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Environmental Monitoring at the Lawrence Livermore National Laboratory

1984 Annual Report

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Foreword

This report is prepared for the U.S. Department of Energy by the Environmental Measurements Group of the Hazards Control Department, Lawrence Livermore National Laboratory. Data are obtained through the combined efforts of the Nuclear Chemistry Division and the Hazards Control Department. In addition to the authors listed, the following personnel made significant contributions to this report:

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① Lawrence Livermore National Laboratory	⑦ Vasco Road
② Sandia National Laboratories, Livermore	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	

Frontispiece. Lawrence Livermore National Laboratory (looking west).

Environmental Monitoring at the Lawrence Livermore National Laboratory 1984 Annual Report

Introduction

The Laboratory

The Lawrence Livermore National Laboratory (LLNL) is located about 64 km east of San Francisco, California, in the Livermore Valley of eastern Alameda County, approximately 5 km east of the city of Livermore. The site, which occupies an area of 2.54 km², is surrounded by open

agricultural areas on the north, east, west, and part of the south side. Sandia National Laboratories, Livermore, occupies a portion of the adjoining property on the south, and the nearest residential area is 0.8 km from LLNL's west perimeter. Of the nearly 5.1 million people who live within 80 km of LLNL (Fig. 1), 50,000 live in Livermore.

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

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

In 1984, LLNL employed approximately 8500 people.

Much of LLNL's materials testing and high-explosives diagnostic work is conducted at Site 300, 16 km southeast of Livermore. Located in the sparsely populated hills of the Diablo Range, Site 300 covers an area of 27 km². Figure 1 shows the location of LLNL and Site 300 with respect to the city of Livermore and surrounding areas.

The Site

The Livermore Valley has a climate characterized by mild, rainy winters and warm, dry summers. The highest and lowest annual rainfalls on record are 782 mm and 138 mm, with a 114-year average of 369 mm. Rainfall for the 1983–1984 water year (October 1, 1983 through September 30, 1984) was 350 mm. Surface water drainage from the Valley is from east to west through various arroyos; the outfall is near Sunol in the southwest corner of the Valley. Prevailing winds are from the west and southwest during April through September. During the remainder of the year, wind directions are variable, as shown by the wind rose in Fig. 2.

The LLNL site is situated on a northwesterly sloping alluvial flood plain bordering the low hills of the Livermore Uplands to the south. Groundwater is found at depths of 15 to 30 m below the LLNL site with a gradient indicating a generally westward flow. The lithology of the area consists of a series of unconsolidated marine and continental sedimentary units such as sandstones, gravels, silts, and clays overlying the interbedded sandstones of the Franciscan Formation. The hilly terrain surrounding the Valley is used for cattle and sheep pasture, and the principal agricultural products in the vicinity of LLNL are grapes and wine, cattle, and poultry.

Water bodies near LLNL include the South Bay Aqueduct, which runs from the northeast to southwest, 0.2 km to the southeast; the Patterson Pass water treatment facility, about 1.2 km east of LLNL; and, Frick Lake, a sag pond that is dry most of the year, 4 km north of LLNL. Aquatic recreation (boating, fishing, and swimming) is available at Lake Del Valle, about 8 km south of LLNL, and at the Shadow Cliffs Recreation Area, 11 km to the west. Lake Isabel, 9 km to the southwest, is a fee-for-fishing area.

LLNL normally receives its treated water from the Hetch Hetchy Aqueduct (which supplies San Francisco), located 11 km southwest of Livermore.

LLNL storm water is channeled through storm sewers designed to accommodate a 10-year flow. Open ditches are used in undeveloped areas of the site. Arroyo Seco crosses LLNL at the southwest corner. Arroyo Las Positas originally crossed the northeast section of the site. However, in 1965, as part of an erosion-control program, Arroyo Las Positas was channeled north to the northeast corner of the site, and then west along the north perimeter to an outlet at the northwest corner. This outlet, which also constitutes the main pathway for LLNL's surface drainage (storm and irrigation), runs north to the Western Pacific tracks, then west where it joins Arroyo Seco. The *LLNL Master Site Plan* calls for a small lake to be established in the center of the project. Provisions have been made for rerouting on-site water drainage to fill this lake during the rainy season.

LLNL's sewage 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 via a pipeline and discharged into San Francisco Bay. The LWRP was connected to this pipeline on February 8, 1980. While the LWRP effluent is still used for summer irrigation of nearby Livermore city property, it is no longer discharged to Arroyo Las Positas, as was done during the wet season before construction of the pipeline.

Environmental Monitoring

A strict effluent-control program that emphasizes controlling effluents at the source has been in effect since LLNL began operation. The Environmental Monitoring program evaluates the effectiveness of these measures, documents whether

Direction	Average wind-direction frequency by percent (m/s)									Total	Average speed (m/s)
	0-2	2-3	3-5	5-7	7-9	9-11	11-16	16-20	>20		
N	1.6	0.3	0.2	0	0	0	0	0	0	2.1	1.6
NNE	2.1	0.6	0.3	0	0	0	0	0	0	3.0	1.7
NE	3.3	0.7	0.1	0	0	0	0	0	0	4.1	1.5
ENE	2.8	0.8	0.1	0	0	0	0	0	0	3.7	1.5
E	1.5	0	0	0	0	0	0	0	0	1.5	1.0
ESE	1.8	0.1	0	0	0	0	0	0	0	1.9	1.1
SE	2.6	0.1	0	0	0	0	0	0	0	2.7	1.2
SSE	1.8	0	0.1	0	0	0	0	0	0	1.9	1.1
S	1.8	0.2	0.1	0	0	0	0	0	0	2.1	1.4
SSW	3.1	0.5	0.2	0	0	0	0	0	0	3.8	1.6
SW	6.3	3.1	1.8	0.2	0	0	0	0	0	11.4	2.1
WSW	10.2	6.6	3.2	0.2	0	0	0	0	0	20.2	2.1
W	9.2	3.3	1.6	0	0	0	0	0	0	14.1	1.8
WNW	5.4	2.5	0.6	0	0	0	0	0	0	8.5	1.8
NW	2.0	0.4	0.1	0	0	0	0	0	0	2.5	1.4
NNW	1.1	0.1	0.1	0	0	0	0	0	0	1.3	1.4
Calm										15.2	
Total	56.6	19.3	8.5	0.4	0	0	0	0	0	100.0	1.6

Figure 2. Wind rose showing the average annual wind direction and speed during 1984 (measurements were made at 40 m above the ground).

effluents from LLNL and Site 300 operations are within applicable standards, and estimates the impact of these operations on the environment. Sensitive monitoring equipment is used that can detect radioactive and nonradioactive pollutants at environmental background levels. The program includes the collection and analysis of air, soil, water, sewer effluent, vegetation, foodstuffs, and milk samples. Also, environmental background radiation is measured at numerous locations in the vicinity of LLNL using gamma and neutron dosimeters.

Each spring, LLNL reports the results of environmental monitoring for the previous year, noting significant changes in either the scope of the program or the levels of effluents. This report is prepared in compliance with the DOE Manual 5484.1, *Environmental Protection, Safety, and Health Protection Information Reporting Requirements*.

Summary

Air Samples

In 1984, the annual average airborne gross beta activity in Livermore Valley air samples was 1.5×10^{-14} $\mu\text{Ci/ml}$, essentially unchanged from 1983. Airborne ^{238}U concentrations at Site 300 were higher than those at Livermore because of the "depleted" uranium (a by-product of ^{235}U enrichment) used in high-explosive tests at the Site. However, these concentrations were well below the standards set by DOE. The average gross alpha activity shows no significant change from 1983 data. The annual average beryllium concentrations were less than 1% of the local air pollution standard at both the LLNL perimeter and Site 300. The beryllium concentrations can be accounted for by the natural beryllium in typical airborne dust. The total tritium released to the atmosphere in 1984 was 7354 Ci, of which 5000 Ci was accidentally released June 8, 1984. The total quantity of ^{13}N - ^{15}O released in 1984 was 81 Ci.

Soil Samples

The concentrations of ^{239}Pu in the soil of the Livermore Valley are similar to those from previ-

ous years. The highest value of 30×10^{-9} $\mu\text{Ci/g}$ (0.25% of the standard), found east of the LLNL perimeter, is attributed to wind-deposited contamination from solar evaporation pits. The process was discontinued many years ago. The proposed EPA soil standard for unrestricted use is 12×10^{-6} $\mu\text{Ci/g}$. The remaining areas reflect world-wide fallout and naturally occurring concentrations of nuclides.

Appendix A is a tabulation of 1984 environmental monitoring data. Graphics have been used in the body of the report to aid in interpretation. When appropriate, the tabulated data contain maximum, minimum, and average values. Radioactivity values are tabulated with the associated counting uncertainties at the 2σ (95% confidence) level. Unless otherwise stated, the minimum detection limit of these measurements is assumed to have been reached when the 2σ error is $\pm 100\%$. In the case of radioactivity measurements, an attempt has been made to assess the potential impact on people from the observed environmental levels of artificially produced radionuclides. This assessment is made by calculating the radiation doses delivered to people and comparing these with the much larger radiation dose received locally from natural sources.

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 426 $\mu\text{g/g}$ is typical of previous years' data.

During 1984, a number of special assessments were in progress that involved the analyses of soil samples. These assessments are being done to investigate the contamination, if any, at Site 300 (landfills and a chemical handling facility) and at LLNL (a gasoline tank leak, a landfill, and potential groundwater contamination sources). The soil samples were analyzed for various contaminants (metals, gasoline, TCE, PCE, PCBs, 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 Samples

Water samples collected in the Livermore Valley and at Site 300 exhibit gross beta and tritium activities within the ranges previously observed in these areas. Two water samples from Site 300 showed an above-average level of gross alpha activity (17.0 and 7.5 pCi/liter). This activity has been found to be naturally occurring uranium at concentrations well within those specified in *DOE Manual 5480.1*. Some groundwater monitoring wells near a landfill at Site 300 show sharply elevated concentrations of tritiated water. The highest value measured was 8.9×10^{-5} $\mu\text{Ci/ml}$. Traces of TCE (5 ppb) and DCE (1 ppb) were detected in wells down-gradient of this pit. Also, traces of TCE (2 ppb) were found in groundwater down-gradient from another landfill at Site 300. This landfill site is under active investigation.

During 1984, a number of special assessments were in progress that involved the analyses of groundwater samples. These assessments are being done to investigate the contamination, if any, at Site 300 (landfills, a settling lagoon, and a chemical handling facility) and at LLNL (a gasoline tank leak, a landfill, and potential groundwater contamination sources). The water samples were analyzed for various contaminants (metals, gasoline, TCE, PCE, PCBs, 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.

The discharge of tritiated water (HTO) into the sanitary sewer system in 1984 was 1.7 Ci, unchanged from the previous year. The discharge of ^{239}Pu was 3.2 μCi , or about 1/2 of the amount from the previous year. Tritium analyses were also made on well-water samples collected near the LWRP. These analyses, begun in 1977, were made to determine the extent to which low levels of tritium in the LWRP effluent may be migrating into groundwater. As was found during earlier surveys, the highest tritium values (11×10^{-7} $\mu\text{Ci/ml}$) were detected in test wells down-gradient of LLNL near Arroyo Las Positas. Since the LWRP effluent is no longer discharged to the arroyo, the primary means of tritium movement to nearby groundwater has been eliminated. Tritium concentrations observed in local wells in 1984 were generally the same as previous years' measurements.

Vegetation and Foodstuff Samples

Tritium levels found in the Livermore Valley and Site 300 vegetation were comparable to those observed in 1983. An exception is vegetation collected from a landfill area at Site 300. This sample contained an elevated level (5.58×10^{-4} $\mu\text{Ci/ml}$ HTO) in the water recovered.

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

Doses

The 1984 average annual gamma-radiation doses at the LLNL perimeter and off-site locations were 48 mrem and 50 mrem, essentially unchanged from the previous year. Although a 14-MeV neutron generator (in Bldg. 212), near the south perimeter, continued to elevate the annual radiation doses at the adjacent fenceline (45 mrem), it was down sharply from 1983 (113 mrem). This reduction in neutron dose was due to less use of the equipment during 1984 and the reinstallation of some shielding which had been removed temporarily for an experiment. The annual radiation dose at LLNL's south perimeter is within allowable standards in *DOE Manual 5480.1*. The area adjacent to the fenceline is not routinely occupied. It is subject only to transient traffic on East Ave. and the parking lot across the street. Based on a 1975 study,¹ the maximum potential dose to an individual off-site with a dose of 45 mrem/y at the fenceline would be less than 1 mrem/y. Maximum radiation doses from airborne effluents were 0.04 mrem at the site boundary, 0.02 mrem to the nearest neighbor, and 0.25 person-rem within an 80-km radius.

Monitoring Data—Collection, Analysis, and Evaluation

Radioactive Monitoring

Airborne Radioactivity

Concentrations of various airborne radionuclides are measured at the LLNL perimeter, off-site locations near LLNL, and at Site 300. Sampling locations are shown in Figs. 3 through 5. The six samplers on the LLNL perimeter, seven of the off-site samplers (Fig. 5), and the nine samplers at Site 300 (Fig. 4) use $5.2 \times 10^{-2} \text{ m}^2$ Whatman-41 cellulose filters. These samplers are operated at average flow rates of 400 to 700 liters/min. The filters are cut in half; one half of each filter is retained for beryllium analysis. An easily dissolved filter and a low trace-metal background are required for these analyses. Whatman 41 represents a balance between such requirements and particulate-collection efficiency.² The remaining samplers in the Livermore Valley (Fig. 5) use $8.11 \times 10^{-3} \text{ m}^2$ glass-fiber filters (Flanders F-700) and

are operated at a flow rate of 80 liters/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 LLNL-perimeter and Site-300 filters are also counted for specific gamma-emitting radionuclides using low-background Ge(Li) detectors. Following gamma counting, the LLNL perimeter filters from individual locations and the Site 300 composites are analyzed for the presence of ^{239}Pu , ^{238}Pu , ^{235}U , and ^{238}U . Selected off-site samples from the Livermore Valley and the city of Tracy are analyzed for ^{239}Pu .

Tables A-1 and A-2 in Appendix A show airborne gross alpha and gross beta activities for the Livermore Valley samples, and Tables A-3 and A-4 show corresponding activities for Site 300. Both locations showed about the same concentrations as 1983.

Figure 3. LLNL perimeter locations for air-sampling stations and neutron dosimeters.

Figure 4. Site 300 on-site air-sampling locations.

Figure 5. Livermore Valley air-sampling locations.

Tables A-5 and A-6 list the activities of the principal radionuclides that contribute to the gross beta activity in Livermore and Site 300 samples. These activities are determined by gamma-spectra analysis. Table A-7 shows the concentration of plutonium on air filter samples collected in Tracy and the Livermore Valley. Tables A-8 and A-9 show the concentrations of airborne ^{239}Pu , ^{235}U , and ^{238}U in the LLNL perimeter and Site 300 air samples. Location 14 at the east perimeter showed slightly higher concentrations of plutonium-in-air than the other sample sites. The highest monthly sample was collected during June, 2.4×10^{-17} $\mu\text{Ci}/\text{ml}$, and represented 0.04% of the concentration guide value. The higher concentration of ^{238}U at Site 300 is a result of the "depleted" uranium (a by-product of ^{235}U enrichment) used at the Site. The uranium concentrations are well below the concentration guides (CG) in *DOE Manual 5480.1* (see Appendix B).

Concentrations of airborne tritiated water (HTO) were determined for each of the LLNL perimeter air-sampling locations (Fig. 3) and at off-site locations S1 and S2 (Fig. 5). Water vapor was collected on silica-gel samplers that operated at a flow rate of about 0.5 liters/min for a 2-week period. The collected water was recovered by vacuum drying the silica gel at 150°C , and the HTO was measured by liquid-scintillation counting. Table A-10 shows average monthly HTO concentrations observed at each sampling location; the overall annual average concentration is 3.1×10^{-11} $\mu\text{Ci}/\text{ml}$. The highest monthly concentration occurred in February and was observed at location 13. This concentration, 12×10^{-11} $\mu\text{Ci}/\text{ml}$, is 0.06% of the DOE standard. Location 12 showed the highest annual average concentration, probably because this location is so close to one of the tritium effluent sources (the 14-MeV neutron generator).

Radioactivity in Soil

An intensive soil-sampling program conducted in 1971 and 1972 provided a data base on the concentration ranges of various radionuclides in soil near LLNL and at Site 300. Since 1972, soil sampling in the vicinity of LLNL and at Site 300 has been part of a continuing LLNL surveillance 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 random from the list of locations sam-

pled in the 1971-1972 study. Figure 6 shows the 1984 soil-sampling locations in the Livermore Valley and Fig. 7 indicates the locations at Site 300 where annual samples have been collected since 1973.

All samples were collected to a depth of 5 cm. After collection, the samples were dried, ground, and blended. Plutonium-239 content was determined in each sample following an acid-leaching procedure. For gamma-spectra analysis, approximately 300-g aliquots of soil were sealed in 200- cm^3 thin-walled cans of aluminum and counted with a Ge(Li) detector.

The data in Table A-11 are in the range of those reported in the previous year.³ Figure 8 is a distribution plot of these activities.

Table A-12 shows the ^{239}Pu , ^{137}Cs , and ^{238}U activities in the Site 300 samples. There were negligible changes from activities observed in previous samples collected in the same locations.³ Figure 9 is a distribution plot of these activities.

High-explosive tests at Site 300 often involve the use of depleted uranium. Accordingly, soil samples are taken annually 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.^{4,5} The uranium data shown in Table A-12 are comparable to those observed during 1983.

Radioactivity in Sewage

Radioactive wastewater is treated to reduce activity levels to the lowest levels practicable and well below standards in *DOE Manual 5480.1*. After treatment and analysis, the liquid effluents are released into the city of Livermore's sanitary sewer system at the outfall located at the northwest corner of LLNL. The effluent is continuously monitored at the outfall for pH, selected metals, and radioactivity.

Liquid wastes from Livermore's sanitary sewer system are treated at the LWRP, a tertiary sewage-treatment plant that serves residential, commercial, and industrial water users in Livermore. The salt content of the LWRP effluent presented a problem for groundwater quality locally and in the Niles Cone aquifers. Accordingly, as part of the Livermore-Amador Valley Wastewater Management program, a pipeline was constructed to transport wastewater out of the valley for discharge into the San Francisco Bay. The Livermore sewage plant was connected to this pipeline on

Figure 6. Livermore Valley soil-sampling locations.

February 8, 1980. Although the effluent will still be used for irrigation of municipal property during summer months, it will no longer be discharged into the arroyo, thus eliminating the primary means of tritium migration to local and downstream groundwater.

Representative San Francisco Bay water samples were collected before and after the LWRP's connection to the pipeline. Results of tritium analysis of these samples indicate no significant difference between the two sample sets.⁶

Samples of the LLNL and LWRP liquid effluents are collected daily. Table A-13 compares the monthly composite activity levels of certain radionuclides in the LLNL effluent with those in

the effluent from the LWRP. All concentrations are well below standards in *DOE Manual 5480.1* for discharge into the sanitary sewer system.

Radioactivity in Water

Water samples are collected from the various Livermore Valley and Site 300 locations shown in Figs. 10 and 11. These samples are analyzed for gross alpha and gross beta activity. Tables A-14 and A-15 show the gross alpha activities in Livermore Valley and Site 300 samples. Gross beta activities for Livermore and Site 300 samples are shown in Tables A-16 and A-17.

Livermore sampling locations 11, 16, 24, 26, and 29 (Fig. 10) are surface water sources (ponds,

Figure 7. Site 300 soil-sampling locations.

creeks, and reservoirs), and location 20 is the collection site of LLNL rainfall. The other locations are domestic water sources. Gross alpha and beta activities in Livermore water samples collected in 1984 were below EPA and State of California standards for drinking water.⁷

Figure 8. Distribution plot of ^{239}Pu in soil samples collected in the Livermore Valley during 1984.

Storm-water samples were collected at three locations (influent, effluent, and the LLNL lake) during the first rain following the dry season and analyzed for gross alpha, gross beta, and tritiated water. The alpha and beta in all samples were below the limit of sensitivity, 9% and 3% of the concentration guides, respectively. The tritium concentration of the effluent was less than 0.7% of the concentration guide.

Site 300 water samples (Fig. 11) were collected from on-site wells (locations 1-6 and 22), off-site wells (locations 7 and 23), and an off-site creek (location 14). Location 20 is Site-300 rainwater, and location 21 is a spring-fed pond near Bunker 812. Two locations showed elevated gross alpha concentrations which specific analyses have identified to be natural uranium: location 4, a well near the Site 300 entrance, which has displayed these results in previous years; and location 21, the spring-fed pond, which was investigated during 1981. Neither the EPA⁷ nor the State of California⁸ specifies a limit for natural uranium in drinking water. In their limit for gross alpha activity, uranium is specifically excluded from the total. The uranium concentrations were well within those specified in DOE Manual 5480.1 (2×10^{-5} $\mu\text{Ci/ml}$).

The water samples from the Livermore Valley and Site 300 are also analyzed for tritium activity. Because of the low tritium levels typically found, it is necessary to distill and electrolytically enrich the samples before liquid-scintillation counting. Tables A-18 and A-19 show the data for the Livermore and Site 300 samples, respectively. The samples have concentrations that are well below recommended concentration guide values. The highest concentration of tritium in water, $28.9 \times 10^{-7} \mu\text{Ci/ml}$, occurred in the Livermore Valley rain (location 20) which was collected during October. This represents 0.1% of the concentration guide for drinking water. Water samples from monitoring wells near a landfill at Site 300 show much higher concentrations of tritiated water ($8.9 \times 10^{-5} \mu\text{Ci/ml}$). These samples are discussed in the Special Monitoring Assessments section of this report. Tables A-18 and A-19 also include an estimate of the annual dose that may be delivered

Figure 9. Distribution plot of ^{239}Pu in soil samples collected at Site 300 during 1984.

Figure 10. Livermore Valley water-sampling locations.

