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Environmental Monitoring at the Lawrence Livermore National Laboratory Annual Report 1987

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Manuscript date: April 1988

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EP

1 Lawrence Livermore National Laboratory	7 Vasco Road
2 Sandia National Laboratory	8 East Avenue
3 South Bay Aqueduct	9 Greenville Road
4 Arroyo Seco	10 Lupin Way
5 Arroyo Las Positas	11 Interstate 580
6 Nearest residential area	12 New Patterson Pass Road

Frontispiece. Lawrence Livermore National Laboratory (looking west).

Preface

This report is prepared for the U.S. Department of Energy by the Environmental Guidance and Monitoring Division 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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Contents

List of Figures	vii
Abstract	1
Summary	1
Introduction	4
Environmental Monitoring	4
The Laboratory and Adjacent Sites	4
The Livermore Site	6
Site 300	8
Environmental Monitoring—Methods and Results	12
Methods	12
Air Monitoring	12
Soil Monitoring	13
Sewage Monitoring	14
Routine Water Monitoring	17
Vegetation and Foodstuff Monitoring	19
Milk Monitoring	20
Environmental Radiation Monitoring	20
Noise Monitoring	24
Compliance Groundwater Monitoring	25
Results	25
Air Monitoring	25
Soil Monitoring	29
Sewage Monitoring	31
Routine Water Monitoring	31
Vegetation and Foodstuff Monitoring	32
Milk Monitoring	33
Environmental Radiation Monitoring	33
Noise Monitoring	33
Compliance Groundwater Monitoring	33
Environmental Impact of LLNL Operations	36
Radioactive Airborne Effluents	36
Radioactive Liquid Effluents	36
Nonradioactive Liquid Effluents	37
Groundwater Quality	38
Changes to the Environmental Monitoring Program	38
Deviations from the Sampling Program	38
Quality Assurance	38
Special Monitoring Assessments	39
Livermore Site Groundwater Project	39
Area West of LLNL	40
Southeast LLNL and Vicinity	40
Gasoline in Soil and Groundwater	41
East Traffic Circle Landfill and Taxi Strip/Old Salvage Yard Areas	41
EG&G Aerial Survey	41
TCE at Site 300	41
Underground Tank Testing	42
Tritium in Groundwater at Site 300	42
Burn Pit Operation	43
High-Explosives Wastewater Lagoons and Impoundments, Site 300	43
Permits and Environmental Evaluations	44
Air Permits	44
Groundwater Investigation	44
Liquid Waste Discharge	44

Solid Waste Landfills	44
Other Hazardous Waste Operations	44
Environmental Impact Report for Contract Renewal	45
Environmental Assessments	45
Citations and Agreements	45
Appendices	
Appendix A. Data Tables	47
Appendix B. Statistical Methods	97
Appendix C. Radiation Protection Standards	99
Appendix D. Sampling and Analytical Procedures for Environmental Monitoring at Lawrence Livermore National Laboratory	103
Appendix E. Discharge Limits to the Sanitary Sewer System of the City of Livermore	113
Appendix E. Methods of Dose Calculations	117
Appendix G. Deviations from the Sampling Program	123
Appendix H. Quality Assurance Plan	127
References	162

List of Figures

1. Estimated population distribution (in thousands) within 80 km of Livermore by sectors	5
2. Wind rose showing the average annual wind direction and speed during 1987	7
3. Approximate groundwater surface elevations (feet above mean sea level), 11 NE and vicinity	9
4. Topography and groundwater surface elevations, Site 300	11
5. Air sampling locations, Livermore site perimeter	12
6. Air-sampling locations, Site 300	13
7. Air-sampling locations, Livermore Valley	14
8. Soil-sampling locations, Livermore Valley	15
9. Soil-sampling locations, Site 300	16
10. Water sampling locations, Livermore Valley	17
11. Water-sampling locations, Site 300	18
12. Groundwater sampling locations, Livermore Valley	19
13. Stormwater-runoff sampling locations	20
14. Vegetation-sampling locations, Livermore Valley	21
15. Vegetation-sampling locations, Site 300	22
16. Locations of gamma and neutron dosimeters, Livermore site perimeter	23
17. Locations of gamma dosimeters, off site	24
18. Monitoring wells analyzed for water quality parameters, off site	26
19. Gross alpha and beta activity on air filters, Livermore site perimeter	27
20. Gross alpha and beta activity on air filters, Livermore Valley	27
21. Gross alpha and beta activity on air filters, Site 300	28
22. Concentration of beryllium on air filters: (a) Livermore site and (b) Site 300 and City of Tracy	30
23. Off-site gamma radiation background	34
24. Landfills and monitoring wells, Site 300	35

Environmental Monitoring at the Lawrence Livermore National Laboratory Annual Report 1987

Abstract

This report documents the results of the Environmental Monitoring Program at the Lawrence Livermore National Laboratory (LLNL) for 1987. To evaluate the effect of LLNL operations on the local environment, measurements were made of direct radiation and a variety of radionuclides and chemical pollutants in ambient air, soil, sewage effluents, surface water, groundwater, vegetation, foodstuff, and milk at both the Livermore site and nearby Site 300. This report was prepared to meet the requirements of Department of Energy Order 5484.1. Evaluations were made of LLNL's compliance with all applicable guides, standards, and limits for radiological and nonradiological releases to the environment. The data indicate that the only releases in excess of applicable standards were four releases to the sanitary sewer. LLNL operations had no adverse impact on the environment during 1987.

Summary

The Environmental Quality Verification Group (EQVG) at the Lawrence Livermore National Laboratory (LLNL) conducts an environmental monitoring program to verify the effectiveness of control measures and to assess the potential impacts to the environment resulting from LLNL operations. Potential hazardous emissions include tritium, plutonium, uranium metals, solvents, and common laboratory chemicals. This report, prepared in compliance with U.S. Department of Energy (DOE) Order 5484.1, presents the environmental monitoring data for the Livermore site and nearby Site 300, LLNL's high-explosives testing site.

To evaluate the impact of LLNL operations on the environment, measurements were made of direct radiation and a variety of radionuclides and chemical pollutants in ambient air, soil, surface and groundwater, vegetation and foodstuff, and sewage effluents. In addition, evaluations were made of LLNL's compliance with regulations, guides, and orders for environmental monitoring and concentrations of pollutants in environmental

media. Measurements and evaluations are summarized below.

Air Monitoring

All measurements of airborne pollutants at the Livermore site perimeter, Livermore Valley, and Site 300 sampling locations were well below regulatory limits in 1987.

Location 15 showed the highest annual average ^{239}Pu concentration at $1.00 \times 10^{-15} \mu\text{Ci/mL}$. This is approximately twice the highest annual average observed in 1986, but still represents only 0.05% of the regulatory limit. Location 15 also showed the highest annual average ^{238}U concentration at $1.03 \times 10^{-4} \mu\text{g/m}^3$, which is only slightly above the highest annual average observed in 1986. This value represents 0.03% of the regulatory limit. No gamma-emitting radionuclides were detected above background levels. Location 15 also showed the highest annual average concentration of beryllium at $5.1 \times 10^{-5} \mu\text{g/m}^3$.

which is slightly less than the highest annual average observed in 1986. This value represents 0.5% of the regulatory limit. Location 14 showed the highest annual average tritium concentration at 1.09×10^{-10} $\mu\text{Ci/mL}$. This value represents 0.09% of the regulatory limit and is approximately one-half of the highest 1986 value.

Gross radioactivity measurements are made for the purpose of screening and trending airborne radioactivity values. The gross alpha and gross beta values showed no significant trends in 1987.

The total amount of tritium released to the atmosphere by LLNL in 1987 was 2751 Ci, approximately 1329 Ci in the form of tritiated water. An additional 570 Ci of tritiated water were released by Sandia National Laboratories, Livermore (SNLL). The total quantity of ^{14}N - ^{15}O released in 1987 was 48 Ci at the Livermore site and 14 Ci at Site 300. The maximum off-site dose attributable to these airborne radioactive emissions was 0.08 mrem, which is far less than the Environmental Protection Agency (EPA) limit of 25 mrem/y.

Soil Monitoring

The concentrations of ^{239}Pu in the soil of the Livermore Valley are similar to those observed in previous years, with the exception of elevated values in samples taken at the Livermore Water Reclamation Plant (LWRP). The highest value of 526×10^{-6} $\mu\text{Ci/g}$ represents 4.2% of the proposed EPA soil standard for unrestricted use of 12×10^{-6} $\mu\text{Ci/g}$. 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 149 $\mu\text{g/g}$ is typical of previous years' data.

During 1987, a number of special assessments were performed that involved the analyses of soil samples. These assessments were done to investigate the contamination, if any, at Site 300 (landfills and an environmental test facility) and at LLNL (a gasoline tank leak, an inactive 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

Compliance Groundwater Monitoring

Some groundwater monitoring wells near landfills at Site 300 showed sharply elevated concentrations of tritiated water. The highest value measured was 4×10^{-4} $\mu\text{Ci/mL}$; this value is above the California Department of Health Services (DOHS) drinking water limit (State of California, 1977), but was found in an aquifer that is not used for water supplies. Traces of halogenated hydrocarbons were detected in wells downgradient of this area and in groundwater downgradient from another landfill at Site 300. The highest trichloroethylene value observed during routine monitoring in 1987 was 113 ppb in the Bldg. 817 area. Higher values have been observed in areas undergoing special investigations. Nitrate levels in 12 monitoring wells were above DOHS drinking water limits (State of California, 1977). These levels are thought to be naturally occurring.

During 1987, a number of special assessments were performed 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).

Routine Water Monitoring

The amount of tritiated water discharged into the sanitary sewer system in 1987 was 1.4 Ci. The discharge of ^{239}Pu was 6.9×10^{-4} μCi , a 46-fold increase over the amount released in 1986 but still less than 0.01% of the DOE annual discharge limit. The elevated ^{237}Pu was the result of an inadvertent release to the Livermore site sewer system during May 1987. The exact circumstances of the release are still under investigation.

Tritium analyses were also made on water samples collected from monitoring wells near the LWRP. These analyses, begun in 1977, are 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 (8.2×10^{-7} $\mu\text{Ci/mL}$) were detected in test wells downgradient from the LWRP near Arroyo Las Positas. Since the LWRP effluent has not been discharged to the Arroyo Las Positas since 1980, the primary means of tritium movement to nearby groundwater has been eliminated and the concentrations observed are generally decreasing. Tritium concentrations observed in local water supply wells in 1987 were generally the same as in previous years and reflect background levels of tritium.

Water samples collected in the Livermore Valley and at Site 300 exhibit gross beta and tritium activities within the ranges previously observed in these sampling areas. Six water samples from Site 300 showed above-average levels of gross alpha activity (32, 25, 21, 20, 18, and 7×10^{-9} $\mu\text{Ci/mL}$). This activity has been found to be naturally occurring uranium at concentrations well within those specified by DOE (U.S. Department of Energy, 1987a) and below the health advisory level recommended by the DOHS.

Vegetation and Foodstuff Monitoring

Tritium levels found in the Livermore Valley and Site 300 vegetation were generally comparable to those observed in 1986. Vegetation collected from a landfill area at Site 300 contained substantially higher levels of tritium (up to 2.84×10^{-5} $\mu\text{Ci/mL}$ of recovered water) than other areas, a phenomenon also recorded in 1985 and 1986. This area is under investigation for soil and groundwater tritium contamination, as described in the "Special Monitoring Assessments" section of this report.

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 comparable to those found in European wines, 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.

Environmental Radiation Monitoring

The maximum potential radiological impact from LLNL operations during 1987, as indicated

by off-site doses assessments, was well below all applicable regulatory limits; moreover, it was substantially less than the dose received from background radiation.

The 1987 average external gamma-radiation ("fence-post") doses measured at the Livermore site perimeter and off-site locations were 65 mrem and 64 mrem, respectively, indicating no significant difference between the average perimeter dose and the average off-site dose (which is considered to represent background). In addition, these doses are consistent with the 1986 results, which indicates there was no significant external dose to any member of the public in the vicinity of LLNL.

The annual average neutron dose at the Livermore site perimeter was 5.0 mrem. The neutron dose near the south perimeter showed slightly elevated levels for the second quarter of 1987, 5.7 mrem. This was caused by the operation of a 14-MeV neutron generator in Bldg. 212 during that time.

The maximum combined inhalation/submersion doses from airborne emissions at the site perimeter and to the nearest resident were 0.08 mrem and 0.06 mrem, respectively. This is well below the EPA's limit of 25 mrem/y for this pathway. The calculated committed (50-y) effective dose equivalent to the maximally exposed member of the public from all sources and pathways during 1987 was 0.3 mrem. The DOE radiation protection limit to the public is 100 mrem/y. For comparison, the average resident of the Livermore Valley received a dose of approximately 100 mrem from natural background radiation during this same time period. The estimated collective effective dose equivalent to the population within 80 km (50 miles) of LLNL was 0.52 person-rem during 1987.

The doses presented above were calculated using conservative assumptions; they are not the doses actually received by anyone. The doses received by any actual individual would be considerably less. Thus these maximum credible doses show that LLNL operations had no significant impact on the public during 1987.

Introduction

The Environmental Quality Verification Group (EQVG) at the Lawrence Livermore National Laboratory (LLNL) conducts an environmental monitoring program to verify the effectiveness of control measures and to assess the potential impacts to the environment and public resulting from operations at LLNL and, incidentally, from Sandia National Laboratories, Livermore (SNLL). Potential hazardous emissions include tritium, uranium, plutonium, metals, solvents, and common laboratory chemicals. Because of its proximity to the Livermore site and the extensive environmental monitoring program at LLNL, SNLL does not duplicate LLNL's program. This report presents the environmental monitoring data for both laboratories and Site 300; however, the radiological dose assessment, investigations, environmental assessments, and permitting activities have been performed for Livermore site and Site 300 emissions only.

Environmental Monitoring

Strict effluent-control programs that emphasize controlling effluents at the source have been in effect at LLNL and SNLL since operations began. The data collected by the EQVG are used for three purposes: (1) to assess the effectiveness of these control measures at the Livermore site, Site 300, and SNLL; (2) to assess compliance with applicable standards; and (3) to estimate 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, sewage effluent, vegetation, foodstuffs, and milk samples. In addition, 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 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 1987 environmental monitoring data. Radioactivity values are

tabulated with the associated counting uncertainties at the 2σ (95% confidence) level. See Appendix B for a discussion of the statistical methods used to calculate these data. The impact on the public caused by releases of radioactive materials in the vicinity of LLNL is assessed based on effluent discharges and measurements of environmental media. Doses are calculated at the points of maximum exposure in an area accessible to the public and to the total population residing within an 80-km (50-mile) radius of LLNL. Doses from natural sources are also reported for comparison. These doses are compared with radiation protection standards in Appendix C. This assessment is made for LLNL effluents only. The dose assessment and other detailed environmental information for SNLL are contained in the 1987 *Environmental Monitoring Report, Sandia National Laboratories, Livermore* (Devlin, 1988).

The Laboratory and Adjacent Sites

LLNL is located about 64 km (39 miles) east of San Francisco, California, in the Livermore Valley of eastern Alameda County, approximately 5 km (3 miles) east of the City of Livermore. SNLL is located adjacent to LLNL's southern boundary. Nearly 6 million people live within 80 km (50 miles) of LLNL (see Fig. 1); of these, approximately 54 000 live in Livermore.

LLNL, 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 require research in such basic scientific disciplines as 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 (HE) diagnostic work is conducted at Site 300, located in the sparsely populated hills of the Diablo Range, 24 km (15 miles) southeast of Livermore. Figure 1 shows the location of the Livermore site with respect to its surrounding areas. In 1987, LLNL employed approximately 8200 people.

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

SNLL 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 1987, SNLL employed approximately 1100 people.

LLNL and SNLL are separate facilities, with different DOE operations headquarters and different local management. Some of SNLL's monitoring data are included here because the two sites are adjacent and they conduct similar operations. The complete report of environmental monitoring data for SNLL is published in the *1987 Environmental Monitoring Report, Sandia National Laboratories, Livermore* (Devlin, 1988).

The Livermore Site

LLNL's Livermore site is 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 miles) long, east to west, and averages 11 km (7 miles) 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, which is 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.). Rainfall at the Livermore site for 1987 was 315 mm (12.4 in.). Previously, rainfall was calculated for a water year running from October 1 to September 30 of the following year. For simplicity, we are now reporting by calendar year. The last three months of 1986 (which were not included in the 1986 water year) had rainfall of 26.4 mm (1.04 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 Livermore site and SNLL include the South Bay Aqueduct, which runs from northeast to southwest, 0.2 km (0.1 miles) to the southeast of the Livermore site; the treatment tanks and reservoir of the Patterson Pass water treatment facility, about 1.2 km (0.7 miles) east of the Livermore site; Frick Lake, an area of enclosed drainage 4 km (2.4

miles) north of the Livermore site, 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 miles) northwest of the Livermore site. Lake Del Valle, a water storage reservoir 8 km (4.9 miles) south of the Livermore site, provides aquatic recreation (swimming, boating, and fishing), as does the Shadow Cliffs Regional Park, 11 km (6.7 miles) to the west. Lake Isabel, 9 km (4.9 miles) 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 the Livermore site and SNLL normally receive their treated water supply from the Hetch Hetchy Aqueduct (which supplies San Francisco), located 11 km (6.7 miles) 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 "Compliance Groundwater Monitoring" subsections and the "Special Monitoring Assessments" section of this report). More detailed discussions of these investigations can be found in Stone et al., 1982; Stone and Ruggieri, 1983; Carpenter et al., 1984; and Weiss Associates, 1985. The remainder of this subsection has been summarized from the reports of these investigations and from data supplied by Zone 7 of the Alameda County Flood Control and Water Conservation District, the agency responsible for groundwater management in the Livermore Valley basin.

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 Livermore Valley and is encountered beneath the Livermore 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

Livermore 10 meters 1987

Direction	Average annual percent frequency of wind direction vs. wind speed (m/s)									Average speed (m/s)
	0-2	2-3	3-5	5-7	7-9	9-11	11-16	16-20	>20	
N	1.4	0.4	0.8	0.8	0.6	0.2	0.0	0.0	0.0	4.3
NNE	1.3	0.8	1.1	0.4	0.2	0.0	0.0	0.0	0.0	3.9
NE	1.5	1.1	1.2	0.1	0.0	0.0	0.0	0.0	0.0	3.9
ENE	1.7	1.0	1.0	0.3	0.0	0.0	0.0	0.0	0.0	4.0
E	3.3	0.7	0.3	0.1	0.0	0.0	0.0	0.0	0.0	4.3
ESE	5.8	0.5	0.0	0.1	0.1	0.0	0.0	0.0	0.0	6.5
SE	3.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.9
SSE	2.0	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	2.4
S	2.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.7
SSW	2.6	1.0	0.6	0.2	0.0	0.0	0.0	0.0	0.0	4.4
SW	3.9	3.7	6.2	2.8	0.6	0.0	0.0	0.0	0.0	17.2
WSW	4.2	4.1	4.9	1.0	0.1	0.1	0.0	0.0	0.0	14.4
W	2.4	2.7	5.1	0.9	0.0	0.0	0.0	0.0	0.0	11.2
WNW	1.5	0.8	1.0	0.5	0.0	0.0	0.0	0.0	0.0	3.8
NW	1.5	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.9
NNW	1.4	0.2	0.3	0.2	0.1	0.0	0.0	0.0	0.0	2.2
Calm	—	—	—	—	—	—	—	—	—	9.1
Total	40.2	18	23	7.5	1.7	0.4	0.1	0.0	0.0	100.0

Winds are based on 15-min averages.

Figure 2. Wind rose showing the average wind direction and speed during 1987.

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. During 1987, approximately 10 million cubic meters (8500 acre-ft) of groundwater were extracted for domestic and agricultural use in the Livermore Valley. Most of this volume was pumped from municipal supply wells in Pleasanton and Livermore. In 1987, groundwater use represented approximately 27% 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 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 Livermore site, the depth to water table varies from about 43 m (140 ft) to 8 m (25 ft) according to observations during 1987. Figure 3 shows a contour map of water table elevations (feet above mean sea level) for April, 1987. 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 Livermore 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 flow under the northern and western portions of the site is generally westward. Under the southeast corner of the site, there is an apparent groundwater depression, a phenomenon that has been further investigated; a detailed description of findings to date is provided in Dresen and Nichols (1986). Aquifer tests on monitoring wells in the vicinity of the Livermore site 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 gradi-

ents, yields groundwater velocity estimates of 5 to 90 m/y. The range in these values reflects the heterogeneity typical of the more permeable of the alluvial sediments that underlie the area.

On the Livermore site, storm water is channeled through storm sewers designed to accommodate a 10-y 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 the site'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 Livermore site.

The combined sewage from the Livermore site 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 the San Francisco Bay. A small portion of the treated effluent from the LWRP is used for summer irrigation of nearby Livermore city property.

The developed portion of the Livermore site occupies an area of 2.54 km² (1.0 miles²); 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 miles²). The developed portion of the SNLL site occupies an area of 0.75 km² (0.2 miles²); additional lands are being acquired for security buffer zones on the east and west sides of the SNLL site. There is a business park to the southwest of the Livermore site and one to the north. Although 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 miles) from the west perimeter of the developed portion of the Livermore site.

Site 300

Site 300, LLNL's HE testing site, is located 24 km (15 miles) east of the Livermore site in the Altamont Hills of the Diablo Range. It occupies an area of

Figure 3. Approximate groundwater surface elevations (feet above mean sea level), Livermore site and vicinity.

30.3 km² (10.2 miles²). The topography of the site is irregular, with a series of steep hills and ridges oriented along a generally northwest/southeast trend; these hills and ridges are separated by intervening ravines. The elevation ranges from approximately 150 m (506 ft) at the southeast corner of the site to approximately 538 m (1750 ft) in the northwestern portion. The climate is generally similar to that at the Livermore site, 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 last three months of 1986 totaled 16.9 mm (0.69 in.). Rainfall for 1987 was 224 mm (9.15 in.). For the 15-y period from 1973 through 1987, the average rainfall was 266 mm (10.87 in.), with a maximum of 518 mm (21.16 in.) and a minimum of 145 mm (5.93 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; 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 and Panoche Formations that outcrop 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 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; and Buddemeier, 1985). 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, tending to follow 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).

Drinking and process 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 deep confined 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. Localized perched water-bearing zones have been identified adjacent to the 834 complex in the southeastern portion of Site 300 and in the vicinity of Bldg. 815 in the south-central portion of the site. The spring south of the HE Process Area wastewater impoundment is a groundwater outcrop of the Bldg. 815 perched water-bearing zone. 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 92 m (300 ft) 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 administrative area in the southeast corner of Site 300 is discharged to a lined pond for digestion and evaporation. Other facilities at Site 300 are served by septic tanks.

The Carnegie State Vehicular Recreation Area is located south of the western portion of Site 300. Adjacent to Site 300 to the east is an HE test facility operated by Physics International; a similar facility operated by SRI International is located approximately 1 km (0.6 miles) 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 miles) to the northeast.

Legend

- Fault:**
 - - - - - Dashed where inferred; dotted where concealed; queried where existence doubtful
 — 800 — Groundwater surface elevation contour

Figure 4. Topography and groundwater surface elevations, Site 300.

Environmental Monitoring—Methods and Results

Methods

Environmental monitoring samples are analyzed by LLNL or commercial laboratories. When applicable, Environmental Protection Agency (EPA) standard methods are used to collect and analyze the samples. If EPA standard methods are not available, LLNL develops its own procedures. Appendix D is a synopsis of those procedures.

Air Monitoring

Concentrations of various airborne radionuclides and beryllium are measured at the Livermore site perimeter, at off-site locations near the Livermore site, and at Site 300. Sampling locations are shown in Figs. 5 through 7. The six samplers on the Livermore site perimeter (Fig. 5), the eight samplers at Site 300 (Fig. 6), and seven of the off-site Livermore Valley samplers (Fig. 7) use

Figure 5. Air-sampling locations, Livermore site perimeter.

$5.2 \times 10^{-2} \text{ m}^2$ Whatman 41 cellulose filters. These samplers are operated at average flow rates of 400 to 1000 L/min. The filters are cut in half; one half of each filter is retained for beryllium analysis (as a monthly composite). An easily dissolvable filter and a low trace-metal background are required for these analyses. Whatman 41 represents a balance between such requirements and particulate-collection efficiency (Lindeken et al., 1963). The remaining off-site samplers (Fig. 7) use $8.11 \times 10^{-3} \text{ m}^2$ glass-fiber filters (Flanders F-700) and are operated at a flow rate of 85 L/min. All air filters are changed weekly.

After a four-day delay for decay of the radon-thoron daughters, gross alpha and beta activities on the filters are determined with an automatic gas-flow proportional counter. Monthly composites of Livermore site perimeter and Site 300 filters are also counted for gamma-emitting radionuclides using low-background Ge(Li) detec-

tors. Following gamma counting, the site perimeter filters from individual locations and the Site 300 composites are analyzed for the presence of ^{239}Pu , ^{235}U , and ^{238}U . Selected off-site samples from the Livermore Valley and the City of Tracy are analyzed for ^{239}Pu .

Concentrations of airborne tritium are determined for each of the Livermore site perimeter air-sampling locations, off-site locations S1 and S2, and four additional Livermore Valley locations. Water vapor is collected on silica-gel samplers operated at a flow rate of about 0.7 L/min for a two-week period. The collected water is recovered by freeze-drying, and the tritiated water is measured by liquid-scintillation counting.

Soil Monitoring

An intensive soil-sampling program conducted in 1971 and 1972 provided a data base for the concentration ranges of various radionuclides

Figure 6. Air-sampling locations, Site 300.

Figure 7. Air-sampling locations, Livermore Valley.

in soil near the Livermore site and at Site 300. Since 1972, soil sampling in the vicinity of the Livermore site and at Site 300 has been part of a continuing LLNL monitoring program to document any changes in environmental levels of radioactivity that have occurred and to evaluate any increase in radioactivity that might have resulted from LLNL operations. As in previous years, a group of soil samples was collected at sites selected at random from the list of Livermore Valley locations sampled in the 1971-1972 study. Figure 8 shows the 1987 soil-sampling locations in the Livermore Valley, and Fig. 9 indicates the locations at Site 300. Eleven of the Site 300 soil samples were collected from locations that have been sampled annually since 1973. In 1986, two additional sample locations were added in drainage channels where surface runoff might be expected to concentrate suspendable particulate material.

All samples are collected to a depth of 5 cm. After collection, the samples are dried, ground, and blended. Plutonium-239 content is determined in each sample following an acid-leaching procedure. For gamma-spectra analysis, approximately 300-g aliquots of the soils are sealed in 200-cm³ thin-walled cans of aluminum and counted with a Ge(Li) detector.

Sewage Monitoring

The Livermore site discharges approximately 400 000 gal per day of wastewater to the City of Livermore sewer system. This wastewater contains sanitary sewage and industrial effluent from both LLNL and SNLL. The wastewater is controlled to minimize contamination. A small amount of the effluents from LLNL buildings exceeds permissible pollutant levels and is treated to reduce pollutants to the lowest levels practical and below applicable standards. Radioactive materials in the waste are reduced to levels well below DOE and LWRP discharge limits (U.S. Department of Energy, 1987a). An on-line monitoring system and flow proportional sampler are located at the outfall from the Livermore site. The effluent is continuously monitored for pH, selected metals, and radioactivity. If warning levels are exceeded, an alarm is registered at the LLNL Fire Dispatchers Station, which is manned 24 h a day. A sanitary sewer spill plan and a trained response team have been established to minimize effects of a spill should one occur. The monitoring system provides a continuous check on waste control. It also provides an alert mechanism that is triggered if waste is discharged above set limits.

Figure 8. Soil-sampling locations, Livermore Valley.

LLNL is in the process of upgrading the existing liquid effluent outflow monitoring system to allow more accurate assessment of many of the parameters of concern. In addition, LLNL is evaluating a system of satellite monitoring stations and a diversion structure to operate in conjunction with the sewer monitoring system. The diversion system would help to ensure that wastewater triggering an alarm is retained at LLNL for evaluation and disposal. The satellite monitoring stations would be positioned in the outflow lines of those buildings with historical records of accidental releases. They would not monitor the full range of parameters, but only those pertaining to the building or facility being monitored.

A representative fraction of the total waste stream is collected by a flow proportional sampler

and composited over a 24-h period. These samples along with grab samples from the LWRP effluent are collected daily. The daily composite samples are analyzed for gross alpha, gross beta, and tritium activity. Samples of the Livermore site and LWRP effluent are also each combined to form a monthly composite for ^{137}Cs , ^{239}Pu , and heavy metal analyses. The LWRP digesters are sampled monthly and analyzed for gross radioactivity and heavy metals; they are also sampled quarterly for plutonium analysis. In addition, samples of the LLNL sewage effluent are collected quarterly and analyzed for parameters specified on LWRP's National Pollutant Discharge Elimination System permit. Discharge limits imposed by the City of Livermore are shown in Appendix E.

Figure 9. Soil-sampling locations, Site 300.

Figure 10. Water-sampling locations, Livermore Valley.

Since February 1980, the LWRP 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 to irrigate 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 from the LWRP.

