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Environmental Monitoring at the Lawrence Livermore Laboratory 1979 Annual Report

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W. J. Silver, C. L. Lindeken
J. H. White, R. W. Buddemeir

April 25, 1980

Lawrence
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Laboratory

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LAWRENCE LIVERMORE LABORATORY
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214

FOREWORD

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

J. M. Bazan
E. K. Butterfield
H. C. Capwell
A. Conover
K. J. Davidson
R. J. Dupzyk
A. L. Gazlay
K. S. Griggs
R. Gunnink
D. W. Hosmer

Y. M. Kwok
J. D. Lum
M. A. Auyong
K. R. Peterson
N. H. Rogers
C. W. Sundbeck
R. D. Szidon
A. J. Toy
K. M. Wong

CONTENTS

Foreword	ii
Introduction	1
Summary	5
Monitoring Data—Collection, Analysis, and Evaluation	5
Radioactive Monitoring	5
Airborne Radioactivity	5
Radioactivity in Soil	8
Radioactivity in Sewage	9
Radioactivity in Water	12
Radioactivity in Vegetation and Foodstuffs	13
Radioactivity in Milk	13
Environmental Radiation Measurements	14
Nonradioactive Monitoring	16
Airborne Beryllium	16
Heavy Metals Released to Livermore Sanitary Sewer	17
Physical and Chemical Analysis of LLL and Site 300 Sewage	17
Noise Pollution	17
Pesticide Monitoring	17
Environmental Impact of LLL Operations	18
Radioactive Airborne Effluents	18
Radioactive Liquid Effluents	18
Quality Assurance	19
References	20
Appendix A. Tables	A-1
Appendix B. Discharge Limits to the Sanitary Sewer System of the City of Livermore	B-1
Appendix C. Environmental Activity Concentration—Guide Levels	C-1
Appendix D. Sampling and Analytical Procedures for Environmental Monitoring	D-1
Appendix E. Method of Dose Calculations	E-1

Frontispiece. Lawrence Livermore Laboratory (looking from southeast).

1. LLL	7. Arroyo Road
2. Sandia	8. East Avenue
3. South Bay Aqueduct	9. Greenville Road
4. Arroyo Seco	10. Lugin Way
5. Arroyo Las Positas	11. Interstate 580
6. Nearest residential area	

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INTRODUCTION

The Lawrence Livermore Laboratory (LLL) is located about 64 km east of San Francisco, California in the Livermore Valley of Southern Alameda County, approximately 5 km east of the city of Livermore. The site, which is 180 m above sea level, occupies a 2.54-km² area surrounded by open agricultural areas on the north, east, west, and part of the south side. Sandia Laboratories Livermore, occupies a portion of the adjoining property on the south, and the nearest residential area is 0.8 km from the Laboratory's west perimeter. Of the nearly 4.8 million people (Fig. 1) who live within 80 km of the Laboratory, 50,000 live in Livermore.

Established in 1952, the Laboratory is operated for the Department of Energy (DOE) by the University of California and currently employs approximately 7100 people. Although the research and development of nuclear weapons has always been the primary mission of LLL, additional programs include biomedical studies and both magnetic fusion and laser-fusion research. Programs to develop nonnuclear energy technologies have also been established.

Much of the Laboratory's materials testing and high-explosives diagnostic work is conducted at Site 300, 16 km southeast of Livermore. At an elevation of approximately 375 m in the sparsely populated hills of the Diablo Range, Site 300 covers an area of 27 km².

The Livermore Valley has a climate characterized by mild, rainy winters and warm, dry summers. Annual rainfall averages about 360 mm, and rains occur predominantly between November and April, usually in connection with Pacific storms. Rainfall for the 1978-1979 season (July 1, 1978 through June 30, 1979) was 301 mm; rainfall for the 1977-78 season was 448 mm, considerably above average. During the two drought periods, 1975-76 and 1976-77, rainfall totals were 138 and 196 mm, respectively. Surface water drainage from the Valley

is from east to west through various arroyos with the outfall 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 windrose pattern in Fig. 2.

The Livermore site is situated on a northwesterly sloping alluvial flood plain bordering the low hills of the Livermore Uplands to the south. The lithology of the area consists of a series of unconsolidated marine and continental sedimentary units such as sandstones, gravels, silts, and clays overlaying 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 are grapes and wine, cattle, and poultry.