Figure 11. Site 300 water-sampling locations.

to an adult who consumes water containing the listed tritium concentrations. These doses, which are all less than 0.01 mrem, are based on a water consumption of 2 liters/day and the dose-conversion factors contained in *ICRP 30*⁹ (see Appendix C).

As noted previously, treated effluent from the LWRP is used to irrigate nearby municipal property. This effluent contains low levels of tritium which come from normal LLNL operational releases to the sanitary sewer system. As part of a study begun in 1977,¹⁰ 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 were in the immediate vicinity of the LWRP; however, additional samples were also collected from areas at some distance. Locations sampled during 1984 are indicated in Fig. 12, and the tritium data are shown in Table A-20. The highest tritium values appear in wells down-gradient of the LWRP. Tritium activities in all samples were well below the guidelines for water as stated in the EPA's National Interim Primary Drinking Water Regulations for Community Wa-

ter Systems.⁶ The tritium levels in these wells are similar to those observed in the 1983 samples.

Radioactivity in Vegetation and Foodstuffs

Native vegetation samples are collected quarterly at locations in the Livermore Valley (Fig. 13) and at Site 300 (Fig. 14). These samples are freeze-dried and the tritium activity in the recovered water is determined by liquid-scintillation counting. Table A-21 shows the tritium data for vegetation collected in the Livermore Valley. The whole-body radiation doses shown in Table A-21 were derived using the dose-conversion factors in *ICRP 30*⁹ and the dose-pathway model from NRC Reg. Guide 1.109.¹¹ Conservatively assuming that an adult's diet comprises vegetables with similar tritium concentrations and meat and milk derived from livestock fed on grasses of these concentrations, these potential doses are all less than 0.05 mrem/y.

Table A-22 shows the 1984 tritium data for Site 300 vegetation. Locations 6 and 13 are adjacent to an area that contains tritium-contaminated debris from a firing table. As a result of the seasonal rains, the tritium apparently entered an

Figure 12. Livermore Valley groundwater-sampling locations.

aquifer whose outflow is in the area where these samples are routinely collected. Although observed in prior years, this concentration rose sharply at location 6 to a maximum value of $5.58 \times 10^{-4} \mu\text{Ci/ml}$ in 1984. The calculated annual average dose due to vegetation at this location is 3.1 mrem, using the conservative pathway modeling assumptions. This contamination is further described in the Special Monitoring Assessments section of this report.

Beginning in 1977, as a means of evaluating the possible impact of LLNL effluents on locally grown foodstuff, the tritium content of Livermore Valley wines was measured and compared with that found in other California wines and European wines.⁸ Wine samples collected in 1984 were catalytically oxidized to carbon dioxide and water, and the tritium content of the recovered water was measured by gas proportional counting. The data in Table A-23 represent the analysis of samples purchased in 1984. As found since 1977, the tritium levels of the Valley wines were somewhat higher than those of California wines produced from grapes grown outside the Valley, but similar to those of the European wines sampled.

Samples of honey produced from a variety of flower sources both in and outside the Livermore Valley were analyzed for tritium content. Following the oxidation of the samples in a Parr oxygen bomb, the tritium content of the water produced was determined by gas proportional counting. The data in Table A-24 show that the tritium content of Livermore Valley honey samples is comparable to that of honey from neighboring areas.

Radioactivity in Milk

During 1984, goat-milk samples were obtained from three farms within about 5 km of LLNL. Cow's milk was also sampled when available from one of the farms. A portion of each sample was vacuum-distilled and the distillate analyzed for tritium activity by liquid-scintillation counting. Another portion was oven-dried, and the residue blended and gamma counted in a Ge(Li) system. The activities of the ^{137}Cs , ^{40}K , and ^3H in the samples are shown in Table A-25. The annual average concentration of tritium in milk was $1.2 \times 10^{-7} \mu\text{Ci/ml}$. 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 liters/y and on the models previously referenced. The only dose above 1 mrem to an individual is from naturally occurring ^{40}K . The doses due to ^3H , ^{40}K , and ^{137}Cs were calculated using dose factors from ICRP 30.⁹

Environmental Radiation Measurements

Quarterly, environmental radiation is measured at the 22 LLNL perimeter locations (Fig. 15) and at the 47 off-site locations (Fig. 16). These measurements are obtained with thermoluminescence dosimeters using a previously published procedure.¹² Based on past measurements,¹³ environmental terrestrial exposure rates in the Livermore Valley vary from 30 to 60 mR/y. Cosmic radiation, calculated from the local elevation and geomagnetic latitude according to the data of Lowder and Beck,¹⁴ is approximately 35 mR/y.

Figure 13. Livermore Valley vegetation-sampling locations.

Figure 14. Site 300 vegetation-sampling locations.

Table A-26 shows the quarterly and annual radiation doses for the perimeter locations. When a TLD packet (changed quarterly) is missing, the annual dose is calculated by extrapolating the quarters of data available to a one-year period. The average annual dose of 48 mrem at the perimeter does not differ significantly from the 50 mrem off-site average. Both agree with the previous year's values of 51 and 50 mrem.

Figure 17 presents the 1984 annual frequency distribution of environmental dose rates observed at the 47 off-site locations. Figure 18 is a dose-distribution plot combining LLNL perimeter and off-site measurements. The dosimeter that recorded the highest dose (73 mrem) was near an off-site industrial plant where radiography is performed.

Environmental neutron dose rate measurements using ^{235}U track-etch detectors are also

made at eight locations on the LLNL site perimeter. A detailed description of the detector and the spark-counting procedure has been published.¹⁵ Neutron-monitoring locations are shown in Fig. 3 and 1984 quarterly measurements are shown in Table A-27. Location 3 received the highest annual neutron dose, 44.9 mrem, because of its position near Bldg. 212, the 14-MeV neutron generator, but it was much lower than the preceding year's dose of 113 mrem. This 60% reduction in dose reflects decreased use of the neutron generator and replacement of shielding, originally removed for an experiment in September 1982.

Nonradioactive Monitoring

Beryllium in Air

Beryllium monitoring of air, both at the source and near LLNL property boundaries, has

Figure 15. LLNL perimeter locations for gamma dosimeters.

Figure 16. LLNL off-site locations for gamma dosimeters.

always been a part of LLNL's safety program. Monthly, halves of the filters from the LLNL perimeter and Site 300 are composited by sample location. Following sample preparation, the beryllium content of the solutions is determined by atomic absorption analysis.

Tables A-28 and A-29 show average monthly concentrations of airborne beryllium for LLNL pe-

rimeter and Site 300 sampling locations, respectively. The concentrations, which average less than 1% of the ambient concentration limit established by the Bay Area Air Quality Management District (BAAQMD), can be accounted for by re-suspension of surface soil containing naturally occurring beryllium. Local soils contain approximately 1 ppm of beryllium, and Livermore's air typically contains 10-100 μg of particulates per cubic meter. By using a value of 50 $\mu\text{g}/\text{m}^3$ for an average dust load and 1 ppm for beryllium content of this dust, an air-borne beryllium con-

Figure 17. Annual off-site gamma radiation background for 1984.

Figure 18. TLD dose-distribution plot for the LLNL perimeter and Livermore Valley during 1984.

centration of $5.0 \times 10^{-5} \mu\text{g}/\text{m}^3$ can be calculated. This value is in good agreement with the data in Tables A-28 and A-29. These concentrations are plotted in Figs. 19 and 20.

Nonradioactive Pollutants in Sewage

As noted previously, sanitary sewage from LLNL is treated at the LWRP. This effluent is continuously monitored for pH, radioactivity, and selected metal ions, before it enters the Livermore sewer system.¹⁶ Sewage samples representative of daily flow are collected and composited monthly. These composites are analyzed for the metals shown in Table A-30.

In addition, samples of LLNL sewage effluent are collected quarterly. These samples are analyzed for the parameters specified on LWRP's permit (National Permit Discharge Elimination System). Table A-31 shows the data for 1984. All data demonstrate compliance with the city of Livermore's discharge limits listed in Appendix D.

Noise Pollution

As noted elsewhere, LLNL's high-explosive diagnostic work is conducted at Site 300. Because Site 300 is remote, these experiments can be performed with minimal off-site impact from annoying noises or damaging overpressures. On the basis of meteorological measurements made twice each day, a limit is set on the weight of high explosives that can be detonated without impact in populated areas. To monitor these limits, four microbarograph sensors are maintained in or near the city of Tracy. The probability of overpressure is greatest in the Tracy area because of the direction of the prevailing winds. There were no complaints of overpressures attributed to LLNL operations at Site 300 during 1984.

Pollutants in Storm Runoff

Beginning in 1975, LLNL's environmental surveillance program was expanded to include

Figure 19. Concentration of beryllium on air filters at the LLNL perimeter for 1984.

Figure 20. Concentration of beryllium on air filters at Site 300 for 1984.

pesticide monitoring. Pesticides used at LLNL include herbicides, fungicides, and insecticides. The most probable way pesticides used at LLNL could be transported to the off-site environment is by entrainment in surface runoff water. Most of this surface drainage leaves LLNL via a ditch at the northwest corner of the property. A sample was collected from the ditch following the first major storm.

This sample was extracted with organic solvents, and the extracts were analyzed by gas-liquid chromatography using a variety of detectors. Data obtained from these analyses were compared with the pesticides listed in Title 22 of the California Health and Safety Code.⁷ No materials were detected in the samples at concentrations exceeding the state-adopted standards for these organic chemicals. These data are shown in Table A-35.

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

Groundwater Monitoring for Compliance

Groundwater monitoring for compliance is conducted under two programs at LLNL. One program involves groundwater investigations; a description of monitoring efforts under this program is included in the Special Monitoring Assessments section of this report. The other program involved routine groundwater monitoring which is conducted to meet the requirements specified in CRWQCB, Central Valley, Waste Discharge Orders, the State Department of Health Services (DOHS) Interim Status Document requirements, and the U.S. EPA Resource Conservation and Recovery Act (RCRA) groundwater-monitoring requirements. This latter program is described below.

To comply with CRWQCB Order 80-183, samples are collected monthly from wells that are down-gradient from Site-300 liquid discharge sites (locations 4, 5, 14, and 22 are shown in Fig. 11). Any increase in total organic carbon, specific conductance, chlorides, or total hardness could indicate migration of industrial effluents. The data shown in Table A-32 do not indicate contamination. Waste Discharge Order 80-184, also issued by the CRWQCB, Central Valley, requires

monthly sampling for gross alpha, gross beta, tritium, and beryllium at Site-300 groundwater monitoring locations. The highest concentration of beryllium for the monitoring locations was less than 10 parts per billion (ppb). Gross alpha, gross beta, and tritium results were previously discussed in the section on Radioactivity in Water.

As part of Site 300's RCRA monitoring program, groundwater monitoring was conducted in the vicinity of two active landfills, Pit 1 and Pit 7 which are shown in Fig. 21; one up-gradient well and at least three down-gradient wells were sampled and analyzed for the drinking-water parameters, groundwater-quality parameters, and indicators of groundwater pollution specified in 40 CFR 265.92. In 1984, traces of TCE, ranging from 2 to 5 ppb were detected in wells down-gradient of both pits and DCE (1 ppb) was detected down-gradient of Pit 7. These wells will continue to be checked as part of the groundwater monitoring program. In the Pit 7 area, elevated tritium was found and a close-in groundwater investigation was initiated. This investigation is being reviewed by the CRWQCB, Central Valley staff and is described in the Special Monitoring Assessment section of this report.

Environmental Impact of LLNL Operations

Radioactive Airborne Effluents

In 1984, a total of 7354 Ci of tritium was released to the atmosphere from Bldg. 212 (14-MeV neutron generator), Bldg. 331 (Tritium Facility), and Bldg. 292 (Rotating Target Neutron Source)[see Table A-33]. Of this quantity, an estimated 5000 Ci of HT was inadvertently released June 8, 1984. Approximately 1045 of the remaining 2354 Ci was released as HTO, and is the quantity used to calculate doses since the contribution from HT to the dose is insignificant. Eighty-one Curies of the short-lived radionuclides, ^{13}N - ^{15}O , were released from Bldg. 194 (electron-positron linear accelerator).

Comparative releases of radioactive effluents at Livermore during the 9-year period from 1976 through 1984 are shown in Table A-34. The Livermore reactor was shut down on March 31, 1980, because of a lack of programmatic need. Closure of this facility removed the local source of ^{41}Ar as a contributor to the site radiation dose to the public.

Table A-33 also contains estimated radiation doses to the public from these radioactive airborne effluents. Three dose-reference points were

Figure 21. Landfills and monitoring wells at Site 300.

used: (1) the "fence-post" dose at that location on the site boundary where maximum exposure rates exist, (2) the dose to the nearest resident, and (3) the person-rem dose within a radius of 80 km.

Dose calculations were made using a continuous-point-source computer code based on the Gaussian plume model.¹⁷ 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 from an instrumented tower. Meteorological data was provided by the Sandia National Laboratories, Livermore, situated 650 m south of the LLNL perimeter. The LLNL 40-m sensors were inoperative during 1984, awaiting relocation to a site near the northern boundary. From records of these data, wind speed, wind direction, and atmospheric stability estimates were tabulated at 1/4-h intervals over the calendar year. Variance in the horizontal wind direction was used to estimate Pasquill-Gifford stability categories based on the method described by Slade.¹⁸ 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. From annual effluent data, the release rate Q (in curies per second) was calculated for each of the principal radionuclides released to the atmosphere, and the concentrations at the site boundary and the nearest resident were calculated from appropriate χ/Q values. "Nearest resident" means that resident receiving the highest dose from each radioactivity release point, not necessarily the resident nearest to the site boundary. Dose estimates were based on the dose-conversion factors in ICRP 30.⁹ The results indicate that the maximum estimated dose to the nearest resident was less than 0.02 mrem.

Table A-33 shows a combined population dose of less than 0.25 person-rem from ^3H and neutron activation products in LLNL airborne effluents. This dose is based on a population of 5.1×10^6 within 80 km of LLNL. Using 100 mrem/y as a typical average radiation dose from natural sources, the comparable natural radiation dose the same group receives is 5.1×10^5 person-rem. By comparison, the population dose from LLNL operations is negligible.

Radioactive Liquid Effluents

Low-level radioactive wastewater is treated to reduce radioactivity to levels as low as reasonably achievable and well within applicable health and safety standards. The treated effluent is then discharged into Livermore's sanitary sewer system. During 1984, 0.32×10^{-5} Ci ^{239}Pu and 1.7 Ci HTO were released into the sewer. Table A-13 shows that the average annual concentration of these radionuclides represents $7 \times 10^{-6}\%$ and $4 \times 10^{-3}\%$ of the DOE standards, respectively.

Nonradioactive Liquid Effluents

The metals in sewage are listed in Table A-30. The quantities of metals discharged did not interfere with the LWRP's discharging effluents within limits set by the CRWQCB, San Francisco Bay.

The first rains of the season, which were collected as storm water runoff, showed no detectable level of specified total identifiable chlorinated hydrocarbons. The influent enters LLNL from the east perimeter, flows into the lake, and the effluent exits LLNL at the NW corner. These data are displayed in Table A-35.

Quality Assurance

During 1984, LLNL participated in the EPA's Environmental Radioactivity Laboratory Intercomparison Studies program. Table A-36 shows the comparison of analyses by LLNL with the known values and the averages of all participants. The plus or minus values are calculated for 1σ .

Table A-37 shows the comparative analyses by LLNL with the DOE Environmental Measurements Laboratory.

LLNL participated in an international intercomparison of dosimeters for environmental monitoring that was organized by the U.S. DOE with the cooperation of the U.S. EPA. The study, conducted during 1984, was comprised of submitting dosimeters to be deployed in the vicinity of former nuclear device tests from early April until mid-July. Following exposure, these field dosimeters and the laboratory calibration and control dosimeters were returned, read, and compared. About 100 participants from 25 countries took part in the study. The average field exposure for all dosimeters entered in the Intercomparison was $75.8 \text{ mR} \pm 6.0$ (3σ uncertainty). The LLNL reported value was $76.4 \text{ mR} \pm 11.3$ (2σ uncertainty).

A part of the LLNL Quality Assurance program is accomplished through replicate sampling (Table A-38). Duplicate air samples for particulates are collected weekly on a schedule of alternate months at one of the six perimeter locations taken in sequence. Duplicate air samples which collect tritiated water on silica gel are taken bi-weekly at one of the perimeter locations during the intervening months. Duplicate samples of sewer effluent from LLNL and the LWRP are collected each week and analyzed for gross alpha, beta, and HTO.

To test the reproducibility of the sampling and analytical procedures, the ratios of the duplicates are compared. The sewage samples described here are limited to those collected on or about the beginning of each month.

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

Special Monitoring Assessments

The following is a brief description of the special assessments which were initiated or were in progress in 1984 and which are being discussed with state, federal, or local environmental agencies. Included is a summary of each project and the status of the assessment and any remedial actions. References are listed which give the detailed status of each special assessment.

Solvent Contamination of Groundwater Investigation

A study in 1983 evaluated the potential for contamination of groundwater beneath LLNL and

revealed the presence of low levels of organic solvents.¹⁹ Part-per-billion concentrations of DCE, TCE, PCE, DCA, TCA, and chloroform were found in the groundwater beneath LLNL and private wells immediately west of LLNL. The investigation to define the origin and extent of contamination, conducted between December 1983 and May 1984, included the analyses of 537 soil samples and 72 water samples.²⁰ Trace quantities of solvents were detected in the soil at several locations. The highest concentration, 5.7 ppm TCE, was located on site near the southern boundary.

PCE was the principal contaminant in the wells west of LLNL. A private well located near the southwest boundary contained the highest

PCE levels, between 310 and 490 ppb.

A second phase of investigative²¹ was started in September 1984 to understand the vertical and horizontal extent of contamination on- and off-site, and carefully monitor groundwater quality in the area.

As part of this investigation, LLNL staff are conducting a records search to survey past and present use, storage, and disposal of hazardous waste.

East Traffic Circle Landfill

An abandoned on-site landfill, near the east LLNL boundary, was discovered on July 19, 1984 during construction activities.²² Soil samples were collected and analyzed for priority pollutants including Title-22 hazardous constituents and PCB.

Of the approximately 9000 m³ of soil contaminated with lead, zinc, copper, cadmium, and PCB, 5000 m³ were removed to a PCB landfill and a Class-I landfill.²³ The remaining 4000 m³ is scheduled to be removed during 1985.

In addition, small quantities of low-level radioactive material were found in isolated pockets during the excavation. The radioactive material was identified as ¹³⁷Cs, ²²⁶Ra, depleted uranium, ²³²Th, and ²⁴¹Am. A total of approximately 6 m³ of this soil was put into drums and sent to the LLNL Toxic Waste Group for disposal.

Gasoline Contamination of Soil and Groundwater

An estimated 65,000 liters of gasoline leaked from four underground storage tanks, located near LLNL's southern boundary, between October 1978 and March 1979. These tanks, no longer in use, were installed during the Navy's occupation of the property in the 1940s and have been used for storage of gasoline for the LLNL automotive fleet. Forty-three soil samples were analyzed from 20 boreholes drilled around the tank site. The data showed soil contamination to groundwater depth, with the highest value being 14,000 ppm gasoline in soil. Two monitoring wells showed contamination¹⁹; the highest concentration reported was 110 ppm.

LLNL has contracted with an independent consultant to further assess the area and to take remedial action.

Pistol Range Landfill (Pit 6)—Site 300

Records show that capacitors suspected to be contaminated with PCB, waste drums, gas cylinders, beryllium and mercury-contaminated materials, chemicals, and other potentially hazardous waste were buried in this pit, at the southwest corner of Site 300, between 1964 and 1970.

Water samples from six monitoring wells developed at the landfill and a well 0.2 km down-gradient used by the nearest resident have been analyzed.

Low levels of organics (20 to 30 ppb toluene and 39 ppb methylene chloride) were detected in soil samples.²⁴ No PCB, beryllium, or pesticides have been detected in the well samples. Naturally occurring uranium and iron have been detected in the well down-gradient to the landfill.

A final report will be issued in 1985.

High-Explosive (HE) Wastewater Lagoon—Site 300

For many years, HE-processing rinsewater at Site 300's machining and formulations facilities has been directed through clarifiers and weirs to remove particulate HE. This wastewater was discharged into unlined lagoons.

During the spring of 1984, LLNL tested the process wastewater to determine if it is hazardous waste regulated by the EPA or the DOHS. In April, the settling-tank sludge and lagoon sediments for one of the most heavily used facilities were sampled and analyzed using EPA toxicity and DOHS California Assessment Manual (CAM) waste-extraction techniques and a total digestion for metals.

The conclusions derived from these tests are that the tank sludge and lagoon sediments are not toxic, based upon the EPA toxicity data. The tank sludge and lagoon sediments are not hazardous, based upon the DOHS (CAM) waste-extraction test for metals. The tank sludge, but not the wastewater, was found to be hazardous based upon fish toxicity.

A doubly lined surface impoundment (evaporation pond) has been constructed to replace the existing unlined lagoons. The new impoundment has a synthetic liner, underlain by a leachate collection system, and a clay secondary liner. Process

wastewater from several of the explosives facilities proximate to the new impoundment will be plumbed directly to the impoundment after the particulate HE has been removed by the clarifier and weir systems. Water from the other HE facilities will be temporarily collected in aboveground retention tanks and periodically hauled to the new impoundment for disposal.²⁵

West Burial Pit Area—Site 300

This burial pit site consists of one active (pit 7) and three inactive (pits 3, 4, and 5) landfills. The principal waste is comprised of rubble from tests (wood, cardboard packaging, and scrap metal) and gravel which surfaces the test areas (firing tables). These materials are contaminated with depleted uranium, beryllium, and occasionally, natural uranium or thorium. Some experiments have included tritium. Currently, four wells surrounding the area are sampled quarterly for all RCRA (40 CFR 265) recommended parameters. The concentrations of tritium in groundwater from two of these wells have increased significantly between July 1983 and December 1984: well 7-1, 14,000 to 23,000 pCi/liter and well 7-3, 8000 to 89,000 pCi/liter.

