sludge use or disposal developed pursuant to the Solid Waste Disposal Act, the Clean Air Act, the Toxic Substances Control Act, or state criteria applicable to the sludge management method being used.

(g) Any waters or wastes that contain more than 100 mg/liter of freon extractable fat, oil, or grease.

(h) Any substance that will cause the POTW to violate its NPDES Permit or the receiving water quality standards.

(i) Any wastewater with objectionable color not removed in the treatment process, such as, but not limited to, dye wastes and vegetable tanning solutions.

(j) Any wastewater having a temperature that will inhibit biological activity in the POTW treatment plant resulting in interference, but in no case wastewater with a temperature at the introduction into the POTW which exceeds 40°C (104°F).

(k) Any pollutants, including oxygen demanding pollutants (BOD, etc.) released at a flow rate and/or pollutant concentration that a user knows or has reason to know will cause interference to the POTW.

(l) Any wastewater containing any radioactive wastes or isotopes of such half-life or concentration as may exceed the limits established by the state or federal regulatory agency applicable to the POTW user.

(m) Any wastewater that causes a hazard to human life or creates a public nuisance.

(n) Any waters or wastes containing total dissolved solids increment greater than 300 and 125 mg/L, nor chloride increment greater than 75 mg/L, increase during a single cycle use of the water supply, unless a city permit is obtained to exceed this limit.

(o) Any water or wastes having a BOD greater than 300 (the average BOD for residential users), unless a city permit is obtained.

(p) Any waters or wastes containing more than 300 mg/L of suspended solids (the average suspended solids for residential users), unless a city permit is obtained.

When the Superintendent determines that a user(s) is contributing to the POTW, any of the above enumerated substances in such amounts as to interfere with the operation of the POTW, the Superintendent shall (1) advise the user(s) of the impact of the contribution on the POTW, and (2) develop effluent limitations for such user(s) to correct the interference with the POTW.

Section 18.62.2 Federal Categorical Pretreatment Standards.

Upon the promulgation of the Federal Categorical Pretreatment Standards for a particular industrial subcategory, the Federal Standard, if more stringent than limitations imposed under this article for sources in that subcategory, shall immediately supersede the limitations imposed under this article. The Superintendent shall notify all affected users of the applicable reporting requirements under 40 CFR, Section 403.12.

Section 18.62.3 Modification of Federal Categorical Pretreatment Standards.

Where the city's wastewater treatment system achieves consistent removal of pollutants limited by Federal Pretreatment Standards, the city may apply to the state/EPA for modification of specific limits in the Federal Pretreatment Standards. "Consistent Removal" shall mean reduction in the amount of pollutant or alteration of the nature of the pollutant, by the wastewater treatment system, to the less toxic or harmless state, in the effluent that is achieved by the system in 95% of the samples taken when measured according to the procedures set forth in Section 403.7 (c) (2) of (Title 40 of the Code of Federal Regulations, Part 403)—"General Pretreatment Regulations for Existing and New Sources of Pollution" promulgated pursuant to the Act. The city may then modify pollutant discharge limits in the Federal Pretreatment Standards if the requirements contained in 40 CFR, Part 403, Section 403.7, are fulfilled and prior approval from state/EPA is obtained.

Section 18.62.4 Specific Pollutant Limitations.

No person shall discharge wastewater containing in excess of:

0.1	mg/l. arsenic
0.2	mg/l. cadmium
2.0	mg/l. copper
1.0	mg/l. cyanide
1.0	mg/l. lead
0.01	mg/l. mercury
1.0	mg/l. nickel
0.2	mg/l. silver
1.0	mg/l. total chromium
3.0	mg/l. zinc

0.02	mg/L. total identifiable chlorinated hydrocarbons
1.0	mg/L. phenolic compounds
0.01	mg/L. polychlorinated biphenyls

Section 18.62.5 **State Requirements.**

State requirements and limitations on discharges shall apply in any case where they are more stringent than Federal requirements and limitations or those in this article.

Appendix G. Sampling and Analytical Procedures for Environmental Monitoring at Lawrence Livermore National Laboratory

Sample collection and analysis procedures are an integral part of the quality assurance program developed for environmental monitoring at Livermore. These procedures provide a basis for verifying that sampling and analytical activities are being performed as specified.