Water bodies adjacent to the Laboratory include the South Bay Aqueduct, which runs from the northeast to southwest, 1.8 km to the southeast; the Patterson Pass water treatment facility, about 2 km east of LLL; and Frick Lake, 4 km north of LLL, which is dry most of the year. Aquatic recreation (boating, fishing, and swimming) is available at Lake Del Valle, about 8 km south of LLL, and at the Shadow Cliffs Recreation Area, 11 km to the west.

The Laboratory normally receives all its treated water from the Hetch Hetchy Aqueduct (which supplies San Francisco) located 11 km southwest of Livermore. Laboratory storm water is channeled through storm sewers designed to accommodate a 10-year flow. Open ditches are used in undeveloped areas of the site. Two arroyos (See Frontispiece) traverse LLL: Arroyo Seco at the southwest corner and Arroyo Las Positas, which 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

FIG. 1. Estimated population distribution by sectors within 80 km of Livermore.

Wind direction frequency (%) Livermore 1979.

Month	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	CALM
January	9.7	5.5	8.3	5.8	5.1	3.2	3.5	2.3	3.3	3.8	12.5	8.7	7.6	3.5	3.4	6.8	7.0
February	5.5	6.9	5.7	4.4	4.2	3.3	2.9	3.2	5.0	9.5	14.1	11.8	7.3	3.5	1.7	3.0	7.9
March	5.5	5.7	7.5	3.8	4.1	2.5	1.6	2.5	3.7	7.5	14.8	10.8	12.0	6.6	2.3	2.8	6.3
April	2.8	2.2	3.4	2.1	1.6	1.5	1.2	1.3	2.5	7.8	24.5	16.6	15.2	8.0	2.3	2.0	5.0
May	6.7	2.3	1.1	0.8	1.0	0.7	0.8	0.6	1.7	3.9	20.6	19.9	22.2	7.4	2.1	3.6	4.6
June	8.7	2.7	1.3	1.0	0.6	0.3	0.6	0.6	2.1	5.1	21.8	20.5	15.7	4.5	2.1	5.1	7.2
July	2.4	1.3	1.7	0	0	0	0	0.2	1.3	4.7	31.3	27.2	22.5	2.8	0.7	0.8	2.7
August	0.5	0.3	0	0.3	0	0	0.2	0.3	1.1	5.8	37.9	28.6	19.1	2.7	0.9	0.5	1.3
September	4.5	5.6	4.2	1.9	1.4	1.2	1.3	1.1	2.6	5.9	18.5	21.0	15.9	4.6	1.4	2.4	6.5
October	5.2	3.3	5.2	2.6	1.6	1.2	1.3	2.2	3.8	8.3	17.4	18.1	11.0	4.5	2.2	2.6	9.7
November	4.8	9.9	15.8	9.0	6.8	3.5	2.1	2.6	3.7	5.6	9.3	6.1	3.6	1.7	2.2	3.7	9.6
December	27.8	6.8	11.9	6.9	6.0	3.4	1.9	2.3	3.4	3.4	4.7	3.6	2.2	1.9	2.4	3.9	7.6
Annual average	7.0	4.4	5.4	3.2	2.7	1.7	1.5	1.6	2.9	5.9	19.0	16.1	12.9	4.3	2.1	3.1	6.3

FIG. 2. Average annual wind direction and speed pattern at Livermore during 1970. (Measurements are made at 40 m.)

along the north perimeter to an outlet at the northwest corner. This outlet, which also constitutes the main pathway for the Laboratory's surface drainage (storm and irrigation), runs north in a 5.7×10^{-3} -km² channel to the Western Pacific tracks, then westward where it joins Arroyo Seco. The LLL Master Site Plan calls for a small lake to be established in the center of the project. Provisions have been made for rerouting surface water drainage from the east to fill this lake during the rainy season.

Groundwater is found at depths of 15 to 30 m below the LLL site with a gradient indicating a generally westward flow. Because stream runoff is a major source of groundwater recharge, considerable attention is given to radiological monitoring of the arroyos draining the valley and to the groundwater wells west of the Laboratory. Laboratory sewage is discharged into the City of Livermore's sanitary sewer system and processed at the Livermore Water Reclamation Plant (LWRP).