Routine Water Monitoring

This subsection describes the ongoing monitoring program for surface and domestic water in the vicinity of the Livermore site and at Site 300. Expanded water-quality monitoring efforts are described in the "Compliance Groundwater Monitoring" subsections; 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, 15, 16, 23, 24, 26, and 29 are surface water sources (ponds, creeks, aqueducts, or reservoirs). Location 20 is the rainfall collection site for the Livermore site. The other six locations are domestic water supply wells. Site 300 water samples (Fig. 11) were collected from on-site wells (locations 1 through 6 and 22, 24), off-site wells (location 23), and two off-site creeks (locations 7 and 14). Location 21 is the Site 300 rain gauge, and location 29 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, a small fraction of treated effluent from the LWRP is used to irrigate nearby municipal property. This effluent contains low levels of tritium that come from normal LLNL

Figure 11. Water-sampling locations, Site 300.

Fig. 12. Groundwater-sampling locations, Livermore Valley.

and SNLL 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 LWRP; however, additional samples were also collected from areas at some distance away. Locations sampled during 1987 are shown in Fig. 12.

Beginning in 1975, LLNL's Environmental Monitoring Program was expanded to include surface runoff monitoring. The program 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, radioactivity, 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 of the rain

season. Station 1 is the influent to the east side of the Livermore site 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 that collects surface drainage from the southeast area of the Livermore site; and station 6 is the Arroyo Seco channel effluent at the western boundary of the Livermore site buffer zone (Vasco Road). No storms created sufficient runoff for sampling during the spring of 1987. Therefore, only data for runoff during the fall of 1987 are presented.

Water samples from 22 locations surrounding Site 300 were collected during the spring and summer of 1987 and analyzed for the DOHS drinking water parameters (State of California, 1977). This analysis was designed to characterize the general water quality (both surface and groundwater) of the area around Site 300.

Vegetation and Foodstuff Monitoring

Vegetation samples are collected quarterly at locations in the Livermore Valley (Fig. 14) and at

Figure 13. Stormwater-runoff sampling locations.

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 1987 were analyzed for tritium. The wine samples were vacuum-distilled and analyzed by liquid-scintillation counting. Because of a laboratory instrument malfunction, the wines could not be analyzed with the usual procedure, which consists of oxidizing the wine to water and carbon dioxide, then measuring the water by gas proportional counting.

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

Milk Monitoring

During 1987, goat-milk samples were obtained from five farms within about 5 km of the

Livermore site. Three of these farms produced milk only during the spring, and are no longer producing milk. 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 1-L aliquot was gamma counted in a Marinelli beaker on a Ge(Li) system.

Environmental Radiation Monitoring

External dose rates from penetrating radiation (primarily gamma rays) are measured at 22 Livermore site perimeter locations (Fig. 16) and 55 off-site locations (Fig. 17). These measurements are made with thermoluminescent dosimeters (TLDs) using previously published procedures (Lindeken et al., 1975). The TLDs contain two types of phosphors: $\text{CaF}_2:\text{Dy}$ (Harshaw TLD-200) and LiF (Harshaw TLD-700). The TLD chips are housed in a plastic holder 350 mm in diameter and 3 mm thick, and are held in place by a thin

Figure 14. Vegetation-sampling locations, Livermore Valley.

Figure 15. Vegetation-sampling locations, Site 300.

Figure 16. Locations of gamma and neutron dosimeters, Livermore site perimeter.

Figure 17. Locations of gamma dosimeters, off site.

plastic cover. The dosimeters are mounted in the field on existing structures (such as fence lines) at approximately 1 m above ground level. The dosimeters are exchanged quarterly.

The TLDs measure environmental radiation exposure rates in milliroentgens (mR). The exposure rates are converted to dose equivalent units (mrem) to compare with existing dose standards. Throughout this report, the conversion factor relating mR to mrem in a beta/gamma radiation field is assumed to be 1.0.

The TLDs measure radiation exposure from all sources of penetrating radiation. These include natural sources, fallout from nuclear weapons testing, as well as any contribution from LLNL. Off-site dosimeters are located in areas where access to the general public is not restricted. These areas are considered background and are used for comparison with the perimeter dosimeters.

LLNL is in the process of changing the TLDs from the Harshaw to a Panasonic UD 814 that employs thulium-activated calcium sulfate phosphor.

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

Noise Monitoring

As noted earlier, LLNL's HE open-air 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 at least twice each day, a limit is set on the weight of HE

that can be detonated without impact in populated areas. To monitor this limit, five microbarograph sensors are maintained in or near the City of Tracy because Tracy is in the direction of the prevailing winds.

Compliance 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 Trichloroethylene (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 as well as routine compliance monitoring around landfill and wastewater surface impoundment units, as required by the California Regional Water Quality Control Board (CRWQCB), Central Valley Region, and the EPA. The latter program is described below.

In the vicinity of Site 300 landfills, groundwater monitoring is regulated by the 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 Title 40, Part 265.92, of the *Code of Federal Regulations* (Office of the Federal Register, 1986a). At Pit 7, eight monitoring wells are sampled quarterly for purgeable priority pollutants (pursuant to 40 CFR 265.92), lead, beryllium, gross alpha, gross beta, and tritium. Pit 7 wells also provide monitoring for inactive landfills 3, 4, and 5.

Groundwater from wells that monitor Pits 2 and 8 is also analyzed as described for Pit 7, as well as for nitrate, nitrite, ammonia, and total kjeldahl nitrogen. Wells K2-04, K2-04S, and K2-04D were sampled during the fourth quarter of 1987; the results of the analysis are included in this report. Well NC2-07, located at the site's western boundary, is the most downgradient monitoring point for Pits 2, 3, 4, 7, and 8. This well is analyzed quarterly for tritium and semiannually for gross alpha, gross beta, and purgeable priority pollutants.

Pit 6 is monitored for drinking water parameters, groundwater quality parameters, and indicators of groundwater contamination, as specified in Title 40, Part 265.92, of the *Code of Federal Regulations* (Office of the Federal Register, 1986a), because records indicate that waste, including capacitors

suspected to be contaminated with polychlorinated biphenyls (PCB), beryllium, mercury, miscellaneous chemicals, and other potentially hazardous wastes were buried in this pit between 1964 and 1973.

In 1985, the Central Valley Region of the CRWQCB 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 nonhazardous HE process wastewater and photo rinse water. Samples from four wells are analyzed quarterly for pH, total organic halides (TOX), total organic carbon (TOC), specific conductance, several explosives compounds (HMX, RDX, nitrate, nitrite), purgeable priority pollutants, and metallic elements. Quarterly, an attempt is made to sample the five lysimeters underlying the surface impoundments. If water is present, it is analyzed for HE compounds.

As part of the special assessments studies at Site 300, a monitoring network was established in the southeastern area of the site. These wells are sampled on a quarterly or monthly basis for volatile organic compounds (VOCs) using EPA method 601. This network is described in more detail in the section titled "Special Monitoring Assessments."

Site 300 has eight standby wells that are, or have been, used for the production of drinking water. Only three are currently being used for production. Quarterly samples from these wells are analyzed for gross alpha, gross beta, tritium, chromium, copper, lead, beryllium, and purgeable priority pollutants. The radiological analyses are considered to be part of the "Routine Water Monitoring" Program and are discussed earlier in the subsection by that name.

As described in the "Special Monitoring Assessments" section, numerous wells were installed as part of the LLNL Groundwater Project. As these new wells were installed, water samples were collected and analyzed for the DOHS primary drinking water standards (State of California, 1977) and for organic compounds identified by EPA method 624/625. Well locations are shown in Fig. 18.

Results

Air Monitoring

Airborne Radioactivity. Figure 19 shows airborne gross alpha and gross beta activities for the Livermore site perimeter. Figure 20 shows these activities for the Livermore Valley, and Fig. 21

Figure 18. Monitoring wells analyzed for water-quality parameters, off site.

Figure 19. Gross alpha and beta activity on air filters, Livermore site perimeter.

Figure 20. Gross alpha and beta activity on air filters, Livermore Valley.

Figure 21. Gross alpha and beta activity on air filters, Site 300.

shows them 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 DOE. LLNL collects these data to ensure that releases of radionuclides other than those specifically analyzed for (see below) will be detected and to identify trends in the LLNL environs. The values reported are similar to those observed in 1986. Gross alpha and gross beta values show no significant differences between samples taken at Site 300, the Livermore site perimeter, and Livermore Valley. 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 uranium and thorium and their decay products.

Tables A-1 and A-2 list the activities of selected gamma-emitting radionuclides that normally contribute to the gross beta activity in the Livermore site perimeter and Site 300 samples. Of the nuclides tabulated, ⁷Be and ⁴⁰K are naturally occurring. The primary source of the ¹³⁷Cs 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 ²³⁹Pu, which could be 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 by releases such as the Chernobyl accident. In addition to providing baseline data on global fallout, analysis of these fission products enables LLNL to monitor the containment of the small inventories of mixed fission products and radiochemical tracers used at the Laboratory.

Table A-3 shows the concentration of plutonium on air filter samples collected in Tracy and the Livermore Valley. Tables A-4 and A-5 show the concentrations of airborne ²³⁹Pu, ¹³⁷Cs, ²³⁸U, and ²³⁸U (depleted uranium) in the Livermore site perimeter and Site 300 air samples, respectively. Location 1 at the southeast corner of the Livermore site showed slightly higher concentrations of plutonium in air than the other sample locations. The highest monthly sample was collected during May at location 15. This concentration of 10.85×10^{-17} μCi/mL represents 0.5% of the DOE derived concentration guide value (U.S. Department of Energy, 1987). No other significant differences between locations or samples were noted, and the overall levels determined were essentially the same as those reported in 1986. Small quantities of ²³⁸U are used at Site 300; in years previous

to 1986 and in 1987, higher concentrations of this nuclide were observed at Site 300 than at the Livermore site perimeter. The 1986 ratios $^{235}\text{U}/^{238}\text{U}$ showed very little deviation from the concentration in natural uranium. The $^{235}\text{U}/^{238}\text{U}$ ratios for two months of 1987 show significant deviations from the natural ratio, indicating the presence of depleted uranium from Site 300 operations. The measured concentrations of ^{238}U are well below the derived concentration guides (U.S. Department of Energy, 1987a).

Table A-6 shows the average biweekly tritiated water-vapor concentrations observed at each sampling location; the overall annual average concentration was $7.0 \times 10^{-11} \mu\text{Ci/mL}$ at the Livermore site perimeter. The highest biweekly concentration occurred in January and was observed at location 2. This concentration, $85.3 \times 10^{-11} \mu\text{Ci/mL}$, is 0.9% of the DOE standard. Location 14 showed the highest annual average concentration, $10.9 \times 10^{-11} \mu\text{Ci/mL}$. These values were generally similar to those reported in other years, except for slightly elevated concentrations at ten locations between January and May.

Elevated tritium values were first observed in the routine analysis of data from September through December 1986. Tritium concentrations in early fall were elevated, then decreased until the last two weeks in December, when tritium levels peaked. The highest concentration for 1986 and 1987 was reported during this period at Livermore site perimeter location 14 at $4480 \times 10^{-12} \mu\text{Ci/mL}$, 2.2% of the DOE derived concentration guides (Department of Energy, 1987b). Similarly high values were reported at perimeter locations 14 and 15 in that same period. Concentrations of tritium in the first part of 1987 were elevated, but showed a generally decreasing trend until May of 1987, when they reached normal levels.

An investigation of these tritium elevations showed that tritium in vegetation data corroborated tritium in air data, as four locations in the first quarter of 1987 showed values ranging from 3.2 to 20.4 times the peak values reported in 1986 (see the subsection titled "Vegetation and Foodstuff Monitoring"). The locations with the highest values were in the same vicinity as the air samplers showing the highest concentrations. Sample locations showing the highest concentrations were also in the path of the most prevalent wind through the Livermore site and SNLL. A re-analysis of samples showing the highest concentration confirmed the initial values, and discussions with the technical staff ruled out any possibility of sample contamination. The tritium quality-assurance data

collected for the tritium monitoring program were evaluated by the EQVC Quality Assurance Program coordinator and were judged as generally good. Thus, this portion of LLNL's investigation indicated that the tritium elevation was real.

Stack emission data from tritium-using facilities at the Livermore site indicated no unusually large releases of tritium during the periods showing the highest values. SNLL also indicated that no unusual releases had occurred. LLNL's investigation revealed no other facilities in the area likely to be using large quantities of tritium. In summary, LLNL measured a significant increase in environmental tritiated water levels, most likely the result of a large release of tritiated water vapor whose source could not definitely be attributed to LLNL or SNLL operations.

Beryllium in Air. Tables A-7 and A-8 show average monthly concentrations of airborne beryllium for the Livermore site perimeter and Site 300 (including the City of Tracy) sampling locations. The concentrations, which average less than 1% of the ambient concentration limit established by the Bay Area Air Quality Management District and the San Joaquin County Air Pollution Control District, can be attributed to resuspension of surface soil containing naturally occurring beryllium. Local soils contain approximately 1 ppm of beryllium, and Livermore's air typically contains 10 to 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 airborne 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-7 and A-8. The monthly airborne beryllium concentrations for the Livermore site, Site 300, and the City of Tracy are plotted in Fig. 22.

Soil Monitoring

Table A-9 presents data on the concentrations of ^{239}Pu , ^{40}K , ^{137}Cs , ^{232}Th , and ^{238}U in soil at the Livermore Valley sampling locations. The rationale for including the naturally occurring nuclides (^{40}K , ^{232}Th , and ^{238}U) and the long-lived fission product (^{137}Cs) has been presented above in the subsection "Airborne Radioactivity." The concentrations and distributions observed are within the ranges reported in previous years. Elevated levels of ^{239}Pu were first observed in soils near the LWRP during the early 1970s.

Table A-10 shows the ^{239}Pu , ^{40}K , ^{137}Cs , and ^{238}U activities in the Site 300 samples. Because HE tests

Figure 22. Concentration of beryllium on air filters: (a) Livermore site and (b) Site 300 and the City of Tracy.

at Site 300 occasionally 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 et al., 1986; Gudiksen et al., 1973; and Holland et al., 1987). 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. The concentrations of tritium (as tritiated water), ^{137}Cs , and ^{239}Pu measured in the sanitary sewer effluent from LLNL and LWRP are presented in Table A-11. During 1987, there were no inadvertent releases of radioactive materials to the sanitary sewer system that exceeded any discharge limits. The annual average concentration of tritium in the LLNL sanitary sewer effluent was $2.3 \times 10^{-6} \mu\text{Ci/mL}$, about 0.02% of the DOE allowable discharge limit to a public sewer system. The annual average ^{137}Cs concentration of $5.2 \times 10^{-10} \mu\text{Ci/mL}$ is only 0.003% of the DOE discharge limit. The concentrations of tritium and ^{137}Cs remain generally consistent with those observed during 1986.

Elevated levels of ^{239}Pu were observed in the LLNL sanitary sewer effluent starting in May, decreasing to near average levels by the end of 1987. The annual average ^{239}Pu concentration in the sanitary sewer was $1.1 \times 10^{-9} \mu\text{Ci/mL}$, about 0.008% of the DOE allowable discharge limit. This represents a 37-fold increase over the 1986 average, but is still well within health and safety standards. Correspondingly, elevated ^{239}Pu levels were observed in effluent and sludge at the LWRP (see Table A-11). The unusually high ^{239}Pu levels are discussed further in a subsequent section, "Environmental Impact of LLNL Operations."

On August 4, 1987, 11 000 L of liquid waste containing small amounts of the radionuclides ^{182}Ta , ^{95}Zr , and ^{95}Nb were released to the sanitary sewer system, causing a radiation alarm at the LLNL sewer monitoring station. The highest concentrations of ^{182}Ta , ^{95}Zr , and ^{95}Nb measured in the waste stream were 2.8×10^{-6} , 1.2×10^{-6} , and $2.1 \times 10^{-6} \mu\text{Ci/mL}$, respectively. The DOE discharge limit to a public sanitary sewer system is 1×10^{-4} , 2×10^{-4} , and $3 \times 10^{-4} \mu\text{Ci/mL}$ for ^{182}Ta , ^{95}Zr , and ^{95}Nb , respectively. The entire release was less than 3% of the limit and well

within LLNL guidelines. These radionuclides were not detected by the routine analysis performed prior to a release from a retention tank to the sewer system. More routine analyses are now performed to prevent further occurrences of this nature.

Nonradioactive Pollutants in Sewage. The monthly average metal concentrations in the LLNL sanitary sewer effluent are listed in Table A-12. The results of quarterly monitoring for metals and other physical and chemical characteristics of the sanitary sewer effluent are provided in Table A-13. These tables present the average concentration of various parameters and reflect LLNL's usual compliance with the City of Livermore ordinance (Appendix E).

LLNL also has a monitoring alarm system that automatically collects sewer effluent samples if preset warning levels are exceeded. Four such excursions occurred in 1987. Personnel at the LWRP were notified of each of the events before the material reached the plant. During two of the events, they chose to divert the influent as a precaution, but returned both diversions to the treatment plant waste stream when metal concentrations were confirmed to be normal.

Routine Water Monitoring

Radioactivity in Water. Tables A-14 and A-15 show the gross alpha activities in Livermore Valley and Site 300 water samples. Gross beta activities for Livermore and Site 300 samples are shown in Tables A-16 and A-17. Gross alpha and beta activities in these surface and domestic water samples collected in 1987 were below EPA and DOHS standards for drinking water (U.S. Environmental Protection Agency, 1977; State of California, 1977). Location 4, a well near the Site 300 entrance, showed an elevated gross alpha concentration of $20 \times 10^{-9} \mu\text{Ci/mL}$ during the first quarter and $25 \times 10^{-9} \mu\text{Ci/mL}$ during the third quarter. Location 3, another well near the entrance to Site 300, showed a value of $21 \times 10^{-9} \mu\text{Ci/mL}$ during the third quarter. Location 5, also a well near the Site 300 entrance, showed a value of $32 \times 10^{-9} \mu\text{Ci/mL}$ during the third quarter. Location 21, an on-site creek, showed an elevated gross alpha level of $7.2 \times 10^{-9} \mu\text{Ci/mL}$ during the third quarter. Similar observations in the past have been traced to the natural uranium content of the groundwater. The DOHS recommends an action level of $10 \times 10^{-9} \mu\text{Ci/mL}$ and a health advisory level of $40 \times 10^{-9} \mu\text{Ci/mL}$ for natural uranium in drinking water. In the DOHS limit for gross alpha activity, uranium is specifically excluded from the total. The uranium concentrations

(6×10^{-7} $\mu\text{Ci/mL}$) were well within those specified by DOE (U.S. Department of Energy, 1987a) and below the health advisory level recommended by DOHS.

Stormwater samples were collected at four locations during a major rain early in March: the influent to the Livermore site, effluent to the Arroyo Las Positas, SNLL effluent to the Arroyo Seco, and the Livermore site effluent to the Arroyo Seco. The samples were analyzed for gross alpha, gross beta, tritiated water, and various physical and chemical pollutants.

Table A-18 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 highest tritium value was 1.85×10^{-5} $\mu\text{Ci/mL}$ measured at location 5, which is the outfall to Arroyo Seco, near the southwest corner of LLNL. This is a small fraction of the DOE derived concentration guide limit.

Tables A-19 and A-20 show the tritium data for the Livermore Valley and Site 300 samples, respectively. The samples have concentrations that are well below recommended concentration guide values. The highest concentration of tritium in water, 36.3×10^{-7} $\mu\text{Ci/mL}$, occurred in the Livermore Valley rain (location 20) that was collected during January. This represents 0.2% of the concentration guide and 20% of the permissible concentration specified by the DOHS for drinking water (State of California, 1977).

Tables A-19 and A-20 also include an estimate of the annual (effective) 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 L/day and the dose-conversion factors contained in ICRP 30 (International Commission on Radiological Protection, 1980). The actual dose (if any) from these water sources would be considerably less since they are not used as drinking water sources. Methods used to calculate doses are presented in Appendix F.

Data for VOCs and metals from the production wells at Site 300 are covered under the "Compliance Groundwater Monitoring" results subsection of this report, as these wells fall under both sampling regimes.

Results from off-site water monitoring in the vicinity of Site 300 are presented in Table A-21. There are no indications of impacts attributable to Site 300 operations. Most samples were brackish, which is consistent with the marine origin of the

Altamont hills. Ten samples had nitrate levels in excess of the 10-mg/l. maximum contaminant level (MCL) specified by the DOHS (State of California, 1977). In addition, one sample had lead and one sample had gross beta levels in excess of MCLs. LLNL believes the gross beta and nitrate to be of natural origins. The lead may be of natural origins, or it may be an artifact of well equipment installation.

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-22. The highest tritium values appear in wells downgradient of the LWRP. These wells are used to monitor the groundwater quality in the vicinity of the LWRP, and are not used as drinking water sources. 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 (1977). The tritium levels in these wells are similar to those observed in the 1986 samples.

In accordance with the 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 because no runoff was generated from the landfill sites.

Pollutants in Storm Runoff. Most potential pollutants in the storm runoff were not present at detectable levels. Of those species with measurable concentrations, none exceeded the permissible concentrations set forth in the State of California's regulations for public water supplies (State of California, 1977). 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-23.

Vegetation and Foodstuff Monitoring

Table A-24 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 0.08 mrem/y.

Table A-25 shows the 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 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 13) was $3.9 \times 10^{-5} \mu\text{Ci/mL}$. The calculated annual average dose from vegetation at this location is 0.3 mrem, using the conservative pathway modeling assumptions. In actuality, this dose would never be received since vegetation at Site 300 is neither consumed directly nor used for grazing livestock. This tritium is further described in the "Special Monitoring Assessments" section of this report.

The data in Table A-26 represent the analyses of wine samples purchased in 1987. 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. The average tritium level of the Livermore Valley wines was somewhat above that of the European wines sampled, but the ranges overlapped considerably. The levels of tritium measured in Livermore Valley wines represent no health concern.

The data in Table A-27 show that the tritium content of Livermore Valley honey samples is not significantly different than that of honey from neighboring areas.

Milk Monitoring

The activities of ^{137}Cs , ^{40}K , and ^3H in goat-milk samples collected this year are shown in Table A-28; no other nuclides were present at detectable levels. The highest concentration of tritium in milk was $4.3 \times 10^{-7} \mu\text{Ci/mL}$. 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 L/y and on the models previously referenced. The dose resulting from ^3H (Table A-28) was calculated using dose factors from ICRP 30 (International Commission on Radiological Protection, 1980).

Environmental Radiation Monitoring

Table A-29 shows the quarterly and annual gamma radiation dose-equivalents for the perimeter locations, and Table A-30 presents data for the off-site locations. When a T¹D is missing, the annual dose is calculated as four times the average quarterly dose determined from available data. The average annual dose equivalent of 65 mrem at

the perimeter does not differ significantly from the 64-mrem off-site average.

The TLDs measure radiation exposure from all sources of penetrating radiation. These include natural sources (cosmic and terrestrial), fallout from nuclear weapons testing, and any contribution from LLNL operations. 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 local elevation and geomagnetic latitude according to the data of Lowder and Beck (1966), is about 35 mR/y. The exposures measured at the LLNL perimeter fall within these predicted values. In addition, the external dose rates measured at the LLNL perimeter are identical to the off-site dose rates, which are considered natural background. This indicates that there is no significant contribution to the external dose rate at or beyond the Livermore site fence line from LLNL operations.

Figure 23 presents the 1987 frequency distribution of environmental gamma dose rates measured at the 55 off-site locations. The dose rate has remained the same as previous years.

Table A-31 presents the data for the perimeter neutron dosimeters. The highest annual dose occurred at location 3, which historically has had the highest neutron dose rate because of its proximity to the 14-MeV neutron generator in Bldg. 212. The average neutron dose for 1987 was 5 mrem, not significantly higher than the 1986 value.

Noise Monitoring

There were no complaints of overpressures attributed to LLNL operations at Site 300 during 1987.

Compliance Groundwater Monitoring

Data for the groundwater monitoring wells at Site 300 (Fig. 24) are presented in Table A-32a. In Pit 1 (Table A-32b), during the first quarter, 0.0012 mg/L of mercury and 53 $\mu\text{g/L}$ of TOX were observed in the upgradient well K1-07. These constituents were not observed again in this well for the remainder of the year. There were isolated occurrences of 10 $\mu\text{g/L}$ of a pentane in well K1-03 during the third quarter and 4 $\mu\text{g/L}$ of toluene in K1-07 and 26 $\mu\text{g/L}$ of TOX in K1-01C during the fourth quarter. Xylenes, which appeared sporadically in 1986 below State of California action levels, were not observed in 1987. The elevated levels of nitrate in the Pit 1 wells have been shown to be natural constituents of the area groundwater (Buddemeier et al., 1987a; Carlsen et al., 1987).

Figure 23. Off-site gamma radiation background.

Table A-32c shows TCE, 1,1-dichloroethylene, and tritium concentrations in the Pit 7 area to be similar to those reported last year. The investigations of TCE and tritium at Site 300 are further discussed in the "Special Monitoring Assessments" section of this report. Trimethyl silanol was observed in well NC7-25 in the second quarter. There were isolated occurrences of very small amounts of purgeable halocarbons in NL7-25 and NC7-47. Trichlorofluoromethane was observed sporadically throughout the year, but never consistently in any one well. Trichlorofluoromethane is a very common laboratory reagent, and its presence is considered to be the result of laboratory contamination.

Table A-32d includes monitoring data from Pit 2 (wells K2-01B, K2-04, K2-04D, and K2-04S), Pit 6 (well K8-01), and well NC2-07. As mentioned above, the elevated nitrate levels are considered to be natural constituents of this area's groundwater.

In the third and fourth quarters, TCE began to be detected in well K8-01 at the State of California action level of $5 \mu\text{g/L}$. Additional characterization of this pit is being conducted as part of the continuing investigation of TCE in the soils and groundwater of Site 300. Wells K2-01C and K2-04S showed tritium above the MCL, and are part of the Site 300 Tritium Investigation. Both of these investigations are discussed in the "Special Monitoring Assessments" section.

The trace organics observed in Pit 6 well EP6-08 (Table A-32e) during the second quarter returned to below detection limits during the third quarter. Similarly, the trichlorofluoromethane detected in well K6-04 during the third quarter was not detected in the fourth quarter. TOX in well K6-04, which was slightly elevated in the fourth quarter of 1986, was not observed above detection limits in this well during 1987. Starting in the second quarter and continuing through the fourth

Figure 24. Landrills and monitoring wells, Site 300.

quarter, small amounts of TCE were detected in well EP6-09. A slight increase in TOX was also observed in this well during these quarters. Further investigation of this TCE occurrence in the vicinity of Pit 6 is planned for 1988.

Data for the HE Process-Water Surface Impoundments are given in Table A-32f. The lysimeters underlying the impoundments produced no water throughout the year. Monitoring well 817-01 continues to show levels of RDX (an HE compound) just above the detection limit. Levels of TOX slightly above detection levels continue to be detected in all wells, although inconsistently between quarters. [RCRA mandates that the Student's t-tests comparing 1987 TOX concentrations to the 1986 background set be performed. These tests showed no statistically significant increase in TOX concentrations throughout 1987 (Armstrong and Brown, 1987; Buddemeier et al., 1987a; Brown et al., 1987; and Carlsen et al., 1987).] Elevated nitrate, selenium, and arsenic levels have been consistently detected in all 817 area wells since

1985, and are considered natural constituents of the groundwater (Carlsen et al., 1987). Levels of TCE in excess of the State of California action level were observed in wells 817-03 and 817-04 and piezometer 817-03A. Investigations into the RDX in 817-01 and the TCE occurrences are discussed further in the "Special Monitoring Assessments" section.

Results of organic and inorganic analyses of the production wells, both used and unused, at Site 300 are presented in Table A-32g. Radiological results are presented in Tables A-15, A-17, and A-20 and are discussed in the "Routine Water Monitoring" subsection of this report. Various hydrocarbons were observed in unused production wells 3, 6, and 7. Wells 6 and 7 are in the General Service Area, which is currently part of the TCE investigation. Well 3 is downgradient of Pit 8. As discussed above, investigations are planned for 1988 to determine the extent to which this pit may be impacting groundwater quality.

Environmental Impact of LLNL Operations

Radioactive Airborne Effluents

In accordance with DOE environmental protection orders and other Federal and State requirements, the EQVG assessed the environmental impact from radiological operations at LLNL during 1987. 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.

In 1987, a total of 2751 Ci of tritium were released to the atmosphere from operations at LLNL. Of the 2751 Ci, approximately 1329 Ci were released as tritiated water, the quantity used to calculate doses since the contribution from tritiated hydrogen gas (which comprised the remainder of the releases) to the dose is insignificant. Approximately 570 Ci of tritiated water were released by SNLL; this quantity is not included in dose calculations for LLNL operations. Releases of the short-lived radionuclides ^{13}N - ^{15}O from Bldg. 194 (the electron-positron linear accelerator) totalled 48 Ci. An additional 14 Ci of ^{13}N - ^{15}O were released from the Advanced Test Accelerator (ATA) at Site 300. This was the total airborne radioactive emission from Site 300. Because of the distance of Site 300 from the Livermore site, the dose assessment for Site 300 is conducted separately, and is not included with the Livermore site doses. Comparative releases of radioactive effluents at LLNL (including Site 300) during the 7-y period from 1981 through 1987 are shown in Table A-33.

During 1987, an open-air experiment was conducted at the ATA. Calculations predicted that small quantities of short-lived ^{13}N and ^{15}O could be produced by the experiment. Measurements made to monitor the production of activated air indicated trace quantities in the immediate vicinity of the ATA; however, at greater distances from the ATA, still on site, and at the nearest site perimeter, no such traces were detectable.