This appendix describes the sampling procedures employed by the Environmental Quality Verification Program, and the analytical determinations and preparation for radio counting by the LLNL Hazards Control Department personnel. The radiochemical methods used by the LLNL Nuclear Chemistry Division, were described in detail in Appendix F in the 1985 Annual Environmental Monitoring Report and published as a separate manual (LLNL M-122 Rev. 1, *Radiochemical Methods of the Site Environmental Monitoring Program, Jan. 1985*). This manual is revised and re-issued biennially; interim changes in procedures are noted in the environmental monitoring annual report.

Some analyses are performed by independent contractors. LLNL contracts with laboratories certified by the State of California whenever possible, and requires its contractors to maintain adequate quality assurance programs and documentation of methods.

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Sampling and Analytical Procedures

Introduction

Written procedures have been prepared for each environmental monitoring activity at LLNL as part of its quality assurance program. The sample collection and analysis procedures described herein have been reviewed and approved by those responsible for managing the monitoring program. During a program audit, such written documentation can be used to verify that sampling and analytical procedures meet program specifications.

The "Sampling" sections describe the procedures used for each sample medium monitored. A general description of each medium is usually provided. This is followed by the collection procedure used, the provisions for sample identification, and the schedule for sample replication.

The "Analysis" sections cover the analyses of the samples collected. General comments on each sample medium analyzed are followed by specific descriptions of standards and calibrations, analytical procedures, and/or counting procedures as applicable for each medium.

Air Sampling

Continuously operating air samplers are used at LLNL to measure the concentration of airborne particulate radioactivity, beryllium, and tritiated water. Samplers placed at six locations around the LLNL perimeter and at nine locations at Site 300 measure particulate radioactivity and beryllium. Particulate radioactivity is also measured at 11 off-site locations near LLNL. Tritiated water samplers are operated at the six LLNL perimeter locations and at six off-site locations. In all cases, the samplers are placed to reasonably ensure that any significant concentration of effluents from LLNL operations would be detected regardless of local meteorology.

Collection

Particulates

Samples taken at the LLNL perimeter, selected off-site locations in the Livermore Valley, and at Site 300 are collected on $5.2 \times 10^{-2} \text{ m}^2$ Whatman filters using Hi-Vol samplers with average flow rates of 700 liters/min. These flow rates are verified at monthly intervals with a portable field-calibration unit. If a Hi-Vol air sampler fails, it is repaired and then calibrated with a spirometer that was itself calibrated by using an immersion unit certified by the National Bureau of Standards (NBS).

The remaining off-site samples in the Livermore Valley are collected on $7.5 \times 10^{-3} \text{ m}^2$ Flanders F-700 glass-fiber filters at a flow rate of 80 liters/min. The flow-rate indicators are generally calibrated annually.

Tritiated Water

Samples of tritiated-water vapor are collected by drawing air through silica-gel-packed columns at flow rates of about 0.5 liters/min. The average flow rate is calculated from the initial and final flow rates, which are measured with a rotometer that is calibrated annually. Columns are exchanged biweekly.

Identification

Particulates

Particulate samplers run continuously, and the filters are exchanged weekly. Each filter is identified by its location, the date on, date off, the elapsed sampling time, and the flow rate. Filters are placed in glassine envelopes and are transported to the laboratory, where this information is transferred to log

sheets and each filter sample is given a serial number that accompanies it throughout the analysis. Half of each LLNL-perimeter and Site-300 filter is used for beryllium analysis; the other half is retained for radioactivity measurements.

Tritiated Water

Tritiated-water vapor samplers run continuously, and the silica-gel holders are exchanged biweekly. Each sample is identified by the location, the date on, the date off, the elapsed sampling time, and the flow rate. This information is transferred to log sheets in the laboratory, and each sample is given a serial number that accompanies it throughout the analysis.

Replication

Particulates

At bimonthly intervals, a particulate air sampler is operated in parallel with the permanent sampler at one of the six LLNL perimeter locations. This parallel operation is continued for one month, the filters are exchanged weekly, and both filters are submitted for analysis in the usual manner. Bimonthly rotation of the extra sampler among the six locations ensures the samplers are checked annually. The replicate samples are then compared with respect to gross alpha and beta activities and to ^{239}Pu content.

Tritiated Water

Parallel samples of tritiated-water vapor are collected at the LLNL perimeter locations during alternate months from those in which particulate replicates are being collected.

Soil Sampling

Soil samples are collected annually within the Livermore Valley and at Site 300. Radiochemical analyses of these samples serve to document any changes that may have occurred during the year. Approximately 20 sampling sites within the Livermore Valley are chosen at random from a list of 125 locations which provided the data base of various nuclides in the soil near LLNL. The same sampling sites are used each year at Site 300 to provide an ongoing comparison, with additional sampling sites added from time to time to expand coverage or test specific hypotheses.