During the dry season, most of the treated effluent from the LWRP is used for irrigating the Livermore golf course, the lawns of the Livermore airport, and nearby agricultural land (forage crops). The remainder is discharged to Arroyo Las Positas. During the wet season, most of the effluent is discharged to the arroyo.

The salt content of this effluent presents a problem for both local groundwater quality and that of downstream aquifers. Accordingly, as part of the Livermore-Amador Valley Wastewater Management program, a pipeline was constructed to transport wastewater out of the valley to be discharged into the San Francisco Bay. The LWRP was connected to this pipeline in February 1980.

A strict effluent control program that places maximum emphasis on controlling effluents at the source has been in effect since the Laboratory began operation. An environmental monitoring program is maintained to: (1) evaluate the effectiveness of these control measures, (2) document whether ef-

fluents from the Laboratory and Site 300 operations are within applicable standards, and (3) determine the impact of these operations on the environment. Sensitive monitoring equipment is used that can detect radioactive and nonradioactive pollutants well below environmental background levels. The program also includes the collection and analysis of air, soil, water, LLL and LWRP sewer effluents, vegetation, and milk samples. Environmental background radiation is measured at numerous locations in the vicinity of the Laboratory using gamma and neutron dosimeters.

Each spring, the Laboratory submits a report containing the results of environmental monitoring for the previous year. This report is prepared in compliance with the DOE Manual Chapter 0513, "Effluent and Environmental Monitoring and Reporting" (DOE MC 0513). Significant changes in either the scope of the program or the levels of effluents are noted.

Appendix A is a tabulation of 1979 environmental monitoring data. Because the earthquake of January 24, 1980 damaged Laboratory equipment used in some of the analyses, some of the samples collected in late 1979 could not be analyzed in time to be included in this report. 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. Error limits, when accompanying these data, reflect uncertainties in the analyses at the 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 from observed environmental levels of artificially produced radionuclides. This assessment is made by calculating the whole-body or critical-organ doses delivered to man and comparing these with the much larger radiation dose received locally from natural sources.

SUMMARY

In 1979, the annual average airborne gross beta activity in Livermore Valley air samples was $2.6 \times$

10^{-14} $\mu\text{Ci/ml}$, or less than half the average observed in 1978. There were no atmospheric nuclear shots in

1979; therefore, fission products seen in the January air filters are probably a result of residual activity from the December 14, 1978 nuclear test in China. Airborne ^{238}U concentrations at Site 300 were higher than those at Livermore because of the "depleted" uranium (a byproduct 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 annual beryllium concentrations were less than 1% of the appropriate standard at both the Laboratory perimeter and Site 300.

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. One well-water sample from Site 300 shows an above-average level of gross alpha activity. This activity has been found to be naturally occurring uranium at concentrations well within those specified in DOE MC 0524.

Tritium analyses were made on well-water samples collected near the Livermore Water Reclamation Plant (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 ground water. As was found during the 1977 and 1978 surveys, the highest tritium values were detected in wells west of the plant near Arroyo Las Positas; however all concentrations were well below the standards set by DOE.

Tritium levels found in the Livermore Valley

and Site 300 vegetation were also comparable to those observed in 1978. As a means of evaluating the possible impact of Laboratory 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 Livermore Valley wines were found to be within the range in both European wines and surface waters throughout the world and somewhat higher than those in California wines. Honey produced in the Livermore Valley contained tritium levels between the levels in Valley surface water and vegetation.

For 1979, the median annual gamma-radiation dose at the Laboratory perimeter was 61 mrem, and the median off-site background dose was 59 mrem. The difference between these values is not statistically significant. A 14-MeV neutron generator near the south perimeter continued to be a source of elevated radiation. However, by performing many of the high-flux experiments at the new rotating target neutron source facility (Building 292), the radiation dose rates at the Laboratory's south perimeter were reduced well below DOE standards.

Assessments of the calculated radiation dose to an individual from the environmental concentrations listed in this report demonstrates that the dose contribution from Laboratory operations in 1979 was small compared with the dose received locally from natural sources.