LLNL has initiated an investigation to identify and characterize the tritium sources, characterize the saturated and unsaturated transport pathways for the released tritium, and to expand the present monitoring network's capability to give prompt and easily interpretable warnings of future releases of tritium or other contaminants.²⁶

TCE Spill at Site 300

TCE is used as a heat-exchange fluid in the testing facilities and is also provided for shop use. At Site 300, pump and valve leaks, system overflows, and past housekeeping practices have resulted in TCE spills. This material has been found in soil, rock, and/or water at five locations at Site 300. Twenty-three exploratory and soil-sampling holes have been drilled and 5 groundwater wells were completed to define the boundaries of contamination. The surface two feet of contaminated soil has been removed, aerated, and replaced. The spill areas were covered with PVC sheeting to prevent infiltration and retard further percolation to groundwater.²⁷ These areas may need further assessment and clean-up actions. The equipment has been improved to prevent future spills at these facilities.

Permits and Environmental Assessments

In 1984, LLNL held several environmental permits, orders, and notices that were issued for operations at Site 300 and LLNL. A short description of these follows.

Air Permits

During 1984, LLNL was issued 176 permits; 82 of these were fee sources and 94 were exempt sources. These permits allowed the operation of 99 boilers for space heat, 31 degreasers, 4 vehicle service stations, 4 spray booths, 18 storage tanks, and other miscellaneous equipment until their expiration date, July 1, 1985. At that time, LLNL will renew permits for regulated sources. LLNL air-pollution sources are regulated by BAAQMD and the San Joaquin Air Pollution Control District regulates Site-300 sources.

Liquid Waste Discharge

A Waste Discharge Order (Number 80-183) was issued to LLNL by the CRWQCB, Central

Valley in 1980 for liquid waste discharge at Site 300. This order covers craft-shop rinsewater discharge to drywells, photolab rinsewater discharge to the ground, and the high-explosives wastewater lagoons described in the Special Assessments Monitoring section. Craft-shop and photolab discharges to the ground have been terminated, and construction started in 1984 to build a double-lined surface impoundment to replace the lagoons.

Another Waste Discharge Order, Order 82-105, was issued for Site 300's cooling tower discharges. Flow meters are to be purchased and installed to meet requirements.

Solid Waste Landfills

Eight landfills were addressed in a Waste Discharge Order (80-184) issued by the CRWQCB, Central Valley. Diversion ditches and groundwater monitoring wells have been constructed to meet the specified requirements, and funds have been requested for upgraded covers. Two of the

landfills are active landfills, and, therefore, are also subject to requirements specified in an Interim Status Document (ISD) issued by DOHS. A few operational issues, such as landfill covers, are being discussed with state regulators.

As discussed previously under the section on Groundwater Monitoring for Compliance, the landfills are circled by at least one up-gradient well and three down-gradient wells to detect any changes in groundwater quality. Since tritium has been detected in the vicinity of the west landfills, action plans have been submitted to the CRWQCB, Central Valley and have been implemented in 1984. A discussion of the tritium study can be found in the Special Monitoring Assessments section.

Other Hazardous Waste Operations

Both Site 300 and LLNL have ISDs issued by the DOHS for generation, treatment, and disposal of hazardous waste. Facilities are being upgraded

and funding for new and replacement treatment facilities has been submitted for approval. State Hazardous Waste Operations Plans are being prepared for the Livermore Site and updated for Site 300 as steps toward obtaining final hazardous waste operating permits from the DOHS. Also, in order to obtain a final RCRA permit from the U.S. EPA, a Part-B application was filed for LLNL's incinerator, and a trial burn is planned pending EPA approval. A Part-B application is also being prepared for Site-300 facilities to meet 1985 filing deadlines for land-disposal facilities.

Only one project required the preparation of an environmental assessment this year. The U.S. DOE proposes to acquire 424 acres adjacent to LLNL to be used as a buffer zone to enhance site security.²⁸ This acquisition will prevent the industrial development in the buffer zone. Environmental impact, including surface disturbance, high noise level, site erosion, and decreased air quality, will be temporary and minimized by the use of standard precautions.

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Appendix A. Tables

The statistical values (2σ estimates) that accompany individual measurements of radioactivity in the following tables are the result of counting statistics. The minimum detection limit is assumed to be reached when the 2σ estimate is $\pm 100\%$. Statistical values for groups of data such as annual averages are calculated standard deviations of the mean (average). Blank samples are routinely analyzed.

Air filter blanks consist of collection media which have been handled and processed in the same way as samples. The average values are: for ^{238}U , $0.20 \mu\text{g}/\text{blank} \pm 38\%$ SDM; for ^{235}U , $0.0013 \mu\text{g}/\text{blank} \pm 27\%$ SDM; for ^{239}Pu , below the detection limit of $4 \times 10^{-9} \mu\text{Ci}/\text{sample}$.

Water blanks are tap water which have been analyzed just as the samples. The average values are: for ^{137}Cs , $2 \times 10^{-11} \mu\text{Ci}/\text{ml} \pm 47\%$ SDM; for ^{239}Pu , $5 \times 10^{-13} \mu\text{Ci}/\text{ml} \pm 83\%$ SDM.

Washed and ignited sand is used for the soil blank. The ^{239}Pu content is below the detection limit of $4 \times 10^{-9} \mu\text{Ci}/\text{sample}$. No data have been corrected for background values.

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

Location ^a	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average	% SDM	% CG ^b
	(10 ⁻¹⁴ $\mu\text{Ci}/\text{ml}$)														
Perimeter															
1	0.8	0.7	0.5	0.5	0.6	0.5	0.6	0.5	0.6	0.6	0.7	0.5	0.6	14	3
2	NA ^d	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.3	0.4	0.4	0.5	17	3
12	0.8	0.7	0.4	0.5	0.5	0.6	0.6	0.4	0.5	0.4	0.4	0.4	0.5	28	3
13	0.4	0.3	0.3	0.3	0.3	0.2	0.4	0.3	0.4	0.5	0.7	0.5	0.4	35	2
14	0.6	0.5	0.4	0.7	0.7	0.4	0.6	0.6	1.0	0.5	0.6	0.7	0.6	25	3
15	0.4	0.3	0.2	0.3	0.3	0.4	0.5	0.4	0.5	0.3	0.3	0.3	0.3	21	2
Valley															
3	1.4	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.4	0.5	0.5	0.6	46	3
4	0.5	0.6	0.4	0.5	0.5	0.4	0.5	0.5	0.6	0.6	0.6	0.5	0.5	16	2
5	0.7	0.6	0.5	0.5	0.5	0.5	0.7	0.6	0.8	0.6	0.5	0.7	0.6	20	3
6	0.7	0.6	0.4	0.5	0.7	0.5	0.6	0.7	0.8	0.5	0.6	0.6	0.6	18	3
7	0.8	0.8	0.5	0.5	0.6	0.5	0.7	0.6	0.8	0.8	0.5	0.6	0.6	21	3
8	0.6	0.6	0.5	0.5	0.5	0.5	0.7	0.5	0.5	0.6	0.5	0.5	0.5	13	3
9	0.8	0.8	0.7	0.7	0.9	0.6	0.9	0.5	0.9	0.5	0.6	0.6	0.7	22	4
10	0.4	0.3	0.3	0.2	0.3	0.3	0.4	0.3	0.4	0.6	0.4	0.4	0.3	27	2
11	0.8	0.8	0.5	0.6	0.6	0.5	0.6	0.4	0.7	0.5	0.5	0.5	0.6	21	3
16	1.0	NA	0.5	0.5	0.5	0.4	0.6	0.5	0.6	0.5	0.6	0.5	0.6	28	3
17	0.6	0.5	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.6	0.6	0.6	0.6	14	3
Annual average													0.5	21	3

^a See Figs. 3 and 5.

^b % SDM = % standard deviation of mean at 1σ (used throughout Appendix A).

^c Concentration guide (CG) = $2 \times 10^{-14} \mu\text{Ci}/\text{ml}$.

^d Not available (used throughout Appendix A).

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

Location ^a	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average	% SDM	% CG ^b
	(10 ⁻¹⁴ μCi/ml)														
Perimeter															
1	2.1	1.3	1.1	0.8	1.1	0.8	1.0	0.8	2.0	1.0	0.8	2.0	1.2	41	1
2	NA	0.6	1.0	0.7	1.0	0.8	1.3	0.9	1.4	1.0	0.8	1.5	1.0	29	1
12	1.8	1.1	0.9	0.8	0.9	0.9	1.1	0.8	1.4	1.1	0.9	1.6	1.1	30	1
13	1.6	1.0	0.9	0.6	0.8	0.7	0.8	0.7	1.2	1.1	0.8	1.1	1.0	28	1
14	1.8	1.1	1.0	0.6	0.8	1.0	1.2	1.0	2.0	1.5	1.1	1.9	1.3	36	1
15	1.8	1.0	0.9	0.7	0.9	0.8	1.1	0.7	1.2	1.0	0.9	1.6	1.1	32	1
Valley															
3	1.5	0.6	1.2	0.7	0.8	0.9	0.9	0.7	1.8	1.2	0.9	1.6	1.1	36	1
4	1.8	1.1	1.1	0.8	0.9	0.8	1.0	0.9	1.6	1.1	0.7	1.7	1.1	33	1
5	2.9	2.4	2.0	2.0	2.2	2.2	2.5	2.3	2.7	2.4	2.1	2.6	2.4	12	2
6	2.8	2.3	1.9	1.7	2.0	2.0	2.2	1.9	2.7	2.4	2.1	2.4	2.2	15	2
7	2.8	2.3	1.9	2.0	2.1	2.2	2.4	2.3	2.6	2.0	2.2	2.5	2.3	12	2
8	2.4	1.4	1.2	0.9	1.2	0.9	1.4	1.0	1.8	1.4	1.1	2.4	1.4	36	1
9	3.2	3.1	2.7	2.4	2.7	2.6	3.0	2.1	2.6	2.6	2.2	2.3	2.7	14	3
10	1.5	1.2	1.0	0.8	1.0	0.9	1.2	1.0	1.6	1.0	0.6	1.1	1.1	26	1
11	3.0	2.7	2.5	2.0	2.4	2.2	2.1	1.9	2.3	2.4	1.9	2.3	2.3	14	2
16	1.4	NA	0.9	0.7	0.9	0.7	1.2	1.0	1.8	1.4	1.1	1.7	1.2	32	1
17	1.8	1.0	0.9	0.8	1.0	0.9	0.9	1.0	1.7	1.2	0.8	1.7	1.1	33	1
Annual average													1.5	40	2

^a See Figs. 3 and 5.

^b CG = 1×10^{-12} μCi/ml.

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

Location ^a	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average	% SDM	% CG ^b
	(10 ⁻¹⁵ μCi/ml)														
1	0.3	0.3	0.3	0.2	0.3	0.3	0.5	0.4	0.5	0.2	0.3	0.3	0.3	29	2
2	0.4	0.4	0.6	0.4	0.6	0.7	1.2	1.2	1.4	0.7	0.8	0.9	0.8	43	4
3	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.4	0.3	18	1
4	NA	0.5	0.3	0.4	0.5	0.4	0.5	0.4	0.5	0.4	0.4	NA	0.4	16	2
5	0.4	0.4	0.4	0.3	0.4	0.4	0.6	0.7	0.8	0.6	0.5	0.4	0.5	30	2
6	0.8	0.8	0.5	0.5	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.5	0.6	18	3
8	0.5	0.4	0.4	0.4	0.4	0.4	0.8	0.5	0.6	0.5	0.5	0.4	0.5	29	2
9	0.3	0.3	0.2	0.2	0.3	0.3	0.4	0.3	0.4	0.2	0.2	0.2	0.3	26	1
10	NA	0.4	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3	14	2
Annual average													0.4	38	2

^a See Fig. 4. Location 6 is in city of Tracy.

^b CG = 2×10^{-14} μCi/ml.

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

Location ^a	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average	% SDM	% CG ^b
	(10 ⁻¹⁴ μ Ci/ml)														
1	1.8	1.5	1.3	0.9	1.2	1.2	1.5	1.2	1.5	0.7	1.1	2.0	1.3	28	1
2	2.6	2.2	2.6	1.4	2.1	3.3	4.9	5.3	4.5	2.6	3.1	6.3	3.4	46	3
3	1.3	1.1	1.0	0.5	0.7	0.7	1.0	0.7	0.8	0.8	0.7	2.0	0.9	43	1
4	NA	2.6	1.0	0.8	1.2	1.1	1.3	1.2	1.5	1.0	1.0	NA	1.3	40	1
5	2.0	1.6	1.4	1.0	1.1	1.5	2.0	2.2	2.5	2.2	1.3	2.4	1.8	29	2
6	2.6	1.8	1.2	0.8	1.3	1.2	1.3	1.2	1.6	1.3	1.2	2.2	1.5	34	2
8	1.4	0.9	1.3	1.1	1.4	1.4	2.9	1.6	1.6	1.9	0.9	2.1	1.5	36	2
9	1.6	1.3	1.2	0.7	1.2	1.2	1.4	1.2	1.5	1.1	0.9	1.6	1.2	21	1
10	NA	2.9	1.1	0.8	1.1	1.1	1.1	1.3	1.2	1.0	1.0	0.6	1.2	50	1
Annual average													1.6	47	2

^a See Fig. 4. Location 6 is in city of Tracy.^b CG = 1×10^{-12} μ Ci/ml.

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

Month	⁷ Be [10 ⁻¹³ μ Ci/ml $\pm 2\sigma$ (%)]	⁴⁰ K	¹⁰⁶ Ru	¹²⁵ Sb	¹³⁷ Cs	¹⁴⁴ Ce
		[10 ⁻¹⁶ μ Ci/ml $\pm 2\sigma$ (%)]				
Jan.	0.9 $\pm$ 2	5.6 $\pm$ 52	0.4 $\pm$ 100	0.1 $\pm$ 100	0.3 $\pm$ 40	0.3 $\pm$ 100
Feb.	0.9 $\pm$ 2	4.7 $\pm$ 70	0.1 $\pm$ 100	0.2 $\pm$ 100	0.6 $\pm$ 20	0.4 $\pm$ 100
Mar.	1.0 $\pm$ 2	0.1 $\pm$ 100	0.2 $\pm$ 100	0.2 $\pm$ 100	0.7 $\pm$ 52	0.3 $\pm$ 100
Apr.	0.9 $\pm$ 2	2.9 $\pm$ 60	0.4 $\pm$ 100	0.2 $\pm$ 100	0.4 $\pm$ 26	0.4 $\pm$ 100
May	1.2 $\pm$ 2	5.1 $\pm$ 42	0.3 $\pm$ 100	0.1 $\pm$ 100	0.5 $\pm$ 16	0.3 $\pm$ 100
June	0.8 $\pm$ 2	5.1 $\pm$ 60	0.4 $\pm$ 100	0.1 $\pm$ 100	0.4 $\pm$ 28	0.3 $\pm$ 100
July	1.0 $\pm$ 2	7.6 $\pm$ 34	0.4 $\pm$ 100	0.2 $\pm$ 100	0.4 $\pm$ 28	0.4 $\pm$ 100
Aug.	0.9 $\pm$ 2	6.2 $\pm$ 50	0.4 $\pm$ 100	0.1 $\pm$ 100	0.3 $\pm$ 46	0.3 $\pm$ 100
Sept.	1.3 $\pm$ 2	0.8 $\pm$ 100	0.3 $\pm$ 100	0.1 $\pm$ 100	0.4 $\pm$ 28	0.3 $\pm$ 100
Oct.	1.1 $\pm$ 2	1.8 $\pm$ 100	0.5 $\pm$ 100	0.2 $\pm$ 100	0.2 $\pm$ 64	0.4 $\pm$ 100
Nov.	0.9 $\pm$ 2	1.4 $\pm$ 100	0.5 $\pm$ 100	0.2 $\pm$ 100	0.1 $\pm$ 100	0.4 $\pm$ 100
Dec.	0.9 $\pm$ 2	1.1 $\pm$ 100	0.3 $\pm$ 100	0.1 $\pm$ 100	0.1 $\pm$ 60	0.3 $\pm$ 100
Annual average	1.0	3.5	0.4	0.1	0.4	0.3
% SDM	16	70	34	34	49	16
CG (μ Ci/ml)	4 $\times$ 10 ⁻⁸	1.6 $\times$ 10 ⁻⁷	2 $\times$ 10 ⁻¹⁰	9 $\times$ 10 ⁻¹⁰	5 $\times$ 10 ⁻¹⁰	2 $\times$ 10 ⁻¹⁰
% CG	3 $\times$ 10 ⁻⁴	2 $\times$ 10 ⁻⁷	2 $\times$ 10 ⁻⁵	1 $\times$ 10 ⁻⁶	7 $\times$ 10 ⁻⁶	2 $\times$ 10 ⁻⁵

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

Month	⁷ Be	⁴⁰ K	¹⁰⁶ Ru	¹²⁵ Sb	¹³⁷ Cs	¹⁴⁴ Ce
	[10 ⁻¹³ μCi/ml ± 2σ (%)]	[10 ⁻¹⁶ μCi/ml ± 2σ (%)]				
Jan.	0.9 ± 2	0.5 ± 100	0.2 ± 100	0.1 ± 100	0.4 ± 14	0.2 ± 100
Feb.	1.3 ± 2	1.8 ± 72	0.1 ± 100	0.1 ± 100	0.7 ± 12	0.3 ± 100
Mar.	1.6 ± 2	0.7 ± 100	0.2 ± 100	0.1 ± 100	0.9 ± 8	0.3 ± 100
Apr.	1.2 ± 1	2.4 ± 90	0.2 ± 100	0.1 ± 100	0.6 ± 11	0.2 ± 100
May	1.9 ± 2	3.3 ± 52	0.2 ± 100	0.1 ± 100	0.8 ± 7	0.3 ± 100
June	1.4 ± 2	3.4 ± 51	0.2 ± 100	0.1 ± 100	0.6 ± 11	0.2 ± 100
July	2.0 ± 3	5.5 ± 28	0.2 ± 100	0.1 ± 100	0.7 ± 12	0.3 ± 100
Aug.	1.8 ± 2	3.7 ± 36	0.2 ± 100	0.1 ± 100	0.4 ± 15	0.2 ± 100
Sept.	1.0 ± 2	3.5 ± 56	0.1 ± 100	0.1 ± 100	0.1 ± 24	0.2 ± 100
Oct.	1.2 ± 2	3.7 ± 48	0.3 ± 100	0.1 ± 100	0.2 ± 34	0.3 ± 100
Nov.	1.2 ± 2	0.9 ± 100	0.3 ± 100	0.1 ± 100	0.2 ± 50	0.3 ± 100
Dec.	1.6 ± 2	1.0 ± 100	0.3 ± 100	0.1 ± 100	0.2 ± 42	0.3 ± 100
Annual average	1.4	2.5	0.2	0.1	0.5	0.3
% SDM	25	62	32	None	55	20
CG (μCi/ml)	4 × 10 ⁻⁸	1.6 × 10 ⁻⁷	2 × 10 ⁻¹⁰	9 × 10 ⁻¹⁰	5 × 10 ⁻¹⁰	2 × 10 ⁻¹⁰
% CG	4 × 10 ⁻⁴	2 × 10 ⁻⁷	1 × 10 ⁻⁵	1 × 10 ⁻⁶	1 × 10 ⁻⁵	1 × 10 ⁻⁵

Table A-7. ²³⁹Pu on air filters—selected locations.

Month	Location ^a					
	090-04	090-08	090-10	090-16	090-17	040-06
	[10 ⁻¹⁷ μCi/ml ± 2σ (%)]					
Jan.	0.1 ± 47	0.1 ± 71	0.1 ± 35	0.1 ± 78	0.1 ± 58	0.1 ± 86
Feb.	0.1 ± 52	0.1 ± 70	0.1 ± 36	0.2 ± 96	0.1 ± 53	0.4 ± 68
Mar.	0.1 ± 39	0.1 ± 90	0.1 ± 29	0.1 ± 57	0.1 ± 55	0.1 ± 40
Apr.	0.4 ± 41	0.1 ± 51	0.1 ± 65	0.2 ± 50	0.1 ± 71	0.1 ± 42
May	0.2 ± 27	0.1 ± 43	0.1 ± 50	0.1 ± 50	0.1 ± 45	0.1 ± 83
June	0.2 ± 47	0.1 ± 100	0.1 ± 61	0.1 ± 100	0.1 ± 87	0.1 ± 66
July	0.2 ± 46	0.2 ± 38	0.1 ± 52	0.1 ± 47	0.1 ± 74	0.1 ± 100
Aug.	0.1 ± 72	0.1 ± 68	0.1 ± 85	0.1 ± 100	0.1 ± 70	0.1 ± 100
Sept.	0.1 ± 58	0.1 ± 100	0.1 ± 58	0.1 ± 73	0.1 ± 89	0.1 ± 90
Oct.	0.1 ± 99	0.1 ± 100	0.1 ± 100	0.1 ± 100	0.1 ± 100	0.1 ± 89
Nov.	NA	0.1 ± 100	NA	0.1 ± 60	0.1 ± 90	0.1 ± 100
Dec.	0.1 ± 100	0.1 ± 97	0.1 ± 100	0.1 ± 100	0.1 ± 100	0.1 ± 100
Annual average	0.2	0.1	0.1	0.1	0.1	0.1
% SDM	50	19	None	30	None	69
% CG ^b	3 × 10 ⁻³	2 × 10 ⁻³	2 × 10 ⁻³	2 × 10 ⁻³	2 × 10 ⁻³	2 × 10 ⁻³

^a See Fig. 5. Location 040-06 is in city of Tracy.^b CG = 6 × 10⁻¹⁴ μCi/ml.