Collection

Sampling sites are selected in reasonably level areas that represent undisturbed soil. A 2-m square is marked off in each area, and an 8.25-cm-diam coring tool, designed at LLNL, is used to collect 5-cm-deep samples at the corners and center of the square.

Identification

Five samples of soil collected from each 2-m square are composited in a plastic bag and identified by number. This number is entered in a log book, together with the sampling data and a description of the sample location. The number is used to identify the sample throughout the laboratory analyses and in the annual report.

Replication

During each annual collection of soil samples, approximately 10% of the sites are sampled in duplicate. In such collections, two adjacent cores, 5-cm-deep, are taken from the corners and center of each

2 m square. Separate composites of the five cores are then made, and the composites are identified by successive numbers.

Water Sampling

At quarterly intervals, water samples from surface and groundwater sources in the Livermore Valley and at Site 300 are analyzed for gross alpha and beta radioactivity and for tritium content. These analyses are performed to determine if detectable changes in radioactivity have occurred.

Once each year, groundwater samples from the vicinity of the Livermore Water Reclamation Plant (LWRP) are analyzed for tritium. These analyses are performed to determine the extent (if any) of tritium migration to the groundwater from LLNL's sewage effluent.

Collection

Grab samples of surface sources such as ponds, creeks, and reservoirs are obtained with a tethered plastic pail. A 500-ml sample is collected for tritium analysis in an argon-flushed glass container fitted with a ground glass stopper. Samples for other analyses are collected in 500-ml polyethylene bottles.

Identification

As samples are collected in the field, they are labeled with the sampling location and date. In the laboratory, each sample is assigned the number that accompanies it during analysis.

Replication

During each sample collection period, at least 10% of the water samples are duplicates.

Sewage Sampling

Sewage from LLNL is discharged into the city of Livermore's sanitary sewer system. Radioactive or otherwise hazardous liquid wastes are first treated to reduce concentration levels to within applicable standards before they are released into the sanitary sewer. Sewage samples are collected from LLNL effluent, the treated effluent, and from the digester sludge at the Livermore Water Reclamation Plant.

Collection

LLNL Effluent

A 24-hr composite of LLNL sewage effluent is collected daily by a peristaltic pump that functions 9 seconds every 5 minutes to collect 13 liters daily. Aliquots of this composite are transferred to plastic bottles and are submitted for analysis.

LWRP Effluent

Daily composites of treated effluent from the LWRP are collected by LWRP employees. Aliquots of these composites are placed in 500-ml polyethylene bottles and are retained for weekly collection by LLNL.

LWRP Digester Sludge

Composites from both digesters at the LWRP are collected monthly. The composites consist of aliquots taken from the circulating sewage 3 times a week.

Identification

As each sewage sample is collected in the field, it is labeled with the sampling location and date of sampling. In the laboratory, each sample is assigned a number that accompanies it during analysis.

Replication

LLNL Effluent

Every Wednesday one replicate sample of LLNL effluent is taken for gross alpha, beta, and tritium analysis.

LWRP Effluent

One replicate sample of LWRP effluent is taken every Wednesday and is analyzed for gross alpha, beta, and tritium.

Vegetation Sampling

At quarterly intervals, samples of vegetation (usually native grasses) are collected throughout the Livermore Valley, at Site 300, and at off-site locations near Site 300. After these samples are freeze-dried, the tritium content of the recovered water is determined by liquid-scintillation counting.

Collection

Samples of vegetation are routinely collected from the same locations each sampling period. Grass samples are pulled up or cut close to the ground, and any soil is discarded. The bulk volume of these samples is usually between 0.5 and 1 liter. As each sample is collected, it is placed in a plastic bag and frozen in a dry-ice chest to minimize water loss on the bag's surface. Duplicate samples are collected at each location and are later transferred to a freezer in the laboratory.

Identification

Samples of vegetation collected in the field are labeled according to sample type and location. In the laboratory, each sample is assigned a number that accompanies it until the measurement is reported.

Replication

Two samples of vegetation are collected at each location in case the first sample is lost during analysis or the measurement is in question. At least one set of each group of samples collected is analyzed in duplicate to furnish replicate data.

Milk Sampling

Milk samples are obtained at monthly intervals or when available from three goat farms located about 5 km south and 5 km southeast of LLNL. One of these farms also provides cow's milk on occasion. A portion of each milk sample is freeze-dried, and the tritium content of the recovered water is determined by liquid scintillation. A 1-liter sample is preserved with formaldehyde and gamma-counted in a Marinelli beaker.