MONITORING DATA—COLLECTION, ANALYSIS, AND EVALUATION

RADIOACTIVE MONITORING

Airborne Radioactivity

Concentrations of various airborne radionuclides are measured at Laboratory perimeters, at off-site locations near the Laboratory, and at Site 300. Sampling locations are shown in Figs. 3 through 6. The 6 samplers on the Laboratory perimeter and the 10 samplers at Site 300 use

$5.2 \times 10^{-2}\text{-m}^2$ Whatman-41 cellulose filters. These samplers are operated at an average flow rate of 700 litres/min. Laboratory perimeter and Site 300 air filters are also analyzed for beryllium as part of the Laboratory's nonradioactive monitoring program. An easily dissolved filter and a low trace-metal background are requirements for these analyses. Whatman 41 represents a balance between such requirements and particulate collection efficiency.¹ Off-site samplers throughout the Livermore Valley

FIG. 3. LLL on-site environmental sampling locations.

use $4.56 \times 10^{-3} \text{ m}^2$ glass-fiber filters (Flanders F-700) and are operated at a flow rate of 80 litres/min. All air filters are changed weekly. Perimeter and Site 300 filters are cut in half, and half of each filter is retained for beryllium analysis (see "Nonradioactive Monitoring").

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 Laboratory perimeter and Site 300 filters are also counted for specific gamma-emitting radionuclides

using a Ge(Li) detector equipped with Compton suppression.² Following gamma counting, the Laboratory's perimeter filters are grouped by sampling locations. These individual samples and the Site 300 composites are analyzed for the presence of ^{239}Pu , ^{238}Pu , ^{137}Cs , ^{235}U , and ^{238}U .

Tables 1 and 2 in Appendix A show airborne gross alpha and gross beta activities for the Livermore Valley samples, and Tables 3 and 4 show corresponding activities for Site 300.

Average annual gross beta activity in both Livermore and Site 300 air samples was less than

FIG. 4. LLL off-site environmental sampling locations.

half that observed during 1978.³ There were no atmospheric nuclear shots in 1979. Tables 5 and 6 list the activities of the more abundant gamma-emitting radionuclides that contribute to the beta activity in Livermore and Site 300 samples. The fission products seen on the January air filters, which were below the limit of sensitivity during the remainder of the year, may be a result of subsequent passes of debris from the December 14, 1978 nuclear shot by the Chinese. Table 7 shows the concentration of plutonium in air filter samples collected in the Livermore Valley. Tables 8 and 9 show the concentrations of airborne ^{239}Pu , ^{137}Cs , ^{235}U , and ^{238}U in Livermore perimeter and Site 300 air samples. The higher concentration of ^{238}U at Site 300 is a result of the "depleted" uranium (a byproduct of ^{235}U enrichment) used at the Site. As noted, however, the uranium concentrations are well below the concentration guides (CG) in DOE MC 0524.

Concentrations of airborne tritiated water (HTO) were determined for each of the LLL perimeter air-sampling locations shown in Fig. 3 and at two off-site locations (S1 and S2 in Fig. 4). Water vapor was collected on silica-gel samplers that operated at a flow rate of about 0.5 litres/min for a two-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 10 shows average monthly HTO concentrations observed at each sampling location with an overall average annual concentration of $4.0 \times 10^{-11} \mu\text{Ci}/\text{ml}$. The highest HTO concentration was observed at the west site boundary, Location 13, during January. That concentration ($1.2 \times 10^{-10} \mu\text{Ci}/\text{ml}$) is less than 1/10 of 1% of the appropriate standard.

As noted, winds during the late fall and winter are quite variable. Therefore, Location 12 shows the

FIG. 5. Site 300 on-site environmental sampling locations.

highest annual average concentration, probably because this location is so close to one of the tritium effluent sources (the 14-MeV neutron generator) and because it is downwind from this facility most of the year. The average annual HTO concentration at Location 12 is about 40% lower than that observed in 1978. This reduction is a result of the transfer of many of the high-flux experiments to Building 292, located in the northwest quadrant of the Laboratory.