The DOE requires all contractors to calculate air pathway doses using the EPA's Clean Air Act Code (CAAC), which contains the AIRDOS-EPA and RADRISK models. LLNL has not yet fully tailored the CAAC to site-specific exposure and meteorological parameters. For this reason, the

CAAC was run by Oak Ridge National Laboratory using a variety of assumptions, which were necessary to complete the calculations. In the future, site-specific meteorology and exposure data will be developed for LLNL's use in the CAAC. The results of this calculation are presented in Table A-34a. We also computed doses using our previous Continuous-Point-Source Code. The results of this calculation are presented in Table A-34b.

The annual average external dose at the Livermore site boundary (that is, the fence-post dose) was 65 mrem (Tables A-29 and A-31). This dose is not statistically different from the off-site annual average background dose of 64 mrem (Table A-30).

The inhalation/submersion dose calculations are based on the total quantity of radioactive material released to the atmosphere during 1987. These doses and their respective locations are as follows:

- The site boundary: 0.18 mrem.
- The nearest resident: 0.10 mrem.
- The maximum off-site exposure: 0.18 mrem.

The maximally exposed individual is a hypothetical member of the public who receives the maximum potential radiation dose from all realistic environmental exposure pathways. The effective dose equivalent to the hypothetical maximally exposed member of the public was 0.3 mrem (Table A-34c).

The collective population dose to all individuals residing within an 80-km radius of LLNL was 0.52 person-rem (Table A-34d). This dose is based on a population of 6.0×10^6 within 80 km of LLNL. Using 100 mrem/y as a typical average from natural sources, the comparable natural radiation dose is 6.0×10^5 person-rem.

Table A-34d compares the dose to the public resulting from LLNL operations with the dose to the public from natural or other background sources. The dose resulting from LLNL operations is negligible.

Appendix F contains definitions of the doses discussed in this subsection and the mathematical equations used to calculate them.

Radioactive Liquid Effluents

Facility liquid effluents with the potential of containing radioactive materials are routed to retention tanks; they are not discharged directly to the sanitary sewer system. These retention tanks

function to collect potentially contaminated liquids until a thorough characterization can be performed. When a retention tank becomes full, a sample of the liquid is analyzed to determine pollutant concentrations. If needed, the wastewater can be treated at LLNL's Hazardous Waste Management Facility to reduce radioactivity to the lowest levels reasonably achievable and well below discharge limits. Once treated and below acceptable limits (verified by resampling and analysis), the liquid waste is discharged to the City of Livermore sanitary sewer system.

Table A-33 summarizes the liquid and airborne releases over the past seven years. During 1987, a total of 1.4 Ci of tritiated water were discharged to the sanitary sewer. This amount is well within environmental protection standards established by DOE, and is within the range reported over the past seven years.

Elevated levels of ^{239}Pu were observed in the LLNL sanitary sewer effluent during 1987. These measurements were made at the LLNL sewer monitoring station, located at the sanitary sewer outfall. These samples are a representative fraction of the combined sanitary effluent from the Livermore site. The highest concentration ($1.1 \times 10^{-8} \mu\text{Ci/mL}$) occurred in May, followed by decreasing levels through the end of the year.

A total of $6.9 \times 10^{-4} \text{ Ci}$ of ^{239}Pu was estimated to have been released during 1987. The highest concentration was well below (only 0.008%) the DOE discharge limit for ^{239}Pu .

The sanitary sewage from the Livermore site is discharged to the City of Livermore sanitary sewer system and treated at the LWRP. Consequently, higher than normal levels of ^{239}Pu were also observed in the LWRP effluent and digester sludge (Table A-11). The LWRP composite sample for May had the highest value ($8.4 \times 10^{-11} \mu\text{Ci/mL}$) in 1987, compared to the 1986 average of $4.0 \times 10^{-13} \mu\text{Ci/mL}$. The second quarter sludge sample from the LWRP showed a ^{239}Pu concentration of $1 \times 10^{-5} \mu\text{Ci/g}$, compared to $7.7 \times 10^{-8} \mu\text{Ci/g}$ for the first quarter.

The DOE has established limits for discharging radionuclides to a public sewer system. These limits have been derived to adequately protect public health and minimize detriment to the environment; thus these limits are very restrictive. The levels of ^{239}Pu observed in the LLNL effluent during 1987 were substantially below the DOE limit (0.01%), representing negligible impact to public health or the environment. Moreover, a release to the sanitary sewer presents even less risk because

of the absence of possible routes of intake. An evaluation has identified the location at which the material entered the sewer system; however, the exact circumstances behind the release are still being investigated.

Nonradioactive Liquid Effluents

Four incidents of materials in the sanitary sewer system in excess of LLNL's internal alarm limits were recorded in 1987. None of these releases resulted in damage to the LWRP.

On January 6, an LLNL employee erroneously released wastewater from a retention tank before properly neutralizing it. The release, which did not impact the LWRP, caused a high pH excursion that lasted approximately 25 min. The maximum pH was 10.6. Appropriate LLNL personnel were reinstructed in proper retention tank release guidelines, and pH verification procedures were improved to prevent future incidents.

On October 24, approximately 9500 gal of sewage containing slightly elevated concentrations of zinc and chromium were discharged to the sanitary sewer system. As a precaution, LWRP operators diverted the sewage, but returned the material to the waste stream when analysis showed metal concentrations to be normal. The exact cause of the excursion could not be confirmed, but may have been associated with a release from a cooling tower earlier in the day. As a precaution, a new cooling tower additive was obtained to replace the zinc-containing material previously used in all cooling towers, and a procedure for analyzing the cooling tower water prior to discharge was implemented.

On December 7, an unexplained low pH of 2.75 was detected in the sanitary sewer. The pH returned to normal in approximately 6 min. The discharge did not impact the LWRP.

On December 13, approximately 2700 gal of sewage containing elevated levels of copper and zinc were discharged into the sanitary sewer system. The approximately 5 oz of metals were accompanied by a low pH believed to be due to sulfuric acid. Metal concentrations returned to allowable discharge limits in less than 30 min and the pH within 45 min. As a precaution, the LWRP operator diverted approximately 4 h of influent flow to a retention basin. Metal concentrations in the diverted flow were determined to be equivalent to normal levels, and the sewage was pumped back into the waste stream for treatment.

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, and flows into the lake; the effluent exits LLNL primarily at the northwest corner, with a lesser outflow at the southwest corner.

Groundwater Quality

The tritium and TCE in groundwater at Site 300 are considered to have minimal adverse im-

pact because they have not migrated off site, and the tritium- and TCE-containing aquifers are not used for potable water supplies.

The solvents in groundwater at or near the Livermore site are not considered to have any major adverse impacts since they are not in portions of aquifers that are currently used for potable water supplies. Corrective actions are being investigated.

Changes to the Environmental Monitoring Program

During 1987, the Environmental Monitoring Program instituted a number of changes. These changes are permanent in nature and, therefore, differ from the deviations from the sampling program discussed in the next section.

- A comparison between the old air particulate samplers and a new model was conducted in 1987. The results indicated that no significant bias existed. The new model samplers will gradually be placed in service, replacing the old ones.

- In 1987, milk-sampling locations 8 and 11 were dropped. The owners of the goats informed LLNL of their intention to stop milking the goats. In May, sampling location 12 was added, and in October, sampling location 13 was added.

- Doses at the site perimeter are now calculated to the outer edge of the newly acquired buffer zone.

- The Environmental Monitoring Annual Report was changed as follows:

- Data for gross alpha and gross beta on air filters are now presented in graphs rather than in tabular form.

- Violations brought to LLNL's attention are reported to appropriate regulatory agencies.

- An air emission inventory has been included.

- Several new groundwater monitoring wells were added at the Livermore site, as described in the "Special Monitoring Assessments" section of this report.

- Well K1-06 was officially dropped from the monitoring program at Site 300 because of insufficient water for pumping.

- Wells K2-04S and K2-04D were added at Site 300 to sample the two aquifers sampled by K2-04. Well K2-04 was drilled out and grouted to prevent it from becoming a conduit between the two aquifers.

Deviations from the Sampling Program

Appendix G lists those regularly scheduled samples for which data is not reported either because of an inability to collect the sample or loss during analysis. Table G-1 lists air particulate de-

viations, air tritium deviations, groundwater deviations, vegetation deviations, milk deviations, and environmental radiation monitoring deviations.

Quality Assurance

On September 18, 1987, the EQVG issued a Quality Assurance Plan (attached as Appendix H). This document meets the requirements of the

American National Standard Institute/American Society of Mechanical Engineers; Resource Conservation Recovery Act; and the Comprehensive

Environmental Response, Compensation, and Liability Act. It is now being implemented. Implementation is expected to be complete by the end of 1988. The Quality Assurance Plan sets forth the following data quality goals:

- Accuracy— $\pm 10\%$ as determined by interlaboratory comparisons or analysis of samples with known concentrations of the parameters of interest.

- Precision— $\pm 30\%$ at the 95% confidence level as determined by the use of duplicate sampling techniques.

- Completeness—data capture (number of samples actually collected divided by the number of samples scheduled to be taken) equal to or greater than 85% for all sampling media.

In addition to the above requirements, the "Data Analysis Procedure" (issued by EQVG as part of the implementation of the Quality Assurance Plan) requires that a regression analysis be performed on all data from the duplicate sampling regime if more than eight data pairs are available. Data quality goals for the regression are as follows:

- Correlation coefficient of 0.8 or greater.
- Y-intercept of the regression line of -0.5 to 0.5 .

- Slope of the regression line of 0.9 to 1.1.

During 1987, LLNL participated in the EPA's Environmental Radioactivity Laboratory Intercomparison Studies Program. Table A-35a shows the comparison of analyses by LLNL with the known values and the averages of all the participants. The errors are calculated at the 1σ level. The only analyses outside of the EQVG accuracy goals and the EPA control limits were the gross beta on air filter analyses for the April 20, 1987 and August 28, 1987 intercomparison studies. These gross beta values have been investigated

and found to be the result of calibration practices employed by LLNL's Hazards Control Laboratory, which routinely analyzes environmental air filters for gross radioactivity. Since the gross radioactivity numbers are used solely for screening and trending purposes, it is not considered cost effective to modify the calibration procedures at this time. The ^{65}Zn in water value was not considered critical since this isotope is not commonly used at LLNL.

LLNL also participated in the 1987 intercomparison study by the DOE Environmental Measurements Laboratory. The data from this study is presented in Table 35b. Seven of the analyses fall outside of the $\pm 10\%$ accuracy goal. Of these seven, ^{239}Pu in soil, ^{239}Pu in water, ^{137}Cs in water and ^{238}U in air are far enough from the goal to be of concern. These analyses are being investigated by LLNL's Nuclear Chemistry Division.

Table A-36 presents data generated by the duplicate sampling regime. The regression analyses for these sample media where enough data pairs were generated to allow the analyses show good agreement between the routine samples and the quality assurance duplicates, with the exception of the LWRP tritium samples. This deviation is considered to be caused by the proximity of the levels to the detection limit. Individual ratios of the quality assurance duplicates to the routine samples do occasionally exceed the data goal of $\pm 30\%$, but never for a sustained period, which would indicate a bias in the sampling and analysis system. The ratio of 8.51 for Site 300 vegetation is the result of spatial variation in tritium concentrations near areas contaminated with tritium from fireable debris. It is also the result of the need to collect the samples over a large area because of the scarcity of vegetation.

Special Monitoring Assessments

The following is a brief description of the special monitoring assessments that were initiated or were in progress in 1987 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, 1987. References are cited that give the detailed status of special assessments for which additional reports have been published.

Livermore Site Groundwater Project

In 1987, investigations continued to define the extent of VOCs in groundwater and to evaluate various remedial action alternatives. The CRWQCB issued Site Clean-up Order No. 87-108 to update and replace Waste Discharge Order 85-134.

LLNL was placed on the National Priorities List on July 21, 1987. This will bring more EPA

oversight. Negotiations are currently in progress for an inter-agency agreement covering investigation and remediation activities.

Field efforts in 1987 included installation of 53 monitoring wells, completion of 19 two-day pump tests, testing of experimental remedial water treatment systems, and the installation of a vapor/water extraction well in the Bldg. 403 area. These activities are discussed in monthly progress reports, which are submitted to regulatory agencies (Dresen et al., 1987a-g; Devany et al., 1987; and Webster-Scholten et al., 1987a,b).

As of December 31, 1987 the groundwater monitoring network consisted of 184 LLNL monitoring wells and 18 private or county wells. The analytical results for samples collected from these wells are presented in the above mentioned monthly progress reports. Background investigation of the use, storage, and disposal of hazardous materials at LLNL is presented by Dreicer (1985). Recent evidence shows that operations associated with the former Livermore Naval Air Station and its successors, who occupied the LLNL site from 1942 to 1951, were major contributors of VOCs in groundwater (U.S. Department of Energy, 1987a).

The current status of various location-specific project phases is discussed below.

Area West of LLNL

As a result of discussions with the CRWQCB, 11 new monitoring wells were installed west of the southwest corner of LLNL to further define the vertical and horizontal extent of VOCs. As a result of data obtained from these wells, the composite VOC plume is now believed to be 1300 m (4200 ft) long by 1100 m (3600 ft) wide by about 3 to 40 m (10 to 120 ft) thick, and consists of a main tetrachloroethylene (PCE) plume and two smaller TCE subplumes.

The main plume is dominated by PCE at concentrations of up to about 1100 ppb at the apparent source. Analytical data indicating the presence of PCE in unsaturated soil, collected near the storm sewer discharge in the Arroyo Seco, confirm that storm sewer discharge was the source for the main plume (Webster-Scholten, 1987b). As previously reported, data indicate that VOCs associated with this source have migrated westward in interfingering northwest-dipping heterogeneous unconsolidated sediments. Near the apparent source of this plume, VOCs are present from 5 m (16 ft), the approximate depth of the Arroyo Seco channel, to about 50 m (170 ft). Near the leading edge of the plume, VOCs are not present below about 60 m (200 ft).

One of the smaller subplumes, located near monitoring well 218, is dominated by TCE at concentrations up to 590 ppb. The source is currently believed to have been previous storm sewer discharges into an unlined drainage ditch near the west entrance, or discharge of solvents by the Navy to what were unpaved areas on the west side of the landing mat. This plume extends about 460 m (1500 ft) to the northwest of monitoring well 218, and does not appear to extend below a depth of 40 m (130 ft).

The other subplume, also dominated by TCE, appears to have intersected the main plume. The origin of this plume may be past solvent use and disposal practices in the Bldg. 212 and Bldg. 227 areas.

Significant progress was made this year investigating remedial action alternatives. Hydraulic tests indicate that water-bearing sediments have hydraulic conductivities ranging from about 0.12 to 61 m/day (Dresen et al., 1987h). Horizontal hydraulic communication within the same water-bearing zone up to about 615 m (2000 ft) and vertical communication between water-bearing zones up to about 15 m (50 ft) have been observed. An inventory of private wells west of the Livermore site was conducted to help assess the beneficial uses of groundwater near the Livermore site (Dresen et al., 1987a). Modeling efforts using the analytical mass transport model PLUME and the numerical model SUTRA (Rogers, 1987) are in progress. Remedial alternatives are discussed in Dresen et al. (1987h). A proposal for pilot groundwater extraction and treatment west of LLNL was submitted to the CRWQCB, EPA, and DOHS for review.

Southeast LLNL and Vicinity

Groundwater chemistry and site history indicate that there may have been three sources of VOCs, consisting primarily of TCE (in concentrations up to 2000 ppb) with differing ratios of other VOCs, which "fingerprint" each source in this area (McConachie and Hoffman, 1986; Dresen and Nichols, 1986).

In the Bldg. 518 area, VOCs extend no more than about 60 to 110 m (200 to 350 ft) to the west, northwest, northeast, and southeast; 280 m (900 ft) to the southwest, and to depths of less than 50 m (165 ft).

In the Bldg. 612 yard/Bldg. 514 area evidence of VOCs have been detected. Further plume definition is under way.

Hydraulic tests conducted this year, and data generated from three new wells, corroborated the

hydrogeologic conclusions presented in Dresen and Nichols (1986). Hydraulic conductivities ranging from 0.32 to 11.8 m/day were observed. These data, combined with gradient data and an assumed porosity of 0.25 yield an average groundwater velocity of 5.7 to 88.4 m/y. A summary of well installation and hydraulic testing in the southeast corner of LLNL is given in Webster-Scholten et al. (1987b) and Dresen et al. (1987a-h).

Gasoline in Soil and Groundwater

An estimated 65 000 L of gasoline leaked from four underground storage tanks located near Bldg. 403 prior to March 1979. Previous reporting of investigative work conducted in the Bldg. 403 area includes Carpenter (1984), Materials (1985), and Dresen et al. (1986). These investigations indicated that concentrations of various gasoline components exceed State and Federal action levels for both soil and groundwater.

Further refinement in assessing the extent of gasoline in soil and groundwater continued in 1987. Unsaturated soil collected in borehole G5B-15, near the suspected leak, showed up to 11 000 ppm of total fuel hydrocarbons (Webster-Scholten, 1987b). Eight new monitoring wells were installed, and new data generated from these wells indicate that fuel hydrocarbons have migrated in groundwater further south than previously reported. Our data indicate that the plume has migrated about 150 m (500 ft) north, west, and east, and about 250 m (800 ft) southeast.

During 1987 extensive testing was conducted of spray aeration and vacuum degasifier systems for use in remedial water processing. Discussion of the performance and design of these systems is presented in the above mentioned monthly reports. As a result of our testing, the vacuum degasifier system appears to be the most appropriate technology for removal of gasoline components from groundwater.

An experimental vapor/water extraction well was installed near the leak site to investigate whether gasoline can be removed efficiently in the unsaturated zone using vacuum extraction (Webster-Scholten et al., 1987b). Testing of this well is expected to begin in early 1988.

East Traffic Circle Landfill and Taxi Strip/Old Salvage Yard Areas

Work is currently under way to determine the extent of VOCs in groundwater in the east traffic circle landfill and the taxi strip/old salvage yard areas. VOCs dominated by TCE in concentrations up to 2800 ppb are present in the 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 5800 ppb and 1300 ppb, respectively. Other VOCs appear in lower concentrations. Several hydraulic tests were conducted in this area during 1987.

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 was twofold: (1) to document at a given point in time the location of areas where gamma radioactivity was 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.

Due to litigation concerning the survey procedures, the final report has not been issued. LLNL plans to include survey results in the 1988 Environmental Monitoring Annual Report.

TCE at Site 300

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 housekeeping practices have resulted in TCE spills. TCE 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. The surficial two feet (0.61 m) of soil, containing up to 12 000 mg/kg of TCE, was removed from portions of the Bldg. 834 and Bldg. 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 and housekeeping practices at these complexes have been improved to prevent future spills.

In 1985, following consultation with the CRWQCB, 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 found to contain up to 160 000 ppb of TCE. This work led to the identification of TCE

in soil at one additional location, the Bldg. 833 area. Results of these investigations were reported to the CRWQCB, Central Valley Region, during 1986 (Carpenter et al., 1986).

In an effort to define the distribution of TCE and other VOCs at Site 300, additional field studies were undertaken during the latter portion of 1986 and during 1987. As a result of this work, 35 additional monitoring wells were drilled and several special purpose borings were completed. The TCE plume at the Bldg. 834 Complex, the area of largest concentration of TCE in groundwater at the site, has been delineated and a feasibility study is being prepared. Investigations of TCE in soils and groundwater in other areas of Site 300 are continuing. Results are reported quarterly to the CRWQCB, Central Valley Region, and to the DOHS.

Underground Tank Testing

The LLNL Tank Project monitors and tests all underground tank systems to determine their structural integrity in accordance with the LLNL Tank Testing Program. This program complies with the testing requirements set forth in Title 23 of the *California Administrative Code* (State of California, 1986), Regional Water Quality Control Board Waste Discharge orders, and Resource Conservation and Recovery Act regulations for hazardous waste tank systems.

Fifty-one product tank systems (diesel, gasoline, etc.) were tested in 1987. Three systems failed the leak-tightness test (the precision test required by NFPA Code 329). Sites for potential leakage were discovered in all three systems. All leak sites were located in the upper portions of the underground piping, above the normal operating level of liquid containment. Two of these systems were repaired and put back into service. One system was closed. In all cases, soil contaminated with diesel fuel in concentrations greater than 1000 ppm was removed and disposed of as hazardous waste.

Product tank systems will continue to be monitored and tested on an annual basis. Testing underground portions of wastewater retention systems will resume in 1988.

Tritium in Groundwater at Site 300

During 1983 and 1984, increases in tritium concentrations were observed in monitoring wells downgradient from experimental and waste dis-

posal areas in the West Firing Area of Site 300. In 1984, concentrations in excess of the state limit for drinking water (2×10^4 pCi/L or 2×10^{-5} μ Ci/ml.) were observed in wells K7-01, K7-03, and K2-01 (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., 1987b). The information that follows is summarized from those reports. Table A-32 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 that has been observed is approximately 1×10^6 pCi/L (or 1 μ Ci/L). 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 Bldg. 850, an HE 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 Bldg. 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 the velocity and direction of groundwater flow and tritium migration and determining the extent of tritium dispersal into East Firing Area groundwater. Through continued monitoring and well drilling, we are investigating the hydrologic effects of the Elk Ravine Fault and the hydrologic connections between the Bldg. 850 tritium source area and tritium plume in the East Firing Area. Results are routinely reported to the CRWQCB, Central Valley Region, and DOHS.

Burn Pit Operation

Site 300 operates a burn pit area near Bldg. 829 to burn waste and paper potentially contaminated with HE. The facility is regulated by the EPA and DOHS and is operated in accordance with Title 40, Part 265.382, of the *Code of Federal Regulations* (Office of the Federal Register, 1986a).

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.

An operating plan for the burn facility has been submitted to the DOHS. To prepare for closure of the existing HE burn facility, between November 1986 and February 1987 we investigated the soils and rocks underlying the pit area. Eight exploratory borings were drilled, one of which was converted to a groundwater monitoring well. Small quantities of HE compounds HMX and RDX as well as minor amounts of VOCs were detected in some of the borings. A summary of the investigation and the analytical results are presented in Ruggieri et al., 1987.

High-Explosives Wastewater Lagoons and Impoundments, Site 300

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

The industrial wastewater discharged to the lagoons has been tested in past years. Results indicated that effluents are not hazardous, based upon DOHS waste extraction tests (State of California, 1977) and EPA toxicity tests. Fish toxicity tests were also run.

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 waste stream is nonhazardous.

In 1987, the CRWQCB determined (on the basis of data supplied by L.L.N.I.) that the wastewater and sludge/sand layer at the bottom of the impoundments are nonhazardous, and therefore the impoundments are not subject to the requirements of the Toxics Pit Cleanup Act. This information has also been supplied to EPA in support of the position that the impoundments are not subject to RCRA regulations.

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* (State of California, 1986) 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 an HE 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 abandoned, unlined wastewater lagoons in the HE Processing Area, an investigation was begun during 1986.

Two additional upgradient monitoring wells were drilled during 1986 adjacent to well 817-1. No HE compounds were detected in water samples obtained from these wells. In addition, soil samples were obtained from boreholes at 12 locations within the 806/807 lagoon complex and analyzed for HE compounds. Low levels of the HES 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 (21.5 m). The results of the investigation of the 806/807 area were reported to the CRWQCB (Crow et al., 1986).

During late 1986 and 1987, soil samples were obtained from boreholes drilled in the other abandoned HE lagoons. Low levels of HE compounds and metals were detected in most samples (Buddemeier et al., 1987c,d; Ruggieri et al., 1987).

Data from past and recent sampling were submitted in a report to the CRWQCB, Central Valley Region, to address provisions of the Toxics Pits Cleanup Act (Steenhoven, 1987).

The unlined lagoons were removed from service in 1984 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.

Permits and Environmental Evaluations

During 1987, LLNL held several environmental permits, orders, and notices that were issued for operations at the Livermore site and at Site 300.

Air Permits

In 1987, LLNL was issued 163 permits to operate equipment at Livermore and Site 300. The permits allow the operation of 98 hot water/steam boilers, 26 degreasers, 11 machine shops (which share a particulate abatement cyclone), 5 diesel fuel storage tanks, 5 paint spray booths, 2 gasoline pump islands, 2 gasoline storage facilities (with tanks), and 14 miscellaneous items. Livermore site permits expire July 1, 1988; Site 300 permits expire January 31, 1989. 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. Table 1 shows emissions for the various permitted sources.

Groundwater Investigation

As described in the "Special Monitoring 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.

Table 1. Emissions by source category (lb per day, estimated).

	Part.	TOG	NO _x	SO _x	CO
Livermore site					
Boilers	2	13	97		10
Solvent cleaners		70			
Paint booths		14			
Incinerator	1				1
Miscellaneous		12			1
Totals	3	109	97		12
Site 300					
Boilers			16		1
Service station		0.6			
Miscellaneous		0.2			
Totals		0.8	16		1

Note: Part. = Particulates, TOG = total organic gases (precursors and nonprecursors), NO_x = nitrogen oxides, SO_x = sulfur oxides, and CO = carbon monoxide.

Liquid Waste Discharge

An application was submitted to the CRWQCB in 1987 for renewal of Waste Discharge Requirement No. 82-105, which covers cooling tower blowdown at Site 300.

Site Cleanup Order No. 87-108 was issued in 1987 by the Bay Region of the Water Quality Control Board. This order rescinds Waste Discharge Requirements 85-134 and 86-95, which regulated liquid discharges from the Livermore site groundwater investigation.

In 1987 LLNL filed a National Pollution Discharge Elimination System permit application for discharge of groundwater from hydraulic pump tests at the Livermore site.

Solid Waste Landfills

Eight landfills are covered in Waste Discharge Order No. 80-184 issued by the CRWQCB, Central Valley Region. The two active landfills, Pits 1 and 7, 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 "Compliance Groundwater Monitoring" methods subsection, the landfills are circled by wells so that changes in groundwater quality can be detected. 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.

TCE in groundwater has been detected in the Pit 7 and HE areas. A discussion of the TCE investigation can be found in the "Special Monitoring Assessments" section.

Other Hazardous Waste Operations

Both Site 300 and the Livermore site have Interim Status Documents issued by the DOHS for storage, treatment, and disposal of hazardous wastes. Hazardous waste facilities are being upgraded, and the design for a new storage and treatment facility is complete. Permit applications for the planned facility have been prepared and submitted to DOHS and the Bay Area Air Quality Management District.

The "Part B" application for the existing incinerator at the Livermore site is currently under review by the EPA and the DOHS. A trial burn is planned. The Operations Plan for the existing storage and treatment facility at the Livermore site was submitted to the DOHS in December 1985; it is still being reviewed.

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

Environmental Impact Report for Contract Renewal

The University of California renewed its contract with DOE for the operation and management of LLNL. The decision to continue management and operation of LLNL constituted a "project" under the California Environmental Quality Act. Prior to making the decision, the University addressed environmental impacts associated with continuing LLNL activities. The University assessed these impacts through the environmental impact report (EIR) process. The final EIR was published on July 28, 1987 (University of California, 1987) and certified by the University of California on September 18, 1987.

Environmental Assessments

The National Environmental Policy Act (NEPA) requires an environmental evaluation to be performed for every new major federal action. This includes all new DOE funded major construction, programs or projects at the Livermore site and Site 300.

Several NEPA documents are in the process of being prepared, reviewed by DOE, or revised to reflect DOE comments. These include Environ-

mental Assessments for the High Explosives Application Facility, a research facility with test and diagnostics equipment for performing advanced HE experiments; the Nuclear Directed Energy Research Facility, a facility that will provide an environment for basic research in physics, materials science, and engineering in support of the objectives of the Strategic Defense Initiative; the Nuclear Test Technology Complex, a facility that will house and consolidate LLNL's physics and engineering support activities associated with the Nuclear Test Program; and the Environmental Compliance and Cleanup Project, LLNL's environmental remediation project.

In addition, an environmental impact statement (EIS) has been under preparation for the Decontamination and Waste Treatment Facility, a complete, modern facility to process and treat LLNL's radioactive, hazardous, and mixed waste. This EIS has been reviewed by DOE and was provided to relevant State agencies for review in December 1987. The EIS is being revised to reflect the latest information affecting the projects.

Citations and Agreements

LLNL was cited by the Bay Area Quality Management District for using paints with a VOC concentration above regulatory limits. A settlement agreement was reached during the summer of 1987.

LLNL was cited in 1986 by the EPA for violations relating to PCB recordkeeping and leaking transformers. A settlement agreement was reached in February, detailing recordkeeping changes and giving a time schedule for the removal of 12 PCB transformers.

In late 1987, a settlement agreement was reached with the DOHS for violations noted during past inspections of Site 300.