Air Analysis

Environmental air samples are analyzed for gross alpha and beta activity, plutonium, uranium, gamma-emitting radionuclides, and beryllium.

Gross Alpha and Beta Counting

After a 4-day delay to allow for decay of the radon-thoron daughters, all environmental radioactivity air filters are counted for alpha and beta activity. Counting is done in a Sharp gas-proportional counter using 20-minute counting periods. Normally, this counter is used only for environmental samples to avoid possible contamination.

Standards and Calibration

Separate ^{239}Pu and ^{90}Sr standards on 5-cm-diam stainless-steel planchets are used for determining alpha and beta counting efficiencies, respectively. These standards are traceable to NBS or to equivalent certification sources. Counting-efficiency measurements are made with each set of filters counted, and a background count is taken at the beginning of each run and between each set of 10 samples. Records are kept of background and counting-efficiency variations in the Sharp counter.

Gamma Spectrometry

Each week at sampling stations along the LLNL perimeter and at Site 300, air filters are placed together, sealed in a 214-cm³ aluminum can, and submitted for gamma analysis.

Plutonium and Uranium

The air filters are ashed and then dissolved in a mixture of nitric acid and hydrochloric and/or hydrofluoric acid (HF). Plutonium and uranium are then separated by an ion-exchange process. Plutonium is then further purified by ion exchange, electroplated onto a stainless steel disk, and submitted for alpha spectrometry. Uranium is further purified by ion exchange and submitted for analysis by mass spectrometry.

Beryllium

Every month half of each weekly LLNL-perimeter and Site-300 paper air filter is composited by sampling location. Two paper filters at a time are wet-ashed with a mixture of 80% nitric and 20% perchloric acid. The solutions are then evaporated to a few milliliters, taking care to prevent the samples from baking dry. After the samples are diluted with water, they are filtered, any residues are discarded, and the filtrates are diluted to 100 ml with deionized water.

Quantification is done by atomic absorption spectrophotometry with electrothermal atomization. Quality control includes a reagent blank with blank filters, a blank spiked with 200-ng Be, and several samples spiked with essentially carrier-free ^7Be .

Standards of 1, 2, and 5 $\mu\text{g/liter}$ are prepared by diluting an intermediate 1-ppm stock solution obtained from an NBS-traceable 1000-ppm stock dilution. The diluent in all cases is 1% HNO_3 in water.

Water Analysis

Environmental water samples are analyzed for gross alpha and beta activity, tritium, and beryllium.

Gross Alpha and Beta Activity

A 100-ml sample or less, depending on the solid content, is digested with a mixture of 80% HNO_3 and 20% HClO_4 and dried. The residue is taken up with HNO_3 and a few milliliters of H_2O_2 (5%). The solution is evaporated to about 5 ml and transferred to a 5-cm-diam serrated, stainless-steel planchet. After drying and flaming the planchet, the sample is counted for 30 min in a Sharp 3-1/4-in. proportional counter.

A blank is processed together with each set of samples.

Standards and Calibration

The ^{239}Pu and ^{90}Sr standards are used with every sample set (see similar entry under Soil Analysis). Background measurements are made between every 10 sample-counting measurements.

Tritium

Low-level samples are electrolytically enriched and then counted by liquid-scintillation spectrometry. Each counting set includes a total of eight standards to establish quench corrections and eight blanks for background determination.

Beryllium

A 100-ml sample is digested with HNO_3 . The residue is diluted to 100 ml with deionized water, and the analysis is completed using atomic absorption spectrophotometry, as described for air analysis.

Sewage Analysis

Sewage samples are analyzed for gross alpha and beta activities, tritium, plutonium, cesium, and selected metal ions. Except for tritium analyses, all sewage samples are wet-digested with a mixture of 20% HClO_4 and 80% HNO_3 . Those sewage samples for tritium analysis are distilled to reduce quenching before counting.

Gross Alpha and Beta Radioactivity

About 25 ml of an 80/20 mixture of HNO_3 and HClO_4 is added to a 500-ml aliquot (100 ml of LWRP effluent), and the mixture is heated to dryness on a hotplate. The residue is taken up in 10 ml HNO_3 and 5 ml H_2O_2 (5%). The volume is reduced to 3–5 ml on a hotplate, transferred to 5-cm-diam planchets, and counted.