Radioactivity in Soil

An intensive soil-sampling program conducted in 1971 and 1972 provides a data base for the concentration range of various radionuclides in soil near the Laboratory and at Site 300. Since 1972, soil sampling in the vicinity of LLL and at Site 300 has been part of a continuing LLL surveillance program

to document any changes in environmental levels of radioactivity that may have occurred and to evaluate any increase in radioactivity that might have resulted from Laboratory operations. During 1979, 26 soil samples were collected from various locales in the Livermore Valley. Most of these sampling locations were randomly selected from a listing of locations that were sampled during the 1971-72 program. Figure 7 shows the 1979 soil-sampling location, and Fig. 8 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 the HASL acid-leaching procedure.⁴ Table 11 lists the plutonium activities observed in samples collected within the

FIG. 6. Site 300 off-site environmental sampling locations.

Livermore Valley during 1979, and Fig. 9 is a distribution plot of these activities. Table 12 shows the plutonium activities in the Site 300 samples. There were negligible changes from those observed in previous samples collected in the same locations.³

Samples 779, 780, and 781 represent a resampling of the area where elevated plutonium was reported in 1978.³ Plutonium levels in these samples, as well as in those samples collected when the area was resampled in 1978, are in the range attributable to global fallout. Sample pairs 733 and 734, and 745 and 746 were collected in the field as replicates, while samples 730A, 738A, and 746A represent duplicate aliquots taken from well mixed samples. The results suggest that most of the variability is associated with sample inhomogeneity and environmental variation rather than with the radiochemical procedures.⁵ Sample 782 in Table 12 is a resample at the location at Site 300 (See Fig. 8) where Sample 778 was collected. Analysis of sample 782 showed the plutonium to be in the range attributable to global fallout.

For gamma-spectra analysis, approximately 300-g aliquots of soil were sealed in 200-cm³, thin-

walled cans of aluminum and counted in the Ge(Li) spectrometer.² The results of the gamma-spectra analysis of Livermore Valley soil samples are shown in Table 11.

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 ²³⁵U/²³⁸U ratio of the soil. Isotopic uranium measurements were made with isotopic dilution mass spectrometry. As in the past, the analysis indicated that isotopic perturbation is essentially limited to areas adjacent to the firing bunkers.^{6,7} The isotopic uranium data shown in Table 12 are comparable to those observed during 1978. Plutonium and ¹³⁷Cs levels are also in the range found in Site 300 soil samples collected in 1978.

Radioactivity in Sewage

Liquid radioactive wastes are treated to reduce activity levels to the lowest levels practicable and well below standards in DOE MC 0524. After treatment, the liquid wastes are released into the city of

FIG. 7. Locations of soil samples collected in the Livermore Valley during 1979.

FIG. 8. Locations of soil samples collected inside the Site 300 boundary.

FIG. 9. Distribution plot of ^{239}Pu in soil samples collected in the Livermore Valley during 1979.

Livermore's sanitary sewer system at the LLL outfall shown in Fig. 3. This effluent is continuously monitored for pH and radioactivity.

Liquid wastes from Livermore's sanitary sewer system are treated at the LWRP, a 200-litre/s tertiary sewage-treatment plant that serves residential, commercial, and industrial water users in Livermore. After a primary settling process to remove solid matter, the liquid is passed through trickling filters, then through an aeration stage, and on to a final sedimentation phase. The purified sewage is then filtered through charcoal, chlorinated to kill pathogenic bacteria, and dechlorinated before being released from the plant.

During the dry season, most of the treated effluent is used for irrigating the Livermore Golf Course, the lawns of the Livermore Airport, and nearby agricultural land (forage crops). The remainder of the effluent is discharged to Arroyo Las Positas, and during the wet season most of the effluent is discharged into the arroyo. The water in Arroyo Las Positas flows into Arroyo Mocho, then into Arroyo de la Laguna, and finally into Alameda Creek. Because the LWRP effluent may contain low levels of tritium from routine LLL releases to the sanitary sewer system, tritium measurements have been made on samples collected from wells throughout the Valley, from Arroyo de la Laguna, and from aquifers in the Niles Cone area. Results of the most recent measurements are contained in this report under "Radioactivity in Water." In all cases the tritium activities are well below the DOE standards for water in uncontrolled areas.