Appendix A. Data Tables

Table A-1. Gamma activity on air filters—Livermore site perimeter.^a

Month	⁷ Be	⁴⁰ K	¹³⁷ Cs	⁶⁰ Co	¹²⁵ Sb
	[10 ⁻¹³ μCi/mL ± 2σ (%)]	[10 ⁻¹⁶ μCi/mL ± 2σ (%)]			
Jan.	1.02 ± 2	3.32 ± 70	0.16 ± 60	— ^b	— ^b
Feb.	1.07 ± 2	— ^b	0.15 ± 64	— ^b	— ^b
Mar.	1.78 ± 2	7.40 ± 52	0.19 ± 38	— ^b	— ^b
Apr.	2.26 ± 2	7.75 ± 42	0.20 ± 72	— ^b	4.59 ± 56
May	1.36 ± 4	5.95 ± 28	0.21 ± 48	0.16 ± 44	— ^b
June	1.37 ± 2	6.18 ± 42	0.25 ± 46	0.16 ± 68	— ^b
July	0.74 ± 2	7.30 ± 26	0.21 ± 56	1.78 ± 56	— ^b
Aug.	1.31 ± 2	6.74 ± 32	— ^b	2.84 ± 38	— ^b
Sept.	1.48 ± 2	7.11 ± 46	0.26 ± 50	— ^b	— ^b
Oct.	1.35 ± 2	6.63 ± 34	0.23 ± 38	— ^b	— ^b
Nov.	1.10 ± 2	2.08 ± 52	0.11 ± 34	— ^b	— ^b
Dec.	0.84 ± 2	2.86 ± 68	— ^b	— ^b	— ^b
Average	1.31	5.75	0.20	1.24	— ^c
SDM (%)	30	33	22	92	— ^c
DCG (μCi/mL)	5 × 10 ⁻⁸	9 × 10 ⁻¹⁰	4 × 10 ⁻¹⁰	8 × 10 ⁻¹¹	1 × 10 ⁻⁹
Percent of DCG	3 × 10 ⁻⁴	6 × 10 ⁻⁵	5 × 10 ⁻⁶	2 × 10 ⁻⁴	5 × 10 ⁻⁵

^a All Livermore site perimeter samples composited.^b Not detected.^c Too small a data set to calculate an average or standard deviation. Percent of DCG is based on largest value.

Table A-2. Gamma activity on air filters—Site 300.^a

Month	⁷ Be	⁴⁰ K	¹³⁷ Cs	⁶⁰ Co	¹²⁵ Sb
	[10 ⁻¹³ μCi/mL ± 2σ (%)]	[10 ⁻¹⁶ μCi/mL ± 2σ (%)]			
Jan.	0.93 ± 2	— ^b	0.22 ± 16	0.07 ± 32	— ^b
Feb.	1.20 ± 2	2.05 ± 56	0.24 ± 18	0.05 ± 70	— ^b
Mar.	1.36 ± 2	— ^b	0.11 ± 32	— ^b	0.31 ± 38
Apr.	2.56 ± 2	4.18 ± 44	0.20 ± 20	— ^b	— ^b
May	1.60 ± 2	3.16 ± 26	0.17 ± 30	— ^b	— ^b
June	1.82 ± 4	4.19 ± 40	0.20 ± 20	— ^b	— ^b
July	1.30 ± 2	3.13 ± 38	0.17 ± 28	— ^b	— ^b
Aug.	2.12 ± 2	4.05 ± 28	0.13 ± 40	— ^b	— ^b
Sept.	2.19 ± 2	4.64 ± 64	0.39 ± 20	— ^b	— ^b
Oct.	1.67 ± 2	4.93 ± 24	0.19 ± 32	— ^b	— ^b
Nov.	1.10 ± 2	— ^b	0.11 ± 28	— ^b	— ^b
Dec.	1.03 ± 2	2.54 ± 44	0.09 ± 48	— ^b	— ^b
Average	2.47	3.65	0.19	— ^c	— ^c
SDM (%)	118	25	91	— ^c	— ^c
DCG (μCi/mL)	5 × 10 ⁻⁸	9 × 10 ⁻¹⁰	4 × 10 ⁻¹⁰	8 × 10 ⁻¹¹	1 × 10 ⁻⁹
Percent of DCG	5 × 10 ⁻⁴	4 × 10 ⁻⁵	5 × 10 ⁻⁶	8 × 10 ⁻⁶	3 × 10 ⁻⁶

^a All Site 300 samples composited.^b Not detected.^c Too small a data set to calculate an average or standard deviation. Percent of DCG is based on largest value.

Table A-3. Plutonium-239 on air filters—Livermore Valley.

Month	Sampling location ^a						
	3	4	8	10	16	17	6
	[10 ⁻¹⁷ μCi/mL ± 2σ (%)]						
Jan.	0.01 ± 50	0.01 ± 71	≤0.01	≤0.01	0.02 ± 50	0.02 ± 42	≤0.01
Feb.	0.02 ± 58	0.02 ± 41	≤0.01	0.03 ± 34	0.03 ± 45	≤0.01	≤0.01
Mar.	0.02 ± 49	≤0.01	0.01 ± 71	0.01 ± 48	≤0.01	0.03 ± 40	0.01 ± 71
Apr.	0.01 ± 46	0.04 ± 21	0.02 ± 29	0.03 ± 26	0.02 ± 40	0.03 ± 35	0.03 ± 38
May	0.04 ± 29	0.02 ± 49	0.03 ± 43	0.02 ± 47	0.06 ± 20	0.03 ± 43	0.01 ± 73
June	0.06 ± 29	0.52 ± 9 ^b	0.01 ± 60	0.03 ± 28	0.01 ± 48	0.03 ± 41	0.03 ± 46
July	0.02 ± 50	0.04 ± 21	0.03 ± 32	0.01 ± 51	0.04 ± 27	≤0.01	0.05 ± 22
Aug.	0.01 ± 65	0.02 ± 35	0.01 ± 82	0.02 ± 29	0.05 ± 29	0.03 ± 35	0.03 ± 30
Sept.	0.13 ± 27	0.06 ± 25	0.02 ± 71	0.01 ± 58	0.06 ± 39	0.04 ± 45	0.06 ± 41
Oct.	0.03 ± 47	0.04 ± 33	0.01 ± 71	0.04 ± 30	0.04 ± 39	0.03 ± 38	0.10 ± 28
Nov.	≤0.01	0.01 ± 65	≤0.01	0.02 ± 41	0.04 ± 37	≤0.01	0.01 ± 81
Dec.	0.03 ± 55	≤0.01	0.06 ± 34	≤0.01	0.08 ± 26	0.03 ± 39	≤0.01
Average	0.04	(0.10) ^b 0.05	0.02	0.02	0.04	0.03	0.04
SDM (%)	103	(166) ^b 121	74	47	57	17	80
Percent of DCG ^c	2 × 10 ⁻³	(5 × 10 ⁻³) ^b 2.5 × 10 ⁻³	1 × 10 ⁻³	1 × 10 ⁻³	2 × 10 ⁻³	1.5 × 10 ⁻³	2 × 10 ⁻³

^a See Fig. 7 for sampling locations. Location 6 is in the City of Tracy.^b Outlier. Values with outlier included are in parentheses.^c DCG for Pu in air = 2 × 10⁻¹⁴ μCi/mL or 2 × 10⁻² pCi/m³.

Table A-4. Plutonium and uranium on air filters—Livermore site perimeter.

Month	Location ^a	²³⁹ Pu ^b [10 ⁻¹⁷ μ Ci/mL]	²³⁵ U [10 ⁻⁷ μ g/m ³]	²³⁸ U [10 ⁻⁵ μ g/m ³]	²³⁵ U/ ²³⁸ U [10 ⁻³]
Jan.	1	0.04 $\pm$ 58	3.64	5.10	7.1
	2	0.03 $\pm$ 39	3.02	4.33	7.0
	12	0.01 $\pm$ 58	3.61	5.32	6.8
	13	0.01 $\pm$ 63	3.62	5.08	7.1
	14	0.02 $\pm$ 28	2.64	3.64	7.3
	15	0.04 $\pm$ 19	2.94	4.14	7.1
Feb.	1	0.01 $\pm$ 30	0.39	0.43	9.0
	2	0.08 $\pm$ 20	2.80	3.93	7.1
	12	0.04 $\pm$ 35	3.71	5.34	6.9
	13	$\leq$ 0.01	3.07	4.35	7.1
	14	0.02 $\pm$ 48	1.96	2.79	7.0
	15	0.03 $\pm$ 29	3.43	4.86	7.1
Mar.	1	0.77 $\pm$ 7	4.76	6.60	7.2
	2	0.01 $\pm$ 42	2.90	4.18	6.9
	12	0.03 $\pm$ 39	4.66	6.70	7.0
	13	$\leq$ 0.01	4.46	6.38	7.0
	14	0.02 $\pm$ 43	2.41	3.45	7.0
	15	0.02 $\pm$ 51	9.46	13.30	7.0
Apr.	1	0.99 $\pm$ 9	8.81	12.40	7.1
	2	0.03 $\pm$ 31	5.86	8.14	7.2
	12	0.26 $\pm$ 21	8.41	12.00	7.0
	13	0.04 $\pm$ 54	9.45	13.20	7.2
	14	0.07 $\pm$ 32	5.55	7.74	7.2
	15	0.11 $\pm$ 25	11.10	15.50	7.2
May	1	0.57 $\pm$ 10	7.29	10.28	7.1
	2	0.04 $\pm$ 26	4.06	5.69	7.1
	12	0.14 $\pm$ 24	6.83	10.01	6.8
	13	0.02 $\pm$ 59	6.97	9.96	7.0
	14	0.06 $\pm$ 25	4.03	5.69	7.1
	15	10.85 ^c $\pm$ 3	7.58	10.85	7.0
June	1	0.47 $\pm$ 6	6.51	9.31	7.0
	2	0.01 $\pm$ 37	3.43	4.80	7.1
	12	0.08 $\pm$ 30	7.33	10.44	7.0
	13	0.04 $\pm$ 23	11.71	16.52	7.1
	14	0.09 $\pm$ 14	4.00	5.62	7.1
	15	0.04 $\pm$ 28	5.96	8.40	7.1

Table A-4. (Continued).

Month	Location ^a	²³⁹ Pu ^b [10 ⁻¹⁷ μCi/mL]	²³⁵ U [10 ⁻⁷ μg/m ³]	²³⁸ U [10 ⁻⁵ μg/m ³]	²³⁵ U/ ²³⁸ U [10 ⁻³]
July	1	0.53 ± 7	6.76	9.62	7.0
	2	0.01 ± 41	3.14	4.35	7.2
	12	0.04 ± 35	5.77	8.35	6.9
	13	0.11 ± 22	9.09	12.75	7.1
	14	0.15 ± 13	4.51	6.40	7.0
	15	0.14 ± 15	7.07	10.09	7.0
Aug.	1	1.84 ± 5	11.75	16.50	7.1
	2	0.02 ± 28	3.82	5.34	7.1
	12	0.04 ± 43	8.94	12.72	7.0
	13	0.06 ± 33	9.51	13.35	7.1
	14	0.06 ± 27	5.41	7.66	7.1
	15	0.06 ± 30	7.02	9.96	7.1
Sept.	1	0.38 ± 11	6.16	8.68	7.1
	2	0.02 ± 43	4.66	6.52	7.1
	12	0.10 ± 25	8.45	12.00	7.0
	13	0.04 ± 48	12.00	16.90	7.1
	14	0.15 ± 17	5.90	8.28	7.1
	15	0.58 ± 9	8.96	12.60	7.1
Oct.	1	0.30 ± 8	6.00	8.44	7.1
	2	0.03 ± 24	4.51	6.33	7.1
	12	0.08 ± 16	8.54	12.06	7.1
	13	0.06 ± 22	7.52	10.58	7.1
	14	0.06 ± 20	5.60	7.91	7.1
	15	0.07 ± 20	10.53	14.90	7.1
Nov.	1	0.05 ± 23	1.74	2.52	6.9
	2	0.03 ± 26	2.16	3.10	7.0
	12	0.10 ± 15	5.21	7.43	7.0
	13	0.02 ± 54	3.17	4.61	6.9
	14	0.04 ± 33	2.14	3.09	6.9
	15	0.04 ± 34	6.67	9.48	7.0
Dec.	1	0.07 ± 21	4.51	6.38	7.1
	2	0.02 ± 30	4.43	6.24	7.1
	12	0.08 ± 20	7.38	10.41	7.1
	13	0.02 ± 45	5.52	7.43	7.4
	14	0.05 ± 24	4.40	6.19	7.1
	15	0.05 ± 26	6.42	9.01	7.1

Table A-4. (Continued).

Annual averages									
Location	²³⁹ Pu			²³⁵ U			²³⁸ U		
	10 ⁻¹⁷ µCi/mL	SDM (%)	Percent of DCG ^d	10 ⁻⁷ µg/m ³	SDM (%)	Percent of DCG ^e	10 ⁻⁵ µg/m ³	SDM (%)	Percent of DCG ^f
1	0.50	104	0.025	5.69	54	0.0012	8.02	54	0.027
2	0.03	70	0.0014	3.73	27	0.0008	5.25	27	0.017
12	0.08	80	0.0042	6.57	30	0.0014	9.4	28	0.031
13	0.04	70	0.0021	7.17	45	0.0015	10.01	45	0.034
14	0.07	68	0.0033	4.05	36	0.0009	5.71	36	0.019
15	(1) ^c	(309) ^c	(0.05) ^c	7.26	35	0.0016	10.26	35	0.034
	0.11	143	0.0054						

^a See Fig. 5.^b In all tables, activity listed as ²³⁹Pu includes activity due to ²⁴⁰Pu.^c Outlier. Values with outlier included are in parentheses.^d DCG = 2×10^{-14} µCi/mL for ²³⁹Pu activity in air or 2×10^{-2} pCi/m³.^e DCG = 1×10^{-13} µCi/mL (= 0.047 µg/m³) for ²³⁵U activity in air.^f DCG = 1×10^{-13} µCi/mL (= 0.3 µg/m³) for ²³⁸U activity in air.

Table A-5. Plutonium, cesium, and uranium on air filters—Site 300.

Month	^{239}Pu [10^{-17} $\mu\text{Ci/mL} \pm 2\sigma$ (%)]	^{137}Cs [10^{-16} $\mu\text{Ci/mL}$]	$^{239}\text{Pu}/^{137}\text{Cs}$ [10^{-2}]	^{235}U [10^{-7} $\mu\text{g/m}^3$]	^{238}U [10^{-5} $\mu\text{g/m}^3$]	$^{235}\text{U}/^{238}\text{U}$ [10^{-3}]
Jan.	0.03 ± 8	0.22 ± 16	1.4	1.0	1.5	6.4
Feb.	0.05 ± 18	0.24 ± 18	2.1	1.0	1.5	6.7
Mar.	0.02 ± 13	0.11 ± 32	1.8	1.4	2.3	6.0
Apr.	0.08 ± 13	0.20 ± 20	4.0	6.1	8.9	6.8
May	≤ 0.27	0.17 ± 30	15.9	5.4	14.1	3.8
June	0.04 ± 7	0.20 ± 20	2.0	3.6	5.5	6.5
July	0.05 ± 7	0.17 ± 28	2.9	2.9	4.3	6.8
Aug.	0.03 ± 10	0.13 ± 40	2.3	4.1	5.8	7.0
Sept.	0.08 ± 9	0.39 ± 20	2.1	5.0	7.1	7.0
Oct.	0.10 ± 5	0.19 ± 32	5.3	5.2	7.5	6.9
Nov.	0.16 ± 5	0.11 ± 28	14.5	5.9	23.4	2.5
Dec.	0.04 ± 7	0.09 ± 48	4.4	4.6	6.8	6.8
Average	0.08	0.19		3.9	7.4	
SDM (%)	90	42		49	83	
DCG ($\mu\text{Ci/mL}$)	2×10^{-14}	4×10^{-10}		$4.7 \times 10^{-2} \mu\text{g/m}^3$	$0.3 \mu\text{g/m}^3$	
Percent of DCG	4×10^{-3}	5×10^{-6}		8×10^{-4}	2×10^{-2}	

Table A-6a. Tritium in air—Livermore site perimeter.

Month	Sampling location ^a					
	1	2	12	13	14	15
	[10 ⁻¹¹ µCi/mL ± 2σ (%)]					
Jan.	— ^b — ^b	3.2 ± 3 85.3 ± 1 ^c	6.6 ± 2 8.0 ± 2	4.3 ± 3 6.2 ± 2	— ^b 29.2 ± 1 ^d 1.6 ± 4 1.6 ± 4 ^d	3.2 ± 3 1.6 ± 4
Feb.	41.6 ± 1 53.9 ± 1 ^c	7.8 ± 2 6.3 ± 2	15.2 ± 1 64.8 ± 1 ^c	63.8 ± 1 ^c — ^b	10.6 ± 2 109.1 ± 1 ^{c,d} 2.0 ± 4	6.4 ± 2 2.0 ± 4
Mar.	9.9 ± 2 6.6 ± 2 ^d 3.4 ± 4 2.6 ± 4 ^d	3.7 ± 3 2.2 ± 4	13.2 ± 2 7.0 ± 2	— ^b — ^b	8.2 ± 2 3.0 ± 4	25.3 ± 1 ^c 3.6 ± 3
Apr.	15.2 ± 1 7.9 ± 2 ^d 2.6 ± 5 2.1 ± 5 ^d	4.5 ± 3 5.6 ± 3 ^d 2.6 ± 3 4.6 ± 3 ^d	9.2 ± 2 12.3 ± 1	3.7 ± 3 3.4 ± 3	14.7 ± 1 5.5 ± 3 ^d 6.8 ± 2 3.2 ± 4	4.1 ± 3 1.7 ± 5
May	5.6 ± 2 9.6 ± 2 ^d 5.1 ± 3 2.4 ± 3 ^d	4.5 ± 3 2.6 ± 5 2.6 ± 6 ^d	11.2 ± 2 3.8 ± 3	3.7 ± 3 2.9 ± 4	7.2 ± 2 6.5 ± 3 ^d 7.1 ± 2 7.6 ± 2 ^d	4.8 ± 3 5.7 ± 3
June	4.8 ± 3 6.6 ± 3 ^d 5.3 ± 4 3.4 ± 4 ^d	2.3 ± 5 2.8 ± 6 ^d 2.4 ± 7 2.2 ± 6 ^d	3.5 ± 5 — ^b	2.2 ± 5 2.0 ± 7	6.2 ± 3 4.2 ± 4 ^d 6.3 ± 3 5.8 ± 3 ^d	4.0 ± 3 3.1 ± 4
Jul.	3.3 ± 4 3.5 ± 5 3.3 ± 5	1.6 ± 8 1.5 ± 9 0.6 ± 19	2.6 ± 4 1.4 ± 47 0.7 ± 14	1.4 ± 8 1.1 ± 10 ^d 1.1 ± 11 0.1 ± 100 0.4 ± 26 ^d	5.9 ± 3 4.5 ± 3 3.1 ± 5	2.0 ± 6 2.8 ± 5 1.4 ± 8
Aug.	3.6 ± 4 4.7 ± 5	1.6 ± 9 2.5 ± 6	1.5 ± 7 3.1 ± 5	1.0 ± 10 1.1 ± 11 ^d 1.7 ± 8 2.5 ± 6 ^d	4.5 ± 3 6.9 ± 3	2.9 ± 4 3.7 ± 4
Sept.	8.8 ± 2 3.0 ± 5 5.4 ± 3	1.7 ± 8 1.5 ± 9 6.7 ± 3	4.4 ± 4 3.2 ± 5 3.3 ± 5 ^d 22.9 ± 1 24.1 ± 1 ^d	— ^b 0.7 ± 16 ^d 1.3 ± 10 2.9 ± 4	6.2 ± 2 4.2 ± 4 4.1 ± 3	3.0 ± 4 2.0 ± 7 2.2 ± 5
Oct.	4.9 ± 4 3.2 ± 5	3.8 ± 4 2.9 ± 5	2.6 ± 5 4.0 ± 5 3.7 ± 5	2.1 ± 8 2.9 ± 8	4.5 ± 4 3.1 ± 5	2.1 ± 6 1.7 ± 8
Nov.	10.0 ± 2 2.3 ± 5	3.2 ± 5 2.8 ± 5	3.9 ± 4 4.5 ± 4	1.3 ± 10 — ^b	2.1 ± 8 2.6 ± 5	1.4 ± 9 1.8 ± 7 ^d 1.5 ± 6

Table A-6a. (Continued).

Month	Sampling location ^a					
	1	2	12 [10 ⁻¹¹ μCi/mL ± 2σ (%)]	13	14	15
Dec.	2.2 ± 6 1.5 ± 5	2.8 ± 5 2.1 ± 4	3.6 ± 4 6.7 ± 2	1.9 ± 6 0.8 ± 9	2.5 ± 5 7.6 ± 2	1.8 ± 6 3.0 ± 4 ^d 2.4 ± 4 0.9 ± 8 ^d
Average ^c	6.6 (8.3) ^c	3.2 (5.8) ^c	6.9 (9.0) ^c	2.1 (4.5) ^c	6.8 (10.9) ^c	2.7 (3.5) ^c
SDM (%)	116 (140) ^c	53 (255) ^c	88 (139) ^c	67 (272) ^c	83 (195) ^c	49 (125) ^c
Percent of DCG ^f	3 × 10 ⁻²	2 × 10 ⁻²	3 × 10 ⁻²	1 × 10 ⁻²	3 × 10 ⁻²	1 × 10 ⁻²
Dose (mrem) ^g	7 × 10 ⁻²	5 × 10 ⁻²	7 × 10 ⁻²	4 × 10 ⁻²	9 × 10 ⁻²	3 × 10 ⁻²

^a See Fig. 5 for sampling locations.^b No data. See "Deviations from the Monitoring Program" section.^c Outlier. Values with outlier included are in parentheses.^d Quality assurance samples.^e Livermore site perimeter overall average = 4.7 ± 96 (7.0 ± 81).^f DCG = 2 × 10⁻⁷ μCi/mL or 2 × 10⁵ pCi/m³.^g This dose is the effective dose equivalent, and was calculated from the annual average with outlier.

Table A-6b. Tritium in air—Livermore Valley.

Month	Sampling location ^a					
	S-1	S-2	V04 [10 ⁻¹¹ µCi/mL ± 2σ (%)]	V07	V09	V17
Jan.	4.7 ± 3 1.6 ± 5	2.5 ± 4 8.0 ± 2	— ^b 1.5 ± 5	5.2 ± 2 — ^b	2.8 ± 4 1.8 ± 6	2.1 ± 6 11.2 ± 2
Feb.	12.2 ± 2 1.0 ± 8	3.7 ± 3 2.5 ± 4	18.3 ± 1 ^c 0.6 ± 11	8.0 ± 2 1.4 ± 6	3.6 ± 4 — ^b	4.0 ± 3 — ^b
Mar.	9.4 ± 2 4.1 ± 3	2.4 ± 5 1.5 ± 6	2.3 ± 5 1.2 ± 5	55.6 ± 1 ^c 1.5 ± 6	2.4 ± 5 2.9 ± 4	1.3 ± 8 0.7 ± 15
Apr.	3.0 ± 4 1.5 ± 6	1.6 ± 6 1.9 ± 5	1.8 ± 5 1.8 ± 5	3.5 ± 3 1.2 ± 7	8.4 ± 2 3.6 ± 3	1.1 ± 8 3.0 ± 4
May	4.3 ± 3 3.5 ± 4	2.6 ± 4 3.0 ± 4	2.4 ± 6 5.4 ± 3	1.8 ± 6 5.2 ± 3	4.2 ± 3 2.7 ± 4	4.3 ± 3 3.1 ± 4
June	1.5 ± 7 1.2 ± 10	0.9 ± 10 0.3 ± 30	3.3 ± 4 2.1 ± 6	1.1 ± 10 0.3 ± 36	2.8 ± 4 1.9 ± 7	1.7 ± 7 0.7 ± 13
Jul.	2.1 ± 6 1.3 ± 9 0.9 ± 13	1.3 ± 10 0.3 ± 32 — ^b	2.7 ± 5 2.8 ± 5 2.3 ± 6	0.9 ± 13 1.2 ± 11 0.6 ± 20	0.7 ± 15 0.9 ± 12 0.6 ± 16	0.8 ± 13 0.3 ± 30 0.7 ± 17
Aug.	1.9 ± 7 2.5 ± 6	1.0 ± 10 5.7 ± 3	3.4 ± 4 2.3 ± 6	0.6 ± 16 2.2 ± 7	0.3 ± 34 1.4 ± 10	0.2 ± 40 3.4 ± 5
Sept.	5.7 ± 3 1.4 ± 9 3.0 ± 4	0.9 ± 9 0.8 ± 12 5.4 ± 3	4.8 ± 4 0.8 ± 6 3.7 ± 4	1.1 ± 11 0.7 ± 16 1.0 ± 10	0.7 ± 17 0.4 ± 25 1.0 ± 10	0.6 ± 13 0.8 ± 13 0.9 ± 8
Oct.	2.1 ± 6 2.5 ± 6	3.6 ± 4 — ^b	— ^b 2.0 ± 8	0.2 ± 36 1.1 ± 19	0.6 ± 17 0.5 ± 22	1.6 ± 9 0.7 ± 19
Nov.	4.7 ± 3 1.8 ± 7	1.6 ± 7 2.1 ± 6	1.1 ± 11 1.6 ± 7	1.6 ± 8 — ^b	1.5 ± 10 1.5 ± 8	0.7 ± 17 1.0 ± 11
Dec.	— ^b 1.5 ± 6	1.3 ± 9 1.4 ± 6	1.7 ± 8 — ^b	0.8 ± 12 0.3 ± 24	— ^b 0.3 ± 24	0.8 ± 13 0.8 ± 10
Average ^c	3.2	2.3	2.3 (3) ^d	1.8 (4) ^d	1.9	1.5 (1.9) ^d
SDM (%)	84	79	51 (116) ^d	106 (280) ^d	93	81 (122) ^d
Percent of DCG ^e	2 × 10 ⁻²	1 × 10 ⁻²	1 × 10 ⁻²	1 × 10 ⁻²	1 × 10 ⁻²	6 × 10 ⁻³
Dose (mrem) ^f	3 × 10 ⁻²	2 × 10 ⁻²	2 × 10 ⁻²	3 × 10 ⁻²	2 × 10 ⁻²	2 × 10 ⁻²

^a See Fig. 7 for sampling locations.^b No data. See "Deviations from the Monitoring Program" section.^c Livermore Valley overall average = 2.2 ± 55 (2.7 ± 62).^d Outlier. Values with outlier included are in parentheses.^e DCG = 2 × 10⁻⁷ µCi/mL or 2 × 10⁵ pCi/m³.^f This dose is the effective dose equivalent, and was calculated from the annual average with outlier.

Table A-7. Beryllium on air filters —Livermore site perimeter.

Month	Sampling location ^a					
	1	2	12 (10 ⁻⁵ µg/m ³)	13	14	15
Jan.	0.6	2.6	3.2	2.5	1.5	1.8
Feb.	1.3	4.9	5.0	4.0	2.4	4.4
Mar.	2.6	2.2	3.5	3.8	2.0	7.0
Apr.	5.9	4.5	3.0	6.2	4.3	9.3
May	3.4	2.9	3.1	4.3	2.2	4.7
June	3.8	4.1	5.1	7.4	3.3	4.7
July	3.4	2.3	3.2	4.8	2.1	4.7
Aug.	8.7	3.6	0.8	7.5	4.4	5.7
Sep.	3.2	3.4	5.9	7.1	3.5	5.9
Oct.	3.2	4.8	4.5	6.0	3.8	5.5
Nov.	0.7	2.3	0.7	3.8	0.9	4.2
Dec.	2.2	3.4	3.8	2.7	1.9	3.7
Average ^b	3.3	3.4	3.5	5.0	2.7	5.1
SDM (%)	76	29	46	36	43	36
Percent of ACG ^c	0.3	0.3	0.3	0.5	0.3	0.5

^a See Fig. 5.

^b Livermore site perimeter overall annual average = 3.8×10^{-5} µg/m³.

^c Ambient concentration guide set by the Bay Area Air Quality Management District is 0.01 µg/m³ (1000×10^{-5} µg/m³).

Table A-8. Beryllium on air filters—Site 300.

Month	Sampling location ^a								
	1	2	3	4	5 (10 ⁻⁵ µg/m ³)	6 ^b	8	9	10
Jan.	0.6	0.5	0.2	0.4	1.3	0.3	0.7	0.8	3.7
Feb.	1.0	0.7	0.7	1.0	1.6	0.7	0.8	1.0	3.3
Mar.	17.4	0.9	1.2	1.1	2.5	1.3	1.0	1.9	4.9
Apr.	7.5	4.3	4.8	10.4	6.6	5.6	0.5	1.6	— ^c
May	2.0	2.1	2.4	2.7	3.2	1.2	1.2	5.3	4.1
June	2.8	2.3	2.0	3.2	3.2	0.6	1.7	2.3	5.4
July	1.9	1.3	1.8	1.9	2.2	0.8	1.5	3.4	3.8
Aug.	3.0	2.5	3.4	2.6	4.5	0.6	1.8	3.8	6.6
Sep.	0.4	2.6	2.0	2.6	3.9	5.2	1.4	3.7	7.2
Oct.	4.0	2.5	6.2	1.2	3.6	4.0	2.7	0.2	7.9
Nov.	3.2	0.8	1.3	2.4	1.8	10.0	0.4	3.9	2.2
Dec.	1.6	0.2	2.0	1.7	2.3	2.5	0.7	1.4	3.9
Average ^d	3.8	1.7	2.3	2.6	3.1	2.7	1.2	2.4	4.4
SDM (%)	508	113	184	281	153	204	64	160	226
Percent of ACG ^e	0.4	0.2	0.2	0.3	0.3	0.3	0.1	0.2	0.4

^a See Fig. 6. for sampling locations.^b Tracy firehouse.^c No data.^d Site 300 overall annual average = 2.7×10^{-5} µg/m³.^e Ambient concentration guide set by the Bay Area Air Quality Management District is 0.01 µg/m³ (1000×10^{-5} µg/m³).

Table A-9. Various radionuclides in soil—Livermore Valley (sampling depth = 0 to 5 cm).