Tritium

A 5-ml aliquot of sewage sample is added to 15 ml of Packard Instagel in a 25-ml screw-cap polyethylene bottle. Then, 15 ml of Instagel is used to prepare a background for the sample, and both are placed in the refrigerated detection chamber of the Packard scintillation counter for a 1-h temperature equilibration prior to counting. The sample and background are each counted for 100 min.

Plutonium

Plutonium is separated by co-precipitation with manganese dioxide (MnO_2). The manganese dioxide is then ashed and dissolved in nitric acid (HNO_3) and hydrogen peroxide (H_2O_2). Plutonium is purified by ion exchange, electroplated onto a stainless steel disk, and submitted for alpha spectrometry.

Cesium

Cesium is separated by ion exchange with *ammonium molybdophosphate* (AMP). The AMP crystals are transferred to a counting vial with concentrated hydrochloric acid (HCl), which is then submitted for gamma spectrometry.

Heavy Metals

Monthly composites of I.I.N.I. sewage effluent are analyzed for cadmium, chromium, copper, iron, lead, nickel, silver, aluminum, beryllium, and zinc.

A composite is prepared by combining daily samples of 500 ml, as follows: nitric acid (80%) and $HClO_4$ (20%) are added to the first 500-ml daily sample of the month, and the mixture is reduced in volume to about 100 ml. Each subsequent day, the daily sample is added and the total volume is reduced to about 100 ml. After the last 500 ml from the last day is added, the combined volume is reduced to about 50 ml. When cool, about 50 ml deionized water is added, and the liquid is filtered through No. 40 Whatman paper. The paper is then placed in a platinum crucible and digested with about 5 ml HF, 16 ml HNO_3 , and 4 ml $HClO_4$ to a residue of about 4-5 ml. Water is added and the liquid is refiltered. The residue is discarded. The filtrates are combined, transferred to a 100-ml volumetric flask, and brought to volume with deionized water. The metal content is determined with a Perkin-Elmer Model 5000 atomic-absorption spectrophotometer. The required standards are prepared by dilution of 1000-ppm, NBS-traceable stock solution.

Soil Analysis

Soil samples are analyzed for gamma-emitting radionuclides, plutonium, and uranium.

Gamma

The soils are dried at $110^\circ C$ for a minimum of two days, pulverized, passed through a 32-mesh sieve, blended, sealed in a 238-cm³ aluminum can, and submitted for gamma spectrometry.

Plutonium

The soil is leached by heating for four hours with a mixture of concentrated HNO_3 and HCl . The plutonium is then separated and purified by ion exchange and electroplating as described above.

Vegetation Analysis

Vegetation samples are analyzed for tritium by freeze-drying and analyzing the resultant water by either liquid scintillation spectrometry or gas proportional counting.

Milk Analysis

Milk samples are analyzed for tritium by freeze-drying and analyzing the resultant water by liquid scintillation spectrometry. Milk samples are also analyzed by gamma spectrometry: a direct count of 938 mL of milk preserved with 20 mL of formaldehyde placed in a Marinelli beaker.

Wine Analysis

Wine samples are analyzed for tritium by combustion in a Peterson furnace, which catalyzes the wine to CO_2 and H_2O . The resultant water is then analyzed by gas proportional counting.

Honey Analysis

Honey is analyzed for tritium by digesting the samples in a Parr Bomb followed by gas proportional counting.

Appendix H. Effects of the Chernobyl Accident on LLNL Environmental Monitoring Data

(Reprint from: *Nuclear Chemistry Division Annual Report UCAR-10062-86*)

Monitoring Radioactivity Fallout from the Chernobyl Nuclear Reactor Accident

J. M. Beiriger, K. V. Marsh, and R. A. Fallor

Following the accident at the nuclear reactor at Chernobyl, in the Soviet Union, we participated in three studies to evaluate the effects of the accident in the western United States. We intensified our local monitoring program by adding two air-sampling stations and accelerating our normal milk-sampling program. At the request of the Food and Drug Administration (FDA), imported foodstuffs were monitored. We worked with the University of Alaska at Fairbanks on rainwater and air-filter analyses. Increased levels of many radionuclides were found, but none at levels hazardous to the population.

Introduction

When the Chernobyl nuclear reactor accident was reported on April 29, 1986, the Environmental Quality Verification Program (EQVP) was expanded to evaluate the local effects of the accident. Although EQVP conducts an extensive environmental surveillance program,¹ we decided that increased monitoring of the local air and milk would be the most efficient way to obtain information about the local effects of the Chernobyl accident.