The salt content of the treated effluent presents a problem for both local groundwater quality and that of 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 to be discharged into the San Francisco Bay. The Livermore sewage plant was connected to this pipeline in February 1980. Although the effluent will still be used for irrigation, it will no longer be discharged into the arroyo, thus eliminating the primary means of tritium migration to local and downstream groundwater.

Samples of the liquid effluent are collected daily. Table 13 compares the activity levels of certain radionuclides in the LLL effluent with those in the effluent from the LWRP. Plutonium levels in the LLL effluent in January are believed to be

associated with the treatment of a large quantity of transuranic liquid waste during the last quarter of 1978.³ Nevertheless, all plutonium concentrations are well below DOE standards 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. 3 through 6. These samples are analyzed for gross alpha and beta activities with a gas-proportional counter. Tables 14 and 15 show the gross alpha activities in Livermore Valley and Site 300 samples, respectively. Gross beta activities for Livermore and Site 300 samples are shown in Tables 16 and 17.

Livermore sampling locations 11, 16, and 24 (Fig. 4) are surface water sources (ponds, creeks, and reservoirs), and Location 20 (Fig. 2) is the collection site of Livermore rainfall. The other locations are domestic water sources. Gross alpha and beta activities in Livermore water samples collected in 1979 were below both DOE and EPA standards for drinking water.⁸

Site 300 water samples are collected from on-site wells (Fig. 4, Locations 1-7) and off-site creeks (Locations 11 and 14). Location 20 is Site 300 rainwater, and Location 21 is a spring-fed pond near Bunker 812. With the exception of samples from the rainwater and two off-site creeks, all the Site 300 samples came from deep wells and springs. Samples from Location 4 (Table 14), a well near the Site entrance, had a gross alpha level in water that exceeded the drinking water standards of DOE and EPA. Therefore, further specific analyses were performed to identify the source of the radioactivity. No radionuclides were found other than uranium. The uranium concentration was at a level well within that specified in DOE MC 0524. An alpha pulse spectroscopic analysis of the uranium isotopes showed the $^{234}\text{U}/^{238}\text{U}$ activity ratio to be typical of naturally occurring uranium; thus, the source of the uranium is not "depleted uranium" used in Site 300 operations. A ^{226}Ra measurement based on radon emanation and a ^{232}Th analysis using alpha-pulse spectroscopy showed both radionuclides to be less than 0.05 pCi/l. The low ^{226}Ra and ^{232}Th activities probably result from a relatively high pH and high carbonate content in the water of this well. Under these conditions, radium and thorium would be expected to coprecipitate with calcium as caliche, coating the grain surfaces within the aquifer.

Neither the EPA⁸ nor the State of California⁹ specify a limit for natural uranium in drinking water. In their limit for gross alpha activity, uranium is specifically excluded from the total. It should be noted that the limit for natural uranium in water specified in DOE MC 0524 (2×10^{-5} $\mu\text{Ci/ml}$) is based on the fact that the chemical toxicity of uranium as a heavy metal is greater than its toxicity as a radioactive material.

Water samples from the Livermore Valley and Site 300 are analyzed for tritium activity. Because of the low tritium activities, it was necessary to distill and electrolytically enrich the samples before liquid-scintillation counting. Tables 18 and 19 show the data for the Livermore and Site 300 samples, respectively. These data indicate that the samples exhibit concentrations that are well below recommended CG values. Tables 18 and 19 also include an estimate of the annual dose that may be delivered to an adult who consumes water containing the listed tritium concentrations. These doses, which are typically less than 0.1 mrem, are based on the dose conversion factors listed in U.S. NRC Regulatory Guide 1.109.¹⁰

As noted previously, treated effluent from the LWRP is used to irrigate nearby municipal property. During the rainy season, most of the effluent was released directly into Arroyo Las Positas. This effluent contains low levels of tritium which come from normal LLL operational releases to the sanitary sewer system. As part of a study begun in 1977,¹¹ tritium measurements are now made annually on water samples collected from neighboring wells to determine the extent of tritium migration into ground water. Many of the wells were in the immediate vicinity of the LWRP and Arroyo Las Positas; however, additional samples were also collected from areas some distance from the release points. Sampling locations are indicated in Fig. 10, and the tritium data are shown in Table 20. The highest tritium values appear in wells west of the LWRP near Arroyo Las Positas and are essentially unchanged from the activities found in 1978. Tritium activities in all samples were well below the guidelines for water in uncontrolled areas as stated in DOE MC 0524.