Location ^a	²³⁹ Pu	⁴⁰ K	¹³⁷ Cs	²³² Th	²³⁸ U
	[10 ⁻⁹ µCi/dry g ± 2σ (%)]	[10 ⁻⁶ µCi/dry g ± 2σ (%)]	[10 ⁻⁶ µCi/dry g ± 2σ (%)]	[µg/dry g ± 2σ (%)]	[µg/dry g ± 2σ (%)]
1079	4.2 ± 4	15.9 ± 2	0.16 ± 6	0.7 ± 4	1.0 ± 34
1080	1.6 ± 5	10.9 ± 4	0.08 ± 6	0.6 ± 4	0.3 ± 88
1081	5.2 ± 4	13.4 ± 2	0.12 ± 6	0.8 ± 2	0.7 ± 44
1082	2.5 ± 4	16.8 ± 4	0.15 ± 4	0.8 ± 4	0.9 ± 38
1083	1.7 ± 5	12.0 ± 4	0.08 ± 8	0.5 ± 6	0.4 ± 60
1084	6.4 ± 3	10.3 ± 12	0.26 ± 4	1.0 ± 4	1.0 ± 70
1085	3.4 ± 4	15.0 ± 2	0.18 ± 4	0.7 ± 4	0.8 ± 34
1086	1.0 ± 7	12.6 ± 4	0.06 ± 12	0.7 ± 4	0.4 ± 70
1087	2.0 ± 5	12.9 ± 4	0.10 ± 10	0.9 ± 4	0.9 ± 46
1088	2.2 ± 5	5.8 ± 22	0.11 ± 6	0.7 ± 4	0.7 ± 56
1089	4.7 ± 3	18.3 ± 2	0.25 ± 4	1.0 ± 4	1.1 ± 28
1090	526.0 ^b ± 2.5	13.5 ± 4	0.53 ± 12	0.8 ± 4	0.6 ± 46
1091	147.6 ^b ± 2.8	12.8 ± 4	0.83 ± 10	0.8 ± 4	0.5 ± 60
1092 ^c	1.0 ± 7	14.7 ± 4	0.06 ± 14	0.8 ± 4	0.9 ± 44
1093 ^c	1.2 ± 6	12.7 ± 2	0.04 ± 16	0.7 ± 4	0.8 ± 30
1094	3.1 ± 4	11.6 ± 4	0.16 ± 6	0.7 ± 6	0.7 ± 66
1095 ^d	5.0 ± 6	14.5 ± 2	0.29 ± 4	0.8 ± 4	1.0 ± 28
1096 ^d	5.0 ± 4	15.2 ± 4	0.28 ± 4	0.8 ± 4	— ^e
1097	0.2 ± 16	15.5 ± 4	0.01 ± 76	1.0 ± 4	1.2 ± 42
1098	1.3 ± 6	13.4 ± 4	0.09 ± 8	0.9 ± 4	0.5 ± 64
1099	1.1 ± 11	13.5 ± 6	0.07 ± 12	0.8 ± 6	0.8 ± 42
1100	12.4 ± 3	13.9 ± 2	0.05 ± 4	0.7 ± 4	0.8 ± 36
1101	2.7 ± 5	7.6 ± 4	0.18 ± 4	0.6 ± 4	0.6 ± 40
1102	7.4 ± 3	12.3 ± 2	0.45 ± 4	0.7 ± 4	0.9 ± 28
Average	3.4 (30.7)	13.1	0.19	0.8	0.8
SDM (%)	5.4 (21)	21	97	16	31

^a See Fig. 8 for sampling locations.

^b Outlier. Data with outlier included are in parentheses.

^c Samples 1092 and 1093 are duplicates.

^d Samples 1095 and 1096 are duplicates.

^e Not detected.

Table A-10. Plutonium, cesium, and uranium in soil—Site 300 (sampling depth = 0 to 5 cm).

Location ^a	²³⁹ Pu	⁴⁰ K	¹³⁷ Cs	²³⁸ U	²³² Th
	[10 ⁻⁹ µCi/dry g ± 2σ (%)]	[10 ⁻⁶ µCi/dry g ± 2σ (%)]	[10 ⁻⁶ µCi/dry g ± 2σ (%)]	[µg/dry g ± 2σ (%)]	[µg/dry g ± 2σ (%)]
1103	3.6 ± 5	13.6 ± 4	0.17 ± 6	1.0 ± 66	1.1 ± 4
1104 ^b	6.7 ± 4	14.8 ± 4	0.35 ± 4	— ^c	0.9 ± 4
1105 ^b	6.6 ± 4	14.8 ± 2	0.30 ± 4	1.4 ± 32	0.9 ± 4
1106	2.8 ± 5	11.5 ± 4	0.13 ± 6	— ^c	1.0 ± 4
1107	2.9 ± 3	14.5 ± 4	0.12 ± 8	2.2 ± 28	1.5 ± 4
1108	4.6 ± 5	12.3 ± 4	0.21 ± 4	— ^c	0.8 ± 4
1109 ^b	0.5 ± 12	10.8 ± 2	0.03 ± 22	— ^c	0.8 ± 6
1110	2.9 ± 4	16.9 ± 4	0.15 ± 6	0.3 ± 92	0.7 ± 6
1111	0.3 ± 12	10.7 ± 4	0.03 ± 28	1.0 ± 28	0.8 ± 4
1112	3.3 ± 4	13.9 ± 4	0.15 ± 8	0.6 ± 66	1.0 ± 4
1113	0.6 ± 9	11.5 ± 4	0.03 ± 24	1.9 ± 20	0.8 ± 4
1114	4.9 ± 4	13.4 ± 4	0.26 ± 4	— ^c	0.9 ± 4
1115	4.1 ± 4	11.6 ± 6	0.20 ± 6	149.0 ± 2 ^d	2.2 ± 4
1116	2.4 ± 5	16.0 ± 4	0.12 ± 8	1.2 ± 46	1.2 ± 4
1117 ^b	0.5 ± 12	10.1 ± 4	0.03 ± 20	0.3 ± 76	0.6 ± 6
Average	3.1	13.1	0.15	1.1 (59)	1.0
SDM (%)	67	16	66	60 (294)	39

^a See Fig. 9 for sampling locations.

^b Samples 1104 and 1105 are duplicates; samples 1109 and 1117 are duplicates.

^c Not detected.

^d Outlier. Values with outlier included are in parentheses.

Table A-11. Various radionuclides in effluents—LLNL and Livermore Water Reclamation Plant (LWRP).

Month	HTO [10 ⁻⁶ µCi/mL ± 2σ (%)]		¹³⁷ Cs [10 ⁻¹¹ µCi/mL ± 2σ (%)]		²³⁹ Pu [10 ⁻¹² µCi/mL ± 2σ (%)]		²³⁹ Pu [10 ⁻⁸ µCi/g ± 2σ (%)]
	LLNL	LWRP	LLNL	LWRP	LLNL	LWRP	LWRP sludge
Jan.	0.4 ± 5.7	0.2 ± 5.0	72.6 ± 8	6.1 ± 50	13.31 ± 5	0.35 ± 31	
Feb.	1.1 ± 5.0	0.4 ± 5.7	171 ± 4	15.5 ± 24	2.40 ± 14	— ^a	
Mar.	3.5 ± 4.6	0.5 ± 6.0	290 ^b ± 2	≤0.8	6.14 ± 7	0.24 ± 39	7.72 ± 2
Apr.	1.7 ± 5.2	0.2 ± 6.1	3.3 ± 76	3.4 ± 72	10.24 ± 6	0.84 ± 20	
May	6.7 ± 4.2	0.4 ± 6.4	14.3 ± 22	6.5 ± 44	11 100 ^b ± 2	84.32 ^b ± 2	
June	3.3 ± 4.5	0.4 ± 6.0	5.8 ± 48	≤1.2	236 ± 2	10.78 ± 5	1018 ^b ± 6
July	1.3 ± 5.7	0.4 ± 6.3	9.1 ± 28	2.8 ± 58	948 ± 2	3.17 ± 10	
Aug.	3.0 ± 5.3	0.3 ± 6.4	17.8 ± 16	≤1.0	386 ± 2	11.32 ± 6	
Sept.	1.2 ± 5.7	0.3 ± 6.7	7.4 ± 42	≤0.9	518 ± 2	4.13 ± 10	270 ± 2
Oct.	0.8 ± 6.0	0.5 ± 6.2	8.1 ± 28	2.8 ± 80	295 ± 2	2.25 ± 11	
Nov.	3.0 ± 5.6	0.4 ± 6.1	8.7 ± 28	3.6 ± 50	210 ± 2	3.52 ± 11	
Dec.	1.7 ± 5.6	1.2 ± 5.8	11.6 ± 18	≤1.7	115 ± 3	2.34 ± 11	56.15 ± 2
Average	2.3	0.4	9.6 (51.6)	2.8 ^c	249 (1153)	3.89 (11.20)	111 (338)
SDM (%)	75	60	46 (173)	61 ^c	116 (273)	102 (219)	125 (138)
DOE limit (µCi/mL)	1 × 10 ⁻²	N/A	1.5 × 10 ⁻⁵	N/A	1.0 × 10 ⁻⁵	N/A	N/A
Percent of DOE limit	2 × 10 ⁻²	N/A	6.4 × 10 ⁻⁴ (3.1 × 10 ⁻³)	N/A	2.5 × 10 ⁻³ (1.2 × 10 ⁻²)	N/A	N/A

^a No data. See the section titled "Deviations from the Sampling Program."

^b Outlier. Data with outlier included are presented in parentheses.

^c Median value ± median absolute deviation.

Table A-12. Metal discharged to sanitary sewer system: monthly summaries.

	Cd	Cr	Cu	Fe	Pb	Ni	Ag	Zn	Al	Be
Month	(mg/L)									
Jan.	0.002	0.034	0.077	0.87	0.010	0.022	0.0110 ^a	0.15	0.23	0.0010
Feb.	0.017 ^a	0.220 ^a	0.051	0.51	0.100 ^a	0.250 ^a	0.0850 ^a	0.28	2.70 ^a	<0.03
Mar.	0.002	0.040	0.130	0.64	0.011	0.019	0.0082	0.18	0.18	0.0008
Apr.	0.002	0.038	0.048	0.76	0.010	0.012	0.0050	0.17	0.21	<0.0002
May	0.002	0.042	0.130	0.72	0.013	0.016	0.0010	0.18	0.21	0.0004
June	0.002	0.036	0.068	0.44	0.014	0.007	0.0060	0.10	0.19	0.0002
July	0.002	0.054	0.310	0.69	0.027	0.007	0.0060	0.14	0.26	0.0002
Aug.	0.002	0.056	0.340	0.64	0.019	0.014	0.0010	0.12	0.01 ^a	0.0006
Sept.	0.002	0.063	0.630	0.79	0.016	0.011	0.0008	0.20	0.36	0.0002
Oct.	0.002	0.040	0.081	0.06	0.021	0.010	0.0071	0.24	0.28	0.0006
Nov.	0.022 ^a	0.061	0.079	0.79	0.010	0.007	0.0015	0.17	0.58	0.0003
Dec.	0.0017	0.030	0.098	0.68	0.011	0.009	0.0068	0.09	0.33	0.0004
Average	0.002 (0.005)	0.045 (0.060)	0.170	0.63	0.015 (0.022)	0.012 (0.032)	0.0043 (0.0116)	0.17	0.28 (0.46)	0.0004
SDM (%)	5 (141)	26 (87)	1.02	34	39 (115)	42 (215)	68 (201)	33	42 (155)	61

^a Outlier. Data with outlier included are presented in parentheses.

Table A-13. Physical and chemical examinations of LLNL sanitary sewer effluent.

	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.		
	(mg/L)				Average	SDM (%)
BOD	63	89	60	75	72	18
COD	200	210	180	140	182	17
Oil and grease	9	48	44	19	30	63
Phenolics	<0.05	<0.35	<0.05	0.19	0.16	89
Settleable solids (mL/L/hr)	— ^a	8.5	1.7	18	9.4	87
Total dissolved solids	460	400	— ^a	340	400	15
Total organic carbon	45	38	39	60	46	22
Total solids	490	500	— ^a	500	497	1
Total suspended solids	17	30	— ^a	57	35	59
Volatile solids (% total solids)	56	57	— ^a	71	61	14
Ammonia nitrogen (as N)	26	29	31	28	28	7
Chloride	97	85	27	3	53	85
Cyanide	<0.02	<0.02	<0.02	<0.02	<0.02	0
Nitrate nitrogen (as N)	<0.10	<0.01	<0.10	<0.10	<0.08	58
Nitrite nitrogen (as NO ₂)	<0.03	<0.03	— ^a	<0.03	<0.03	0
Sulfate	110	86	53	200	112	56
Total alkalinity (as CaCO ₃)	243	204	126	— ^a	191	31
Total kjeldahl nitrogen (as N)	21	31	34	33	30	20
Total phosphorous (as P)	10	3.6	13	11	9.4	43
Arsenic	<0.001	0.003	<0.002	0.004	<0.002	52
Boron	0.45	0.35	0.27	0.30	0.34	23
Calcium	29	18	9.2	15	18	47
Chromium	0.02	0.08	<0.02	0.19	0.08	103
Copper	0.14	0.06	0.12	0.76	0.27	122
Magnesium	13	10	1.3	1.6	6.5	92
Mercury	0.0003	0.0008	0.0015	0.0013	0.0010	55
Nickel	<0.05	<0.05	<0.05	<0.05	<0.05	0
Potassium	17	— ^a	18	19	18	6
Selenium	0.002	<0.001	<0.001	<0.001	<0.001	40
Sodium	81	— ^a	33	22	45	69
Sodium (as % cations)	42	— ^a	— ^a	— ^a	42	0
Zinc 0.20	0.13	0.17	0.50	0.25	68	

^a No data.

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

Organochlorine pesticides	µg/L		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-14. Gross alpha activity in water—Livermore Valley.

Location ^a	Number of samples	Maximum	Minimum	Average	SDM (%)
		[10 ⁻⁹ μCi/mL ± 2σ (%)]			
11	4	≤2.8	≤2.1	≤2.4	12
15	4	≤3.2	≤2.4	≤2.7	13
16	4	≤6.5	≤2.5	≤4.2	45
19	4	≤2.8	≤2.4	≤2.5	7
20	5	≤4.5	≤3.3	≤3.7	13
23	4	≤2.8	≤1.7	≤2.4	20
24	4	≤4.8	≤1.4	≤2.8	52
26	4	≤2.8	≤2.4	≤2.6	7
29	4	5.0 ± 78	≤0.6	≤2.7	67
31	3	≤3.3	≤2.4	≤2.7	18
34	4	≤2.8	≤1.8	≤2.4	18
37	4	≤3.3	≤0.75	≤2.2	48

^a See Fig. 10 for sampling locations.

Table A-15. Gross alpha activity in water—Site 300.

Location ^a	Number of samples	Maximum	Minimum	Average	SDM (%)
		[10 ⁻⁹ µCi/mL ± 2σ (%)]			
1	4	≤3.3	≤2.0	2.6	21
2	4	≤3.3	≤2.0	2.6	21
3	4	21 ± 38	≤2.0	7.3	126
4	4	25 ± 37	≤2.0	12.4	95
5	4	32 ± 32	≤2.0	10.0	146
6	4	≤33	≤2.0	2.6	21
14	4	≤10	≤2.4	4.6	78
20	3	≤3.4	≤1.5	2.6	38
21	4	7.2 ± 73	≤2.8	4.1	51
22	4	≤3.3	≤2.0	2.6	21
23	3	≤3.3	≤2.4	2.9	16
24	4	≤3.3	≤2.0	2.6	21

^a See Fig. 11 for sampling locations.

Table A-16. Gross beta activity in water—Livermore Valley.

Location ^a	Number of samples	Maximum	Minimum	Average	SDM (%)
		[10 ⁻⁹ μCi/mL ± 2σ (%)]			
11	4	≤7.6	≤7.4	≤7.5	2
15	4	≤7.6	≤2.6	≤6.2	39
16	4	13 ± 66	≤7.4	≤12	27
19	4	≤7.6	≤4.4	≤6.7	23
20	5	≤13	<2.1	≤8.4	47
23	4	≤7.6	≤5.0	≤6.8	18
24	4	≤38	≤5.9	≤15	106
26	4	≤7.6	≤2.1	≤6.1	44
29	4	≤7.6	≤5.4	≤7.0	15
31	3	≤9.2	≤7.4	≤8.0	13
34	4	12 ± 66	≤7.4	≤8.6	26
37	4	≤9.2	≤7.4	≤8.0	11

^a See Fig. 10 for sampling locations.

Table A-17. Gross beta activity in water—Site 300.

Location ^a	Number of samples	Maximum	Minimum	Average	SDM (%)
		[10 ⁻⁹ μCi/mL ± 2σ (%)]			
1	4	≤10	≤5.0	≤7.8	27
2	4	≤10	≤5.0	≤7.8	27
3	4	13 ± 60	≤8.7	10	17
4	4	27 ± 26	≤8.7	18	44
5	4	18 ± 46	≤8.7	12	36
6	4	≤10	6 ± 67	≤8.0	21
14	4	12 ± 79	≤8.7	10	13
20	3	≤8.7	≤3.4	≤6.5	42
21	4	≤10	7 ± 71	≤8.3	16
22	4	≤10	6 ± 83	≤8.0	21
23	3	12 ± 50	≤8.6	10	17
24	4	≤10	≤5	≤7.8	27

^a See Fig. 11 for sampling locations.

Table A-18. Various radionuclides in stormwater runoff.

Location ^a	³ H [10 ⁻⁶ μCi/mL ± 2σ (%)]	Gross alpha (10 ⁻⁹ μCi/mL)	Gross beta (10 ⁻⁹ μCi/mL)
1	1.27 ± 2.5	≤2	≤3
2	— ^b	— ^b	— ^b
3	1.51 ± 2.4	≤2	≤4
4	— ^b	— ^b	— ^b
5	18.5 ± 1.6	≤2	4 ± 2
6	2.60 ± 2.3	≤3	4 ± 2

^a See Fig. 13 for sampling locations.

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

Table A-19. Tritium in water—Livermore Valley.

	Sampling location ^a							
	11 ^b	15 ^b	16 ^b	19 ^c [10 ⁻⁷ μCi/mL ± 2σ (%)]	20 ^d	23 ^b	24 ^b	26 ^b
First quarter	0.41 ± 17	0.62 ± 12	3.13 ± 4	0.63 ± 11	36.3 ± 2 32.0 ± 5 17.1 ± 8	0.72 ± 9	0.91 ± 8	1.35 ± 6
Second quarter	0.52 ± 12	0.41 ± 16	2.33 ± 4	0.58 ± 11	1.04 ± 29	0.34 ± 17	0.46 ± 12	1.57 ± 6
Third quarter	0.42 ± 15	0.42 ± 17	1.09 ± 8	0.78 ± 9	— ^e	0.50 ± 12	0.48 ± 12	1.68 ± 5
Fourth quarter	0.49 ± 12	0.38 ± 15	1.39 ± 6	0.32 ± 17	6.15 ± 3 10.10 ± 3 17.4 0± 2	0.42 ± 13	0.46 ± 14	1.61 ± 5
Average	0.46	0.46	1.98	0.58	17.2	0.50	0.58	1.55
SDM (%)	12	24	47	33	76	33	38	9
Percent of DCG ^f	2 × 10 ⁻³	2 × 10 ⁻³	1 × 10 ⁻³	3 × 10 ⁻³	1 × 10 ⁻¹	2 × 10 ⁻³	3 × 10 ⁻³	8 × 10 ⁻³
Effective dose (mrem)	2 × 10 ⁻³	2 × 10 ⁻³	9 × 10 ⁻³	3 × 10 ⁻³	9 × 10 ⁻²	2 × 10 ⁻³	3 × 10 ⁻³	7 × 10 ⁻³

Table A-19. (Continued).

	Sampling location ^a						
	29 ^b	30 ^g	31 ^c	33 ^h [10 ⁻⁷ µCi/mL ± 2σ (%)]	34 ^h	37 ^c	43 ⁱ
First quarter	0.40 ± 17	0.39 ± 16	0.49 ± 14	— ^e	0.43 ± 14	0.48 ± 14	— ^e
Second quarter	0.36 ± 16	0.32 ± 21	0.35 ± 15	— ^e	0.40 ± 15	0.33 ± 17	1.44 ± 7 9.01 ± 3 9.62 ± 3
Third quarter	0.61 ± 12	0.84 ± 8	0.72 ± 10	— ^e	0.61 ± 11	0.50 ± 13	9.55 ± 15 9.47 ± 15 8.73 ± 16
Fourth quarter	0.47 ± 12	0.46 ± 15	0.29 ± 20	— ^e	0.47 ± 14	0.39 ± 14	10.0 ± 14 11.4 ± 13 14.5 ± 10
Average	0.46	0.50	0.46	—	0.48	0.42	9.30
SDM (%)	24	46	41	—	19	19	37
Percent of DCG ^f	2 × 10 ⁻³	2 × 10 ⁻³	2 × 10 ⁻³	—	2 × 10 ⁻³	2 × 10 ⁻³	5 × 10 ⁻²
Effective dose (mrem)	2 × 10 ⁻³	2 × 10 ⁻³	2 × 10 ⁻³	—	2 × 10 ⁻³	2 × 10 ⁻³	4 × 10 ⁻²

^a See Fig. 10 for sampling locations.^b Surface water.^c Tap water—Livermore locations.^d Rain water.^e No data. See "Deviations from the Sampling Program" section.^f DCG = 2 × 10⁻³ µCi/mL.^g Tap water—LLNL.^h Well water.ⁱ LLNL swimming pool.

Table A-20. Tritium in water—Site 300.

	Location ^a					
	1 ^b	2 ^b	3 ^b	4 ^b	5 ^b	6 ^b
	[10 ⁻⁷ μCi/mL ± 2σ (%)]					
First Quarter	0.20 ± 30	0.30 ± 21	0.05 ± 94	0.13 ± 42	0.13 ± 40	0.10 ± 54
Second quarter	11.4 ± 2	0.27 ± 24	≤0.04	≤0.04	0.20 ± 28	0.05 ± 99
Third quarter	13.8 ± 3	1.55 ± 5	0.24 ± 23	1.03 ± 7	0.26 ± 21	0.1 ± 40
Fourth quarter	14.7 ± 3	0.54 ± 13	≤0.06	0.17 ± 34	0.20 ± 31	≤0.03
Average	10	0.66	0.10	0.34	0.20	0.08
SDM (%)	67	90	98	135	27	59
Percent Quarter of DCG ^c	5 × 10 ⁻²	3 × 10 ⁻³	5 × 10 ⁻⁴	2 × 10 ⁻³	1 × 10 ⁻³	4 × 10 ⁻
Effective Quarter dose (mrem)	5 × 10 ⁻²	3 × 10 ⁻³	5 × 10 ⁻⁴	2 × 10 ⁻³	9 × 10 ⁻⁴	4 × 10 ⁻⁴

Table A-20. (Continued).

	Location ^a					
	14 ^d	20 ^e	21 ^d	22 ^b	23 ^b	24 ^b
	[10 ⁻⁷ µCi/mL ± 2σ (%)]					
First quarter	0.96 ± 9	0.61 ± 11 0.66 ± 10 0.42 ± 17	0.55 ± 14	0.32 ± 20	0.29 ± 26	0.17 ± 40
Second quarter	0.46 ± 12	— ^f	0.11 ± 53	≤0.05	≤0.06	0.07 ± 67
Third quarter	1.01 ± 7	— ^f	0.22 ± 29	0.12 ± 41	0.08 ± 60	≤0.05
Fourth quarter	0.43 ± 15	0.46 ± 43 0.47 ± 15 0.42 ± 16	0.32 ± 18	≤0.02	0.06 ± 68	0.06 ± 77
Average	0.71	0.51	0.30	0.13	0.12	0.09
SDM (%)	44	20	62	106	91	64
Percent of DCG ^c	4 × 10 ⁻³	2 × 10 ⁻³	2 × 10 ⁻³	6 × 10 ⁻⁴	6 × 10 ⁻⁴	4 × 10 ⁻⁴
Effective dose (mrem)	3 × 10 ⁻³	2 × 10 ⁻³	2 × 10 ⁻³	6 × 10 ⁻⁴	6 × 10 ⁻⁴	4 × 10 ⁻⁴

^a See Fig. 11 for sampling locations.^b Well water.^c DCG = 2 × 10⁻³ µCi/mL.^d Surface water.^e Rain water.^f No data available. See the section titled "Deviations from the Sampling Program."

Table A-21. Water-quality parameters in ground and surface waters in the vicinity of Site 300.

Location ^b	Nonradiological analyte ^a (mg/L)						Radiological analyte (10 ⁻⁹ µCi/mL)		
	Arsenic	Barium	Lead	Selenium	Fluoride	Nitrate (as N)	Gross alpha	Gross beta	Tritium
V-1 (NW)	0.004	<0.1	0.001	<0.001	0.57	<0.44	<10	13	<312
V-2 (NW)	<0.001	<0.1	0.004	0.001	0.60	28	<2	<3	<265
V-3 (W)	<0.001	0.1	<0.001	0.004	0.93	47	<4	<3	<254
V-4 (W)	<0.001	<0.1	0.004	0.001	0.55	38	<3	7	<280
V-6 (NE)	<0.001	<0.1	0.024	0.002	0.21	65	<3	6	294
V-7 (E)	0.015	<0.1	0.010	0.003	0.54	34	<3	14	<329
V-8 (E)	0.013	<0.1	0.012	0.005	0.59	26	<5	10	<250
P-1 (E)	0.003	<0.1	0.015	<0.001	0.47	<0.44	<6	<4	<205
C-1 (S)	0.001	<0.1	<0.001	<0.001	0.65	0.66	<3	<4	<239
C-3 (S)	<0.001	<0.1	0.019	<0.001	0.28	0.44	<5	11	<258
F-1 (SE)	0.001	<0.1	0.011	<0.001	0.34	3.3	<3	10	<625
G-1 (S)	<0.001	<0.1	0.001	0.001	0.31	2.0	<5	9	<205
G-2 (S)	0.015	<0.1	<0.001	0.001	1.1	<0.44	<2	14	<244
G-4 (S)	0.004	<0.1	0.14	0.001	0.74	0.49	<2	13	<205
G-5 (S)	<0.001	<0.1	0.004	0.001	0.71	1.5	<2	<5	<205
M-1A (N)	<0.001	<0.1	0.013	<0.001	0.71	8.9	<2	9	<205
M-2A (N)	0.004	<0.1	<0.001	<0.001	0.87	<0.44	<5	34	<266
M-3A (N)	<0.001	<0.1	0.015	0.001	0.80	12	<4	<7	<205
M-6A (NW)	0.009	<0.1	0.012	0.002	0.58	34	<5	7	<377
W-1 (W)	0.003	<0.1	0.003	0.005	0.50	60	<5	28	<350
W-2 (W)	<0.001	<0.1	0.001	<0.001	0.31	125	16	63	<320
W-3 (W)	0.005	<0.1	0.003	<0.001	0.32	<0.44	<7	17	<229

^a Concentrations of cadmium, chromium, mercury, silver, beryllium, and organic primary drinking water standard analytes were below the analytical level of detection for all sampling locations.

^b Compass direction from the center of Site 300 is in parentheses.

Table A-22. Tritium in groundwater—Livermore Valley.

Well identification ^a	Activity [10 ⁻⁷ μ Ci/mL $\pm$ 2 σ (%)]	Percent of DCG ^b
3S1E-1H3	0.1 $\pm$ 52	5 $\times$ 10 ⁻⁴
3S1E-1P2	3.1 $\pm$ 4	2 $\times$ 10 ⁻²
3S1E-1R2	0.7 $\pm$ 10	4 $\times$ 10 ⁻³
3S1E-2R1	2.3 $\pm$ 4	1 $\times$ 10 ⁻²
3S1E-9M2	0.8 $\pm$ 9	4 $\times$ 10 ⁻³
3S1E-11B1	8.2 $\pm$ 3	4 $\times$ 10 ⁻²
3S1E-12A2	1.2 $\pm$ 7	6 $\times$ 10 ⁻³
3S1E-12D2	5.5 $\pm$ 3	3 $\times$ 10 ⁻²
3S1E-12G1	2.7 $\pm$ 4	1 $\times$ 10 ⁻²
3S1E-16L5	0.6 $\pm$ 10	3 $\times$ 10 ⁻³
3S1E-17D2	$\leq$ 0.1	$\leq$ 5 $\times$ 10 ⁻⁴
3S1E-18A5	0.2 $\pm$ 30	1 $\times$ 10 ⁻³
3S2E-7C2	1.2 $\pm$ 7	6 $\times$ 10 ⁻³
3S2E-7P3	0.1 $\pm$ 53	5 $\times$ 10 ⁻⁴
3S2E-16B1	0.2 $\pm$ 22	1 $\times$ 10 ⁻³

^a See Fig. 12 for sampling locations.

^b DCG = 2 $\times$ 10⁻³ μ Ci/mL.

Table A-23. LLNL stormwater runoff—nonradioactive parameters.

Positively detected parameters	Sampling location ^a					
	1	2	3	4	5	6
Physical (mg/L)						
Nitrate (as N)	1.3	— ^b	0.82	— ^b	0.83	0.17
COD	8	— ^b	<5	— ^b	<5	<5
Oil and grease	10	— ^b	7	— ^b	12	<5
Cadmium	0.0007	— ^b	<0.0001	— ^b	<0.0001	<0.0001
Chromium	0.0014	— ^b	<0.0015	— ^b	0.0016	0.0007
Lead	0.003	— ^b	<0.001	— ^b	<0.001	0.002
Mercury	<0.0001	— ^b	0.0002	— ^b	0.0002	0.0002
Silver	0.0001	— ^b	<0.0001	— ^b	<0.0001	<0.0001
Organics (mg/L)						
TOC	9.0	— ^b	7.9	— ^b	8.0	6.2

^a See Fig. 13 for sampling locations.