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

Month	Location ^a	²³⁹ Pu ^b	²³⁵ U	²³⁸ U	²³⁵ U/ ²³⁸ U
		[10 ⁻¹⁷ μCi/ml ± 2σ (%)]	[10 ⁻⁷ μg/m ³ ± 2σ (%)]	[10 ⁻⁵ μg/m ³ ± 2σ (%)]	(10 ⁻³)
Jan.	1	0.1 ± 50	2.9 ± 3	4.3 ± 3	6.7
	2	NA	NA	NA	NA
	12	0.4 ± 30	8.1 ± 3	12.3 ± 3	6.6
	13	0.1 ± 33	1.7 ± 3	2.9 ± 3	7.1
	14	0.2 ± 37	2.5 ± 3	3.1 ± 3	8.1
	15	0.1 ± 40	1.9 ± 3	2.4 ± 3	7.9
Feb.	1	0.1 ± 55	3.1 ± 3	4.4 ± 3	7.0
	2	0.1 ± 45	3.2 ± 3	4.7 ± 3	6.8
	12	0.5 ± 25	6.8 ± 3	9.9 ± 3	6.9
	13	0.1 ± 73	1.7 ± 3	2.6 ± 3	6.5
	14	0.1 ± 50	2.2 ± 3	3.2 ± 3	6.9
	15	0.1 ± 44	1.6 ± 3	2.2 ± 3	7.3
Mar.	1	0.2 ± 46	4.3 ± 3	6.1 ± 3	7.0
	2	0.1 ± 54	4.5 ± 3	6.4 ± 3	7.0
	12	0.4 ± 29	7.6 ± 3	10.9 ± 3	7.0
	13	0.1 ± 42	3.1 ± 3	4.3 ± 3	7.2
	14	0.1 ± 64	3.9 ± 3	5.4 ± 3	7.2
	15	0.3 ± 27	4.3 ± 3	6.0 ± 3	7.2
Apr.	1	0.1 ± 39	4.7 ± 3	6.7 ± 3	7.0
	2	0.2 ± 41	3.5 ± 3	4.8 ± 3	7.3
	12	0.3 ± 33	5.9 ± 3	8.6 ± 3	6.9
	13	0.1 ± 100	3.7 ± 3	5.1 ± 3	7.3
	14	0.4 ± 36	5.2 ± 3	7.2 ± 3	7.2
	15	0.1 ± 54	4.1 ± 3	5.7 ± 3	7.2
May	1	0.2 ± 41	5.4 ± 3	7.9 ± 3	6.8
	2	0.1 ± 100	4.0 ± 3	5.6 ± 3	7.1
	12	0.4 ± 31	6.8 ± 3	9.8 ± 3	6.9
	13	0.1 ± 93	3.9 ± 3	5.6 ± 3	7.0
	14	0.3 ± 42	4.9 ± 3	7.1 ± 3	6.9
	15	0.1 ± 59	5.3 ± 3	7.5 ± 3	7.1
June	1	0.3 ± 37	6.0 ± 3	8.7 ± 3	6.9
	2	0.1 ± 93	4.8 ± 3	6.7 ± 3	7.2
	12	0.5 ± 34	8.0 ± 3	11.7 ± 3	6.8
	13	0.1 ± 54	4.7 ± 3	6.7 ± 3	7.0
	14	2.4 ± 12	5.5 ± 3	7.8 ± 3	7.1
	15	0.1 ± 43	5.3 ± 3	7.4 ± 3	7.2
July	1	0.3 ± 32	6.5 ± 3	9.2 ± 3	7.1
	2	0.1 ± 57	5.7 ± 3	8.1 ± 3	7.0
	12	0.5 ± 22	8.2 ± 3	11.6 ± 3	7.1
	13	0.1 ± 60	4.8 ± 3	6.8 ± 3	7.1
	14	0.7 ± 23	7.0 ± 3	9.9 ± 3	7.1
	15	0.1 ± 49	6.4 ± 3	8.9 ± 3	7.2

Table A-8. (Continued).

Month	Location ^a	²³⁹ Pu ^b	²³⁵ U	²³⁸ U	²³⁵ U/ ²³⁸ U
		[10 ⁻¹⁷ μ Ci/ml $\pm$ 2 σ (%)]	[10 ⁻⁷ μ g/m ³ $\pm$ 2 σ (%)]	[10 ⁻⁵ μ g/m ³ $\pm$ 2 σ (%)]	(10 ⁻³)
Aug.	1	0.1 $\pm$ 76	6.5 $\pm$ 3	9.3 $\pm$ 3	7.0
	2	0.1 $\pm$ 62	5.3 $\pm$ 3	7.5 $\pm$ 3	7.1
	12	0.3 $\pm$ 31	5.9 $\pm$ 3	8.5 $\pm$ 3	6.9
	13	0.3 $\pm$ 85	4.3 $\pm$ 3	6.1 $\pm$ 3	7.0
	14	0.8 $\pm$ 22	8.6 $\pm$ 3	12.3 $\pm$ 3	7.0
	15	0.1 $\pm$ 68	6.2 $\pm$ 3	8.8 $\pm$ 3	7.0
Sept.	1	0.2 $\pm$ 62	9.5 $\pm$ 3	13.4 $\pm$ 3	7.1
	2	0.1 $\pm$ 62	5.2 $\pm$ 3	7.4 $\pm$ 3	7.0
	12	0.5 $\pm$ 29	7.6 $\pm$ 3	10.8 $\pm$ 3	7.0
	13	0.1 $\pm$ 62	5.6 $\pm$ 3	8.0 $\pm$ 3	7.0
	14	0.1 $\pm$ 18	11.5 $\pm$ 3	16.1 $\pm$ 3	7.1
	15	0.1 $\pm$ 42	6.2 $\pm$ 3	8.7 $\pm$ 3	7.1
Oct.	1	0.9 $\pm$ 19	6.1 $\pm$ 3	9.5 $\pm$ 3	6.5
	2	0.1 $\pm$ 60	2.8 $\pm$ 3	4.0 $\pm$ 3	7.1
	12	0.3 $\pm$ 27	5.2 $\pm$ 3	7.4 $\pm$ 3	7.0
	13	0.1 $\pm$ 37	5.0 $\pm$ 3	7.0 $\pm$ 3	7.1
	14	0.4 $\pm$ 31	6.9 $\pm$ 3	9.7 $\pm$ 3	7.1
	15	0.1 $\pm$ 95	4.7 $\pm$ 3	6.6 $\pm$ 3	7.1
Nov.	1	0.3 $\pm$ 36	3.4 $\pm$ 3	5.4 $\pm$ 3	6.3
	2	0.1 $\pm$ 100	2.7 $\pm$ 3	5.0 $\pm$ 3	5.3
	12	0.2 $\pm$ 37	4.0 $\pm$ 3	7.2 $\pm$ 3	5.6
	13	0.1 $\pm$ 100	3.0 $\pm$ 3	5.0 $\pm$ 3	6.0
	14	0.2 $\pm$ 48	3.5 $\pm$ 3	5.8 $\pm$ 3	6.0
	15	0.1 $\pm$ 100	3.1 $\pm$ 3	4.7 $\pm$ 3	6.6
Dec.	1	0.1 $\pm$ 48	2.4 $\pm$ 3	3.6 $\pm$ 3	6.8
	2	0.1 $\pm$ 86	2.5 $\pm$ 3	3.6 $\pm$ 3	6.8
	12	0.2 $\pm$ 34	4.3 $\pm$ 3	6.2 $\pm$ 3	6.9
	13	0.1 $\pm$ 88	2.5 $\pm$ 3	3.6 $\pm$ 3	7.1
	14	0.1 $\pm$ 76	2.6 $\pm$ 3	3.7 $\pm$ 3	7.0
	15	0.1 $\pm$ 72	2.0 $\pm$ 3	2.9 $\pm$ 3	7.0

Annual averages

Location	²³⁹ Pu			²³⁵ U			²³⁸ U		
	10 ⁻¹⁷ μ Ci/ml	% SDM	% CG ^c	10 ⁻⁷ μ g/m ³	% SDM	% CG ^d	10 ⁻⁵ μ g/m ³	% SDM	% CG ^e
1	0.3	89	4 $\times$ 10 ⁻³	5.1	40	3 $\times$ 10 ⁻⁵	7.2	40	5 $\times$ 10 ⁻⁴
2	0.1	20	2 $\times$ 10 ⁻³	4.0	29	2 $\times$ 10 ⁻⁵	5.8	26	4 $\times$ 10 ⁻⁴
12	0.4	29	6 $\times$ 10 ⁻³	6.5	23	3 $\times$ 10 ⁻⁵	9.6	21	6 $\times$ 10 ⁻⁴
13	0.1	48	2 $\times$ 10 ⁻³	3.7	35	2 $\times$ 10 ⁻⁵	5.3	34	4 $\times$ 10 ⁻⁴
14	0.5	134	8 $\times$ 10 ⁻³	5.4	52	3 $\times$ 10 ⁻⁵	7.6	51	5 $\times$ 10 ⁻⁴
15	0.1	45	2 $\times$ 10 ⁻³	4.3	41	2 $\times$ 10 ⁻⁵	6.0	41	4 $\times$ 10 ⁻⁴

^a See Fig. 3.^b In all tables activity listed as ²³⁹Pu includes activity due to ²⁴⁰Pu isotope.^c CG = 6 $\times$ 10⁻¹⁴ μ Ci/ml for ²³⁹Pu (soluble) activity in air.^d CG = 1.9 μ g/m³ for ²³⁵U (insoluble) activity in air.^e CG = 15 μ g/m³ for ²³⁸U (insoluble) activity in air.

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

Month	²³⁹ Pu	¹³⁷ Cs	²³⁹ Pu/ ¹³⁷ Cs (10 ⁻²)	²³⁵ U	²³⁸ U	²³⁵ U/ ²³⁸ U (10 ⁻³)
	[10 ⁻¹⁷ μCi/ml ± 2σ (%)]	[10 ⁻¹⁵ μCi/ml ± 2σ (%)]		[10 ⁻⁷ μg/m ³ ± 2σ (%)]	[10 ⁻⁵ μg/m ³ ± 2σ (%)]	
Jan.	0.1 ± 18	0.4 ± 14	2.5	1.7 ± 3	4.6 ± 3	3.7
Feb.	0.2 ± 12	0.7 ± 12	2.9	1.6 ± 3	2.8 ± 3	5.7
Mar.	0.1 ± 12	0.9 ± 8	1.7	3.2 ± 3	7.8 ± 3	4.1
Apr.	1.0 ± 10	0.6 ± 11	16.3	2.7 ± 3	4.8 ± 3	5.6
May	0.1 ± 20	0.8 ± 7	1.5	3.5 ± 3	5.5 ± 3	6.4
June	0.9 ± 18	0.6 ± 11	16.2	3.5 ± 3	5.4 ± 3	6.5
July	0.1 ± 14	0.7 ± 12	1.4	5.2 ± 3	8.4 ± 3	6.2
Aug.	0.1 ± 20	0.4 ± 15	2.5	13.5 ± 3	53.2 ± 3	2.5
Sept.	0.1 ± 27	0.1 ± 24	10.0	5.8 ± 3	16.5 ± 3	3.5
Oct.	0.1 ± 25	0.2 ± 34	4.8	3.2 ± 3	5.4 ± 3	5.9
Nov.	0.1 ± 44	0.2 ± 50	5.0	6.6 ± 3	30.3 ± 3	2.2
Dec.	0.1 ± 24	0.2 ± 42	5.0	2.5 ± 3	9.1 ± 3	2.7
Annual average	0.3	0.5		4.4	12.8	
% SDM	128	55		74	115	
CG	6 × 10 ⁻¹⁴ μCi/ml	5 × 10 ⁻¹⁰ μCi/ml		1.9 μg/m ³	15 μg/m ³	
% CG	4 × 10 ⁻³	1 × 10 ⁻⁴		2 × 10 ⁻⁵	8 × 10 ⁻⁴	

Table A-10. Tritium (HTO) in air—LLNL perimeter and Livermore Valley.

Month	Perimeter location ^a (10 ⁻¹¹ μCi/ml)						Valley location ^b	
	01	02	12	13	14	15	S1	S2
Jan.	2.1	5.1	2.9	5.5	1.8	2.2	2.1	2.8
Feb.	1.5	5.4	3.3	12.0	2.3	2.5	0.8	1.4
Mar.	2.2	3.6	4.2	4.2	3.6	4.5	1.6	2.8
Apr.	1.2	0.8	1.5	2.1	1.9	2.0	0.5	0.4
May	1.4	1.1	1.7	0.9	2.1	2.8	1.1	1.0
June	3.4	1.7	4.9	2.4	4.1	2.6	1.3	0.8
July	1.9	1.3	3.9	0.8	3.4	1.7	0.8	1.0
Aug.	2.4	1.1	3.2	0.6	5.0	3.4	1.3	0.4
Sept.	5.7	5.2	7.8	3.4	4.7	3.0	2.0	1.9
Oct.	5.1	4.4	9.1	4.2	8.4	7.8	NA	2.5
Nov.	5.6	5.5	5.6	4.1	7.8	4.8	2.3	3.1
Dec.	3.8	4.1	5.3	3.6	3.2	2.7	1.7	3.0
Annual average	3.0	3.3	4.4	3.6	4.0	3.3	1.3	1.8
% SDM	55	59	51	84	54	50	54	59
% CG ^c	2 × 10 ⁻²	2 × 10 ⁻²	2 × 10 ⁻²	2 × 10 ⁻²	2 × 10 ⁻²	2 × 10 ⁻²	6 × 10 ⁻³	9 × 10 ⁻³
Calculated adult whole-body dose (mrem)	2 × 10 ⁻²	2 × 10 ⁻²	3 × 10 ⁻²	3 × 10 ⁻²	3 × 10 ⁻²	2 × 10 ⁻²	1 × 10 ⁻²	1 × 10 ⁻²

^a See Fig. 3.

^b See Fig. 5.

^c CG = 2 × 10⁻⁷ μCi/ml.

Table A-11. Various radionuclides in soil—Livermore Valley (sampling depth = 0–5 cm).

Location ^a	²³⁹ Pu	⁴⁰ K	¹³⁷ Cs	²³² Th	²³⁸ U
	[10 ⁻⁹ μ Ci/dry g $\pm$ 2 σ (%)]	[10 ⁻⁵ μ Ci/dry g $\pm$ 2 σ (%)]	[10 ⁻⁷ μ Ci/dry g $\pm$ 2 σ (%)]	[μ g/dry g $\pm$ 2 σ (%)]	
984	3.0 $\pm$ 10	1.3 $\pm$ 3	1.0 $\pm$ 7	5.9 $\pm$ 5	4.6 $\pm$ 12
985	7.7 $\pm$ 9	1.2 $\pm$ 4	1.0 $\pm$ 8	5.2 $\pm$ 6	3.4 $\pm$ 14
986	15.4 $\pm$ 6	1.0 $\pm$ 4	1.6 $\pm$ 5	5.5 $\pm$ 5	3.1 $\pm$ 15
987 ^b	12.0 $\pm$ 6	1.1 $\pm$ 3	3.4 $\pm$ 4	6.4 $\pm$ 3	2.8 $\pm$ 46
988	12.3 $\pm$ 6	1.0 $\pm$ 3	3.3 $\pm$ 4	6.4 $\pm$ 4	3.4 $\pm$ 46
989	5.0 $\pm$ 8	0.9 $\pm$ 4	1.1 $\pm$ 7	5.2 $\pm$ 5	2.2 $\pm$ 42
990 ^c	2.6 $\pm$ 10	1.1 $\pm$ 4	1.1 $\pm$ 8	6.9 $\pm$ 6	1.3 $\pm$ 66
991	2.4 $\pm$ 10	1.1 $\pm$ 4	1.2 $\pm$ 6	7.0 $\pm$ 5	2.6 $\pm$ 94
992	2.3 $\pm$ 10	1.0 $\pm$ 4	0.9 $\pm$ 7	6.0 $\pm$ 4	4.2 $\pm$ 8
993	1.6 $\pm$ 12	1.2 $\pm$ 4	0.5 $\pm$ 16	6.2 $\pm$ 6	3.5 $\pm$ 42
994	4.5 $\pm$ 9	1.5 $\pm$ 4	0.3 $\pm$ 28	6.9 $\pm$ 6	2.4 $\pm$ 100
995	7.8 $\pm$ 7	0.9 $\pm$ 3	2.4 $\pm$ 4	4.7 $\pm$ 5	1.7 $\pm$ 42
996 ^d	30.1 $\pm$ 5	1.2 $\pm$ 3	2.7 $\pm$ 5	6.9 $\pm$ 4	3.3 $\pm$ 14
997	26.1 $\pm$ 5	1.2 $\pm$ 4	2.8 $\pm$ 4	7.3 $\pm$ 5	1.8 $\pm$ 56
998	5.4 $\pm$ 9	1.6 $\pm$ 3	2.3 $\pm$ 4	6.1 $\pm$ 5	3.9 $\pm$ 9
999	2.8 $\pm$ 12	1.6 $\pm$ 4	1.4 $\pm$ 9	7.7 $\pm$ 6	2.2 $\pm$ 50
1000	3.5 $\pm$ 10	1.5 $\pm$ 4	1.6 $\pm$ 7	6.8 $\pm$ 5	1.9 $\pm$ 74
1001	4.6 $\pm$ 9	1.1 $\pm$ 5	2.1 $\pm$ 5	6.9 $\pm$ 7	2.1 $\pm$ 90
1002	1.1 $\pm$ 16	1.4 $\pm$ 3	0.1 $\pm$ 74	4.9 $\pm$ 5	2.5 $\pm$ 60
1003	5.7 $\pm$ 9	0.8 $\pm$ 4	3.5 $\pm$ 3	4.8 $\pm$ 5	2.5 $\pm$ 66

^a See Fig. 6.

^b Samples 987 and 988 are duplicates.

^c Samples 990 and 991 are duplicates.

^d Samples 996 and 997 are duplicates.

Table A-12. Plutonium, cesium and uranium in soil—Site 300 (sampling depth = 0–5 cm).

Location ^a	²³⁹ Pu	¹³⁷ Cs	²³⁸ U
	[10 ⁻⁹ μ Ci/dry g $\pm$ 2 σ (%)]	[10 ⁻⁷ μ Ci/dry g $\pm$ 2 σ (%)]	[μ g/dry g $\pm$ 2 σ (%)]
969 ^b	4.5 $\pm$ 9	1.6 $\pm$ 5	4.2 $\pm$ 11
970	3.0 $\pm$ 10	1.3 $\pm$ 7	2.5 $\pm$ 40
971	6.2 $\pm$ 4	2.0 $\pm$ 5	2.8 $\pm$ 46
972	5.5 $\pm$ 8	2.4 $\pm$ 5	2.5 $\pm$ 64
973	2.0 $\pm$ 13	0.9 $\pm$ 10	65.2 $\pm$ 5
974 ^c	1.6 $\pm$ 14	0.4 $\pm$ 24	7.3 $\pm$ 13
975	1.4 $\pm$ 9	0.3 $\pm$ 28	7.8 $\pm$ 12
976	5.1 $\pm$ 9	2.1 $\pm$ 6	6.1 $\pm$ 12
977	4.0 $\pm$ 6	1.7 $\pm$ 6	5.8 $\pm$ 10
978	5.4 $\pm$ 8	2.9 $\pm$ 6	426.0 $\pm$ 4
979	6.4 $\pm$ 7	3.1 $\pm$ 4	4.6 $\pm$ 50
980	3.8 $\pm$ 9	1.7 $\pm$ 5	4.9 $\pm$ 12
981	2.5 $\pm$ 11	1.2 $\pm$ 8	3.6 $\pm$ 62
982	4.5 $\pm$ 8	2.3 $\pm$ 5	3.0 $\pm$ 86
983	5.1 $\pm$ 8	0.2 $\pm$ 4	2.5 $\pm$ 78

^a See Fig. 7.

^b Samples 969 and 980 are duplicates.

^c Samples 974 and 975 are duplicates.

Table A-13. Various radionuclides in effluents—LLNL and Livermore Water Reclamation Plant (LWRP).

Month	HTO		¹³⁷ Cs		²³⁹ Pu	
	[10 ⁻⁶ μCi/ml ± 2σ (%)]		[10 ⁻¹¹ μCi/ml ± 2σ (%)]		[10 ⁻¹² μCi/ml ± 2σ (%)]	
	LLNL	LWRP	LLNL	LWRP	LLNL	LWRP
Jan.	2.5 ± 24	0.8 ± 64	4.0 ± 32	1.4 ± 100	7.7 ± 13	0.8 ± 44
Feb.	2.9 ± 23	2.0 ± 65	4.8 ± 22	1.3 ± 84	10.0 ± 15	0.7 ± 46
Mar.	4.2 ± 36	0.8 ± 65	3.6 ± 38	0.5 ± 100	4.2 ± 23	0.3 ± 91
Apr.	4.4 ± 28	0.7 ± 59	3.3 ± 52	1.1 ± 100	8.0 ± 17	0.7 ± 61
May	5.7 ± 30	0.9 ± 65	3.7 ± 36	2.0 ± 66	5.7 ± 23	0.4 ± 67
June	2.6 ± 28	0.6 ± 82	8.8 ± 18	1.1 ± 100	4.2 ± 24	0.5 ± 54
July	3.1 ± 24	0.9 ± 75	7.6 ± 22	1.6 ± 88	5.1 ± 21	0.1 ± 100
Aug.	4.0 ± 20	0.6 ± 83	5.1 ± 34	1.0 ± 100	5.3 ± 21	0.7 ± 57
Sept.	4.0 ± 20	1.1 ± 72	3.0 ± 64	2.2 ± 80	3.6 ± 24	1.4 ± 61
Oct.	3.6 ± 27	0.6 ± 74	5.1 ± 26	1.0 ± 100	5.0 ± 25	0.7 ± 70
Nov.	3.4 ± 33	0.4 ± 67	3.0 ± 54	1.9 ± 100	18.2 ± 11	0.4 ± 67
Dec.	3.0 ± 42	0.7 ± 78	3.2 ± 46	1.6 ± 100	5.6 ± 17	0.5 ± 70
Annual average	3.6	0.8	4.6	1.4	6.9	0.6
% SDM	25	49	41	39	58	53
CG (μCi/ml)	0.1 × 10 ⁻¹	3 × 10 ⁻³	4 × 10 ⁻⁴	2 × 10 ⁻⁵	1 × 10 ⁻⁴	5 × 10 ⁻⁶
% CG	4 × 10 ⁻³	3 × 10 ⁻²	1 × 10 ⁻⁵	7 × 10 ⁻⁵	7 × 10 ⁻⁶	1 × 10 ⁻⁵

Table A-14. Gross alpha activity in water—Livermore Valley.