Radioactivity in Vegetation and Foodstuffs

Each month, vegetation samples (usually native grasses) are collected throughout the Livermore Valley, at Site 300, and at off-site locations

near Site 300, as shown in Figs. 3 through 5. These samples are freeze-dried, and the tritium activity in the recovered water is determined by liquid-scintillation counting. Table 21 shows the tritium data for vegetation collected in the Livermore Valley. The whole-body radiation doses shown were derived using the dose conversion factors in the U.S. NRC Regulatory Guide 1.109,¹⁰ assuming that the observed activities were typical of those in edible vegetation grown in the Livermore area. These potential doses are all less than 1 mrem/y.

Table 22 shows the 1979 tritium data for Site 300 vegetation. Location 6 is 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 aquifer whose outflow is in the area where Location 13 samples are routinely collected.

Beginning in 1977, as a means of evaluating the possible impact of Laboratory 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.¹¹ Wine samples collected in 1979 were catalytically oxidized to carbon dioxide and water, and the tritium content of the recovered water was measured by liquid scintillation. The data in Table 23 represent a composite of 25 samples collected in 1977 and 10 samples collected in 1979. As found in 1977, the tritium levels of the Valley wines remain within the range in both the European wines and surface waters throughout the world and somewhat higher than those California wines produced from grapes grown outside the Valley.

Samples of honey produced from a variety of flower sources in 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 liquid scintillation. The data in Table 24 show that the tritium content of these honey samples ranges between the levels found in Livermore Valley surface water and vegetation in the vicinity of the Laboratory. Thus, there appears to be no concentration of tritium activity through this food chain.

Radioactivity in Milk

During 1979, goat milk samples were obtained from several farms within about 5 km of the Laboratory. Before analysis, the samples were oven

FIG. 10. Location of groundwater samples collected in the Livermore Valley during 1978.

dried and the resultant concentrates gamma counted in a Ge(Li) system. Each vacuum-distilled sample was then analyzed for tritium activity by liquid-scintillation counting. The activities of the ^{137}Cs , ^{40}K , and ^3H in the samples are shown in Table 25. 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 litres/yr and on the models previously referenced. The only dose to an individual above 1 mrem is from naturally occurring ^{40}K .

Environmental Radiation Measurements

Quarterly, environmental radiation is measured at the 12 LLL perimeter locations (Fig. 3) and

at the 41 off-site locations (Fig. 11). 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 3 to 7 $\mu\text{R}/\text{h}$. Cosmic radiation, calculated from the local elevation and geomagnetic latitude according to the data of Lowder and Beck,¹⁴ is approximately 4 $\mu\text{R}/\text{h}$.

Table 26 shows quarterly and annual radiation doses (in mrem) derived from measured exposure rates at perimeter locations. The operation of a 14-MeV neutron generator adjacent to the south boundary fence was responsible for elevated dose rates at Location 5 on the south site boundary directly opposite this facility. However, these dose

FIG. 11. Location of TLDs in the vicinity of LLL.

rates are lower than those observed during 1978 because many high-flux experiments normally performed at this location are now being performed in Bldg. 292 in the northwest quadrant of the Laboratory.

The median annual off-site dose rate of 59 mrem (Fig. 12) is identical to that observed in 1978. Although the median annual perimeter dose rate of 61 mrem is slightly lower than the 64 mrem of 1978, this difference is not considered statistically significant. Locations 10, 11, and 12 are near a linear accelerator facility. Figure 12 shows the 1978 annual frequency distribution of environmental dose rates observed at the 41 off-site locations. The dosimeter that recorded the highest dose (92 mrem) was near an off-site industrial plant where radiography is frequently performed. Figure 13 is a dose-distribution plot combining Laboratory perimeter and off-site measurements. Doses above those typical of environmental background have been identified in the comments above or are noted in Table 26.