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

The following organic compounds would have been reported had they appeared above the detection limits indicated below:

Title 22 organics (mg/L)	Purgeable priority pollutants (EPA 624) (μg/L)
2,4,5-TP (Silvex)	0.2
2,4-O	1.0
Endrin	0.1
Lindane	0.05
Methoxychlor	0.2
Toxaphene	1.0
	Acrolein
	10
	Acrylonitrile
	10
	All other analytes
	1

Table A-24. Tritium in vegetation—Livermore Valley.

	Sampling location ^a							
	4	15	20	23	29	31	32	33
	[10 ⁻⁷ µCi/mL of moisture content ± 2σ (%)]							
First quarter	3.4 ± 33	48.6 ± 3	33.3 ± 4	85.5 ± 2 65.9 ± 3	46.2 ± 4	11.4 ± 11	2.7 ± 41	4.6 ± 25
Second quarter	5.2 ± 22	25.0 ± 6	5.1 ± 23	16.8 ± 8	14.3 ± 9	7.8 ± 15	3.9 ± 29	2.2 ± 51
Third quarter	3.7 ± 33	9.9 ± 14	1.5 ± 81	26.5 ± 6	10.3 ± 13	10.5 ± 13	≤1.2	≤1.2
Fourth quarter	19.5 ± 8	— ^b	9.9 ± 14	— ^b	22.4 ± 7	16.5 ± 9	7.9 ± 17	≤1.2
Average	8.0	37.4	12.4	42.9	21.6	11.1	4.6	2.3
SDM (%)	97	66	115	87	67	30	63	70
Effective dose (mrem) ^c	1 × 10 ⁻²	7 × 10 ⁻²	2 × 10 ⁻²	8 × 10 ⁻²	4 × 10 ⁻²	2 × 10 ⁻²	8 × 10 ⁻³	4 × 10 ⁻³

^a See Fig. 14 for sampling locations.^b No data. See "Deviations from the Sampling Program" section.^c This dose represents the total effective dose from the forage-cow-milk pathway.

Table A-25. Tritium in vegetation—Site 300.

	Sampling location ^a					
	1	2	3	6	12	13
	[10 ⁻⁷ µCi/mL of moisture content ± 2σ (%)]					
First quarter	1.8 ± 60 2.7 ± 42	1.8 ± 62	2.7 ± 42	10.5 ± 12	2.0 ± 54	284 ± 1
Second quarter	≤1.1	1.2 ± 92	≤1.1	10.6 ± 12	2.2 ± 50	33.6 ± 5 107 ± 2
Third quarter	≤1.2 ≤1.2	1.6 ± 75	≤1.2	91.8 ± 3	1.4 ± 86	1.7 ± 70
Fourth quarter	≤1.2	≤1.2 ≤1.3 ^b	≤1.2	6.6 ± 20	4.6 ± 28	390 ± 1
Average	1.2 ^c	1.3 ^c	1.2 ^c	29.9	2.6	163.3
SDM (%)	4 ^d	8 ^d	4 ^d	138	55	102
Effective dose (mrem) ^e	2 × 10 ⁻³	2 × 10 ⁻³	2 × 10 ⁻³	5 × 10 ⁻²	5 × 10 ⁻³	3 × 10 ⁻¹

^a See Fig. 15 for sampling locations.^b Quality assurance duplicate sample.^c Median value. See Appendix B.^d Median absolute deviation (%). See Appendix B.^e This dose represents the total effective dose equivalent from the forage-cow-milk pathway.

Table A-26. Tritium in wine.

Sample	Sampling location		
	Livermore wines	Other Californian wines [10^{-7} $\mu\text{Ci/mL} \pm 2\sigma$ (%)]	European wines
1	2.83 ± 30	1.11 ± 74	5.26 ± 17
2	5.18 ± 17	1.51 ± 55	2.89 ± 29
3	2.93 ± 27	1.44 ± 55	2.90 ± 29
4	7.41 ± 12		
Average	4.59	1.35	3.68
SDM (%)	47	16	37

Table A-27. Tritium in honey

Sample	Sampling location [10^{-7} $\mu\text{Ci/mL}$ (in water recovered $\pm 2\sigma$ (%))]	
	Livermore	California
1	1.14 ± 19	1.46 ± 30
2	1.90 ± 12	1.36 ± 17
Average	1.52	1.41
SDM (%)	35	5

Table A-28a. Tritium in milk—Livermore Valley.

	Sampling location				
	5	7	11 [10 ⁻⁷ μ Ci/mL $\pm$ 2 σ (%)]	12	13
Jan.	— ^a	— ^a	— ^a	— ^c	— ^c
Feb.	— ^a	2.4 $\pm$ 46	3.2 $\pm$ 35	— ^c	— ^c
Mar.	— ^a	3.0 $\pm$ 37	2.1 $\pm$ 52	— ^c	— ^c
Apr.	$\leq$ 1.1	1.6 $\pm$ 70	1.6 $\pm$ 70	— ^c	— ^c
May	4.3 $\pm$ 26	3.3 $\pm$ 34	— ^b	3.0 $\pm$ 37	— ^c
June	1.5 $\pm$ 74	1.8 $\pm$ 60	— ^b	$\leq$ 1.1	— ^c
July	— ^a	$\leq$ 1.3	— ^b	$\leq$ 8.3	— ^c
Aug.	— ^a	1.7 $\pm$ 77	— ^b	1.6 $\pm$ 79	— ^c
Sept.	— ^a	2.7 $\pm$ 51	— ^b	2.5 $\pm$ 53	— ^c
Oct.	— ^a	— ^a	— ^b	— ^a	$\leq$ 1.3
Nov.	— ^a	— ^a	— ^b	— ^a	— ^a
Dec.	— ^a	— ^a	— ^b	— ^a	— ^a
Average	2.6	2.2	2.3	2.5 ^d	—
SDM (%)	59	33	36	44 ^e	—
Effective dose (mrem)	5 $\times$ 10 ⁻³	4 $\times$ 10 ⁻³	5 $\times$ 10 ⁻³	5 $\times$ 10 ⁻³	—

^a No data. See "Deviations from the Sampling Program" section.^b No data; location dropped. See "Changes to the Environmental Monitoring Program" section.^c New location. See "Changes to the Environmental Monitoring Program" section.^d Median value. See Appendix B.^e Median absolute deviation (%). See Appendix B.

Table A-28b. Potassium-40 in milk—Livermore Valley.^a

	Sampling location				
	5	7	11 (10 ⁻⁶ µCi/mL ± 2σ (%))	12	13
Jan.	— ^b	— ^b	— ^b	— ^d	— ^d
Feb.	— ^b	1.4	1.4	— ^d	— ^d
Mar.	— ^b	1.6	1.5	— ^d	— ^d
Apr.	2.4	1.5	1.9	— ^d	— ^d
May	2.8	1.8	— ^c	1.9	— ^d
June	1.9	2.1	— ^c	1.9	— ^d
July	— ^b	2.1	— ^c	2.0	— ^d
Aug.	— ^b	1.8	— ^c	1.9	— ^d
Sept.	— ^b	2.0	— ^c	2.0	— ^d
Oct.	— ^b	— ^b	— ^c	— ^b	1.8
Nov.	— ^b	— ^b	— ^c	— ^b	— ^b
Dec.	— ^b	— ^b	— ^c	— ^b	— ^b
Average	2.4	1.8	1.6	1.9	—
SDM (%)	19	15	16	3	—

^a Potassium-40 is a naturally occurring radionuclide and is not an emission from LLNL^b No data; see the section titled "Deviations from the Sampling Program."^c No data; location dropped. See the section titled "Changes to the Environmental Monitoring Program."^d New location. See the section titled "Changes to the Environmental Monitoring Program."

Table A-28c. Cesium-137 in milk—Livermore Valley.

	Sampling location				
	5	7	11 [10^{-9} $\mu\text{Ci/mL} \pm 2\sigma$ (%)]	12	13
Jan.	— ^a	— ^a	— ^a	— ^b	— ^b
Feb.	— ^a	6.06 ± 26^c	3.67 ± 32^d	— ^b	— ^b
Mar.	— ^a	1.83 ± 64	5.74 ± 18	— ^b	— ^b
Apr.	2.75 ± 58	0.96 ± 66	3.85 ± 30	— ^b	— ^b
May	≤ 0.70	2.65 ± 42	— ^e	1.31 ± 56	— ^b
June	2.83 ± 46	1.44 ± 74	— ^e	≤ 1.66	— ^b
July	— ^a	≤ 1.75	— ^e	≤ 0.56	— ^b
Aug.	— ^a	≤ 0.70	— ^e	≤ 1.70	— ^b
Sept.	— ^a	≤ 0.70	— ^e	≤ 1.26	— ^e
Oct.	— ^a	— ^a	— ^e	— ^a	≤ 1.60
Nov.	— ^a	— ^a	— ^e	— ^a	— ^a
Dec.	— ^a	— ^a	— ^e	— ^a	— ^a
Average	2.09	2.01	4.42	≤ 1.31	—
SDM (%)	58	88	26	35	—

^a No data. See "Deviations from the Sampling Program" section.

^b This month ^{134}Cs was also detected at a level of $4.41 \pm 38\% 10^{-9} \mu\text{Ci/mL}$.

^c New location. See "Changes to the Environmental Monitoring Program" section.

^d This month ^{134}Cs was also detected at a level of $1.30 \pm 60\% 10^{-9} \mu\text{Ci/mL}$.

^e No data; location dropped. See "Changes to the Environmental Monitoring Program" section.

Table A-29. Environmental radiation measurements (TLD)—Livermore site perimeter.

Location ^a	Jan.–Mar.	Apr.–June (mrem)	July–Sept.	Oct.–Dec.	Annual
1	21	16	16	— ^b	71 ^c
2	17	14	15	16	62
3	22	12	17	20	71
4	22	12	17	20	71
5	21	13	17	21	72
6	18	13	16	20	67
7	19	15	16	20	70
8	19	15	16	19	69
9	19	13	16	20	68
10	19	14	14	17	64
11	15	17	12	14	58
12	16	15	14	15	60
13	18	13	13	17	61
42	19	13	— ^b	16	64 ^c
47	19	12	15	17	63
48	18	13	15	18	64
49	19	13	15	18	65
50	19	12	14	16	61
52	18	13	15	17	63
53	18	12	15	17	62
54	18	13	15	18	64
56	16	12	14	18	60
Average	19	13	15	18	65

^a See Fig. 16.

^b No data available; dosimeter was missing at collection time.

^c The annual dose is calculated by averaging the doses recorded for the available quarters.

Table A-30. Environmental radiation measurements (TLD)—Livermore Valley.

Location ^a	Jan.-Mar.	Apr.-June (mrem)	July-Sept.	Oct.-Dec.	Annual
14	15	14	16	16	61
15	19	15	14	18	66
16	19	15	16	19	69
17	19	12	16	20	67
18	17	14	— ^b	19	67 ^c
19	— ^b	16	13	18	63 ^c
20	15	17	13	— ^b	60 ^c
21	14	16	13	17	60
22	21	— ^b	14	18	71 ^c
23	17	15	14	19	65
24	22	13	18	18	71
25	21	15	17	20	73
26	18	14	18	20	70
27	— ^b	12	17	20	65 ^c
28	24	12	17	20	73
29	20	12	15	21	68
30	19	— ^b	15	— ^b	68 ^c
31	22	13	16	16	67
32	20	13	15	15	63
33	21	14	17	16	68
34	19	13	16	18	66
35	18	15	16	16	65
36	21	14	17	19	71
37	17	12	15	— ^b	59 ^c
38	— ^b	— ^b	17	16	66 ^c
39	— ^b	— ^b	17	17	68 ^c
40	— ^b	— ^b	17	18	70 ^c
41	21	14	15	18	68
43	20	14	16	19	69
44	22	15	17	17	71
45	15	12	14	17	58
46	15	12	14	17	58
51	17	— ^b	14	17	64 ^c
55	20	15	16	18	69
57	19	14	16	19	68
58	21	12	14	17	64
59	19	14	16	17	66
60	18	13	15	18	64
61	17	10	14	15	56
62	19	13	13	15	60
63	18	12	15	17	62
64	19	12	15	18	64
65	19	14	14	18	65
66	21	16	17	19	73
67	21	14	16	19	70
68	19	15	— ^b	15	65 ^c
69	19	13	14	15	61
70	17	13	— ^b	19	65 ^c
71	— ^b	— ^b	17	21	76 ^c
72	23	16	17	19	75
73	17	12	15	16	60
74	16	12	14	16	58
75	14	13	14	15	56
76	13	7	10	12	42
77	— ^b	11	14	14	52 ^c
Average	19	13	15	18	64

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

Table A-31. Environmental neutron monitoring—Livermore site perimeter.

Location ^a	Jan.–Mar.	Apr.–June (mrem)	July–Sept.	Oct.–Dec.	Total
1	1.0	1.6	1.0	0.8	4.4
2	0.9	1.0	1.2	1.1	4.2
3	1.1	5.7	1.4	1.0	9.2
4	0.9	0.7	1.2	0.8	3.6
5	1.1	1.6	1.0	0.8	4.5
6	1.1	0.7	1.3	0.9	4.0
7	1.2	1.3	1.1	0.8	4.4
8	1.3	1.4	1.4	1.2	5.3
Average	1.1	1.8	1.2	0.9	5.0

^aSee Fig. 16.

Table A-32a. Water-quality parameters for Site 300 monitoring wells.

Parameters analyzed					
Physical	Pits ^a	Approx. detection limit (mg/L) ^b	Title 22 organics	Pits ^a	Approx. detection limit (µg/L) ^b
Antimony	HE	0.1	2,4,5-TP (Silvex)	1, 6	0.2
Arsenic	1, 6, HE	0.001	2,4-D	1, 6	1.0
Barium	1, 6, HE	0.1	Endrin	1, 6	0.1
Beryllium	1, 2, 6, 7, 8, HE	0.01	Lindane	1, 6	0.05
Cadmium	1, 6, HE	0.01	Methoxychlor	1, 6	0.2
Chromium	1, 6, HE	0.02	Toxaphene	1, 6	1.0
Cobalt	HE	0.5			
Copper	HE	0.02			
Iron	1, 6	0.03	Purgeable priority		
Lead	1, 2, 6, 7, 8, HE, PW	0.001	pollutants	1, 2, 6, 7, 8	Detection
Manganese	1, 6, HE	0.01	(EPA Method 624)	HE, and PW	limit (µg/L)
Mercury	1, 6, HE	0.0001			
Molybdenum	HE	0.1			
Nickel	1, 6, HE	0.05	Acrolein		10
Selenium	1, 6, HE	0.001	Acrylonitrile		10
Silver	1, 6, HE	0.01	All other analytes		1
Sodium	1, 6	NA ^c			
Thallium	HE	0.001	B/N, A Ext. Priority		
Vanadium	1, 6, HE	0.2	pollutants		Detection
Zinc	HE	0.01	(EPA Method 625)	Pits 1 and 6	limit (µg/L)
Filterable residue (TDS)	1, 6	NA ^c			
Nonfilterable residue (TSS)	1, 6	1	2,4-Dinitrophenol		25
Total kjeldahl nitrogen	1, 2, 6, 8	0.10	2-Methyl-4,6-Dizotrophenol		50
Ammonia nitrogen (as N)	1, 2, 6, 8	0.10	3,3-Dichlorobenzene		1
Nitrate (as N)	1, 2, 6, 8, HE	0.10	4-Nitrophenol		25
Nitrite (as N)	1, 2, 6, 8, HE	0.01	Bis (2-ethylhexyl)phthalate		100
Fluoride	1, 6	NA ^c	Benzidene		40
Chloride	1, 6	NA ^c	Dibutylphthalate		50
Sulfate	1, 6	NA ^c	Dimethylphthalate		25
Carbonate alkalinity	1, 6	1	N-Nitrosodi-N-Propylamine		40
(as CaCO ₃)			N-Nitrosodimethylamine		80
Bicarbonate alkalinity	1, 6	NA ^c			
(as CaCO ₃)			Other organics	Pits	Approx. detection
Hydroxide alkalinity	1, 6	1			limit (µg/L) ^b
(as CaCO ₃)			Low-level phenolics	1, 6	0.005
Total alkalinity (as CaCO ₃)	1, 6	NA ^c	Explosives		
Conductivity (µmhos/cm)	1, 2, 6, 7, 8, HE	NA ^c	(RDX, TNT, HMX)	1, 6, HE	30
pH (units)	1, 2, 6, 7, 8, HE	NA ^c	TOX	1, 6	25
			TOC (mg/L)	1, 6	1
Purgeable halocarbons and aromatics		Detection			
(EPA Method 601/602)	Pits 1, 6, 7, and PW	limit (µg/L)			
All analytes		0.5			
			Radiological	Pits	Approx. detection
					limit (pCi/L) ^b
			Gross alpha	1, 2, 7, 6, 8	4
			Gross beta	1, 2, 7, 6, 8	4
			Tritium	1, 2, 7, 6, 7, HE	200
			²³⁸ U	1, 6	0.1
			²³⁵ U	1, 6	0.1
			²³⁴ U	1, 6	0.1
			²²⁶ Ra	1, 6	0.1

^a HE = High-Explosive Surface Impoundment; PW = production wells.^b Detection limits can vary from sample to sample depending on such items as matrix interference and instrument sensitivity.^c Not applicable.

Table A-32b. Pit 1 wells.

Positively detected parameters	Well							
	K1-01C	K1-02B	K1-03	K1-04	K1-05	K1-07	K1-08	K1-09
Physical (mg/L)								
Arsenic	0.010	0.010	0.011	0.010	0.014	0.014	0.013	0.013
Lead	0.003	0.001	0.001	0.006	0.006	0.002	<0.001	<0.001
Manganese	0.02	0.02	0.02	0.02	<0.01	<0.01	<0.01	<0.01
Nickel	<0.05	<0.05	0.08	0.12	0.12	0.06	<0.05	<0.05
Sodium	38	38	34	40	35	39	37	36
Filterable residue (TDS)	369	354	342	360	335	358	339	340
Nonfilterable residue (TSS)	1	7	<1	<1	5	<1	13	3
Total kjeldahl nitrogen	0.17	0.22	0.11	0.17	<0.10	<0.10	<0.10	<0.10
Nitrate (as N)	10.7	10.0	12.5	4.4	15.0	16.2	15.3	15.0
Fluoride	0.33	0.33	0.27	0.36	0.46	0.39	0.44	0.41
Chloride	45	37	33	36	36	40	38	37
Sulfate	38	45	35	52	37	33	37	32
Selenium	0.002	0.002	0.005	0.002	<0.001	0.003	0.001	<0.001
Mercury	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0012	0.0003	<0.000
Conductivity μ mhos/cm	522	501	494	515	481	511	479	482
pH (units)	7.8	7.4	7.8	7.7	7.5	7.0	7.8	7.8
Organics								
TOC (mg/L)	1	1	1	1	1	1	1	2
TOX (μ g/L)	26	<25	<25	<25	<25	53	<25	<25
Low-level phenolics (μ g/L)	0.006	0.013	0.032	0.46	0.14	0.070	0.045	0.25
Purgeable priority pollutants (μg/L)								
C ₅ H ₁₂ hydrocarbon ^a	<1	<1	10	<1	<1	<1	<1	<1
Toluene	<1	<1	<1	<1	<1	4	<1	<1
Radiological (pCi/L)								
Gross alpha	<4	<4	<4	<4	<4	4	<4	<4
Gross beta	<4	<4	<4	<4	<4	6	<4	4
²³⁸ U	1.0	1.1	0.5	0.7	0.5	0.7	0.5	<4
²³⁴ U	2.2	2.0	0.9	1.2	1.1	1.6	1.1	0.9

^a Semi-quantified result.

Table A-32c. Pit 7 wells.

Positively detected parameters	Well						
	K7-01	K7-03	K7-05	K7-06	NC7-25	NC7-26	NC7-47
Physical (mg/L)							
Lead	0.003	<0.001	0.001	0.005	0.012	0.021	9.0 ¹⁸
Conductivity (µmhos/cm)	437	382	502	353	— ^a	390	— ^a
pH (units)	7.1	7.0	7.3	7.1	— ^a	7.0	— ^a
EPA Method 601 (µg/L)							
1,1-Dichloroethylene	0.8	2	<0.5	<0.5	<0.5	<0.5	<0.55
Trans-1,2-Dichloroethylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.8
Trichloroethylene	5	5	<0.5	<0.5	<0.5	<0.5	<0.5
1,1,2-Trichloroethane	<0.5	<0.5	<0.5	<0.5	1	<0.5	<0.5
1,1,1-Trichloroethane	<0.5	<0.5	<0.5	<0.5	0.7	<0.5	<0.5
Freon	1.8	1.2	5.9	<0.5	4.7	<0.5	<0.5
Purgeable priority pollutants (µg/L)							
Trimethyl silanol ^b	<1	<1	<1	<1	8	<1	<1
Radiological (pCi/L)							
Gross alpha	<4	<4	<4	<4	12	<4	<4
Gross beta	8	6	<4	<4	13	<4	<4
Tritium	21 600	137 000	<200	<200	375 000	2230	<200

^a Not applicable; well sampled by bailing.^b Semi-quantified result.

Table A-32d. Pits 2, 8, and well NC2-07.

Positively detected parameters	Well					
	K2-01C	K2-04	K2-04D	K2-04S	K8-01	NC2-07
Physical (mg/L)						
Nitrate (as N)	8.4	1.7	9.4	9.3	10.8	— ^a
Ammonia	0.11	0.33	<0.10	<0.10	<0.10	— ^a
Total kjeldahl nitrogen	<0.10	0.33	<0.10	<0.10	0.22	— ^a
Lead	0.005	<0.001	<0.001	<0.001	0.016	— ^a
Conductivity (µmhos/cm)	544	745	445	587	550	735
pH (units)	7.2	6.9	6.8	6.7	7.7	7.7
Purgeable priority pollutants (µg/L)						
Chlorobenzene	<1	<1	<1	<1	1.6	<1
Freon	<1	<1	<1	1	<1	<1
Trichloroethylene	<1	<1	<1	<1	5.0	<1
Radiological (pCi/L)						
Gross alpha	<4	<4	<4	<4	9	<4
Gross beta	7	<4	<4	<4	10	10
³ H	43 375	1250	6160	99 300	246	<200

^a Not analyzed for these parameters.

Table A-32e. Pit 6 wells.

Positively detected parameters	Well					
	K6-01	K6-03	K6-04	EP6-07	EP6-08	EP6-09
Physical (mg/L)						
Arsenic	0.013	0.018	0.014	0.017	0.018	0.014
Chloride	87	88	89	88	92	112
Filterable residue (TDS)	780	720	650	720	690	760
Nonfilterable residue (TSS)	<1	<1	<1	<1	1	<1
Fluoride	0.43	0.48	0.46	0.46	0.40	0.41
Iron	0.18	0.03	0.03	0.05	0.03	<0.03
Manganese	0.07	0.07	<0.01	0.12	<0.01	<0.01
Mercury	0.0002	0.0001	0.0001	0.0002	0.0001	0.0001
Ammonia nitrogen (as N)	0.13	0.25	<0.1	0.27	0.1	<0.1
Total kjeldahl nitrogen	0.15	0.24	0.14	0.26	0.13	0.13
Nitrate (as N)	<0.1	<0.1	4.0	<0.1	2.5	2.1
Selenium	<0.001	0.001	0.002	<0.001	0.004	0.003
Sodium	120	100	96	110	120	120
Sulfate	270	240	180	230	200	230
Lead	0.002	0.003	<0.001	0.004	0.002	0.004
Corrosivity (µmhos/cm)	1079	1014	929	996	989	1060
pH (Units)	7.6	7.0	7.6	7.1	6.9	7.1
Organics						
TOC (mg/L)	1.3	1	1	1	1	1
TOX (µg/L)	<25	<25	<25	<25	<25	42
Low-level phenolics (µg/L)	0.008	<0.005	<0.005	0.008	<0.005	<0.005
EPA Method 601 (µg/L)						
Chloroform	<0.5	<0.5	<0.5	<0.5	0.7	<0.5
Tetrachloroethene	<0.5	<0.5	<0.5	<0.5	0.8	<0.5
1,2-Dichloroethane	<0.5	<0.5	<0.5	<0.5	<0.5	0.7
Trichloroethylene	<0.5	<0.5	<0.5	<0.5	<0.5	2.3
Purgeable priority pollutants (µg/L)						
Trichlorofluoromethane	<1	<1	2	<1	<1	<1
Radiological (pCi/L)						
Gross alpha	<4	<4	<4	<4	11	<4
Gross beta	5	9	10	9	9	11
²³⁸ U	0.4	0.2	0.5	0.1	0.5	1.2
²³⁴ U	0.5	0.1	0.7	0.3	0.7	1.3

Table A-32f. High-Explosive Process-Water Surface Impoundment.

Positively detected parameters	Well				
	817-01	817-02	817-03	817-04	817-03A
Physical (mg/L)					
Selenium	0.039	0.078	0.015	0.019	— ^a
Arsenic	0.048	0.060	0.047	0.040	— ^a
Barium	0.1	<0.1	<0.1	<0.1	— ^a
Nitrate (as N)	22	22	23	25	— ^a
Zinc	0.01	0.06	<0.01	0.07	— ^a
Vanadium	0.2	0.2	0.2	0.2	— ^a
Conductivity (µmhos/cm)	1462	2507	2024	1944	— ^a
pH (units)	7.3	7.8	7.6	7.3	— ^a
Organics					
TOC (mg/L)	1.5	2	2	2	— ^a
TOX (µg/L)	25	27	36	32	— ^a
RDX (µg/L)	47	<30	<30	<30	<30
Purgeable priority pollutants (µg/L)					
Trichloroethylene	<1	<1	23	12	113
Toluene	<1	7	<1	<1	<1

^a Not analyzed for these parameters.

Table A-32g. Production wells.

Positively detected parameters	Well							
	1	3	4 ^a	6	7	8	18 ^a	19 ^a
Physical (mg/L)								
Lead	0.004	0.018	0.007	0.010	<0.001	0.002	0.032	<0.001
Purgeable priority pollutants (µg/L)								
Benzene	<1	1.2	<1	<1	<1	<1	<1	<1
Freon	<1	<1	2	<1	<1	<1	<1	<1
1,2-Dichloroethane	<1	24	<1	67	<1	<1	<1	<1
Methylene chloride	<1	45	<1	29	<1	<1	<1	<1
Tetrachloroethylene	<1	<1	<1	<1	2	<1	<1	<1
Trichloroethylene	<1	<1	<1	4	28	<1	<1	<1
EPA Method 601 (µg/L)								
Trans-1,2-Dichloroethylene	<0.5	<0.5	<0.5	<0.5	0.7	<0.5	<0.5	<0.5
Toluene	<0.5	0.6	<0.5	2	<0.5	<0.5	<0.5	<0.5

^a Only wells 4, 18, and 19 are currently used for the production of drinking water.

Table A-33. Radioactive effluent releases from LLNL, 1981–1987.

Year	Airborne effluents (Ci)		Liquid effluents (Ci)	
	^3H	^{13}N – ^{15}O	^3H	^{239}Pu
1981	2620	344	6.0	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}
1987	2751	62	1.4	6.9×10^{-4}

Table A-34a. Radiation dose from the air pathway, all facilities during 1987 (Clean Air Act Code).^a

Facility	Nuclide/ emission (Ci)	Dose at site perimeter (mrem) ^b	Dose to nearest resident (mrem) ^b	Dose at maximum off-site exposure (mrem) ^b
LLNL				
Tritium facility	$^3\text{H}/2634$	0.07	0.05	0.07
Insulating core accelerator	$^3\text{H}/38$	0.003	0	0.003
Rotating target neutron source	$^3\text{H}/78.5$	0.004	0.003	0.004
Incinerator	$^3\text{H}/0.22$	0	0	0
Linear accelerator	^{13}N – $^{15}\text{O}/48$	0.004	0.003	0.004
Total (LLNL)		0.081	0.056	0.081
Percent of Federal Emission Standard ^c		0.3%	0.2%	0.3%
Site 300				
ATA ^d	^{13}N – $^{15}\text{O}/14.1$	0.002	0	0.002
Percent of Federal Emission Standard ^b		0.008%	0	0.008%

^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/y to the whole body and 75 mrem/y to any critical organ.

^d Advanced test accelerator.

Table A-34b. Estimated radiation dose to the public from LLNL airborne effluents during 1987 (Continuous-Point-Source Code).

Facility	Nuclide/ emission (Ci)	Dose at site perimeter (mrem) ^{a,b}	Dose to nearest resident (mrem) ^{a,b}	Dose at maximum off-site exposure (mrem) ^{a,b}	Collective dose (80-km radius of LLNL) ^a (person-rem)
LLNL					
Tritium facility	³ H/2634	0.12	0.08	0.12	0.49
Insulating core accelerator	³ H/38	0.002	0.001	0.002	0
Rotating target neutron source	³ H/78.5	0.02	0.007	0.02	0.03
Incinerator	³ H/0.22	0	0	0	0
Linear accelerator	¹³ N- ¹⁵ O/48	0.04	0.012	0.04	0
Total (LLNL)		0.018	0.1	0.18	0.52
Site 300					
ATA ^c	¹³ N- ¹⁵ O/14.1	0.002	0	0.002	0

^a Doses are based on the 1329 Ci of HTO released by LLNL. The dose due to the 1422 Ci of HT released by LLNL does not add significantly to the total. SNLL emitted about 570 Ci of HTO, which are not included in these calculations.