Location ^a	Number of samples	Maximum	Minimum	Average	% SDM	% CG ^b
		[10 ⁻⁹ μCi/ml ± 2σ (%)]				
11	4	≤3.4	≤2.8	≤3.1	8	≤11
15	4	≤3.4	≤2.8	≤3.1	8	≤11
16	4	≤6.7	≤3.2	≤4.7	38	≤16
19	4	≤3.4	≤2.8	≤3.1	8	≤11
20	3	≤2.9	≤0.6	≤2.1	63	≤7
24	4	≤3.4	≤2.8	≤3.1	8	≤11
26	4	≤3.4	≤2.8	≤3.1	8	≤11
29	4	≤3.4	≤0.3	≤2.4	58	≤8
31	4	≤3.2	≤0.3	≤1.7	92	≤6
33	4	≤3.2	2.1 ± 91	≤2.8	18	≤9
34	2	≤3.2	≤3.2	≤3.2	None	≤11
37	4	≤3.2	≤2.7	≤3.0	8	≤10

^a See Fig. 10.

^b CG = 3 × 10⁻⁸ μCi/ml.

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

Location ^a	Number of samples	Maximum	Minimum	Average	% SDM	% CC ^b
		[10 ⁻⁹ μCi/ml ± 2σ (%)]				
1	3	≤3.4	≤0.3	≤2.3	74	≤8
2	3	4.3 ± 89	≤3.2	≤3.6	16	≤12
3	4	≤3.2	0.4 ± 70	≤2.3	56	≤8
4	8	17.0 ± 47	≤2.7	≤13.5	35	≤45
5	12	≤3.2	≤0.3	≤2.6	28	≤9
6	3	≤3.4	≤0.3	≤2.3	74	≤8
7	4	≤6.3	≤0.3	≤2.0	140	≤7
14	12	≤3.2	≤0.2	≤2.4	42	≤8
20	5	≤2.9	≤0.2	≤2.3	50	≤8
21	4	7.5 ± 76	≤2.8	≤5.6	36	≤19
22	12	≤3.2	≤0.3	≤2.6	28	≤9
23	4	4.0 ± 99	≤0.2	≤2.4	65	≤9

^a See Fig. 11.

^b CG = 3 × 10⁻⁸ μCi/ml.

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

Location ^a	Number of samples	Maximum	Minimum	Average	% SDM	% CG ^b
		[10 ⁻⁹ μCi/ml ± 2σ (%)]				
11	4	≤12.0	≤8.7	≤9.8	15	≤10
15	4	≤12.0	≤8.7	≤9.8	15	≤10
16	4	≤24.0	≤8.9	≤14.9	48	≤15
19	4	≤12.0	≤8.7	≤9.8	15	≤10
20	3	≤8.6	≤1.7	≤6.3	63	≤6
24	4	≤12.0	≤8.7	≤9.8	15	≤10
26	4	≤9.7	≤1.2	≤7.1	56	≤7
29	4	≤12.0	≤1.8	≤8.0	55	≤8
31	4	≤10.0	≤1.8	≤6.3	60	≤6
33	4	16.0 ± 68	≤8.7	≤12.4	34	≤12
34	2	15.0 ± 64	≤8.9	≤11.9	36	≤12
37	4	≤9.7	≤8.7	≤9.0	5	≤9

^a See Fig. 10.

^b CG = 1 × 10⁻⁷ μCi/ml.

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

Location ^a	Number of samples	Maximum	Minimum	Average	% SDM	% CC ^b
		[10 ⁻⁹ μCi/ml ± 2σ (%)]				
1	3	21.0 ± 51	12.0 ± 67	16.0	29	16
2	3	≤12.0	1.8 ± 89	≤7.8	68	≤8
3	4	15.0 ± 56	≤1.7	≤8.4	64	≤8
4	8	31.0 ± 18	≤8.4	≤19.0	43	≤19
5	12	≤10.0	≤1.8	≤8.2	25	≤8
6	3	18.0 ± 48	11.0 ± 30	13.7	28	14
7	4	33.0 ± 53	≤1.8	≤14.9	87	≤15
14	12	14.0 ± 31	≤3.5	≤9.2	30	≤9
20	5	≤8.7	≤1.6	≤7.1	44	≤7
21	4	13.0 ± 58	6.5 ± 36	10.0	30	10
22	12	14.0 ± 63	2.8 ± 31	8.9	28	9
23	4	12.0 ± 66	6.8 ± 36	≤9.1	24	≤9

^a See Fig. 11.

^b CG = 1 × 10⁻⁷ μCi/ml.

Table A-18. Tritium (HTO) in water—Livermore Valley.

Location ^a	Number of samples	Maximum	Minimum	Average	% SDM	% CG ^b	Calculated adult whole-body dose
		[10 ⁻⁷ μCi/ml ± 2σ (%)]					(mrem)
11	4	0.9 ± 8	0.4 ± 18	0.5	48	2 × 10 ⁻³	3 × 10 ⁻³
15	4	0.7 ± 10	0.5 ± 13	0.6	13	2 × 10 ⁻³	3 × 10 ⁻³
16	4	2.6 ± 4	1.7 ± 5	2.1	23	7 × 10 ⁻³	10 × 10 ⁻³
19	4	0.7 ± 11	0.5 ± 12	0.6	16	2 × 10 ⁻³	3 × 10 ⁻³
20	7	28.9 ± 5	1.7 ± 6	15.6	67	5 × 10 ⁻²	7 × 10 ⁻³
24	4	1.0 ± 8	0.5 ± 13	0.7	31	2 × 10 ⁻³	3 × 10 ⁻³
26	4	2.0 ± 5	1.5 ± 6	1.8	12	6 × 10 ⁻³	8 × 10 ⁻³
29	4	0.5 ± 14	0.4 ± 14	0.4	6	1 × 10 ⁻³	2 × 10 ⁻³
30	3	0.4 ± 17	0.3 ± 17	0.4	11	1 × 10 ⁻³	2 × 10 ⁻³
31	5	0.7 ± 10	0.3 ± 20	0.6	30	2 × 10 ⁻³	3 × 10 ⁻³
33	4	0.8 ± 23	0.7 ± 11	0.7	5	2 × 10 ⁻³	3 × 10 ⁻³
34	2	0.5 ± 14	0.5 ± 12	0.5	None	2 × 10 ⁻³	2 × 10 ⁻³
37	5	0.6 ± 21	0.4 ± 58	0.5	24	2 × 10 ⁻³	2 × 10 ⁻³

^a See Fig. 10.

^b CG = 3 × 10⁻³ μCi/ml.

Table A-19. Tritium (HTO) in water—Site 300.

Location ^a	Number of samples	Maximum	Minimum	Average	% SDM	% CG ^b	Calculated adult whole-body dose
		[10 ⁻⁷ μCi/ml ± 2σ (%)]					(mrem)
1	3	1.9 ± 5	0.5 ± 32	1.1	6?	4 × 10 ⁻³	5 × 10 ⁻³
2	3	0.6 ± 12	0.6 ± 12	0.6	None	2 × 10 ⁻³	3 × 10 ⁻³
3	4	0.2 ± 36	0.0 ± 100	0.1	72	3 × 10 ⁻⁴	4 × 10 ⁻⁴
4	8	0.3 ± 18	0.1 ± 100	0.1	65	5 × 10 ⁻⁴	7 × 10 ⁻⁴
5	12	0.6 ± 11	0.0 ± 100	0.2	76	8 × 10 ⁻⁴	1 × 10 ⁻³
6	3	0.3 ± 19	0.1 ± 100	0.2	81	5 × 10 ⁻⁴	7 × 10 ⁻⁴
7	4	0.3 ± 18	0.1 ± 60	0.2	65	5 × 10 ⁻⁴	7 × 10 ⁻⁴
14	12	1.1 ± 7	0.5 ± 13	0.7	27	2 × 10 ⁻³	3 × 10 ⁻³
20	7	0.9 ± 8	0.4 ± 15	0.6	35	2 × 10 ⁻³	3 × 10 ⁻³
21	4	0.3 ± 20	0.2 ± 34	0.2	24	8 × 10 ⁻⁴	1 × 10 ⁻³
22	12	0.4 ± 16	0.0 ± 100	0.1	91	4 × 10 ⁻⁴	5 × 10 ⁻⁴
23	4	0.4 ± 15	0.1 ± 57	0.2	72	7 × 10 ⁻⁴	9 × 10 ⁻⁴

^a See Fig. 11.^b CG = 3 × 10⁻³.

Table A-20. Tritium (HTO) in groundwater—Livermore Valley.

Location ^a	Well identification	Well depth (m)	Activity	% CG ^b
			[10 ⁻⁷ µCi/ml ± 2σ (%)]	
1	3S1E-1P2	15	7.92 ± 2.8	4 × 10 ⁻¹
2	3S1E-1R2	17	0.84 ± 9.3	4 × 10 ⁻¹
3	3S1E-2K2	14	1.09 ± 6.7	6 × 10 ⁻¹
4	3S1E-2R1	10	4.27 ± 3.3	2 × 10 ⁻¹
5	3S1E-4Q2	27	1.59 ± 5.5	8 × 10 ⁻¹
6	3S1E-8H2	62	1.02 ± 6.9	5 × 10 ⁻¹
7	3S1E-9G1	49	3.02 ± 3.8	2 × 10 ⁻¹
8	3S1E-10A2	27	6.21 ± 6.9	3 × 10 ⁻¹
9	3S1E-11B1	13	11.10 ± 2.6	6 × 10 ⁻¹
10	3S1E-12A2	23	1.93 ± 4.8	10 × 10 ⁻¹
11	3S1E-12D2	14	7.25 ± 2.8	4 × 10 ⁻¹
12	3S1E-12E1	84	1.31 ± 6.1	7 × 10 ⁻¹
13	3S1E-12G1	27	4.83 ± 3.1	2 × 10 ⁻¹
14	3S1E-12H1	104	0.85 ± 8.6	4 × 10 ⁻¹
15	3S1E-16H2	29	0.77 ± 9.2	4 × 10 ⁻¹
16	3S2E-7C2	15	1.68 ± 5.1	8 × 10 ⁻¹
17	3S2E-7N1	41	1.14 ± 6.4	6 × 10 ⁻¹

^a See Fig. 12.^b CG = 2 × 10⁻⁵ µCi/ml.

Table A-21. Tritium (HTO) in vegetation—Livermore Valley.

Location ^a	Number of samples	Maximum [10^{-7} μ Ci/ml $\pm$ 2 σ (%) in water recovered	Minimum	Average	% SDM	Calculated adult whole-body dose (mrem)
4	3	8.9 $\pm$ 13	1.3 $\pm$ 84	5.5	71	1 $\times$ 10 ⁻²
15	4	19.9 $\pm$ 6	7.4 $\pm$ 15	12.8	41	2 $\times$ 10 ⁻²
20	4	29.0 $\pm$ 5	3.8 $\pm$ 28	11.1	109	2 $\times$ 10 ⁻²
23	4	33.4 $\pm$ 4	11.0 $\pm$ 11	21.2	47	4 $\times$ 10 ⁻²
29	4	42.9 $\pm$ 4	11.8 $\pm$ 10	20.2	75	4 $\times$ 10 ⁻²
31	4	35.7 $\pm$ 4	3.9 $\pm$ 28	17.5	89	3 $\times$ 10 ⁻²
32	4	67.7 $\pm$ 3	2.0 $\pm$ 53	21.9	142	4 $\times$ 10 ⁻²
33	4	14.4 $\pm$ 8	1.0 $\pm$ 100	4.8	135	9 $\times$ 10 ⁻³

^a See Fig. 13.

Table A-22. Tritium (HTO) in vegetation—Site 300.

Location ^a	Number of samples	Maximum [10^{-7} μ Ci/ml $\pm$ 2 σ (%) in water recovered	Minimum	Average	% SDM	Calculated adult whole-body dose (mrem)
1	4	2.6 $\pm$ 41	1.0 $\pm$ 100	1.4	55	3 $\times$ 10 ⁻³
2	4	2.9 $\pm$ 37	1.0 $\pm$ 100	1.5	60	3 $\times$ 10 ⁻³
3	4	3.5 $\pm$ 32	1.0 $\pm$ 100	1.7	76	3 $\times$ 10 ⁻³
6	4	5580.0 $\pm$ 1	3.1 $\pm$ 34	1724.5	153	3
12	4	1.9 $\pm$ 55	1.0 $\pm$ 100	1.2	34	2 $\times$ 10 ⁻³
13	3	274.0 $\pm$ 1	1.1 $\pm$ 97	92.6	170	2 $\times$ 10 ⁻¹

^a See Fig. 14.

Table A-23. Tritium (HTO) in wine.

Location	Number of samples	Maximum [10^{-7} μ Ci/ml $\pm$ 2 σ (%) in water recovered	Minimum	Average	% SDM
California	2	1.4 $\pm$ 15	0.7 $\pm$ 32	1.1	47
Europe	3	3.4 $\pm$ 6	2.7 $\pm$ 10	3.0	11
Valley	5	4.3 $\pm$ 7	2.4 $\pm$ 10	3.2	23

Table A-24. Tritium (HTO) in honey.

Location	Number of samples	Maximum [10^{-7} μ Ci/ml $\pm$ 2 σ (%) in water recovered	Minimum	Average	% SDM
California	2	4.9 $\pm$ 6	2.4 $\pm$ 12	3.7	50
Livermore	2	6.0 $\pm$ 6	3.3 $\pm$ 8	4.7	41

Table A-25. Various radionuclides in milk—Livermore Valley.

	HTO [10 ⁻⁷ μ Ci/ml $\pm 2\sigma$ (%)]	⁴⁰ K [10 ⁻⁶ μ Ci/ml $\pm 2\sigma$ (%)]	¹³⁷ Cs [10 ⁻⁹ μ Ci/ml $\pm 2\sigma$ (%)]
Number of samples	11	10	10
Maximum	1.7 $\pm$ 61	2.0 $\pm$ 3	1.8 $\pm$ 66
Minimum	1.0 $\pm$ 100	0.8 $\pm$ 22	0.8 $\pm$ 68
Average	1.2	1.6	1.1
% SDM	18	19	32
Calculated adult whole-body dose (mrem)	2 $\times$ 10 ⁻³	9	2 $\times$ 10 ⁻²

Table A-26. Environmental radiation measurements (TLD)—LLNL perimeter.

Location ^a	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Annual
	(mrem)				
1	12	10	14	13	49
2	11	12	13	12	48
3	13	12	14	14	53
4	13	11	14	14	52
5	13	11	15	13	52
6	13	10	15	13	51
7	12	12	14	14	52
8	11	12	14	13	50
9	12	11	14	14	51
10	11	10	13	12	46
11	9	9	11	10	39
12	15	10	11	10	46
13	12	11	13	13	49
42	12	11	13	12	48
47	11	11	13	12	47
48	11	10	12	12	45
49	12	11	12	12	47
50	12	11	12	12	47
52	12	11	13	12	48
53	12	11	13	12	48
54	11	11	13	13	48
56	12	10	12	12	46
Average	12 $\pm$ 1	11 $\pm$ 1	13 $\pm$ 1	12 $\pm$ 1	48 $\pm$ 3

^a See Fig. 15.

Table A-27. Environmental neutron monitoring—LLNL perimeter.

Location ^a	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Annual
	(mrem)				
1	0.7	1.3	1.4	1.0	4.4
2	1.5	1.2	1.2	1.7	5.6
3	38.0	2.8	3.0	1.1	44.9
4	1.6	1.1	1.0	0.5	4.2
5	2.0	1.0	1.6	0.8	5.4
6	1.6	1.0	0.8	0.6	4.0
7	1.4	1.1	1.4	0.5	4.4
8	1.8	1.8	1.2	1.4	6.2
Average	6.1 ± 12.9	1.4 ± 0.6	1.4 ± 0.7	1.0 ± 0.4	9.9 ± 14

^a See Fig. 3.

Table A-28. Beryllium on air filters—LLNL perimeter.

Month	Location ^a					
	1	2	12 (10 ⁻⁵ µg/m ³)	13	14	15
Jan.	0.9	NA	0.5	1.1	<0.2	<0.1
Feb.	<0.2	<0.3	<0.3	0.9	<0.2	<0.1
Mar.	0.2	0.5	1.3	0.4	0.1	0.1
Apr.	1.2	1.5	2.2	1.0	1.3	0.1
May	2.9	1.7	2.0	0.2	0.4	3.7
June	6.9	4.9	6.1	4.2	4.4	3.7
July	7.0	7.7	3.2	5.5	4.1	3.6
Aug.	8.0	6.5	6.3	4.9	7.1	7.7
Sept.	6.2	3.5	5.2	4.4	7.3	4.4
Oct.	5.9	4.8	4.4	4.3	6.2	6.3
Nov.	2.0	2.4	5.0	2.9	1.3	2.8
Dec.	1.5	1.6	3.0	0.8	1.4	2.0
Average ^b	3.6	3.2	3.3	2.5	2.8	2.9
% SDM	84	76	64	78	100	88
%CG	0.4	0.3	0.3	0.2	0.3	0.3

^a See Fig. 3.

^b Ambient concentration limit set by the Bay Area Air Quality Management District is 0.01 µg/m³.

Table A-29. Beryllium on air filters—Site 300.

Month	Location ^a							
	1	2	3	4	5	8	9	10
	(10 ⁻⁵ µg/m ³)							
Jan.	0.3	0.5	0.4	NA	0.3	<0.1	0.1	NA
Feb.	<0.1	<0.2	<0.1	1.0	1.7	1.9	0.8	1.6
Mar.	1.5	3.5	1.0	0.5	1.8	0.8	0.2	0.3
Apr.	0.3	0.2	0.3	<0.2	0.6	<0.1	0.2	<0.1
May	1.0	1.1	0.7	1.5	1.5	1.5	0.2	0.6
June	2.3	8.7	0.2	4.7	17.0	5.7	2.6	5.1
July	3.8	4.9	1.7	3.0	2.8	5.8	2.0	1.7
Aug.	1.1	4.6	5.3	2.6	3.2	1.6	1.0	5.8
Sept.	2.7	9.2	1.9	4.0	9.8	2.9	2.5	3.9
Oct.	3.3	9.2	3.0	3.0	15.0	3.0	1.4	2.8
Nov.	8.8	6.3	29.0	23.0	3.7	16.0	0.8	2.1
Dec.	0.7	1.8	1.8	<0.5	0.9	5.1	<0.3	<0.7
Average ^b	2.1	4.2	3.8	4.0	4.9	3.7	1.0	2.2
% SDM	113	85	214	162	119	117	90	87
%CG	0.2	0.4	0.4	0.4	0.5	0.4	0.1	0.2

^a See Fig. 4.^b Ambient concentration limit set by the Bay Area Air Quality Management District is 0.01 µg/m³.

Table A-30. Various elements in LLNL liquid effluent.

Month	Cd	Cr	Cu	Fe	Pb	Ni	Ag	Zn	Al	Be
	(mg/liter)									
Jan.	0.002	0.080	0.16	0.54	0.010	0.013	0.005	0.25	0.27	0.000
Feb.	0.001	0.100	0.43	0.12	0.010	0.093	0.060	0.20	0.34	0.000
Mar.	0.002	0.050	0.05	0.07	0.010	0.050	0.020	0.07	0.32	0.000
Apr.	0.001	0.080	0.08	0.44	0.010	0.020	0.020	0.11	0.15	0.000
May	0.001	0.080	0.11	0.53	0.015	0.040	0.030	0.26	0.28	0.000
June	0.002	0.100	0.14	0.69	0.014	0.160	0.040	0.16	0.23	0.000
July	0.002	0.080	0.13	0.65	0.030	0.020	0.020	0.13	0.20	0.000
Aug.	0.002	0.070	0.11	0.35	0.020	0.020	0.020	0.15	0.20	0.000
Sept.	0.002	0.079	0.20	0.56	0.020	0.290	0.020	0.16	0.27	0.000
Oct.	0.001	0.110	0.36	0.57	0.020	0.530	0.020	0.49	0.31	0.000
Nov.	0.002	0.110	0.21	0.61	0.020	0.010	0.030	0.28	0.30	0.000
Dec.	0.001	0.070	0.15	0.45	0.008	0.010	0.016	0.42	0.23	0.000
Average	0.002	0.084	0.18	0.46	0.016	0.105	0.025	0.223	0.26	0.000
% SDM	0.001	0.018	0.11	0.20	0.007	0.158	0.014	0.126	0.057	0.000

Table A-31. Physical and chemical examinations of LLNL liquid effluents.

	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Average	SDM
	(mg/liter)					
BOD	77	54	83	43	64	19
COD	160	53	130	117	115	45
Oil and grease	7.5	23	<5	9	11.1	8
Phenol	0.21	<0.05	<0.05	<0.05	0.09	0.1
Settleable solids (ml/liter/h)	<0.10	0.51	<1	<0.5	0.53	0.4
TIC ^b	ND ^a	ND ^a	ND ^a	ND ^a	ND ^a	
Total dissolved solids	182	195	176	308	215	62
Total organic carbon	59	37	18	37	35	13
Total solids	230	186	148	344	227	85
Total suspended solids	25	20	9	19	18	7
Volatile solids (% total solids)	27	42	62	<1	33	26
Ammonia nitrogen (as N)	28	23	17	17	21	5
Chloride	24	26	25	174	62	74
Cyanide	0.02	<0.02	<0.02	<0.02	0.02	0
Nitrate nitrogen (as N)	<0.1	<0.1	<0.1	<0.1	<0.1	0
Nitrite nitrogen (as N)	<0.01	<0.01	<0.01	<0.1	<0.01	0
Sulfate	42	37	50	69	54	11
Total alkalinity (as CaCO ₃)	128	93	95	133	112	21
Total Kjeldahl nitrogen (as N)	35	28	27	22	28	5
Total phosphorous (as P)	4.3	0.62	3.9	2.6	2.8	2
Arsenic	<0.001	<0.001	<0.002	0.001	<0.001	0
Boron	0.53	0.46	0.37	0.22	0.39	0.1
Calcium	9.5	9.1	10	19	11.9	5
Chromium	0.069	0.04	0.047	0.07	0.056	0
Copper	0.18	0.07	0.078	0.10	0.107	0.1
Magnesium	1.4	1.1	1.1	4.9	2.125	2
Mercury	0.0005	0.0006	0.0013	0.0034	0.0014	0
Nickel	0.010	0.020	0.009	<0.020	0.014	0
Potassium	17	16	20	12	16	3
Selenium	<0.001	<0.001	<0.001	<0.001	<0.001	0
Sodium	28	26	24	50	32	12
Sodium (as % cations)	54	54	43	57	52	6
Zinc	0.21	0.12	0.12	0.20	0.16	0

^a None detected.