Air monitoring is done by pumping large volumes of air through filters that are changed weekly at a total of 22 sites around LLNL, the Livermore Valley, and Site 300. Gamma-emitting radionuclides are measured on these filters by low-background Ge(Li) gamma spectroscopy and the GAMANAL computer code.² Soon after notification of the reactor accident, we installed two additional air samplers so that our normal sampling schedule would not be compromised. Because the prevailing wind is west-southwest in May and June, one sampler was placed on the west perimeter of LLNL and another 1 mi south to assure that the activity measured was not affected by activities at LLNL or Site 300. The

samplers operated at an average flow rate of 400 L/min, and the air filters were changed three times per week.

As part of our normal monitoring program, we analyze goat's and cow's milk from farms in the Livermore Valley. Approximately 1 L of milk is counted in Marinelli beakers on low-background detectors and analyzed as described above. To determine how much radioactivity from Chernobyl was introduced into the local food chain, we accelerated our milk-sampling program from monthly to weekly.

Two organizations asked our assistance in their evaluations of the effects of the Chernobyl accident. The FDA requested that several types of vegetables that are imported from Europe for consumption in California be analyzed for gamma-emitting radionuclides. We also worked with the Geophysical Institute at the University of Alaska, in Fairbanks, to verify radionuclide concentrations in rainwater and samples from air filters.

Air and Rainwater Samples

In normal Livermore Valley air, we routinely detect ^7Be , ^{40}K , and ^{137}Cs by gamma-ray spectroscopy. ^7Be and ^{40}K are naturally occurring isotopes, but

low levels of ^{137}Cs occur primarily from long-term global fallout and fallout resuspension.¹ Following the Chernobyl accident, other isotopes not normally detected were observed in the air-filter samples. These were $^{103,106}\text{Ru}$, $^{129\text{m}},^{132}\text{Tm}$, ^{131}I , ^{134}Cs , ^{140}Ba , ^{212}Pb , and low concentrations of ^{99}Mo , ^{141}Ce , $^{110\text{m}}\text{Ag}$, and ^{125}Sb . All of these isotopes can be attributed to reactor by-products, although ^{212}Pb also occurs naturally.

In our calculations of the concentrations of the isotopes in air, we accounted for the decrease in the air flow rate caused by dust clogging, and for the decay of the short-lived isotopes on the filter during the collection period. Our calculations assumed a constant air concentration during the collection period. Most of the isotopes show a maximum concentration during the collection period of May 7 to May 9 (days 127 to 129 counted from January 1). This peak was followed by a regular damped oscillatory concentration pattern peaking every 6 to 7 d. However, our long collection periods

(2 to 3 d) make it difficult to determine accurate radionuclide deposition times.

Figure 1 shows these trends for ^{103}Ru , ^{131}I , and ^{137}Cs isotope concentrations vs the numerical day at the end of the collection period. To highlight the similarities in the time profiles of the concentrations, each isotope was given a different concentration scale. The same oscillatory trend and concentration level were also seen in air filters obtained near Fairbanks, Alaska.³ There was a direct correlation between the activity in the Alaskan air samples and our own samples.

Figure 1 also shows the radioactive decay of the maximum concentration (at day 129) of ^{131}I , ^{103}Ru , and ^{137}Cs . The decreases in concentrations of ^{131}I and ^{103}Ru appear to follow a trend that would be expected from radioactive decay plus a constant dilution and deposition rate. However, ^{137}Cs does not exhibit this behavior. The relative changes in ^{137}Cs and ^{131}I are nearly identical, which leads us to believe that the iodine and cesium are acting as one

Fig. 1. Variations of the concentrations of ^{137}Cs , ^{131}I , and ^{103}Ru in air. (Day 116, April 26, was the day of the accident at the Chernobyl nuclear plant.) To highlight the similarity in the data, each isotope is given a different maximum on the concentration axis. Units are atoms/ m^3 air. Also shown is the predicted value for pure radioactive decay of the maximum value detected for each isotope. ND = not detected.