^b This dose represents the 50-y committed effective dose equivalent.

during 1987. Dose calculations were made using the Continuous-Point-Source computer code.

^c Advanced test accelerator. ATA accounts for the total emission at Site 300.

Table A-34c. Summary of radiological dose assessment for 1987.

Effective dose equivalent to the maximally exposed individual in the public						
Nuclide	Inhalation/ submersion ^a (mrem)	Pathways		Total		Percent of DOE primary radiation protection standard for the public ^b
		Ingestion- foodstuff (mrem)	Ingestion- water (mrem)	(mrem)	(mSv)	
LLNL						
³ H	0.14	0.08	0.04	0.26	2.6 × 10 ⁻³	0.3%
¹³ N- ¹⁵ O	0.04	0	0	0.04	4.0 × 10 ⁻⁴	0.04%
			Total ^c	0.3	3.0 × 10 ⁻³	0.3%
Site 300						
¹³ N- ¹⁵ O	0.002	0	0	0.002	2 × 10 ⁻⁵	0.002%

^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/y.

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

Table A-34d. Comparison of radiation doses—1987.

Location/source	Individual dose (mrem)	Population dose ^a (person-rem)
LLNL sources		
Maximum off-site dose ^b		
LLNL atmospheric emissions	0.18	0.52
LLNL liquid emissions	0	0
Site 300	0.002	0
Other Sources		
Natural radioactivity ^c		
Cosmic radiation	40	200 000
Terrestrial radiation	50	250 000
Internal (food consumption)	28	140 000
Radon	200	1 000 000
Subtotal (natural)	318	1 600 000
Medical radiation ^d (Diagnostic procedures)	91	460 000
Weapons test fallout	5	25 000
Total other sources	414	2 085 000

^a The population dose is the collective (combined) dose for all individuals residing within an 80-km radius of LLNL.

^b These doses represent the maximum committed effective dose equivalent from all LLNL emissions. It is calculated using the most conservative exposure assumption and is not a dose actually received by any member of the public.

^c These values vary with location and represent approximate averages in the vicinity of LLNL.

^d This dose is an average over the U.S. population.

Table A-35a. Quality assurance analyses for the EPA's Environmental Radioactivity Laboratory Intercomparison Studies Program.

Analysis	Media	Value reported (pCi/L $\pm$ 1 σ)		Normalized deviation ^a from the known value	
		LLNL	Known		
Gross alpha	Water	12.00 $\pm$ 1.00	11.00 $\pm$ 5.00	0.34	
	Air (pCi/filter)	27.66 $\pm$ 2.08	30.00 $\pm$ 8.00	-0.51	
		15.66 $\pm$ 0.58	14.00 $\pm$ 5.00	0.58	
		10.00 $\pm$ 0.00	10.00 $\pm$ 5.00	0.00	
Gross beta	Water	13.33 $\pm$ 0.58	10.00 $\pm$ 5.00	1.15	
	Air (pCi/filter)	54.67 $\pm$ 2.31	43.00 $\pm$ 5.00	4.04	
		80.33 $\pm$ 1.52	66.00 $\pm$ 5.00	4.96	
		36.00 $\pm$ 2.65	30.00 $\pm$ 5.00	2.08	
Tritium	Water	4230 $\pm$ 280	(4487 $\pm$ 218) ^b	0.09 (1.14)	
		2760 $\pm$ 62	(3080 $\pm$ 132)	-0.65 (0.90)	
		4063 $\pm$ 146	(4467 $\pm$ 223)	-1.65 (-0.10)	
Gamma	Water				
		⁶⁰ Co	53.67 $\pm$ 0.58	50.00 $\pm$ 5.00	1.27
		⁶⁵ Zn	102.66 $\pm$ 5.13	91.00 $\pm$ 5.00	4.04
		¹⁰⁶ Ru	106.00 $\pm$ 4.36	100.00 $\pm$ 5.00	2.07
		¹³⁴ Cs	53.33 $\pm$ 0.58	59.00 $\pm$ 5.00	1.96
		¹³⁷ Cs	94.33 $\pm$ 0.58	87.00 $\pm$ 5.00	2.54
	Water				
		⁶⁰ Co	16.67 $\pm$ 0.58	15.00 $\pm$ 5.00	0.58
		⁶⁵ Zn	48.33 $\pm$ 2.89	46.00 $\pm$ 5.00	0.81
		¹³⁴ Cs	22.67 $\pm$ 2.08	25.00 $\pm$ 5.00	-0.81
		¹³⁷ Cs	53.67 $\pm$ 1.15	51.00 $\pm$ 5.00	0.92

^a Acceptable deviations are $\leq \pm 3$.

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

Table A-35b. Quality assurance for the DOE Environmental Measurements Laboratory (EML) Quality Assessment Program.^{a,b}

Analysis	Media	LLNL value	EML value	LLNL/EML ratio
⁷ Be	Air	1000	896	1.12
		4400	4400	0.95
		396	444	0.89
		316	290	1.09
¹³⁷ Cs		469	470	1.00
²³⁸ U		1.97	1.71	1.15
		2.35	1.88	1.25
²³⁹ Pu		5.09	5.23	0.97
		5.79	5.68	1.02
⁴⁰ K	Soil	23.6	20.0	1.18
		0.80	1.05	0.76
		0.21	0.21	1.01
		0.49	0.48	1.02
²³⁹ Pu		0.044	0.029	1.52
		2.35	1.88	1.25
³ H	Water	29.5	33.7	0.88
		19.7	19.1	1.03
		3.63	2.34	1.55
		3.74	2.28	1.64
²³⁹ Pu		0.071	0.137	0.52
		0.186	0.266	0.70

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

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

Table A-36. Quality assurance—duplicate sampling.

Media	Parameter	Data capture (%) ^a	Precision ^b	Ratio ^c	Regression Analysis ^d		
					CorrelationW coefficient	Slope	Y-intercept
Sewage							
LLNL	³ H	97	+218/-158		0.97	0.99	2.6
LWRP	³ H		+59/-80		0.08	-0.08	3.7
Water		95					
Livermore Valley	³ H			1.04			
Site 300	³ H			2.16			
Vegetation		96					
Livermore Valley	³ H			0.98			
Site 300	³ H			8.51			
Air	²³⁹ Pu	97	+85/-42		0.95	1.13	0.0
	³ H	94	+105/-87		0.85	0.75	0.6
	Be	97	+383/-192		0.16	-0.16	0.05
Soil	²³⁹ Pu	100		0.95			
Groundwater	TOC	97		1.23			
	TOX			1.09			
	As			0.98			
Milk	³ H	83		0.83			

^a Ratio of samples collected for that medium to the number of samples scheduled to be collected.

^b Calculated according to the methodology in *Quality Assurance Handbook for Air Pollution Measurement Systems* (EPA 1976) for data sets with more than 8 valid data pairs.

^c Only used for data sets with less than 8 valid data pairs. Value is ratio of QA sample/routine sample.

^d Only calculated for data sets with more than 8 valid data pairs.

Appendix B. Statistical Methods

The following statistical methods were applied to the data presented in this report.

Lower Limit of Detection (LLD). The 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 to give a conservative estimate.

Distribution Analysis. For the 1986 Environmental Monitoring Annual Report (Holland et al., 1987) an effort was made to determine the distribution characteristics of data sets before calculating summary statistics. The differences in summary statistics were found to be of little significance, and the process was very time consuming. Consequently, for this report, all data sets have been treated as though they were normally distributed.

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 (one-third 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 C. Radiation Protection Standards

Operations at Lawrence Livermore National Laboratory (LLNL) are conducted in accordance with a number 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 Order 5480.XX (U.S. Department of Energy, 1987a). Even though this order is in draft form, the standards are in effect. The draft 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 and the National Council on Radiation Protection and Measurements. The primary DOE radiation standards for protection of the public are provided in Tables C-1 and C-2.

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

Table C-1. DOE radiation standard to the public: 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-y) effective dose equivalent from ingestion and inhalation during the calendar year.

Table C-2. Air pathway only.^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, 40 CFR 61 (Office of the Federal Register, 1986b).

Table C-3. Derived concentration guides.

Nuclide	Concentration in air ($\mu\text{Ci/mL}$)	Concentration in water ($\mu\text{Ci/mL}$)
¹ H	$2 \cdot 10^{-7}$	$2 \cdot 10^{-1}$
⁷ Be	$5 \cdot 10^{-8}$	$1 \cdot 10^{-1}$
¹³ N	$2 \cdot 10^{-8}$	—
¹⁵ O	$2 \cdot 10^{-8}$	—
⁴⁰ K	$9 \cdot 10^{-10}$	$7 \cdot 10^{-6}$
¹⁰⁶ Ru	$3 \cdot 10^{-11}$	$6 \cdot 10^{-6}$
¹²⁵ Sb	$1 \cdot 10^{-9}$	$6 \cdot 10^{-5}$
¹³⁷ Cs	$4 \cdot 10^{-10}$	$3 \cdot 10^{-6}$
¹⁴⁴ Ce	$3 \cdot 10^{-11}$	$7 \cdot 10^{-6}$
²³⁵ U	$1 \cdot 10^{-13}$	$6 \cdot 10^{-7}$
²³⁸ U	$1 \cdot 10^{-13}$	$6 \cdot 10^{-7}$
²³⁹ Pu	$2 \cdot 10^{-13}$	$3 \cdot 10^{-6}$

The State of California (1977) specifies maximum contaminant levels (MCLs) for public water supplies as follows:

Gross alpha particle activity (including ^{226}Ra but excluding Rn and U)	—	15 pCi/L. or $1.5 \times 10^{-4} \mu\text{Ci/mL}$.
Gross beta particle activity	—	50 pCi/L. or $5.0 \times 10^{-6} \mu\text{Ci/mL}$.
Tritium	—	20 000 pCi/L. or $2.0 \times 10^{-5} \mu\text{Ci/mL}$.

In the draft order, 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. Sampling and Analytical Procedures
for Environmental Monitoring
at Lawrence Livermore National Laboratory**

Introduction

As part of the Laboratory's Quality Assurance Program, written procedures are prepared for each environmental monitoring activity at LLNL. This appendix describes the sampling procedures used by the Environmental Quality Verification Group and the analytical determinations and preparation for counting used by the Hazards Control Department and the Nuclear Chemistry Division. The radiochemical methods used by the Nuclear Chemistry Division are described in detail in *Radiochemical Methods of the Site Environmental Monitoring Program, Jan. 1985* (Garrison et al., 1985). This manual is revised and issued biennially; interim changes in procedures are noted in the Environmental Monitoring Annual Report.

The sampling sections presented below describe the procedures used for each sample medium monitored. A general description of each medium is usually provided, followed by the collection procedure used, the provisions for sample identification, and the schedule for sample replication. The analysis sections cover the analyses performed on the collected samples. 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.

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

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 Livermore site perimeter and at nine locations at Site 300 measure particulate radioactivity and beryllium. Particulate radioactivity is also measured at 11 off-site locations near the Livermore site. Tritiated water samplers are operated at the six perimeter locations and at six off-site locations. In all cases, the samplers are positioned 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 Livermore site 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 high-volume samplers with average flow rates of 700 L/min. These flow rates are verified at monthly intervals with a portable field-calibration unit. If a high-volume air sampler fails, it is repaired and then calibrated with a spirometer that was itself calibrated 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 L/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 L/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, the 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 Livermore site 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 its 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

A particulate air sampler is operated in parallel with the permanent sampler at one of the six Livermore site 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. Monthly 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 Livermore site perimeter locations during alternate months from those in which particulate replicates are collected. The parallel sampler is operated at the perimeter locations at one-month intervals.

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; this list provides the data base of various nuclides in the soil near the Livermore site. 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 to 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 logbook, 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 Environmental Monitoring Annual Report.

Replication

During each annual collection of soil samples, approximately 10% of the sites are sampled in duplicate. In duplicate 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 a 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 the Livermore site 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 the Livermore site effluent, the treated effluent, and from the digester sludge at the LWRP.

Collection

Livermore Site Effluent

A 24-h composite of Livermore site sewage effluent is collected daily by a peristaltic pump that functions for 9 s every 5 min to collect 13 L. 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 three times a week from the circulating sewage.

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

Livermore Site Effluent

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

LWRP Effluent

One replicate sample of LWRP effluent is taken every Wednesday and is analyzed for gross alpha, gross 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 L. 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 four goat farms near LLNL. A portion of each milk sample is freeze-dried, and the tritium content of the recovered water is determined by liquid-scintillation counting. A 1-L sample is preserved with formaldehyde and then 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 (Be).

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-min 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 to determine 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

Monthly composites of filters from sampling stations along the Livermore site perimeter and at Site 300 are sealed in a 214-cm³ aluminum can, and submitted for gamma analysis.

Plutonium and Uranium

Monthly composites of air filters are ashed and then dissolved in a mixture of nitric acid (HNO_3) and hydrochloric (HCl) and/or hydrofluoric acid (HF). Plutonium and uranium are then separated by an ion-exchange process. Plutonium is 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 Livermore site 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% HNO_3 and 20% perchloric acid (HClO_4). 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 of Be, and several samples are spiked with essentially carrier-free ^7Be .

Standards of 1, 2, and 5 $\mu\text{g/L}$ 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 5% hydrogen peroxide (H_2O_2). The solution is evaporated to about 5 mL and transferred to a 5-cm-diam serrated, stainless-steel planchet. After the planchet is dried and flamed, the sample is counted for 30 min in a Sharp 3 1/4-in. proportional counter. A blank is processed with each set of samples.

Standards and Calibration

The ^{239}Pu and ^{90}Sr standards are used with every sample set. (See similar entry below under "Soil Analysis.") Background measurements are made between every ten 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 to determine background.

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. All sewage samples except those to be analyzed for tritium are wet-digested with a mixture of 20% HClO_4 and 80% HNO_3 . Those sewage samples to be analyzed for tritium 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 an aliquot (500 mL if on site; 100 mL if from the LWRP), and the mixture is heated to dryness on a hotplate. The residue is taken up in 10 mL of HNO_3 and 5 mL of 5% H_2O_2 . The volume is reduced to 3 to 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 the sample and the background are placed in the refrigerated detection chamber of the Packard scintillation counter for a 1-hr temperature equilibration prior to counting. Each is 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 HNO_3 and 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 HCl , which is then submitted for gamma spectrometry.

Metals

Monthly composites of Livermore site 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. HNO_3 (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 of deionized water is added, and the liquid is filtered through No. 40 Whatman paper. The paper is placed in a platinum crucible and digested with about 5 mL of HF , 16 mL of HNO_3 , and 4 mL of HClO_4 to a residue of about 4 to 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 diluting of a 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°C for a minimum of 2 days, pulverized, passed through a 32-mesh sieve, blended, sealed in a 238- cm^3 aluminum can, and submitted for gamma spectrometry.

Plutonium

The soil is leached by heating for 4 h with a mixture of concentrated HNO_3 and HCl . The plutonium is then separated and purified by ion exchange and electroplating.

Vegetation Analysis

Vegetation samples are prepared for tritium by freeze-drying. The resultant water is analyzed for tritium by either liquid-scintillation spectrometry or gas proportional counting.

Milk Analysis

Milk samples are prepared by freeze-drying. The resultant water is analyzed for tritium by liquid-scintillation spectrometry. Milk samples are also analyzed by gamma spectrometry, consisting of a direct count of 938 mL of milk preserved with 20 mL of formaldehyde is 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 E. Discharge Limits
to the Sanitary Sewer System
of the City of Livermore**

Sections 13.32.06, 13.32.08, 13.32.09, 13.32.100, and 13.32.110, of the City of Livermore Municipal Code (1983) state the discharge limits for Livermore's sanitary sewer system. These sections are reprinted below.

Section 13.32.06 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 publically-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/L of freon extractible 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 325 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 13.32.08 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 13.32.09 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 13.32.100 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 13.32.110 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 F. Methods of Dose Calculations

The radiological impact to the public from operations at 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, four potential doses are calculated: LLNL perimeter, nearest resident, point of maximum exposure in an uncontrolled area, and 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 (see 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 dose from external radiation and the committed (50-y) effective dose equivalent from ingestion and inhalation during a 1-y 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-y period following a 1-y exposure. The effective dose equivalents in this report were calculated using the dosimetric parameters recommended by the International Commission on Radiological Protection in Publications 26 (1977) and 30 (1980).

Pursuant to the *National Emission Standards for Hazardous Air Pollutants*, 40 CFR 61, Subpart H (Office of the Federal Register, 1986b), 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 models (AIRDOS-EPA and RADRISK) approved by the Environmental Protection Agency (EPA) 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 1987

Briefly described below are each of the doses used to measure the radiological impact from LLNL during 1987.

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 h per day, 365 days per y. In actuality, no member of the public resides at these locations for extended periods of time, 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 Livermore site perimeter, 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 to 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 building 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 (Office of the Federal Register, 1986b).

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 (χ/Q) through sixteen 22.5° compass sectors and distances from 0.1 to 100 km from potential release points. The average annual χ/Q values have been calculated using local meteorological data. These data were obtained from sensors on the LLNL meteorological tower from a height of 40 m. From records of these data, wind speed, wind direction, and atmospheric stability estimates were tabulated at one-quarter-hour intervals over the calendar year. Digitized meteorological data became available at Site 300 in May of 1986, and were used to perform dispersion calculations for the advanced test accelerator 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 χ/Q values, the radionuclide concentrations at the site perimeter 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 perimeter.

4. Maximally exposed individual dose. This dose represents the maximum credible dose to any "hypothetical" member of the general public. It includes contributions from all potential exposure pathways and is derived using the most conservative but realistic exposure data and assumptions. This hypothetical person is assumed to reside at the point of highest ground-level radionuclide air concentration continuously for 24 h 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 public.

5. Collective population dose. The collective population dose is the dose for all individuals residing within an 80-km radius of LLNL. It is calculated by summing for each sector the average individual dose multiplied by the number of individuals residing in the sector. The collective 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 the NRC Regulatory Guide 1.109, *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluent* (U.S. Nuclear Regulatory Commission, 1977). The dose and dose-rate conversion factor used in these calculations were obtained from the committed dose equivalent tables for DOE dose calculations. These dose conversion factors are consistent with those specified in ICRP 30, *Limits of Intakes of Radionuclides by Workers* (International Commission on Radiological Protection, 1980). Examples of these calculations and assumptions are presented 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:

$$R_{\text{whole body}} = C_w U_w D_w \quad (\text{F-1})$$

where

C_w = concentration (pCi/L),

U_w = intake rate (L/y) = 730 L/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,

$R_{\text{whole body}}$ = effective dose equivalent in mrem from ingestion of 730 L 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 $\mu\text{Ci/mL}$ of tritiated water (HTO) for the maximum exposed individual has been calculated using the following equation:

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

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

where

$$U_{\text{veg}} = \text{intake rate (kg/y)} = 64 \text{ kg/y for maximum-exposed individual,}$$

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

$$D_{\text{HTO}} = \text{dose factor (mrem/pCi)} = 6.3 \times 10^{-8} \text{ mrem/pCi for } ^3\text{H for the adult whole-body ingestion pathway, and}$$

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

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

where

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

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

$$C_{\text{meat}} = (F_1) (Q_1) (C_{\text{veg}}) \exp(-\lambda_1 t_1),$$

$$F_1 = \text{fraction of daily intake of nuclide per kg of animal/fish (pCi/kg in meat per pCi/day ingested by the animal), days/kg,}$$

$$Q_1 = \text{amount of feed consumed (kg/day),}$$

$$C_{\text{veg}} = \text{same as above,}$$

$$\lambda_1 = \text{radiological decay constant, day}^{-1},$$

$$t_1 = \text{time between slaughter to consumption (days).}$$

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

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

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

where

$$U_{\text{milk}} = 310 \text{ L/y.}$$

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

$$C_{\text{milk}} = F_m Q_t C_{\text{veg}} \exp(-\lambda_i t_i).$$

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

Q_t = 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.

$$\begin{aligned} C_{\text{milk}} &= \left(1.0 \times 10^{-2} \frac{\text{day}}{\text{L.}}\right) \left(50 \frac{\text{kg}}{\text{day}}\right) \left(C_{\text{veg}} \frac{\mu\text{Ci}}{\text{ml.}}\right) \left(10^{10} \frac{\text{pCi/kg}}{\mu\text{Ci/ml.}}\right) \\ &\times \exp[-1.5 \times 10^{-4}(2)] = 0.5 \times 10^{10} \frac{\text{pCi/L.}}{\mu\text{Ci/ml.}} \\ &\times C_{\text{veg}} \frac{\mu\text{Ci}}{\text{ml.}} (\text{measured}) \end{aligned}$$

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

$$\begin{aligned} D_{\text{whole body}} (\text{mrem/y}) &= 0.40 \times 10^4 C_{\text{veg}} \mu\text{Ci/ml.} (\text{measured}) + 0.41 \times 10^4 C_{\text{veg}} \mu\text{Ci/mL} (\text{measured}) \\ &+ 0.97 \times 10^4 C_{\text{veg}} \mu\text{Ci/mL} (\text{measured}) = 1.78 \times 10^4 C_{\text{veg}} \mu\text{Ci/ml.} \\ &(\text{measured}). \end{aligned}$$

Inhalation/Submersion Dose

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

A. Inhalation Dose (³H)

$$D_{\text{max}} = C \times U \times D, \quad (\text{F-3})$$

where

C = radionuclide concentration at the receptor,

U = intake rate (the inhalation rate for adult maximally exposed individual is 8400 m³/y), and

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

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

$$C = 3.17 \times 10^4 (\chi/Q)(Q), \quad (\text{F-3a})$$

where

χ/Q = diffusion parameter (s/m³),

Q = release rate, Ci/y,

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

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

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

where DRF , the dose-rate factor, is the external dose-equivalent rate per unit radionuclide concentration

$$\left(\frac{\text{mrem} \times \text{m}^3}{\text{pCi} \times \text{y}} \right). \text{ For } ^{13}\text{N}, DRF = 5.22 \times 10^3 \frac{\text{mrem} \times \text{m}^3}{\text{pCi} \times \text{y}}; \text{ for } ^{15}\text{O}, DRF = 5.25 \times 10^{-3} \frac{\text{mrem} \times \text{m}^3}{\text{pCi} \times \text{y}}.$$

Annual Population Dose

For population dose, the diffusion parameters and population figures for a sector (i) within 80 km of LLNL were summed over all directions (n).

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

where

$$\left[\sum_i^n (\chi/Q)_i P_i \right] = \text{Summation of the } (\chi/Q) \text{ for sector } i \text{ times the population in region } i \text{ for all regions } n, \text{ persons-s/m}^3.$$

Q = release rate, Ci/y,

U = inhalation rate, average individual (adult),

D = dose factor, mrem/pCi,

P_i = the population of the i th sector.

Appendix G. Deviations from the Sampling Program

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

Station	Air particulate monitoring	
	Date	Reason
1	1-13-87	Air sampler malfunction
1	1-20-87	Air sampler malfunction
1	1-27-87	Air sampler malfunction
1	2-03-87	Air sampler malfunction
1	5-12-87	Air sampler malfunction
1	8-18-87	Air sampler malfunction
3	12-08-87	Air sampler malfunction
4	1-13-87	Air sampler malfunction
4	3-17-87	Air sampler malfunction
8	1-27-87	Air sampler malfunction
8	3-03-87	Air sampler malfunction
8	3-31-87	Air sampler malfunction
8	5-26-87	Air sampler malfunction
10	1-06-87	Air sampler malfunction
12	3-03-87	Air sampler malfunction
12	6-02-87	Air sampler malfunction
12	6-30-87	Air sampler malfunction
12	7-21-87	Air sampler malfunction
12	8-25-87	Air sampler malfunction
12	9-08-87	Air sampler malfunction
13	5-19-87	Air sampler malfunction
13	7-14-87	Air sampler malfunction
13	7-21-87	Air sampler malfunction
13	9-01-87	Air sampler malfunction
15	3-17-87	Air sampler malfunction
15	4-28-87	Air sampler malfunction
17	2-24-87	Air sampler malfunction
17	3-24-87	Air sampler malfunction
S300-1	9-01-87	Air sampler malfunction
S300-1	10-20-87	Air sampler malfunction
S300-5	1-27-87	Air sampler malfunction
S300-6	6-30-87	Air sampler malfunction
S300-7	1-13-87	Air sampler malfunction
S300-7	1-20-87	Air sampler malfunction
S300-7	1-27-87	Air sampler malfunction
S300-9	7-7-87	Air sampler malfunction

Table G-1. (Continued).

Station	Air tritium monitoring	
	Date	Reason
1	1-15-87	Air sampler malfunction
1	1-29-87	Air sampler malfunction
4	1-15-87	Air sampler malfunction
4	10-15-87	Air sampler malfunction
4	12-23-87	Flask broken
7	1-29-87	Air sampler malfunction
7	11-25-87	Air sampler malfunction
9	2-26-87	Air sampler malfunction
9	12-10-87	Air sampler malfunction
12	6-04-87	Air sampler malfunction
13	2-26-87	Air sampler malfunction
13	3-12-87	Air sampler malfunction
13	3-26-87	Air sampler malfunction
13	9-03-87	Air sampler malfunction
13	11-25-87	Air sampler malfunction
14	1-15-87	Air sampler malfunction
17	2-26-87	Air sampler malfunction
S1	12-10-87	Air sampler malfunction
S2	7-30-87	Air sampler malfunction
S2	10-29-87	Air sampler malfunction
Station	Vegetation monitoring	
	Date	Reason
15	Fourth quarter	No sample available
23	Fourth quarter	No sample available
Station	Milk monitoring	
	Date	Reason
All	January	Goats not producing
5	February	Goats not producing
5	March	Goats not producing
5	July	No milk available
5	August	No milk available
5	September	No milk available
5, 7, 12	October	Goats not producing
All	November	Goats not producing
All	December	Goats not producing

Table G-1. (Continued).

Station	Water monitoring	
	Date	Reason
33	Entire year	Pump not working
43	January, February, March	Swimming pool closed for repairs
S300-7	Entire year	Permission to sample denied by owners
Stormwater 2	December	Insufficient water
Stormwater 4	December	Insufficient water
Station	Environmental radiation monitoring	
	Date	Reason
01	Fourth quarter	Missing
18	First quarter	Missing
18	Third quarter	Missing
20	Fourth quarter	Missing
22	Second quarter	Missing
30	Second quarter	Missing
30	Fourth quarter	Missing
37	Fourth quarter	Missing
38	First quarter	Missing
38	Second quarter	Missing
39	First quarter	Missing
39	Second quarter	Missing
40	First quarter	Missing
40	Second quarter	Missing
51	Second quarter	Missing
68	Third quarter	Missing
71	First quarter	Missing
71	Second quarter	Missing
77	First quarter	Missing

Appendix H. Quality Assurance Plan

Environmental Protection

Guidance and Monitoring Series

Environmental Quality Verification Group Quality Assurance Plan

R. C. Holland

September 18, 1987

**C. E. DeGrange, Section Leader
Guidance and Monitoring Section**

LAWRENCE LIVERMORE NATIONAL LABORATORY
University of California • Livermore, California • 94550

Environmental Quality Verification Group Quality Assurance Plan

Prepared by: Robert L. Holland
Quality Assurance Coordinator

Approved by: Michael Engler
Group Leader

Approved by: Constance DeHange
Section Leader, Guidance and Monitoring

Contents

Introduction	iv
Quality Assurance Project Plan Locator Page	v
QAP-1 REV. 0 Organization	1
QAP-2 REV. 0 Quality Assurance Program	5
QAP-3 REV. 0 Design Control	9
QAP-4 REV. 0 Procurement Document Control	11
QAP-5 REV. 0 Instructions, Procedures, and Drawings	13
QAP-6 REV. 0 Document Control	15
QAP-7 REV. 0 Control of Purchased Items and Services	17
QAP-8 REV. 0 Identification and Control of Items	19
QAP-9 REV. 0 Control of Processes	23
QAP-10 REV. 0 Inspection	25
QAP-11 REV. 0 Test Control	27
QAP-12 REV. 0 Control of Measuring and Test Equipment	29
QAP-13 REV. 0 Handling, Storage, and Shipping	31
QAP-14 REV. 0 Inspection, Test, and Operating Status	33
QAP-15 REV. 0 Control of Nonconforming Items	35
QAP-16 REV. 0 Corrective Action	37
QAP-17 REV. 0 Quality Assurance Records	39
QAP-18 REV. 0 Audits	41

Introduction

The Environmental Quality Verification Group (EQVG) is the organization within the Guidance and Monitoring Section of the Environmental Protection Department that is responsible for the monitoring of various environmental media in the vicinity of LLNL's Livermore Site and Site 300. This monitoring is carried out to meet the requirements of State and local regulatory agencies as well as Federal agencies (such as the Environmental Protection Agency (EPA) or the Department of Energy (DOE)).

DOE Draft Order 5480.XX of August 15, 1986 requires that DOE facilities have a quality assurance plan that addresses the 18 quality assurance criteria of ANSI/ASME NQA-1; the plan is to be written in the format of ANSI/ASME NQA-1.