^b Total identifiable chlorinated hydrocarbons.

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

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

Table A-32. Site-300 water samples down-gradient from liquid-discharge locations.

Location ^a	Specific conductance (μmhos/cm at 25°C)				Total hardness as CaCO ₃ (mg/liter)				Chloride (mg/liter)				Total organic carbon (mg/liter)			
	4	5	14	22	4	5	14	22	4	5	14	22	4	5	14	22
Month																
Jan.	1400	1110	1520	990	22	39	460	49	148	70	102	61	9	5	16	5
Feb.	1190	950	1370	900	23	46	390	47	160	76	120	69	11	10	14	10
Mar.	1080	920	1470	880	24	49	480	48	142	74	120	68	8	13	12	8
Apr.	1210	956	1470	921	25	43	460	47	150	77	130	70	6	12	15	9
May	1090	881	1550	881	20	44	440	48	151	76	134	67	15	14	18	14
June	1340	1040	1730	960	24	46	410	50	160	77	150	68	8	6	6	5
July	1270	968	1730	943	32	49	470	46	160	76	160	69	5	5	9	5
Aug.	1340	1000	1930	959	24	46	470	50	140	72	170	70	5	6	9	5
Sept.	^b	1000	2050	1220	^b	88	436	80	^b	72	170	77	^b	5	5	5
Oct.	^b	1100	2290	982	^b	80	584	60	^b	101	214	72	^b	13	31	15
Nov.	^b	1100	1540	1110	^b	48	560	50	^b	81	180	64	^b	5	5	5
Dec.	^b	900	810	1700	^b	41	556	54	^b	89	180	66	^b	5	5	5
Average	1240	993	1621	1037	24	51	476	52	151	78	152	68	8	8	12	7
SDM	118	79	374	230	3	15	60	9	8	8	32	4	3	3	7	3

^a See Fig. 11.

^b Samples from location 4 were unavailable Sept. through Dec. due to equipment failure.

Table A-33. Estimated radiation dose to the public from LLNL airborne effluents during 1984.

Nuclide	Facility	Curies	Dose at site boundary (mrem)	Dose to nearest resident (mrem)	Dose within 80-km radius of LLNL (person-rem)
³ H	Tritium facility	7200	0.04 ^a	0.02 ^a	0.22 ^a
	Insulating core accelerator	11	0.02	0.00	0.00
	Rotating target neutron source	143	0.01	0.00	0.03
¹³ N- ¹⁵ O	Linear accelerator	81	0.02	0.00	0.00

^aDoses are based on the 1045 Ci of HTO. The dose due to the 6155 Ci of HT does not add significantly to the total.

Table A-34. Radioactive effluent releases from LLNL from 1976 through 1984.

Year	Airborne effluents (Ci)			Liquid effluents (Ci)	
	⁴¹ Ar	³ H	¹³ N- ¹⁵ O	HTO	²³⁹ Pu
1976	470	3991	1035	10	1.5 × 10 ⁻⁴
1977	380	5210	990	13	3.6 × 10 ⁻⁴
1978	766	5362	1445	9	8.6 × 10 ⁻⁴
1979	383	4517	829	7	9.8 × 10 ⁻⁴
1980	165	2305	1656	5	2.8 × 10 ⁻⁴
1981	0	2620	344	6	9.2 × 10 ⁻⁵
1982	0	2014	584	1.6	4.3 × 10 ⁻⁶
1983	0	3245	855	1.7	6.7 × 10 ⁻⁶
1984	0	7354	81	1.7	3.2 × 10 ⁻⁶

Table A-35. LLNL nonradioactive liquid effluent—storm drain runoff.

Analyses	Influent	Effluent	Lake
	(mg/liter)		
Nitrate nitrogen (as N)	5.7	1.4	1.2
Total phosphorous (as P)	0.60	0.67	1.2
Cyanide	0.06	<0.02	<0.02
Phenols	<0.05	<0.05	<0.05
Oil & grease (freon extractable)	<5.0	5	<5
Surfactants (MBAs)	0.13	0.02	<0.02
Sulfate	42	35	35
TICH ^a	ND ^b	ND	ND

^a Total identifiable chlorinated hydrocarbons.

^b None detected.

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

Organochlorine pesticides	$\mu\text{g/liter}$	Organochlorine pesticides	$\mu\text{g/liter}$
Aldrin	0.05	DDE (mixed isomers)	0.05
Chlordane	0.3	DDD (mixed isomers)	0.05
Endrin	0.1	Heptachlor	0.05
Dieldrin	0.05	Heptachlor epoxide	0.05
BHC (mixed isomers)	0.05	Methoxychlor	0.2
DDT (mixed isomers)	0.1		
Polychlorinated biphenyls	$\mu\text{g/liter}$		
Aroclors 1016-1262	0.3		

Table A-36. Quality-assurance analyses for the participation in the U.S. EPA Environmental Radioactivity Laboratory Intercomparison studies.

Analyses	Media	Value reported (pCi/liter)		Grand average of all Laboratories
		LLNL	Known	
Gross alpha	Water	5	7	7
		4	5	5
		3	3	3
		35	35	NA
Gross beta	Water	26	20	21
		17	16	15
		7	6	7
		160	147	NA
Gross alpha	Air	13	15	16
Gross beta	Air	61	51	56
Tritium	Water	3020 (2574) ^a	2384	2366
		2983 (3492)	3508	3461
		(3173)	3051	3039
		(2763)	2817	2842
		3007 (2817)	2810	2814
		3620 (3223)	3182	3206

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

Table A-37. Quality-assurance analyses for LLNL's participation in the DOE Environmental Measurements Laboratory (EML) Quality Assessment Program.^{a,b}

Analyses	Media	LLNL	EML value	LLNL/EML ratio	LLNL/mean reported
Be ⁷	Air	0.595	0.459	1.30	1.19
Cs ¹³⁷		0.557	0.486	1.15	1.14
Pu ²³⁹		0.399	0.450	0.89	0.84
U (μ g)		0.290	0.243	1.19	1.18
K ⁴⁰	Soil	0.205	0.210	0.98	0.95
Cs ¹³⁷		0.417	0.410	1.02	1.00
Ra ²²⁶		0.102	0.111	0.92	0.90
Pu ²³⁸		0.611	0.540	1.13	1.32
Pu ²³⁹		0.323	0.313	1.03	1.10
Am ²⁴¹		0.873	0.360	2.42	2.22
U (μ g)		1.29	0.830	1.55	1.31
³ H	Water				
Cs ¹³⁷		4.05	4.59	0.88	0.90
Pu ²³⁹		0.294	0.300	0.98	1.11

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

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

Table A-38. Summary of Quality Assurance Program—analyses of replicate sampling.^a

Analyses	Media	Location	Number of samples	Number below LOS (LOS - μ Ci/ml)	Ratio of duplicate $\pm 1\sigma$ (%)
Gross alpha	Air	Perimeter	16	9 (4.3×10^{-16})	1.6 $\pm$ 45
Gross beta		Perimeter	16	0 (1.7×10^{-15})	1.0 $\pm$ 27
HTO		Perimeter	11	0	1.1 $\pm$ 10
Gross alpha	Sewage	LLNL	12	8 (3.5×10^{-10})	3.0 $\pm$ 100
Gross beta		LLNL	12	0 (6.1×10^{-10})	1.0 $\pm$ 26
HTO		LLNL	12	0 (3.0×10^{-7})	1.0 $\pm$ 8
Gross alpha	Sewage	LWRP	12	12 (7.2×10^{-9})	
Gross beta		LWRP	12	6 (10.7×10^{-9})	1.2 $\pm$ 28
HTO		LWRP	12	5 (3.4×10^{-7})	1.0 $\pm$ 19

^a Sample results less than the limit of detection were not used to calculate the ratios.

Appendix B. Environmental Activity Concentration—Guide Levels

The standards for Radiation Protection (*DOE Manual 5480.1*, Chg 2, issued April 29, 1981) state that the average activity of a mixture of radionuclides (whose identities and concentrations are unknown) in air and water should not exceed the following values:

1. Air (controlled area)	$6 \times 10^{-13} \mu\text{Ci/ml}$
2. Air (uncontrolled area)	$2 \times 10^{-14} \mu\text{Ci/ml}$
3. Water (controlled area)	$4 \times 10^{-7} \mu\text{Ci/ml}$
4. Water (uncontrolled area)	$3 \times 10^{-8} \mu\text{Ci/ml}$

If alpha emitters and ^{227}Ac are definitely not present, the following values may be used to determine permissible average activity:

5. Air (controlled area)	$3 \times 10^{-11} \mu\text{Ci/ml}$
6. Air (uncontrolled area)	$1 \times 10^{-12} \mu\text{Ci/ml}$

If ^{129}I , ^{226}Ra , and ^{228}Ra are definitely not present, the following values may be used:

7. Water (controlled area)	$3 \times 10^{-6} \mu\text{Ci/ml}$
8. Water (uncontrolled area)	$1 \times 10^{-7} \mu\text{Ci/ml}$

Both air and water samples are subjected to gross alpha and gross beta measurements. The average annual alpha activities of samples may not exceed the activity values listed as 1–4 above. Since the alpha emitters have been accounted for in the gross alpha measurements and the assumption is made that ^{129}I , ^{227}Ac , ^{226}Ra , and ^{228}Ra are not present in the samples, the average annual gross beta activities of the samples may not exceed the activities listed as 5–8 above. The assumption that ^{129}I , ^{227}Ac , ^{226}Ra , and ^{228}Ra are not present in air and water samples is reasonable in view of the minute quantities of these radionuclides available at LLNL. This reference also states that average tritium activities in off-site water samples may not exceed $3 \times 10^{-3} \mu\text{Ci/ml}$.

The external whole-body radiation dose to workers in controlled areas may not exceed 5 rem/y, and the dose to an individual in an uncontrolled area may not exceed 500 mrem/y. Also, a group of individuals in an uncontrolled area may not receive an average annual dose of more than 170 mrem.

Appendix C. Method of Dose Calculations

The doses shown in this report have been calculated using the models and methods in the Nuclear Regulatory Commission Regulatory Guide 1.109, *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluent*. The dose and dose-rate conversion factor specified by Publication 30 of the International Commission on Radiological Protection, *Limits of Intakes of Radionuclides by Workers*, were used in the calculations. Examples of these calculations and assumptions are shown in this appendix.

Annual Dose from Potable Water

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

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

where

C_w = concentration in pCi/liter,

U_w = intake rate, liters/y,

= 730 liters/y for maximum exposed individual,

D_w = dose factor, mrem/pCi,

= 6.23×10^{-8} mrem/pCi for the whole-body ingestion pathway for an adult, and

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

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

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

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

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

where

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

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

D_{HTO} = dose factor, mrem/pCi = 6.23×10^{-8} mrem/pCi for ^3H for the adult whole-body ingestion pathway,

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

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

where

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

$D_{\text{HTO}} = 6.23 \times 10^{-8} \text{ mrem/pCi}$,

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

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

Q_f = amount of feed consumed, kg/day,

C_{veg} = same as above,

λ_i = radiological decay constant, day⁻¹,

t_i = time between slaughter to consumption, days.

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

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

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

where

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

$$D_{HTO} = 6.23 \times 10^{-8} \text{ mrem/pCi},$$

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

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

Q_f = amount of feed consumed, kg/day,

C_{veg} = same as above,

λ_i = radiological decay constant, days⁻¹,

t_i = transport time from the feed to milk receptor,

$$C_{milk} = \left(1.0 \times 10^{-2} \frac{\text{day}}{\text{liter}}\right) \left(50 \frac{\text{kg}}{\text{d}}\right) \left(C_{veg} \frac{\mu\text{Ci}}{\text{ml}}\right) \left(10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/ml}}\right) \\ \times \exp[-1.5 \times 10^{-4}(2)] = 0.5 \times 10^9 \frac{\text{pCi/liter}}{\mu\text{Ci/ml}} \times C_{veg} \frac{\mu\text{Ci}}{\text{ml}} (\text{measured}) .$$

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

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

Annual Population Dose

To calculate the "fence-line" site boundary, nearest resident, and population doses, a continuous-point-source computer code based on the Gaussian plume model was used.

$$C_{\text{downwind}} = 3.17 \times 10^4 (\chi/Q)(Q) \quad , \quad (3)$$

where

χ/Q = diffusion parameter, sec/m^3 ,

Q = release rate, Ci/y ,

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

C_{downwind} = concentration downwind, pCi/m^3 .

$$D_{\text{max individual}} = U \times C_{\text{downwind}} \times D \quad , \quad (4)$$

where

U = intake rate, $\text{m}^3/\text{y} = 8000 \text{ m}^3/\text{y}$, inhalation rate for adult maximum exposed individual,

$$C_{\text{downwind}} = 3.17 \times 10^4 (\chi/Q)(Q),$$

D = dose factor, mrem/pCi ,

for ^3H , $D = 6.23 \times 10^{-8} \text{ mrem}/\text{pCi} \times 1.5$ to include immersion dose = $9.35 \times 10^{-8} \text{ mrem}/\text{pCi}$,

$$\text{for } ^{13}\text{N}, D = 5.17 \times 10^{-3} \frac{\text{mrem} \cdot \text{m}^3}{\text{pCi} \cdot \text{y}},$$

$$\text{for } ^{15}\text{O}, D = 5.21 \times 10^{-3} \frac{\text{mrem} \cdot \text{m}^3}{\text{pCi} \cdot \text{y}},$$

$$D_{\text{max individual}} = \text{mrem}/\text{y}.$$

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

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

where

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

Q = release rate, Ci/y ,

U = inhalation rate, average individual (adult),

D = dose factor, mrem/pCi .

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

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

Section 18.62 General Discharge Prohibitions.

No person shall contribute or cause to be contributed, directly or indirectly, any pollutant or wastewater which 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 which 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 which 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 which 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 which 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 which contain more than 100 mg/liter of freon extractable fat, oil, or grease.

(h) Any substance which 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 which 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 which 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 which causes a hazard to human life or creates a public nuisance.

(n) Any waters or wastes containing total dissolved solids increment greater than three hundred and twenty-five mg/l, nor chloride increment greater than seventy-five 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 three hundred (the average BOD for residential users), unless a city permit is obtained.

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

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

Section 18.62.2 Federal Categorical Pretreatment Standards.

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

Section 18.62.3 Modification of Federal Categorical Pretreatment Standards.

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

Section 18.62.4 Specific Pollutant Limitations.

No person shall discharge wastewater containing in excess of:

0.1	mg/liter arsenic
0.2	mg/liter cadmium
2.0	mg/liter copper
1.0	mg/liter cyanide
1.0	mg/liter lead
0.01	mg/liter mercury
1.0	mg/liter nickel
0.2	mg/liter silver
1.0	mg/liter total chromium
3.0	mg/liter zinc
0.02	mg/liter total identifiable chlorinated hydrocarbons
1.0	mg/liter phenolic compounds
0.01	mg/liter polychlorinated biphenyls

Section 18.62.5 State Requirements.

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

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

Described herein are sample collection and analysis procedures employed in environmental monitoring at the Lawrence Livermore National Laboratory (LLNL). As an integral part of the quality assurance program developed for environmental monitoring at LLNL, these procedures provide a basis for verifying that sampling and analytical activities are being performed as specified.

The collection of the environmental samples and many of the chemical and radioactivity analyses are performed by the Hazards Control Department. The more complex radiochemical analyses are handled by LLNL's Nuclear Chemistry Division. Some special analyses are contracted to a facility outside LLNL.

Part I of Appendix E describes the sampling procedures, analytical determinations, and preparation for radiocounting by LLNL's Hazards Control Department. Part II, *Radiochemical Methods of the site Environmental Monitoring Program (M-122)*, describes the methods used by LLNL's Nuclear Chemistry Division.

I. Sampling and Analytical Procedures Used by LLNL's Hazards Control Department

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I. Sampling and Analytical Procedures Used by LLNL's Hazards Control Department

Introduction

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

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

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

Air Sampling

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

Collection

Particulates

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

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

Tritiated Water

Samples of tritiated-water vapor are collected by drawing air through silica-gel-packed columns at flow rates of about 0.5 liters/min. The average between the initial and final flow rates is measured by 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, and date off, the elapsed sampling time, and the flow rate. Filters are placed in glassine envelopes and are transported to the laboratory, where this information is transferred to log

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

Tritiated Water

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

Replication

Particulates

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

Tritiated Water

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

Soil Sampling

Soil samples are collected annually within the Livermore Valley and at Site 300. Radiochemical analyses of these samples serve to document any changes that may have occurred during the year. Approximately 20 sampling sites within the Livermore Valley are chosen at random from a list of 125 locations which provided the data base of various nuclides in the soil near LLNL. The same sampling sites are used each year at Site 300.

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 placed in plastic bags and are identified by number. This number is entered in a log book, together with the sampling data and a description of the sample location. The number is used to identify the sample throughout the laboratory analyses and in the annual report.

Replication

During each annual collection of soil samples, at least 10% of the sites are sampled in duplicate. In such collections, two, adjacent cores, 5-cm-deep, are taken from the corners and center of each 2-m square. Separate composites of the five cores are then made, and the composites are identified by successive numbers.

Water Sampling

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

Collection

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

Identification

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

Replication

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

Sewage Sampling

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

Collection

LLNL Effluent

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

LWRP Effluent

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

LWRP Digester Sludge

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

Identification

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

Replication

LLNL Effluent

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

LWRP Effluent

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

Vegetation Sampling

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

Collection

Samples of vegetation are routinely collected from the same locations each sampling period. Grass samples are pulled up or cut close to the ground, and any soil is discarded. The bulk volume of these samples is usually between 0.5 and 1 liter. As each sample is collected, it is placed in a plastic bag and frozen in a dry-ice chest to minimize water loss on the bag's surface. The duplicate samples collected at each location 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 two goat farms located about 5 km south and 5 km southeast of LLNL. One of these farms also provides cow's milk on occasion. A portion of each milk sample is freeze-dried, and the tritium content of the recovered water is determined by liquid scintillation. A 1-liter sample is then preserved with formaldehyde and gamma-counted in a Marinelli beaker.

Air Analysis

Environmental air samples are analyzed for gross alpha and beta activity and beryllium.

Gross Alpha and Beta Counting

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

Standards and Calibration

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

Beryllium

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

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

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

Water Analysis

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

Gross Alpha and Beta Activity

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

A blank is processed together with each set of samples.

Standards and Calibration

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

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

Gross Alpha and Beta Radioactivity

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

Tritium

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

Heavy Metals

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

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

II. Radiochemical Methods of the Site Environmental Monitoring Program

Abstract

This methods manual describes the facilities and methods used by the Site Environmental Monitoring Program of Lawrence Livermore National Laboratory (LLNL) Nuclear Chemistry Division. Included are descriptions of (1) the low-level environmental laboratory and counting facilities, (2) types of samples collected and analyzed, (3) chemical and counting methods used, and (4) quality assurance procedures.

The purpose of this report is to describe the facilities and methods used by the Nuclear Chemistry Division in support of LLNL's Site Environmental Monitoring Program. This provides a single, easy-to-update description of the current program and environmental radio-analytical techniques.

The types of samples analyzed for the Site Environmental Program and the laboratory and counting facilities used for low-level radiochemistry are described in the beginning of the report. The specific methods of analysis, and the quality assurance program comprise the remaining material.

Overview of the Site Environmental Monitoring Program

Sample Types

The Lawrence Livermore National Laboratory's (LLNL) Site Environmental Monitoring Program routinely analyzes five types of samples for heavy elements and/or tritium: air, water, soil, vegetation, and agricultural products. (Flow charts illustrating sample analyses for heavy elements and tritium are to be found in Figs. E-1 and E-2, respectively.)

Weekly air filter samples are collected from LLNL's perimeter, Site 300, and other locations near LLNL¹ and composited monthly. Perimeter and Site 300 air filters undergo gamma analysis followed by analysis for $^{239,240}\text{Pu}$, ^{238}Pu , ^{235}U , and ^{238}U . Filters from other stations are analyzed only for $^{239,240}\text{Pu}$ and ^{238}Pu . Air moisture is collected from eight sites around LLNL's perimeter by pulling a constant air flow through a reservoir of silica-gel desiccant. These biweekly samples are processed to release the water that is subsequently analyzed for tritium.

Daily water samples are collected from LLNL's main sewage line and also from Livermore's Liquid Water Reclamation Plant (LWRP). These samples are composited monthly and analyzed for $^{239,240}\text{Pu}$, ^{238}Pu and ^{137}Cs . A monthly composite of weekly, one-gallon LLNL tap water aliquots is also analyzed for these same nuclides. A quarterly composite of monthly sewer-sludge aliquots is analyzed for $^{239,240}\text{Pu}$ and ^{238}Pu only. Tritium analysis is done on water samples collected quarterly from Site 300 and the Livermore Valley, and 4 monthly Site-300 samples. Samples may originate from wells, creeks, or ponds. Tap water is analyzed for ^3H on a quarterly basis, monthly rain water samples are analyzed when available. Annual soil samples originate from Site 300 and locations selected at random throughout the Livermore Valley. Each sample is given a gamma scan, then analyzed for $^{239,240}\text{Pu}$ and ^{238}Pu and at Site 300 for ^{235}U , ^{238}U .