Fig. 2. Variations of the concentration of ^{212}Pb in air, taken from two air-sampling stations. The early time profile for ^{212}Pb was similar to that for Chernobyl-related fission products. However, the late time concentrations were in excess of earlier values, indicating that there was no relation between the ^{212}Pb and Chernobyl.

chemical species, such as CsI. This conjecture is made plausible by the prediction that CsI could be formed in reactor fuel rods, but lack of data prevents its being tested.⁴

Figure 2 shows the high concentrations of ^{212}Pb that were detected in the air filters. ^{212}Pb occurs naturally as a member of the $4n$ decay series and could be present in large quantities in a reactor that converts thorium to ^{233}U (Ref. 4). The short half-life (10.6 h) of ^{212}Pb requires that the samples be counted soon after they are collected. We did so for the samples from our two post-Chernobyl air samples, but because this practice is not part of our routine sampling method, we are unsure of the normal background of ^{212}Pb and its parent isotopes for our area. Our attention was drawn to the similarity in the concentration profile of the ^{212}Pb and the other isotopes early in the sampling program (prior to days 135). Because of

the lack of background data, we were not sure whether these high values come from reactor debris or occur naturally.

We continued the air-filter sampling program after the fission products attributed to the Chernobyl accident (such as ^{131}I and ^{103}Ru) were no longer detected. The ^{212}Pb levels in the samples collected during this time were in excess of those measured in samples collected early in the sampling program (days prior to 135). We also recounted many of the samples to determine whether the ^{212}Pb was due to collection of a parent isotope, such as ^{232}U or ^{228}Th . The ^{212}Pb always decayed to a value below our detection limit, and in no case was there any evidence of a long-lived parent nuclide of ^{212}Pb . We therefore attribute these high ^{212}Pb values to ^{220}Rn emanations from ^{228}Th that naturally occurs in the soil and not to the accident at the Chernobyl nuclear plant.

In the weeks after the Chernobyl accident, only one rainfall in Livermore produced enough water for analysis. This rainfall occurred on May 5 (day 125), before fallout was detected in our air filters. We counted a May rainwater sample from Alaska that measured 30 pCi/L ^{131}I .

Milk Samples

Low levels of ^{40}K and ^{137}Cs (1.7×10^{-6} and $0.9 \times 10^{-9} \mu\text{Ci/mL}$, respectively) are normally detected in milk samples collected within 5 km of LLNL. However, following the Chernobyl accident, the milk samples contained ^{131}I , which is not normally detected. Figure 3 shows the ^{131}I concentrations vs the numerical day of collection. No elevated radionuclide concentrations were detected in milk samples until the week of May 14 (day 134). The ^{131}I concentrations diminished below the detection limits by the week of June 3 (day 154). No other isotope besides ^{131}I was detected above background values. The concentrations of ^{131}I in milk from farm No. 3 are higher probably because the goats obtain their food only by grazing, while the diets of the animals at the other farms are partially supplemented with stored food that would not have been contaminated with radioactive fallout.

Imported Food Samples

Because the radioactive cloud from the Chernobyl release was carried over northern Italy, the FDA monitored agricultural produce imported from there. To permit expedient release for local importers, personnel at the San Francisco FDA office asked LLNL to help them analyze samples of mushrooms and red endive. The mushrooms were of three types, Portobello, Brown, and Pleurotus, while the endive was a single sample. We divided all the samples into two parts for analysis. The mushroom samples were divided into duplicates, while the

Fig. 3. Concentrations of ^{131}I in milk as a function of collection day. ^{131}I was not detected before day 134 or after day 148. The dashed line shows the predicted ^{131}I decay.

endive was divided into one part consisting of outer and inner leaves and the other of inner leaves only.

Table 1 gives the results of all analyses. All the radionuclides we detected were below FDA limits for human consumption, although the ^{131}I concentration in the outer endive leaves was about one-half of the limit. The large variation in radionuclide concentrations among the mushroom samples most likely reflects different levels of contamination in the specific growing areas, but may indicate that different species have different concentration factors. The presence of contamination on only the outer leaves of the endive probably indicates external contamination directly from the atmosphere, rather than uptake through the soil. Finally, it is interesting to note that all the isotopes associated to be reactor by-products are in lower concentrations than the naturally occurring isotopes ^{40}K and ^{7}Be .

Summary

We began to detect elevated radionuclide concentrations in Livermore air-filter samples about 10 d after the April 26 accident at the Chernobyl nuclear plant. ^{131}I was detected in milk samples about 17 d

	⁴⁰ K ^b	⁹⁹ Mo	¹⁰³ Ru	^{129m} Tc	¹³² Te	¹³¹ I	¹³⁴ Cs	¹³⁶ Cs	¹³⁷ Cs	¹⁴⁰ Ba
Mushrooms ^c										
Portobello-1	—	—	123	—	123	153	—	—	—	—
Portobello-2	3469	11	175	—	103	182	54	9	107	64
Brown-1	—	—	—	—	—	—	—	—	—	—
Brown-2	3239	—	—	—	23	46	—	—	—	—
Pleurotus-1	3630	—	339	—	269	1526	—	—	305	—
Pleurotus-2	3553	—	425	216	267	1907	175	33	320	217
	⁷ Be ^b	⁹⁹ Mo	¹⁰³ Ru	^{129m} Tc	¹³² Te	¹³¹ I	¹³⁴ Cs	¹³⁶ Cs	¹³⁷ Cs	¹⁴⁰ Ba
Endive ^d										
Outer/inner	6465	—	1653	—	595	4419	633	104	1381	511
Inner only	—	—	—	—	—	—	—	—	—	—

^a Counting statistics give an uncertainty of $\pm 10\%$ on most values. — signifies below detection limits.