This quality assurance plan was written to meet the requirements of DOE Draft Order 5480.XX. Each of the 18 criteria has been assigned a Quality Assurance Procedure (QAP). The first section of each QAP states the requirement as taken from ANSI/ASME NQA-1. The goal of this quality assurance plan is to generate data that are precise, accurate, complete, representative, and comparable. The data can then be used as a basis for decision making about the monitoring program and the impacts of LLNL operations. To this end, the following goals are established for all environmental monitoring data:

Accuracy—Data shall be accurate to within $\pm 10\%$ as determined by interlaboratory comparisons, or analysis of samples with known concentrations of the parameters of interest.

Precision—Data shall be precise to within $\pm 30\%$ at the 95% confidence level as determined by the use of duplicate sampling techniques.

Completeness—Data capture shall be equal to or greater than 85% for each sampling media.

Representativeness—Sample collection points shall be chosen to assure that the collected samples are representative of the environmental medium sampled. Methods for choosing sample collection points shall be addressed in the Environmental Surveillance Plan as required by DOE Draft Order 5480.XX.

Comparability—Data will be presented in all reports in the units required by DOE Draft Order 5480.XX or by the appropriate regulatory agency to assure that data are comparable with data produced by other organizations. Wherever applicable, EPA standard methods will be used for sample collection and analysis.

In order to assure that this document also meets the quality assurance requirements of EPA regulations (such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) regulations), a Quality Assurance Project Plan Locator Page has been included that correlates the 16 EPA quality assurance criteria to the 18 ANSI quality assurance criteria.

Quality Assurance Project Plan Locator Page

This page delineates which of the eighteen QAP's meet the sixteen Quality Assurance criteria specified by the Environmental Protection Agency for project plans stated in "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans" QAMS-005/80. This is done to avoid duplication of effort since the areas covered by both the EPA and ANSI documents overlap to a great extent.

Title Page	Title Page
Contents	Contents
Project Description	Introduction
Project Organization and Responsibility	QAP-1
QA Objectives for Measurement of Data in Terms of Precision, Accuracy, Completeness, Representativeness, and Comparability	Introduction
Sampling Procedures	QAP-5,6,9
Sample Custody	QAP-8
Calibration Procedures and Frequency	QAP-12
Analytical Procedures	QAP-9
Data Reduction, Validation, and Reporting	QAP-2
Internal Quality Control Checks and Frequency	QAP-2
Performance and System Audits and Frequency	QAP-18
Preventive Maintenance Procedures and Schedules	QAP-12
Specific Routine Procedures to be Used to Assess Data Precision, Accuracy, and Completeness of Specific Measurement Parameters Involved	QAP-2
Corrective Action	QAP-16
Quality Assurance Reports to Management	QAP-2

QAP-1 Organization

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Buzze
Leader Environmental Quality Verification Group

Constance DeHange
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: The organizational structure, functional responsibilities, levels of authority, and lines of communication for activities affecting quality shall be documented. Persons or organizations responsible for assuring that an appropriate quality assurance program has been established and verifying that activities affecting quality have been correctly performed shall have sufficient authority, access to work areas, and organizational freedom to

- (1) identify quality problems;
- (2) initiate, recommend, or provide solutions to quality problems through designated channels;
- (3) verify implementation of solutions; and
- (4) assure that further processing, delivery, installation, or use is controlled until proper disposition of a nonconformance, deficiency, or unsatisfactory condition has occurred.

Such persons or organizations shall have direct access to responsible management at a level where appropriate action can be effected. Such persons or organizations shall report to a management level such that required authority and organizational freedom are provided, including sufficient independence from cost and schedule considerations.

Response

This plan is designed to cover all EQVG activities that affect the quality of the environmental monitoring program. The plan addresses the 18 criteria of ANSI/ASME NQA-1-1986. Each member of EQVG is responsible for implementing all portions of this QA plan as it applies to his/her specific activities. The Quality Assurance Coordinator for EQVG will be responsible for assessing the implementation of this plan, while responsibilities for review and audit of this QA plan will reside with the LLNL Quality Assurance Office in order to assure that functional independence is maintained.

A. Authorities and Responsibilities

Section Leader, Guidance and Monitoring Section: Retains ultimate responsibility for the operation of the Environmental Quality Verification Group. Responsible for review and approval of all changes to the design of the monitoring program.

Group Leader: Responsible for the day-to-day operation of the EQVG. Responsible for review and approval of all changes to the design of the monitoring program, and all EQVG functional procedures. Responsible for review and approval of the annual environmental monitoring report.

Quality Assurance Coordinator: Responsible for review of all monitoring program design changes and all functional procedures. Responsible for compiling the annual environmental monitoring report. Responsible for periodically assessing the implementation of this QA Plan by the functional sections of the EQVG.

Scientific Support Personnel: Responsible for review and reporting of environmental monitoring data. Responsible for performing required dose assessments.

Technical Support Personnel: Responsible for sample collection, maintenance and calibration of sampling equipment, and maintenance and calibration of the meteorological sensors.

B. Organizational Chart

ENVIRONMENTAL PROTECTION DEPARTMENT

Department Head—Richard Ragaini

GUIDANCE AND MONITORING SECTION

Section Leader—Constance DeGrange

ENVIRONMENTAL QUALITY VERIFICATION GROUP

Group Leader (acting)—Michael Ruggieri

Quality Assurance Coordinator

Robert C. Holland

Scientific Support

see page 3

Technical Support

see page 3

Scientific Support

Dose Assessment

David D. Brekke

Data Analysis/Reporting

Robert C. Holland

David D. Brekke

Michael G. Brown

Tina M. Carlsen

Technical Support

Sample Collection

Marion Heaton

Chantel Aracne

6 technicians (part-time effort)

Computations

Theresa Swatloski

QAP-2 Quality Assurance Program

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Bigger
Group Leader

Constance DeBrange
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: A documented quality assurance program shall be planned, implemented, and maintained in accordance with this Standard, or portions thereof. The program shall identify the activities and items to which it applies. The establishment of the program shall include consideration of the technical aspects of the activities affecting quality. The program shall provide control over activities affecting quality to an extent consistent with their importance. The program shall be established at the earliest time consistent with the schedule for accomplishing the activities.

The program shall provide for the planning and accomplishment of activities affecting quality under suitably controlled conditions. Controlled conditions include the use of appropriate equipment, suitable environmental conditions for accomplishing the activity, and assurance that prerequisites for the given activity have been satisfied. The program shall provide for any special controls, processes, test equipment, tools, and skills to attain the required quality and for the verification of quality.

The program shall provide for indoctrination and training, as necessary, of personnel performing activities affecting quality to assure that suitable proficiency is achieved and maintained.

Management of those organizations implementing the quality assurance program, or portions thereof, shall regularly assess the adequacy of that part of the program for which they are responsible and shall assure its effective implementation.

Response

This document details the Quality Assurance Program for the EQVG. This plan applies only to those aspects of EQVG's activities in operating the environmental monitoring program. This plan specifically does not apply to any research and development projects that may be undertaken by EQVG personnel.

A. Training and Qualification of Personnel

The required qualifications of each position within the monitoring program shall be specified (e.g., as in a job description).

Training for EQVG personnel will follow the system being devised for Environmental Protection as a whole. Personnel will be documented as qualified by the use of a Job Performance Checklist for each of the procedures they are required to perform. A system of periodic retraining, reexamining, recertifying, or reviewing performance will be established.

Training will be performed in order to assure that all personnel are aware of the nature and goals of the Quality Assurance Program.

Training may be performed by the Group Leader, Assistant Group Leader, members of scientific support, or by the technician supervisor. The trainer is responsible for documenting the training in accordance with EPD guidelines, and for forwarding the documentation to the EPD training coordinator for retention.

B. Quality Control Samples

Duplicate samples shall be taken according to the following schedule:

Air particulates: One replicate sampler is run in parallel with a normal sampler at the LLNL and Livermore Valley sites. A replicate sample is not currently taken at Site 300 because all filters are composited for analyses.

Air tritium: One replicate sampler is run in parallel with a normal sampler at the LLNL perimeter.

Surface water: For each sampling round, one replicate sample shall be taken for the Livermore Valley locations, and one replicate sample shall be taken for the Site 300 locations.

Groundwater: For each sampling round, two replicate samples shall be taken for the Livermore Valley groundwater sampling locations, and one replicate sample shall be taken for the Site 300 locations.

Soil: For each sampling round, two replicate samples shall be taken for the Livermore Valley locations, and one replicate sample shall be taken for the Site 300 locations.

Vegetation: A replicate sample shall be taken for each sampling location. One Livermore Valley and one Site 300 replicate sample shall be analyzed during each sampling round.

Milk: One replicate sample shall be taken quarterly.

Sewage: One replicate sample shall be taken each week.

During each sampling round, a field blank will be submitted for the following media: surface water (low tritium water), groundwater (low tritium water), milk (powdered milk reconstituted with low tritium water), sewage (low tritium water). Field blanks for the other media are considered impractical.

All laboratories performing analyses for the monitoring program shall be required to participate in measurement assurance programs. For radiological analyses, the EPA Environmental Radioactivity Laboratory Intercomparison Studies (Cross-check) Program, and

the DOE Environmental Measurements Laboratory (EML) Quality Assessment Program, are acceptable examples.

Periodically, the Quality Assurance Coordinator shall submit blind spikes to the analytical laboratories for analysis. The results of these analyses shall be reported to management as discussed below.

C. Data Handling

Responsibility for the review of data lies with Scientific Support Personnel. Data shall be reviewed in a timely fashion after receipt from the analytical group performing the analysis. This review will be accomplished in accordance with written procedures as specified in QAP-5. The reviewing person shall sign the chain-of-custody form accompanying the data upon receipt of the data. Data shall be plotted on control charts (or the equivalent) to provide easy identification of adverse trends. All data, and the associated control charts and chain-of-custody forms shall be filed in the Document Retention Center at the end of the reporting period (usually in April of the following year).

The previous year's environmental data shall be used to determine average values and 2-sigma error values for the control charts. If two consecutive data points fall outside the 2-sigma limits, or one data point falls outside the 3-sigma error values, these data will be considered to be anomalous and an investigation will be initiated in accordance with QAP-15 and QAP-16 to determine the cause of the anomalous data (whether it be due to sampling or analytical error, or possible sources for a high value that has been determined to be correct).

For all data calculations made by hand, at least 10% shall be independently verified by a knowledgeable individual who was not involved in performing the original calculation.

All manual data inputs shall be independently verified.

Replicate samples failing to meet the quality assurance goals listed in the introduction to this plan will be documented according to QAP-15 and the data dispositioned according to QAP-16.

D. Internal Assessments

Annually, the Quality Assurance Coordinator shall perform an assessment of the implementation of this QA Plan as discussed in QAP-18 of this Plan. This assessment shall be presented to management in the form of an annual quality assurance report.

QAP-3 Design Control

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Ruggen
Group Leader

Constance DeTrange
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: The design shall be defined, controlled, and verified. Applicable design inputs shall be appropriately specified on a timely basis and correctly translated into design documents. Design interfaces shall be identified and controlled. Design adequacy shall be verified by persons other than those who designed the item. Design changes, including field changes, shall be governed by control measures commensurate with those applied to the original design.

Response

This requirement applies to the design of the monitoring program with respect to the following:

- (1) Environmental media sampled.
- (2) Frequency of sampling.
- (3) Location of sampling stations.
- (4) Analyses performed on samples.
- (5) Equipment used for sampling.

The design of the monitoring program will be laid out initially in the Environmental Surveillance Plan as required by the final version of DOE Draft Order 5480.XX. Changes to any of the above-listed criteria (and thereby the Environmental Surveillance Plan) will be considered a design change, and will be controlled by this QA Plan.

All documents pertaining to the design of the monitoring program shall be prepared by personnel technically competent (as outlined in QAP-2, Section A) in this area. Prior to approval, the design shall be verified by competent personnel not directly involved in the development of the design document. This verification shall consist of one or more of the following: performance of design reviews, use of alternate calculations, or the performance of qualification tests. This design verification shall be documented. After verification, the document shall be reviewed and signed by the Section Leader—Guidance and Monitoring, the Group Leader, and the EQVG Quality Assurance Coordinator.

For the initial design (or justification of an existing design), a Design Package will be generated. This Design Package will contain the following documentation:

- (1) A listing of all documents, texts, articles, etc. used as design inputs.
- (2) The design document itself.

The Design Package will be placed in the appropriate file in the Document Retention Center as described in QAP-6.

For all design changes, a revised Design Package will be generated. The same verifications and approvals that were necessary for the original Design Package will be repeated for the revision. The revised Design Package will be placed in the appropriate Document Retention Center file. All superceded Design Packages will be retained in the historical files as described in QAP-6.

QAP-4 Procurement Document Control

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Buzer
Group Leader

Constance DeFrance
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Applicable design bases and other requirements necessary to assure adequate quality shall be included or referenced in documents for procurement of items or services. To the extent necessary, procurement documents shall require suppliers to have a quality assurance program consistent with the applicable requirements of this standard.

Response

Standard LLNL procurement practices and documentation practices will be used for all purchases made by EQVG. EQVG will retain a listing of all major contracts or procurements executed for the monitoring program. This listing will be kept up to date, and retained in the Document Retention Center. The Group Leader will review all procurement documents to ensure that applicable portions of ANSI/ASME NQA-1-1986 (as determined by the Group Leader and the Quality Assurance Coordinator) are specified as requirements in the contract. The contract shall also contain provisions for inspection and audit by EQVG personnel.

QAP-5 Instructions, Procedures, and Drawings

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Ruggie
Group Leader

Constance DeTrange
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Activities affecting quality shall be prescribed by and performed in accordance with documented instructions, procedures, or drawings of a type appropriate to the circumstances. These documents shall include or reference appropriate quantitative acceptance criteria for determining that prescribed activities have been satisfactorily accomplished.

Response

A. Procedures

EQVG procedures shall be written covering sample collection; packaging, shipment, and receipt of samples for off-site analysis; maintenance and calibration of sampling equipment; and reduction, evaluation, and reporting of data. Written procedures shall contain the following sections and headings:

Purpose: Briefly state the purpose and objective of the procedure.

Discussion: Discuss anything special about the nature of the procedure, background, etc. This section may also be used for discussing the scope of the procedure, if warranted.

References: Reference any procedures or documents directly applicable to the subject procedure and necessary for the successful completion of the tasks involved.

Definitions: Define any terms not in common use or that may be subject to multiple interpretations.

Equipment: List the equipment necessary to carry out the procedure.

Procedure: Provide a step-by-step description of the procedure, detailed enough to allow someone with an appropriate technical background to duplicate the procedure.

Documentation: List the appropriate forms that must be completed, disposition of those forms, length and method of storage, and any data transmission to be accomplished.

Acceptance Criteria: List appropriate qualitative or quantitative criteria for determining that prescribed activities have been satisfactorily accomplished.

B. Computer Programs

All computer programs used by EQVG shall be verified prior to initial use and after each modification. This shall be documented in a Design Package as described above in QAP-3. For programs generated in-house, the verification will consist of trial runs being performed and compared with independent hand calculations. For purchased programs, the manufacturer usually can provide adequate documentation of the program.

This information shall be placed in the Document Retention Center.

5

QAP-6 Document Control

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Buzer
Group Leader

Constance DeHange
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: The preparation, issuance, and change of documents that specify quality requirements or prescribe activities affecting quality shall be controlled to assure that correct documents are being employed. Such documents, including changes thereto, shall be reviewed for adequacy and approved for release by authorized personnel.

Response

Design documents shall be controlled by placing the revision number, date, and page number (as page ____ of ____) in the upper right hand corner of each page.

Design documents shall be filed in the Document Retention Center, and retained for the life of the facility. All historical revisions of design documents will be retained as above. The latest revision in the file shall reflect the actual current operating practices of the monitoring program.

Changes to design documents (other than inconsequential editorial changes) shall receive the same review as the original design document unless a different review process is specifically delineated. The only persons authorized to determine whether a change constitutes a minor change (and therefore does not require review) is the group leader.

All procedures necessary for the operation of the monitoring program shall be prepared by personnel technically competent in the area covered by the procedure. Prior to issuance for use, all procedures shall be reviewed and signed by the group leader, and the EQVG Quality Assurance Coordinator.

Procedures shall be controlled by placing the revision number, date, and page number (as page ____ of ____) in the upper right hand corner of each page. All procedures will have the word 'controlled' stamped in red ink on each page of procedures issued for use by EQVG personnel. Any copy of a procedure not so stamped will be considered an unofficial copy and is not suitable for use by personnel in the field. The stamp may only be applied by the Quality Assurance Coordinator, or his designee.

The cover sheet of each procedure will indicate the date of the last review of the procedure, and the scheduled date of the next review.

Procedures will be reviewed annually by personnel familiar with the implementation of the procedure to determine if revision is necessary. If revision is necessary, it shall be handled as described in this section. If it is determined that no revision is necessary, a new cover sheet for the procedure shall be issued indicating the revised review date.

Current procedures, and all historical procedures shall be filed in the Document Retention Center, and retained for a minimum of twenty years. The current revision in the file shall reflect the actual current operating practices of the monitoring program.

A log shall be kept in the Environmental Protection Department File that identifies those personnel who have controlled copies of the procedures. This log will be used to assure that all personnel have the most current revision of the procedures.

The Document Retention Center will also be used to house all other documents pertinent to the monitoring program, such as field log books, sample collection data sheets, and data sheets as received from the analytical laboratories. Final results from the monitoring program will be retained for the life of the facility.

QAP-7

Control of Purchased Items and Services

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Buzer
Group Leader

Constance DeFrance
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: The procurement of items and services shall be controlled to assure conformance with specified requirements. Such control shall provide for the following as appropriate: source evaluation and selection, evaluation of objective evidence of quality furnished by the supplier, source inspection, audit, and examination of items or services upon delivery or completion.

Response

Purchases for the EQVG will be controlled by LLNL's standard procurement practices. All documentation of this process will be filed in the appropriate file in the Document Retention Center.

A written procedure shall be developed which addresses specific areas to be considered during the procurement process. These specific areas shall include, at the minimum, 1) assessment of the proposed contractor's QA plan, 2) assessment of their past QA performance, 3) ability to do the work, and 4) cost factors.

QAP-8 Identification and Control of Items

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Ruggen
Group Leader

Constance DeFrango
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Controls shall be established to assure that only correct and accepted items are used or installed. Identification shall be maintained on the items or in documents traceable to the items, or in a manner which assures that identification is established and maintained.

Response

A. Equipment

All equipment used for sampling shall be controlled by a unique identification number (serial numbers, LLNL inventory numbers, or EQVG assigned numbers are acceptable for this purpose). A list (or other tracking system) shall be maintained that indicates the present operating status of each piece of equipment, its current location, and its calibration status (date of last calibration and date of next scheduled calibration). This tracking system will be maintained by those members of the Technical Support Section responsible for maintenance, calibration, and placement of the equipment.

Consumable materials (such as air filters) shall be controlled by tracking the manufacturer's lot number and the samples they were used on.

B. Sample Chain of Custody

All samples shall have affixed to them a label containing at least the following information:

- Sampling location.
- Sample type.
- Date.
- Initials of the person collecting the sample.

Field Tracking Forms shall be completed in the field as the samples are collected. Specific field tracking forms will be included in the sampling procedures, and shall contain at least the following information: sample location, sample type, date collected, person collecting, and date

Rev. 0
page 2 of 4 .
September 18, 1987

of submittal for analysis. The data from this form will be used to fill out a chain-of-custody form (Form QAP-8-1, or an equivalent form provided by a subcontractor laboratory) to be used during the remainder of the sample processing, up to and including the point of archiving of the data in the Document Retention Center.

Chain-of-Custody Record

Project Name				No. of Containers	Analyses Requested								Remarks
Sampler: (signature)													
Location		Date	Time	Location Description									
I.D.	Type • Position												
•	•												
•	•												
•	•												
•	•												
•	•												
•	•												
•	•												
•	•												
•	•												
•	•												
•	•												
•	•												
•	•												
Relinquished by: (signature)		Date/Time	Received by: (signature)		Relinquished by: (signature)		Date/Time	Received by: (signature)					
Relinquished by: (signature)		Date/Time	Received by: (signature)		Relinquished by: (signature)		Date/Time	Received by: (signature)					
Relinquished by: (signature)		Date/Time	Received for Laboratory by: (signature)		Date/Time	Remarks							
Data relinquished from Lab by: (signature)		Date/Time	Data received in EQVG by: (signature)		Data relinquished by: (signature)		Date/Time	Data received by: (signature)					
Data archived by: (signature)		Date/Time	Distribution of copies: Pink – Sample Collector Canary – Analytical Laboratory White – Return to EQVG										

*See reverse for codes.

Groundwater Samples:

BC = Barcad
BH = Borehole
LY = Lysimeter
NP = Neutron Probe
MW = Monitoring Well
SP = Spring

Non-Groundwater Samples:

AF = Air Filter
AT = Air Tritium
HY = Honey
ML = Milk
MS = Miscellaneous Samples
OW = Other Water
SN = Snoopy
SO = Soil
SW = Sewage
TL = TLD
VG = Vegetation
WI = Wine

QAP-9 Control of Processes

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Ruggen
Group Leader

Constance DeFrango
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Processes affecting quality of items or services shall be controlled. Special processes that control or verify quality, such as those used in welding, heat treating, and nondestructive examination, shall be performed by qualified personnel using qualified procedures in accordance with specified requirements.

Response

All aspects of sample processing shall be addressed by written procedures as described in QAP-5. Provisions shall be made for control of 'emergency' or 'one time' processes that are not covered by the normal procedures. Control of these processes will allow for professional judgement to be exercised, and will also allow for after-the-fact documentation to facilitate rapid response to unusual circumstances.

Personnel performing sample processing shall be qualified as outlined in QAP-2. However, to facilitate on-the-job training, it will be considered acceptable for unqualified personnel to perform sampling activities under the direct supervision of a qualified person. In such instances, both the trainee and the supervising person shall sign all required documentation.

QAP-10 Inspection

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Ruggen
Group Leader

Constance DeFrango
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Inspections required to verify conformance of an item or activity to specified requirements shall be planned and executed. Characteristics to be inspected and inspection methods to be employed shall be specified. Inspection results shall be documented. Inspection for acceptance shall be performed by persons other than those who performed or directly supervised the work being inspected.

Response

This requirement is not considered applicable to the monitoring program. All items used for the sampling program are assured of suitability for the purpose by the procurement process and by initial testing. Inspection points during the sampling process are not considered feasible or necessary.

QAP-11 Test Control

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Bygum
Group Leader

Constance DeBrange
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Tests required to verify conformance of an item to specified requirements and to demonstrate that items will perform satisfactorily in service shall be planned and executed. Characteristics to be tested and test methods to be employed shall be specified. Test results shall be documented and their conformance with acceptance criteria shall be evaluated.

Tests required to collect data, such as for siting or design input, shall be planned, executed, documented, and evaluated.

Response

All new sampling equipment or procedures will be tested before being placed in service. The documentation from these tests will become part of the Design Package as described in QAP-3. The tests shall include, where practicable, the side-by-side testing of the new equipment or procedures with the old system. The new system shall be deemed acceptable when the results of the tests fall within plus or minus the 2-sigma error value of the old system, unless it can be shown through independent methods that the new system is more accurate than the old system, and similar results should not be expected. In this case, the test shall provide enough data to establish a new baseline and 2-sigma error factors. The new test shall provide enough data for this statistical evaluation to be made.

QAP-12 Control of Measuring and Test Equipment

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Ruggen
Group Leader

Constance DeFrance
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Tools, gages, instruments, and other measuring and test equipment used for activities affecting quality shall be controlled and at specified periods calibrated and adjusted to maintain accuracy within necessary limits.

Response

All equipment shall be identified as described in QAP-8. Maintenance and calibration procedures shall be written and controlled as described in QAP-5 and QAP-6. Provisions shall be made in the calibration and operating procedures for acceptable ranges of operation, recalibration schedules, and treatment of 'out of control' equipment. Equipment determined to be 'out of control' shall be immediately removed from service.

All calibrations shall be traceable to National Bureau of Standards Standard Reference Materials (SRM's). The SRM to which the calibration is traceable shall be recorded on the calibration record and filed in the Document Retention Center.

QAP-13

Handling, Storage, and Shipping

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Beyer
Group Leader

Constance DeFrango
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Handling, storage, cleaning, packaging, shipping, and preservation of items shall be controlled to prevent damage or loss and to minimize deterioration.

Response

All sample collection procedures shall contain instructions on proper preservation and packaging of samples. These provisions shall be designed to maintain sample integrity under normal shipping and storage conditions.

Retention times shall be established for all sample types. These required retention times shall be specified in the contracts for all subcontractors handling the samples.

QAP-14 Inspection, Test, and Operating Status

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Ruggen
Group Leader

Constance DeFrango
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: The status of inspection and test activities shall be identified either on the items or in documents traceable to the items where it is necessary to assure that required inspections and tests are performed and to assure that items that have not passed the required inspections and tests are not inadvertently installed, used, or operated. Status shall be maintained through indicators, such as physical location and tags, markings, shop travelers, stamps, inspection records, or other suitable means. The authority for application and removal of tags, markings, labels, and stamps shall be specified. Status indicators shall also provide for indicating the operating status of systems and components of the nuclear facility, such as by tagging valves and switches, to prevent inadvertent operation.

Response

This section applies only to the preoperational testing of equipment and procedures as outlined in QAP-11. Such equipment will clearly be marked 'under test,' and such procedures will be clearly marked 'draft.' These markings shall not be removed until the Design Package has been approved by the Group Leader and the Quality Assurance Coordinator.

QAP-15 Control of Nonconforming Items

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Beyer
Group Leader

Constance DeTrange
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Items that do not conform to specified requirements shall be controlled to prevent inadvertent installation or use. Controls shall provide for identification, documentation, evaluation, segregation when practical, and disposition of nonconforming items, and for notification to affected organizations.

Response

Equipment or materials that have been designated 'out of control' or have failed inspections or tests as described in QAP-11 or QAP-12 shall be physically separated. Provisions shall be made in the tracking system described in QAP-8 for identifying the operational or calibration status of all sampling equipment.

Data that has been determined to be anomalous in accordance with QAP-2 (and its implementing procedures) shall also be considered nonconforming.

Deficiencies noted during assessments of EQVG operations by the Quality Assurance Coordinator shall be treated as nonconformances.

Nonconformances shall be brought to the attention of the Quality Assurance Coordinator who will issue a Nonconformance Report (QAP-15-1). Copies of this form shall be sent to the Group Leader, Assistant Group Leader, and the person responsible for the item in question. Response to the nonconformance and documentation are covered in QAP-16.

Nonconformance Report

Description of Situation
Reported by: _____ Date: _____
Requirement Violated
Response
Responsible party: _____ Date: _____
Response Verified and Accepted
By: _____ Date: _____

QAP-16 Corrective Action

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Buzze
Group Leader

Constance DeTrange
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Conditions adverse to quality shall be identified promptly and corrected as soon as practical. In the case of a significant condition adverse to quality, the cause of the condition shall be determined and corrective action taken to preclude recurrence. The identification, cause, and corrective action for significant conditions adverse to quality shall be documented and reported to appropriate levels of management; follow-up action shall be taken to verify implementation of this corrective action.

Response

Nonconformances are identified as described in QAP-15. All Nonconformance Reports must be responded to in writing within 30 days of the issuance of the Nonconformance Report. The Quality Assurance Coordinator is responsible for verification of the implementation of the corrective action specified on the Nonconformance Report.

Deficiencies noted during the annual audits performed by the LLNL QA Office will be formally responded to by the Section Leader of Guidance and Monitoring.

All completed Nonconformance Reports (which will include the corrective action and verification of the corrective action) shall be archived in the Document Retention Center.

QAP-17

Quality Assurance Records

Prepared by: Robert C. Holland
Quality Assurance Coordinator

Approved by: Michael Ruggen
Group Leader

Constance DeFrance
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Records that furnish documentary evidence of quality shall be specified, prepared, and maintained. Records shall be legible, identifiable, and retrievable. Records shall be protected against damage, deterioration, or loss. Requirements and responsibilities for record transmittal, distribution, retention, maintenance, and disposition shall be established and documented.

Response

Procedures that produce QA records will specify in the Documentation section which documents are QA records, and specify method, length, and place of storage.

A list of Quality Assurance Records will be maintained in the Document Retention Center.

The Document Control Coordinator will be responsible for the functioning of the Document Retention Center, including the establishment of a filing system to ensure retrievability. The functioning of the Document Retention Center shall be detailed in written procedures as specified in QAP-5 and QAP-6.

QAP-18 Audits

Prepared by: Robert L. Holland
Quality Assurance Coordinator

Approved by: Michael Ruggen
Group Leader

Constance DeTrange
Section Leader, Guidance and Monitoring

Requirement

ANSI/ASME NQA-1-1986: Planned and scheduled audits shall be performed to verify compliance with all aspects of the quality assurance program and to determine its effectiveness. These audits shall be performed in accordance with written procedures and checklists by personnel who do not have direct responsibility for performing the activities being audited. Audit results shall be documented and reported to and reviewed by responsible management. Follow-up action shall be taken where indicated.

Response

An annual audit of this Quality Assurance Plan shall be performed by the LLNL Quality Assurance Office, in accordance with their procedures. This audit will be performed for the Section Leader of the Guidance and Monitoring Section.

In addition, the EQVG Quality Assurance Coordinator will perform assessments of the various EQVG functions in such a manner that all functions are assessed annually. These assessments will be performed in accordance with written procedures, and the results will be retained in the Document Retention Center as specified in QAP-17.

The functions of EQVG Quality Assurance personnel shall be specified in written procedures.

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