Quarterly vegetation samples originating from Site 300 and the Livermore Valley are freeze-dried to extract their water for tritium analysis. Cow and goat milk are collected from local farms each month, preserved, and analyzed by direct gamma spectrometry; an aliquot of the same goat milk sample is freeze-dried for subsequent tritium analysis of the extracted water. Locally harvested honey is combusted in a Parr bomb and the resulting water is analyzed for ^3H . Wines from Livermore Valley vineyards, plus controls from other areas, are oxidized in a Petersen furnace and the resulting water is analyzed for ^3H .

Laboratory Facilities

A primary concern when maintaining an environmental-level radiochemical facility is the elimination of contaminants. Several methods are employed to achieve this. The Heavy Elements and Tritium Laboratories are located in a section of the building that is dedicated exclusively to low-level work. Entry is controlled, and visitors must don disposable plastic shoe covers. Hood and counter surfaces are routinely cleaned and the floor is periodically mopped.

Because of tritium's rapid environmental exchange rate, special precautions are taken to maintain a low background in the Tritium Laboratory. Luminous-dial watches are excluded from the facility because they can release levels of tritium much higher than levels measured in routine environmental samples. For handling samples with very low tritium concentrations, argon-atmosphere glove boxes are used. All glassware used for tritium analyses is scrupulously cleaned, dried in an oven at 105°C , and then cooled in an argon atmosphere. Room air moisture is analyzed daily for tritium.

Pieces of equipment such as drying ovens, ashing furnaces, and balances are maintained and reserved for low-level samples. The Heavy Elements Laboratory is provided with an acid-fume scrubber where fumes evolved from perchloric and hydrofluoric acids are washed with a sodium hydroxide solution and then passed through an electrostatic precipitator before being exhausted. Finally, all chemicals used are analytical reagent grade, and all water is distilled and deionized.

Figure E-1. Flow charts of heavy elements analysis separation and purification.

Figure E-2. Low-level tritium determination.

Figure E-3. Counting efficiency vs energy for the Compton suppression system (CSS) and the 20% system (3 liters).

Counting Facilities

Gamma Analysis

Samples requiring low-level gamma analysis are counted on one of 6 counters dedicated for that purpose. One detector is a 15%-relative-efficiency Ge(Li) spectrometer equipped with a Compton suppression system (CSS), while the others are 11 to 20%-relative-efficiency Ge(Li) spectrometers. One of these is dedicated to low-level samples and methods R&D requiring an up-looking detector; its characteristics are summarized in Table E-1 and Fig. E-3. A low-level Ge(Li) well detector will soon become operational and will be dedicated to counting environmental samples. All spectrometers are constructed of materials especially selected for minimal radioactivity in order to attain the lowest possible background (Table E-1). Data are accumulated by LSI/11-controlled Nuclear Data ND 66 multichannel analyzers with individual amplifiers and ADCs. Spectra are computer analyzed on a CDC-7600 with GAMANAL,² or GRPANAL programs designed for the analysis of high-resolution, gamma-ray spectra. The counting efficiencies of these systems vary as a function of the gamma-ray energies as can be seen in Fig. E-3. Typical detection limits for nuclides can be determined from the information given in Fig. E-3 and Table E-1.

Alpha Analysis

Alpha-pulse height analysis is used to determine ^{239,240}Pu and ²³⁸Pu in environmental samples. We use twelve Ge(Li) surface barrier detectors with 450-mm² area and 20% counting efficiency with three Nuclear Data (Model 130) 512-channel analyzers. Samples are normally counted for about 5000 min, which gives an optimal detection limit of approximately 4×10^{-3} pCi per sample. The accumulated spectral data is transferred from the analyzers to paper tape which is read into an LSI/11 computer system for analysis. ALPHAQ, a program designed for plutonium alpha spectra, deciphers the spectra.

During 1985, the ND-130 system will be replaced by an ND-66/LSI/11 MCA system with disk data storage and an upgraded calculational system. Detector and background characteristics will remain as specified.

Table E-1. Backgrounds for the Compton suppression and 20% detector system.

Energy (keV)	Probable source	Compton suppression system		20% detector system (counts/min)
		Suppressed (counts/min)	Unsuppressed (counts/min)	
77.1	228 _{Th}	—	0.27	—
87.4	228 _{Th}	0.006	—	—
186.1	226 _{Ra}	0.004	—	—
238.6	228 _{Th}	0.028	0.027	0.028
295.2	226 _{Ra}	0.012	0.009	0.042
351.9	226 _{Ra}	0.018	0.017	0.017
511.0	Annihilation	0.010	0.105	0.426
583.1	228 _{Th}	0.003	0.013	0.012
609.3	226 _{Ra}	0.005	0.015	0.053
661.6	137 _{Cs}	0.005	0.004	—
727.3	228 _{Th}	—	—	—
860.5	228 _{Th}	—	0.002	—
911.1	228 _{Ac}	0.006	0.006	0.008
968.9	228 _{Ac}	0.003	0.004	—
1119.5	228 _{Ac}	0.002	0.005	0.017
1460.8	40 _K	0.042	0.048	0.045
1764.5	226 _{Ra}	0.005	0.005	0.012

Mass Spectrometry Analysis

Uranium is analyzed on a VG354 mass spectrometer (VG Isotopes, Winsford, Great Britain), which has a 90° single-magnetic sector designed to give two-directional focussing and focal planes oriented normal to the beam axis. This instrument is equipped with both Faraday and electron multiplier detectors. Uranium is analyzed using the multiplier system, which is of the Daly design. Sample throughput is enhanced by a turret source which accepts 16 samples at a time and a capability for automatic operation under the control of the electronic calculator.

The precision and accuracy of the uranium analyses are routinely checked by using NBS standards. Although typical precisions for the 238/235 ratio are on the order of 0.1%, the sample-to-sample variations in mass-fractionation limit our accuracy to about 0.5%. For the typical sample size of 50 ng, minor U isotopes can be measured down to levels of $^{234,236}/^{238} \sim 10^{-5}$. The 235/238 ratio can be determined to within 1% for samples as small as 1 ng.

Tritium Analysis

Routine tritium samples are counted by liquid-scintillation spectrometry. Low-level samples are electrolytically enriched³ prior to counting, and a single 5-ml aliquot of the enriched water is analyzed. For unenriched samples, either two 7-ml or three 5-ml aliquots are used. Each counting set includes a total of eight standards (diluted to 5, 6, and 7 ml), to establish quench corrections, and eight blanks for background determination. Sample, standard, and background aliquots are pipetted into low-potassium liquid-scintillation vials. Under controlled (red/yellow) light, 10 ml of Packard Instagel scintillation cocktail are added to each vial and mixed thoroughly. The set is loaded into the spectrometer with blanks and standards interspersed among the samples and is allowed to reach refrigerated temperature equilibrium. The set is then counted for three cycles of 50 min per vial. Data from the spectrometer are analyzed on a CDC-7600 computer by the SCNTCT program.⁴

For low-volume or low-activity samples, or where rapid ³H analysis is required, a gas proportional counter is used.⁵ Water samples are converted to hydrogen gas by reaction with hot magnesium turnings under vacuum, and the hydrogen is collected in a charcoal trap at liquid-nitrogen temperature. When the sample has been warmed to room temperature, it may be transferred into the proportional counter.⁶ Samples with a total net activity of less than 3 counts/min are counted overnight, samples with activities in the 3–8 counts/min range are counted for a working day, and samples with more than 8 counts/min are counted only long enough to accumulate 1000 counts. The efficiency of the system is updated at least once a month with a tritium standard, and the background (≤ 0.7 counts/min) is measured over weekends.

Sample results are calculated on the CDC-7600 computer using the GASCT program; the file GASLIB contains standard and background information used in the calculation and is updated periodically. Routine detection limits are approximately 2 TU (6.5×10^{-3} pCi/ml) enriched and 50 TU (1.6×10^{-1} pCi/ml) unenriched for liquid scintillation counting, and 0.2 TU (6.5×10^{-4} pCi/ml) enriched and 5 TU (1.6×10^{-2} pCi/ml) unenriched for gas proportional counting.

Two Beckman 9800 Liquid Scintillation counters have been acquired, and low-level counting routines using hand calculations based on counter programs have been developed. These systems have been shown to be as precise and accurate as the Packard unit, and are currently in use for R&D projects and are back-ups to the routine Packard counting procedures.

Methods of Sample Preparation and Analysis

Heavy Elements Analysis

Flow charts illustrating procedures used in heavy elements analysis are shown in Fig. E-1.

Tracers

As a convenience, tracers and carriers used in plutonium and uranium analyses are combined into a single mixed tracer. The mixed tracer is diluted with 2 M HNO_3 to provide the following in a standard 5-ml aliquot: a) 1.4 pCi ^{242}Pu and b) 4.36×10^{13} atoms ^{233}U . For ^{137}Cs gamma-analysis, a 4.8-dpm/ml ^{134}Cs tracer is used.

Air Filter Samples: Counting and Preliminary Chemistry

This section is written as a procedure, in a manner that will allow the reader to duplicate the work we do each year.

Preliminary Treatment and Counting.

- 1) Composite the month's air filters from the laboratory perimeter stations and seal in a 214-cm³ aluminum can for gamma analysis. Upon completion of a 1500-min. count, separate the air filters, by station, into platinum crucibles. Care should be taken to minimize cross-contamination.
- 2) Composite the month's air filters from the Site 300 stations and seal in a 214-cm³ aluminum can for gamma analysis. Upon completion of a 1500-min. count, place all of the Site 300 air filters into a single Pyrex beaker.
- 3) Place other non-gamma-counted Livermore Valley air filters into individual Pyrex beakers by station.
- 4) Add 5 ml of mixed tracer to each sample.
- 5) Dry the air filters in a drying oven at 110°C for at least four hours.
- 6) Ash the air filters at 475°C for at least two days.

Uranium Separation. For samples that require uranium analysis (LLNL perimeter, Site 300, standards, and blanks):

- 1) Transfer ashed samples from Pyrex beakers into platinum beakers with minimum conc nitric acid (HNO_3). Add conc HNO_3 to a total volume of 30 ml to all platinum beakers.
- 2) Add 30 ml of conc hydrofluoric acid (HF).
- 3) Heat the sample to dryness in the acid fume scrubber.
- 4) Add 30 ml each of conc HNO_3 and conc perchloric acid (HClO_4).
- 5) Heat until fuming ceases, in the acid fume scrubber.
- 6) Dissolve as much of the residue as possible by heating with 20 ml of 8 M HNO_3 and a few drops of 30% hydrogen peroxide (H_2O_2). Cool.
- 7) Transfer the solution to a 250-ml plastic bottle using minimal 8 M HNO_3 .

Plutonium Separation. For samples that require only plutonium analysis (Livermore Valley):

- 1) Treat the ashed filter with 60 ml of conc HNO_3 and 20 ml of conc hydrochloric acid (HCl).
- 2) Evaporate the sample to a final volume of 50 ml.
- 3) Transfer the sample to a 250-ml plastic bottle using minimal 8 M HNO_3 .
- 4) Make the sample approximately 8 M HNO_3 by doubling the volume with 0.5 M HNO_3 .

Preparation for Anion Exchange Separation.

- 1) Treat all samples with 0.5 g of sodium nitrite (NaNO_2) to adjust the plutonium valence to +4 for anion exchange, and wait at least four hours before further processing.
- 2) Proceed to the section on anion-exchange separation and heavy-element-purification procedures (p. E-19).

Water Samples

Preliminary Chemistry.

- 1) For laboratory sewage and LWRP samples: add 5 ml of 3 M HCl to each 500-ml aliquot before combining these for the monthly composite. Add 5 ml of mixed tracer plus 4 ml ^{134}Cs tracer to the composite sample.
- 2) For tap-water samples: add 150 ml of 3 M HCl to the sample vessel followed by 5 ml of mixed tracer; add 4 ml ^{134}Cs tracer. Combine the weekly tap-water aliquots in the vessel with stirring.

Plutonium Separation.⁷

- 1) Add 10 ml of saturated potassium permanganate (KMnO_4) to the sample.
- 2) Add 70 ml of 10 M NaOH and check the pH to make sure that it is basic.
- 3) Co-precipitate plutonium with manganese dioxide (MnO_2) by slowly adding 150 ml of 0.1 M manganous chloride (MnCl_2). As MnCl_2 is added, maintain a basic pH by addition of small amounts of 3 M NaOH.
- 4) Pump the sample through a 1- μ cotton filter cartridge to remove the MnO_2 from solution. Save the filtrate. In the laboratory sewage sample, solid material is present before separation. This matter has been found to contain a significant percentage of the ^{137}Cs in the sample. Therefore, cesium is later separated from this filter, by anion exchange (see the section on p. E-19).
- 5) Separate the cotton filter from the filter's plastic core and place it in a one-liter beaker.
- 6) Dry the filter in an oven at 110°C for two days.
- 7) Ash the filter at 475°C for two days.
- 8) Add 100 ml of conc HNO_3 to the ashed MnO_2 cartridge and heat for at least an hour.
- 9) Add 30% H_2O_2 until the MnO_2 has dissolved.
- 10) Evaporate the sample to about 50 ml. Transfer the sample to a 250-ml plastic bottle.
- 11) Make the sample approximately 8 M HNO_3 by doubling the sample volume with 0.5 M HNO_3 .
- 12) Add approximately 0.5 g of NaNO_2 to prepare for anion exchange. Wait at least four hours before continuing processing.
- 13) Proceed to the section on p. E-19 for anion-exchange separation and heavy-element-purification procedures.

Cesium Separation.

- 1) For the laboratory sewage sample, collect the eluates from the anion exchange separation.
- 2) Add 10 M NaOH until samples are basic. Equilibrate in an ice bath for 30–40 min.
- 3) Centrifuge and decant the supernate into a clean beaker. Wash the precipitate with 10 N NaOH at least three times, combining the supernates and discarding the remaining solids.
- 4) Add the supernates to the filtrate solutions from the earlier filtration procedure.
- 5) Add 150 ml 3M HCl to the filtrate. Verify that pH is 1 to 3.
- 6) Add 5 g AMP as a distilled H_2O slurry.
- 7) Allow the AMP to settle overnight.
- 8) Decant the supernate by carefully pumping off the liquid from the AMP. Discard supernate.
- 9) Quantitatively transfer the AMP into a 1-liter beaker with HCl (pH = 1-3).
- 10) Allow the AMP to settle overnight and decant the supernate again.

- 11) Transfer the AMP to a 40-ml glass cone with the pH 1-3 HCl. Centrifuge and discard supernate. Stir and wash with pH 1-3 HCl. Centrifuge and discard supernate. Repeat washing until no brown ppt or discoloration of the AMP remains.
- 12) Quantitatively transfer the AMP to a Prindle vial with the pH 1-3 HCl. Add the HCl to a *total* volume of 20 ml.
- 13) Submit samples for gamma counting.

Sewer Sludge Sample

Preliminary Chemistry.

- 1) Add 5 ml of 3 M HCl to each 500-ml sample and transfer one sample to a tared, labeled 1-liter beaker.
- 2) Add 5 ml of mixed tracer and place the beaker in a drying oven at 150°C.
- 3) As evaporation proceeds, add successively all the sludge aliquots collected during the quarter and evaporate the composite to complete dryness.
- 4) Weigh the beaker and remaining solids to determine the sample weight.
- 5) Ash the sample at 475°C for at least two days.
- 6) Homogenize the sample and remove an aliquot for gamma counting.

Plutonium Separation. Proceed to step 3 of the acid leach method, listed below.

Soil Samples

Preliminary Treatment and Counting.

- 1) Dry the soil sample at 110°C for at least two days.
- 2) Remove rocks and pebbles with diameters greater than 0.5 cm.
- 3) Pulverize the remaining material in a grinding mill.
- 4) Pass the sample through a 32-mesh sieve. Discard the fraction that is greater than 32 mesh.
- 5) Thoroughly blend the sample.
- 6) Pack a 238-cm³ tared aluminum can with the sieved soil for gamma analysis.

Plutonium Separation. (Acid leach method⁸)

- 1) Weigh a 100-g aliquot of the prepared soil.
- 2) Add 5 ml of the mixed tracer.
- 3) Leach the sample by heating for four hours with 300 ml of conc HNO₃ and 100 ml of conc HCl. Control foaming with a few drops of n-octanol.
- 4) Vacuum filter the hot sample through a Buchner funnel fitted with 934 AH glass-fiber filter paper. The supernatant liquid should be clear. Wash the sample twice with approximately 50 ml hot 8 M HNO₃ each wash.
- 5) Determine the molarity of the supernatant liquid by titrating a 0.5-ml aliquot with standardized 1 M NaOH to a phenolphthalein end-point.
- 6) Adjust the molarity of the solution to 8 M HNO₃ with appropriate volume of 0.5 M HNO₃.
- 7) Add about 1 gram of NaNO₂ to the sample to prepare for anion exchange. Wait at least 4 hours before continuing processing.
- 8) Proceed to the section on p. E-19 for anion-exchange separation and Pu purification procedures.

Uranium Separation.

- 1) Weigh 1 gram of prepared soil into a platinum beaker.
- 2) Add 5 ml of the mixed tracer.
- 3) Add 10 ml of conc HNO₃.
- 4) Add 10 ml of conc HF.
- 5) Heat the sample to near dryness in the acid fume scrubber.
- 6) Reconstitute the sample with an addition of 10 ml of conc HF.
- 7) Evaporate the sample to dryness.

- 8) Treat the residue with 20 ml of conc HNO_3 .
- 9) Add 20 ml of conc HClO_4 .
- 10) Heat the sample until the white fumes of HClO_4 are no longer evolved in the acid fume scrubber.
- 11) Dissolve the residue with a minimum volume of 8 M HNO_3 and 2–4 ml of 30% H_2O_2 and heat.
- 12) Transfer the sample to a 40 ml Pyrex centrifuge tube with minimum H_2O .
- 13) Proceed to the section on anion-exchange separation (using air filter resin and wash amounts), Pu, and U purification procedure.

Milk Samples

- 1) Pour 930 ml of milk into a 1-liter Marinelli beaker.
- 2) Add 20 ml formaldehyde while stirring.
- 3) Submit for gamma count.

Anion-Exchange Separation and Heavy-Element Purification Procedures

It is evident from flow charts of the various purification procedures (Fig. E-1) that, excluding the milk chemistry, each purification involves an ion exchange separation. Three different column sizes are used for ion exchange (Fig. E-4). The techniques of column preparation and ion-exchange separations are similar for all procedures, differing only in the size of the columns used and in the amounts of necessary reagents.

Resin Preconditioning.

- 1) Precondition AG 1-X8, 50–100 mesh (Cl^- form) and AG 1-X8, 100–200 (Cl^- form) mesh anion exchange resins by putting the resin in a 2-liter Buchner funnel fitted into a 4-liter filter flask, and
 - a) washing with 8 M HNO_3 (2 liters acid per liter resin),
 - b) washing with conc HCl (2 liters acid per liter resin), and
 - c) Repeatedly washing with H_2O until the eluate has a neutral pH.
- 2) Prepare anion-exchange resin for uranium purification as follows⁸:
 - a) Grade AG 1-X8, 100–200 mesh resin in a counterflow fluid grader, collecting the 30–70 mm/min fraction.
 - b) Wash about 250 ml of the resin with 2 M NaOH .
 - c) Rinse the resin with 8 liters of H_2O .
 - d) Convert the resin to sulfate form with 1 M H_2SO_4 .
 - e) Wash the resin with 4 liters of 0.06 M H_2SO_4 .

Column Loading.

- 1) Fill the column with H_2O .
- 2) Insert a glass wool plug into the bottom of the column to prevent resin loss. Eliminate any air bubbles from this plug.
- 3) Load the required amount of ion exchange resin as an H_2O slurry and allow the resin to settle.
- 4) Insert a glass wool plug into the top of the column. Eliminate any air bubbles from the plug before pressing it onto the top of the resin.
- 5) Rinse out the column with H_2O to remove any loose resin.

Anion-Exchange Separation. See Table E-2 for the appropriate volumes of reagents to be used for each particular sample type.

- 1) Extra-large columns should be used for soil samples, while large columns should be used for water and air filter samples. Load the appropriate size column with preconditioned 1-X8, 50–100 mesh (Cl^- form) anion exchange resin to a height of about 24 cm, followed by 1 cm of preconditioned AG1-X8 100–200 mesh (Cl^- form) anion-exchange resin.
- 2) Condition the column with the appropriate volume of 8 M HNO_3 .
- 3) Filter the sample through 934 AH glass-fiber filter paper onto the column and, if cesium analysis is desired, collect the eluate. The eluate from this step and that from the next step comprise the cesium fraction (proceed to the section on cesium purification and counting, p. E-17).

Figure E-4. Columns used for ion-exchange.

Table E-2. Reagent volumes used in anion exchange separations.

Sample type	Column size	8M HNO ₃ conditions step (ml)	8M HNO ₃ wash (ml)	Conc HCl wash (ml)	NH ₄ I/HCl (ml)	0.1 M HCl (ml)
air filter	large	50	50	100	80	80
water	large	50	50	100	80	—
soil	x-large	100	300	200	150	—

- 4) When the liquid has run through the column, rinse the column reservoir twice with 8 M HNO_3 ; then wash the resin with the appropriate volume of 8 M HNO_3 .
- 5) Rinse the column reservoir with conc HCl, then wash the resin with the appropriate volume of conc HCl to remove thorium contamination.
- 6) Elute plutonium with the appropriate volume of freshly prepared NH_4I -HCl solution (1.5 g NH_4I per 100 ml conc HCl). Add several ml conc HNO_3 and evaporate to dryness. Proceed to the section below for plutonium-purification processing.
- 7) Elute uranium with the appropriate volume of 0.1 M HCl and evaporate to dryness. Proceed to the section on uranium-purification processing.