^b ⁴⁰K and ⁷Be are naturally occurring radionuclides. ⁷Be was not detected in mushrooms.

^c Concentrations in the mushroom samples are expressed as pCi/kg fresh weight as of 1200 PDT 5/9/86. Each replicate weighed about 200 g. Sample 1 of each variety was counted 1 h; sample 2 was counted 60 h.

^d Concentrations in the endive samples are expressed as pCi/kg fresh weight as of 5/12/86. Each replicate weighed about 100 g. Both samples were counted 16 h.

Table 1. Radionuclides in FDA samples.^a

after the accident. The radionuclide concentrations decreased with time through dilution, deposition, and radioactive decay. The radionuclide concentrations in air filters show a damped oscillatory trend that continued into June, while the ¹³¹I concentration in milk diminished below detection limits by the first week of June. The maximum ¹³¹I concentration in Livermore milk was 270 pCi/L, which is well below the acceptable FDA limit of 4000 pCi/kg for children and 8000 pCi/kg for adults. All the radionuclides that we detected in the endive and mushrooms imported from Italy were also below the FDA limits for human consumption. Air-filter data from

Alaska closely correlates with Livermore air-filter data.

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Deposition, Atmospheric Transport, and the Global Distribution of Cosmogenic Radioisotopes

R. C. Finkel*

Since the concentration of ^{10}Be in polar ice is affected by changes in both solar activity and the geomagnetic field, we can use this isotope to trace the history of geophysical parameters. Standard counting methods, however, are not sensitive enough to determine the low concentrations that such geophysical studies would typically involve. Instead, we are planning to apply the techniques of accelerator mass spectrometry (AMS) to such problems, using the AMS facility that is now being developed for LLNL's new FN tandem. For these studies of solar and geomagnetic activity to be successful, other processes that affect isotope concentrations—such as transport and deposition—must be taken into account.

Introduction

^{10}Be concentrations in Greenland snow allow us to trace past changes in such diverse geophysical parameters as solar activity, the flux of galactic cosmic rays, and geomagnetic field intensity. Studies at several sites have already demonstrated the potential usefulness of this isotope:

- Measurements made at two sites in Greenland, Dye-3 (Ref. 1) and Milcent (Ref. 2), have shown that solar modulation from the 11-y Schwabe sunspot cycle causes ^{10}Be concentrations to vary. This correlation permits us to study the history of the Schwabe solar cycle.

- At Camp Century, Greenland, the unexpected constancy of Holocene ^{10}Be concentrations³ suggests that we ought to reconsider archaeomagnetic evidence that the geomagnetic field has varied significantly over the past 7000 y.

- At Milcent, ^{10}Be concentrations in snow deposited around 1700 A.D. are elevated by about 50% as compared with earlier and later times.⁴ 1700 A.D. is roughly the time of the Maunder Minimum, a period when sunspots were almost totally absent. The elevated ^{10}Be concentrations confirm predictions

based on ^{14}C (another cosmogenic isotope) that decreased solar magnetic activity at this time caused a higher terrestrial cosmic ray flux (the solar magnetic field acts as a shield to cosmic rays).

The reliability with which geophysical conclusions can be drawn from ^{10}Be concentration measurements is compromised by other perturbing effects that make it difficult to establish direct connections between measured isotope concentrations and their production rates in ice. In studies of the 11-y Schwabe solar cycle, for example, neutron-monitor data clearly show that the cosmic ray flux in the atmosphere varies by about 30% over the entire cycle. Sunspot numbers and ^{10}Be concentrations at Dye-3 are well correlated between 1940 and 1980, but are only poorly correlated in the earlier part of the twentieth century.¹ To understand why this is so, it is necessary to consider all the parameters that can influence cosmogenic isotope concentrations in snow.

Production Rates

^{10}Be is produced by nuclear spallation of atmospheric oxygen and nitrogen.

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