Plutonium Purification and Plating.⁹

Purification:

- 1) Dissolve the residue by heating with a few milliliters of conc HCl and several drops of 30% H_2O_2 . Make sure that excess H_2O_2 has been evaporated before proceeding.
- 2) Transfer the solution to a 40-ml plastic centrifuge tube with a minimum amount of conc HCl.
- 3) Add 0.5 g of NaNO_2 . Wait at least 4 hours before continuing processing.
- 4) Cap the tube and centrifuge to remove the insoluble sodium chloride (NaCl) formed by the NaNO_2 addition.
- 5) Load a small ion exchange column to a height of about 4 cm with preconditioned Dowex 50-100 mesh anion exchange resin (Cl^- form).
- 6) Condition the resin with 20 ml of conc HCl.
- 7) Load the sample onto the column. Repeat the centrifuging and loading procedures twice.
- 8) When the liquid has run through the column, rinse the sides of the column reservoir with conc HCl, then wash the resin with 20 ml of conc HCl.
- 9) Rinse the column reservoir with 8 M HNO_3 and then wash the resin with 20 ml of 8 M HNO_3 .
- 10) Re-rinse the column reservoir with conc HCl and wash the resin with another 20 ml of conc HCl.
- 11) Elute the plutonium with 20 ml of freshly prepared NH_4I -HCl₄ solution (1.5 g NH_4I per 100 ml conc HCl).
- 12) Add several milliliters conc HNO_3 to the eluate from step 11 and evaporate to dryness.

Plating:

- 13) Assemble the electroplating cell^{9,10} (Fig. E-5).
 - a) Clean a polished 2.54-cm-diam x 0.05-cm-thick stainless-steel disc, engraved with the sample identification number.
 - b) Place the disc at the bottom of a stainless steel base to serve as the cathode.
 - c) Place a teflon washer on top of the disc and secure a labeled glass chimney in place with a teflon support, stainless steel ring, and brass wing nuts to form a watertight seal around disc.
 - d) Fill the cell with water to test for leakage.
- 14) Add 1 ml conc sulfuric acid (H_2SO_4) to the residual salts of plutonium eluate.
- 15) Heat the sample until copious white fumes are evolved.
- 16) When the sample has cooled, dilute with 2 ml of 1 M H_2SO_4 .
- 17) Add two drops of 0.1 M methyl red indicator.
- 18) Transfer the sample to the electroplating cell with a minimum volume of 1 M H_2SO_4 .
- 19) Titrate the sample to a yellow end point (pH 6.2) with conc NH_4OH .
- 20) Back titrate five drops past the red end point (pH 4.4) with 1 M H_2SO_4 .
- 21) Use a 0.064-cm-thick platinum wire, coiled at the bottom, as the anode.
- 22) Electroplate at 1.0 amp for 70-90 min.
- 23) Before completion, add 1 ml of conc NH_4OH to the cell and continue plating for one min.
- 24) As quickly as possible:
 - a) disengage the power supply;
 - b) remove the anode;
 - c) discard the solution;

Figure E-5. The plutonium electroplating cell.

- d) rinse the cell with 0.1 M NH_4OH ;
 - e) disassemble the cell;
 - f) rinse the disc with 0.1 M NH_4OH ;
 - g) rinse the disc with acetone.
- 25) Determine $^{239,240}\text{Pu}$ and ^{238}Pu on the disc by alpha spectrometry.

Uranium Purification.¹¹

- 1) Dissolve the sample in 1–2 ml conc HNO_3 with heat and transfer with water to a 50-ml glass centrifuge tube.
- 2) Add 1 ml (5 mg/ml) lanthanum carrier to all uranium samples except those that may have hydroxides present.
- 3) Make the sample basic with conc NH_4OH . Uranium is coprecipitated with the $\text{La}(\text{OH})_3$. Soil samples may contain enough iron to coprecipitate uranium with $\text{Fe}(\text{OH})_3$ in those samples.
- 4) Heat the sample in an 80°C water bath for at least five minutes.
- 5) Centrifuge and discard the supernatant liquid.
- 6) Dissolve the $\text{La}(\text{OH})_3$ (or $\text{Fe}(\text{OH})_3$) with a minimum of 1 M H_2SO_4 .
- 7) Dilute the solution to 5 ml with H_2O .
- 8) Repeat steps 3 through 7 twice.
- 9) After dissolving the $\text{La}(\text{OH})_3$ and diluting to 5 ml a third time, dilute to 15 ml with 0.06 M H_2SO_4 .
- 10) Load a small ion exchange column to a height of 2 cm with preconditioned AGI-X8, 100-200 mesh uranium anion exchange resin (sulfate form).
- 11) Condition the resin with 10 ml of 0.06 M H_2SO_4 .
- 12) Load the sample into the column.
- 13) When the liquid has run through the column, rinse the column reservoir four times with 5 ml of 0.06 M H_2SO_4 , allowing the reservoir to drain completely between rinses.
- 14) Wash the resin with 5 ml of conc HCl.
- 15) Wash the resin with 5 ml of 6 M HCl.
- 16) Elute the uranium into Savillex 15 ml round-bottom teflon vials with 10 ml of 0.1 M HCl.
- 17) Evaporate to dryness under a heat lamp.
- 18) Determine uranium in the sample by mass spectrometry.

Tritium Analysis

A flow chart illustrating sample processing procedures used in tritium analysis is shown in Fig. E-2.

Air Moisture

Reservoir Preparation.

- 1) Bake silica gel desiccant in a vacuum oven at 100°C for at least 24 hours, then cool and store in an argon atmosphere.
- 2) Fill a clean reservoir vessel (Fig. E-6, below) with silica gel in an argon atmosphere.
- 3) Plug the neck with glass wool and seal the reservoir with a stopper.

Air-Moisture-Sample Processing.

- 1) After the silica gel has been used to sample atmospheric moisture, determine the weight of the silica gel sample that is contained in the reservoir.
- 2) Mix the silica gel thoroughly to achieve homogeneity.
- 3) Remove an aliquot of about 300 cc and precisely determine its weight.
- 4) Construct the freeze-dry assembly (Fig. E-7). Caution—vacuum grease should not be used.
 - a) Attach the trap to the vacuum port with a triangle seal and three wing nuts.
 - b) Insert a coarse 11.0-cm filter paper and a 9-cm screen into the bottom of the adapter.
 - c) Attach o-rings to the neck of the adapter and the jar.

Figure E-6. The silica gel reservoir.

- d) Insert the adapter into the trap while simultaneously opening the vacuum valve. Vacuum will hold the apparatus together.
- e) Evacuate the trap and check for leaks.
- f) Fill the trap's reservoir 1/3 full with Dowanol (or equivalent).
- g) Slowly add dry ice (CO_2) chunks to the reservoir until full.
- h) Backfill the trap with argon and remove the adapter and jar.
- 5) Transfer the silica-gel aliquot to the freeze dry jar; reassemble.
- 6) Pump the assembly down, valve off, and check for leaks.
- 7) After the pressure has stabilized, envelop the jar in a heating mantle set for 100–150°C.
- 8) Continue to heat the sample for at least 24 hours. Add dry ice as needed and evacuate the freeze dry assemblies individually every two hours until the pressure stabilizes.
- 9) Backfill the trap with argon, remove the jar, and seal the opened trap end with a paraffin sheet.
- 10) Allow the silica gel to cool in a closed, tared container, and then reweigh to determine the amount of water lost.
- 11) Remove the Dowanol and dry ice from the trap, allow the foam water sample to melt, and transfer the melt water to an appropriate containers.
- 12) Determine the tritium concentration in this water by liquid scintillation spectrometry.

Water Samples

The tritium concentration in water is normally too low to permit a direct liquid scintillation or proportional beta analysis. These samples must instead undergo a preliminary distillation to remove any physical or chemical contaminants followed by an electrolytic enrichment to increase the amount of tritium relative to the sample volume.

Distillation.

- 1) Pour approximately 500 ml of the water sample into a doublenecked, round-bottom boiling flask.
- 2) Through a distillation top, attach an argon line to the side neck of the flask and assemble the water distillation apparatus (Fig. E-8).

Figure E-7. The freeze dry assembly.

Figure E-8. The water distillation apparatus.

- 3) Attach the drain and water line to the condenser and check for leaks.
- 4) Turn on the heating mantle (set for 100-110°C) and distill the entire sample.
- 5) Transfer the distilled sample from the receiving flask to a clean bottle and seal.

Enrichment.³ The enrichment assembly (Fig. E-9), consists of an iron cathode-nickel anode unit supported in a Pyrex cell by Teflon baffle plates. Additional sample is added to the cell from a top-mounted, 250-ml delivery-flask reservoir. During enrichment, the sample reservoir is under an argon atmosphere while the enrichment cell is maintained at a constant 6.0°C in a water bath. An enrichment set consists of two standards, a blank, and seven to nine samples. The enrichment procedure is carried out as follows:

- 1) Insert the electrode unit into the enrichment cell.
- 2) Add 1.5×10^{12} moles of sodium hydroxide (as 1.6 ml of 9.4 M NaOH) to the cell.

NOTE: To avoid the tritium contamination of commercial reagent-grade sodium hydroxide, tritium-free NaOH is synthesized by dissolving 1/4 lb of sodium peroxide (Na_2O_2) in 313 ml of tritium-free water. The NaOH is stored in an argon atmosphere and periodically checked via gas conversion/gas proportional counting for its tritium level.

- 3) Measure a 250-ml aliquot of the water sample.
- 4) Fill the enrichment cell to the 50-ml line and pour the remaining 200 ml of sample into the delivery flask.
- 5) Complete the enrichment cell assembly pulling the electrode wires through the cell head side-arm. Do not use grease around any ground glass joints.
- 6) Immerse the enrichment cell in the 6.0°C water bath.
- 7) Connect the electrodes to a 3-amp constant current power supply.

NOTE: The electrolysis process at 3 amps evaporates about 1 ml of solution every hour. It is therefore necessary to refill the cell to 50 ml daily. When filling the cell, connect the argon supply to the argon connection top to exclude contaminated air from the assembly. If the cell cannot be filled every day (over the weekend for example), turn the power supply down to 1 amp.

- 8) When the sample reservoir is empty (8-12 days) and the cell volume is 25 ml, electrolyze at 0.3 amp to a volume of 5-7 ml (about 10 days).
- 9) When the 5-7 ml volume is attained, disconnect the power supply, remove the enrichment assembly from the water bath, and remove the delivery flask and cell head from the enrichment cell.
- 10) Neutralize the sample by bubbling carbon dioxide through the sample. This is done to release the hydrogen that is bound in the sodium hydroxide.
- 11) Attach the enrichment cell to a vacuum through a distillation head and a preweighed receiving bulb (Fig. E-10).
- 12) Cool the bulb with dry ice/methanol and evacuate the system.
- 13) Using a heating mantle, distill the sample in the enrichment cell, periodically relieving the pressure buildup in the system by opening the vacuum valve.
- 14) At completion, allow the receiving bulb to warm to room temperature. Reweigh to determine the final volume of water.
- 15) Enriched samples are analyzed for tritium by liquid scintillation spectrometry. The computer program, SCNTCT, is used to compute the enrichment factors as part of the final calculations.

Vegetation

Vegetation samples are analyzed quarterly. They are stored in plastic bags below 0°C to prevent loss or contamination of their water content. The analysis is as follows:

- 1) Construct the freeze dry assembly (Fig. E-7), according to instructions in the previous section.
- 2) As quickly as possible—
 - a) Remove sample from the freezer, cut top of the bag open, and weigh.
 - b) Backfill the trap with argon and remove the jar and adapter.
 - c) Pack the bagged sample into the freeze dry jar.
 - d) Attach the adapter to the jar.
 - e) Attach the jar and adapter to the trap, evacuate and valve off from the vacuum pump.
 - f) Repeat for each sample.

Figure E-9. The enrichment cell assembly.

Figure E-10. Enrichment cell head and receiving bulb for vacuum distillation.

The vegetation freeze drying process takes about four days to complete. During this time dry ice must be added to the cold fingers when needed and each sample assembly must be evacuated periodically and checked for leaks.

- 3) Upon completion, remove the jar by backfilling the trap with argon and seal the trap opening with a paraffin sheet.
- 4) Remove the Dowanol and dry ice from the trap. Allow the ice sample to melt.
- 5) Reweigh the bagged vegetation sample to determine the volume of water removed.
- 6) Transfer the water sample from the trap to an appropriate sample container.
- 7) If the volume of water in the sample exceeds 10 ml, tritium can be determined by liquid scintillation spectrometry. Otherwise, it must be determined by gas proportional counting.

Milk

- 1) Put approximately 50 ml of milk into a two-ounce glass jar with lid, seal in a plastic bag and freeze.
- 2) Construct the freeze-dry assembly (Fig. E-7).
- 3) As quickly as possible—
 - a) Remove sample from the freezer, remove plastic bag and jar lid.
 - b) Put sample jar into the freeze-dry jar.
 - c) Attach the adapter to the jar.
 - d) Back fill the trap with argon and remove the freeze-dry jar and adapter.
 - e) Attach the jar and adapter to the trap, evacuate, and valve off from the vacuum pump.
 - f) Repeat for each sample.

The milk freeze-drying process takes about four days to complete. During this time, dry ice must be added to the cold fingers when needed and each sample assembly must be evacuated periodically and checked for leaks.

When complete, take down as with silica gel or vegetation, and transfer the water sample from the trap to an appropriate sample container. Tritium is determined by liquid scintillation spectrometry.

Gas Conversion

The general features of the gas conversion and counting system are described elsewhere (p. E-15). A more detailed description of laboratory facilities and procedures may be found in Refs. 5 and 6. Since the exact procedures are dependent on the equipment used, the interested reader is referred to the abovementioned sources.

Quality-Assurance Procedures

Purpose

The quality-assurance procedures of the Site Environmental Monitoring Group are designed to ensure that results of sample analyses are both accurate and reproducible. An additional objective is to be able to trace results to either stored samples or stored records. Therefore, included in "QA Procedures" are storage of samples and sample data, processing of duplicate blank and standard samples, and verification of results.

Storage of Sample Data and Results

Sample Sheets for Heavy Elements Analyses

Laboratory worksheets are maintained for all samples. When a sample is received, initial information about the sample is recorded on the sheet. Sample number, date, type, and volume or weight, as well as the date received are recorded. Any additional relevant information about the sample is also recorded. As the sample is processed, the chemical and counting procedures used are documented on the sample sheet, as are the chemist's initials and the date of the processing. Finally, any special information or unusual circumstances concerning the sample are recorded. All sample sheets for the current year are stored in the laboratory, while those from previous years are archived.

Analysis Results

Results of gamma analysis are stored on magnetic tapes. Computer printouts of gamma results generated by the gamma analysis programs GAMANAL and GRPANL are also stored for at least a full year after the analysis is completed.

Results from plutonium alpha analysis are stored on paper tape. Paper tape output containing alpha data and computer printouts containing both counting results and actual alpha spectra, all of which are generated by the alpha analysis program ALPHAQ, are stored permanently. Computer printouts containing results of uranium analysis by mass spectrometry are stored permanently. Note that multiple methods of storage are used for all sample data. In addition, all samples with the exception of those analyzed for uranium are stored permanently and may be re-counted (see the section on sample storage for information).

Sheets for Tritium Analysis

As with heavy-element analysis, laboratory worksheets are maintained for all samples analyzed for tritium. Upon receipt of a sample, sequentially numbered worksheets are filled out with preliminary sample information. Type of sample, date of receipt, originator's identification number, and any additional relevant information concerning the sample are recorded on the sample sheet. All sample sheets are filled out in duplicate; one copy remains with the sample while it is being processed, while a carbon copy is kept separately in a worksheet notebook. As the sample is processed, procedural steps are noted on the worksheets. After processing, the original copy of the samplesheet replaces the carbon copy in the worksheet notebook. Original sample sheets are stored permanently.

Storage of Results

Results of all samples analyzed, either by gas proportional counting or liquid scintillation counting, are stored in a computer file called LOG. Scintillation counting results are also stored in a separate SEMP file called SCNSTR. Computer printouts of results determined by gas counting are stored with the actual sample sheets, while two different types of printouts containing liquid scintillation results are stored separately.

Sample Storage

Heavy Elements

Whenever possible, samples that have been processed and counted are stored in their final form. This ensures that samples may be re-counted and results re-calculated if there is any doubt as to the validity of original results.

- A) Canned gamma samples, including soils, and special samples, are stored indefinitely in their gamma cans.
- B) Plated plutonium samples that have been alpha-counted are stored indefinitely.
- C) Cesium samples are stored in Prindle vials.
- D) Samples analyzed for uranium cannot be stored since the samples are evaporated completely in mass spectrometry analysis.

Tritium

Samples analyzed for tritium are stored at least until analytical results have been obtained and verified, and for as long as is practical thereafter. Some samples may be stored in their original forms (e.g., wine, honey), while others cannot be and must be stored in some processed form (e.g., vegetation). When possible, a duplicate sample is taken initially to ensure that at a later point, a "duplicate" result may be obtained if necessary (see the section on duplication of samples).

Vegetation and Silica-Gel Samples. Water collected from these samples is stored five to six months for routine samples and one year for special samples.

Milk Samples. Water collected from the freeze-drying of routine milk samples is also stored for five to six months.

Water Samples. Low-tritium water (<300 TU) is enriched prior to liquid scintillation counting, and may therefore be stored in either the unenriched and enriched forms. Unenriched water samples are stored up to six months (the limitations here are space and equipment), while enriched samples are stored up to one year. Water that is higher in tritium content (>300 TU), which is not enriched, is stored up to six months after analysis is completed.

Wine and Honey Samples. Wine and honey samples are stored in their original form for at least six months.

"QA" Samples

EML Samples

Samples are received from the EML (U.S. Department of Energy Environmental Measurements Laboratory, New York, New York) approximately every six months and are analyzed for a variety of nuclides. Types of samples analyzed include soil, water, air filters, and vegetation. The procedures used for analyzing the soil samples are identical to those described previously for routine soil samples. Procedures used in the analysis of the EML air filters, vegetation, and water samples do not, however, exactly follow the routine procedures given in that section, but require special processing as follows.

EML Air Filters. Air filters are first gamma counted in a plastic petri dish. One half of the dish is nested inside the other half, enclosing the air filter. Additional glass fiber filters are enclosed on the non-counter side to ensure that the filter to be counted is held in tightly. The entire assembly is then taped and gamma counted. After counting, the chemical procedures used follow those used for routine samples.

EML Vegetation Samples. The procedures used in processing vegetation are basically the same as those used in processing routine LLNL perimeter air filters. First, a pre-determined amount of sample is weighed out; it should contain approximately the same amount of plutonium as the tracer to be added. The

approximate amount of plutonium in the sample is indicated on the information sheet accompanying the EML samples. Tracer is added, and the sample is dried at 105°C for at least four hours and then ashed at 475°C for at least two days. The "wet ash" procedure using HNO_3/HF followed by $\text{HNO}_3/\text{HClO}_4$ (see p. E-16), is then performed twice in order to fully digest the sample.

EML Water Samples. Approximately 25 ml is removed from the 1-liter water sample, vacuum-distilled, and then three 7-ml aliquots are analyzed for tritium by liquid scintillation counting. The remaining water is analyzed for heavy elements, ordinarily only plutonium and cesium. A 200-ml aliquot is taken and diluted to 15 liters, and then analyzed according to routine procedure. A blank, containing 15 liters of deionized, distilled water, is analyzed concurrently.

Storage of EML Results. Computer printouts of all EML results are stored indefinitely. EML results are also entered into the data base ENV, in a table designated specifically for EML data.

EPA Samples

EPA water samples (U.S. Environmental Protection Agency Environmental Monitoring Systems Laboratory, Las Vegas, Nevada) are received every two months. They are analyzed only for tritium, by a direct liquid scintillation count; no distillation or enrichment is involved. Results are stored in the SEMP computer files LOG (containing all tritium analysis results) and SCNSTR (containing all scintillation count results). Computer printouts containing all scintillation count results include EPA results.

Duplication of Samples

All types of samples are duplicated periodically to ensure reproducibility of results. Some samples (i.e., vegetation and other samples analyzed by freeze-drying) are always duplicated so that an alternate sample may be run in case of a processing error.

Heavy Elements.

1) Air Filters

A duplicate sample is taken at one air filtering station every other month. Since there are six perimeter air filtering stations, and the extra sampler is moved to a different site bimonthly, all sampling stations are checked once a year.

2) Water Samples

Daily water samples are duplicated once weekly. These duplicate samples are analyzed separately.

3) Soil Samples

At least ten percent of the annual soil samples received are duplicate samples. These duplicates are analyzed with the original soil samples.

Tritium.

1) Vegetation

Vegetation is sampled quarterly, and two vegetation samples are taken at each sampling location. Duplicate samples are not routinely analyzed, although one such sample is analyzed quarterly as a QA "check."

2) Silica Gel Samples

A duplicate sample is collected and analyzed from a different station each month.

3) Water Samples

At least 10% of all water samples submitted for SEMP analysis are duplicate samples.

Internal Standards and Blanks

Heavy Elements.

1) *Air Filter* standards prepared with stock solutions of plutonium and uranium are analyzed with routine air filters every other month. Air filter blanks are included with every month's air filter samples, and are analyzed monthly with the routine samples.

2) *Water* blanks are normally analyzed every month. EML water samples, which are analyzed along with a "blank" suffice as biannual standards.

3) Soil samples analyzed annually are first gamma counted, then processed chemically. An NBS soil sample is run as a gamma standard, but is not analyzed chemically. A blank comprising "washed and ignited" sand (Mallinckrodt) is run with the routine soil samples being processed.

Tritium. Tritium standard solutions of approximately $5.5 \times 10^{-3} \mu\text{Ci/ml}$ are made at various water dilutions and serve as standards for liquid scintillation counting. Another standard solution of approximately $8.3 \times 10^{-6} \mu\text{Ci/ml}$ is made up from a stock solution, and is run with each enrichment set. This standard is also used as a gas proportional counter/liquid scintillation counter cross-check.

Dead water (<3 TU) is used as a blank for enrichment sets. Hydrogen gas is used to determine background in the gas counter.

Verification of Results

Once processing of a sample is completed, the result is checked against past results for the same type and location of sample. Any significant discrepancy here may necessitate recounting or possibly even reprocessing of the sample. The flow of sample data is also checked to ensure that no mistakes were made in transferring information.

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