Environmental neutron dose-rate measurements are also made at eight locations on the LLL site perimeter using ^{235}U track-etch detectors. A detailed description of the detector and the spark-counting procedure has been published.¹⁵ Neutron monitoring locations are shown in Fig. 3. With the exception of Location 3, all levels are within the range typical of natural background (12 mrem). Location 3 monitors the ICT, and the elevated dose, 180 mrem, is a result of operations conducted within this facility.

FIG. 12. Annual off-site gamma radiation background for 1979.

FIG. 13. TLD dose-distributions plot for the LLL perimeter and Livermore Valley during 1979.

NONRADIOACTIVE MONITORING

Airborne Beryllium

Beryllium monitoring of air both in-plant and at or near LLL property boundaries has always been a part of the Laboratory's safety program. Monthly, half of every filter from the LLL perimeter and Site 300 is composited by sampling location and then wet digested. Next, the beryllium content of the solutions is determined by atomic absorption analysis.

Tables 27 and 28 show average monthly concentrations of airborne beryllium for LLL perimeter and Site 300 sampling locations, respectively. There appear to be no differences between the levels at Site 300, where beryllium is frequently expended in high-explosive experiments, and those observed at Livermore. The concentrations, which are two to three orders of magnitude below the emission standard, can be accounted for by the resuspension of surface soil containing naturally occurring beryllium. Local soils contain approximately 1 ppm of beryllium, and Livermore's air typically contains 10–100 g of particulates per cubic metre. By using a value of $50 \mu\text{g}/\text{m}^3$ for an average dust load and 1 ppm for beryllium content of this dust, an airborne beryllium concentration of $5.0 \times 10^{-5} \mu\text{g}/\text{m}^3$ can be calculated. This value is in good agreement with the data in Tables 27 and 28. These concentrations are plotted in Figs 14 and 15. Average annual concentrations are less than 1% of the appropriate standard.

Heavy Metals Released to Livermore Sanitary Sewer

As noted previously, sanitary sewage from the Laboratory is treated at the LWRP, a 200-litre/s tertiary sewage-treatment plant serving residential, commercial, and industrial users in Livermore. This effluent is continuously monitored for pH and radioactivity before it enters the Livermore sewer system.¹² Monthly, sewage samples representative of daily flow are collected and composited, and the composites analyzed for the metals shown in Table 29.

Physical and Chemical Analysis of LLL and Site 300 Sewage

Samples of Laboratory sewage effluent are collected quarterly. These samples are subjected to a variety of analyses, including biochemical oxygen demand, ammonia, nitrate, total nitrogen content, alkalinity, and total solids. Table 30 shows the data for 1972, and Table 31 shows results obtained on similar quarterly samples collected from the oxidation pond at Site 300.

Noise Pollution

As noted elsewhere, the Laboratory's high-explosive diagnostic work is conducted at Site 300. Because Site 300 is so 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. The Laboratory received no complaints regarding possible overpressures associated with Site 300 operations during 1979.

Pesticide Monitoring

Beginning in 1975, the Laboratory's environmental surveillance program was expanded to include pesticide monitoring. The pesticides used at LLL include herbicides, fungicides, and insecticides. The most probable way pesticides used at LLL could be transported to the off-site environment is by entrainment in surface runoff water. Most of this

FIG. 14. Beryllium concentration in LLL perimeter air filters during 1979.

FIG. 15. Beryllium concentration in Site 300 air filters during 1979.

surface drainage leaves the Laboratory via a ditch at the northwest corner of the property.

Samples from the ditch were collected following the first fall storm in October 1979. These samples were extracted with organic solvents, and the extracts were analyzed by gas-liquid chromatography (GLC) using a variety of detectors. Data obtained from these analyses were compared with the pesticides listed in Title 22 of the California Administrative Code.⁹ No materials were detected in the samples at concentrations exceeding the State-adopted standards for these organic chemicals.

ENVIRONMENTAL IMPACT OF LLL OPERATIONS

Radioactive Airborne Effluents

In 1979 (see Table 32), radioactive airborne effluents consisted of an estimated 383 Ci of ⁴¹Ar from Bldg. 281 (reactor), a total of 4517 Ci of tritium from Bldg. 212 (14-MeV neutron generator) and Bldg. 331 (tritium facility), and 829 Ci of ¹⁵O₂-¹³N₂ from Bldg. 194 (electron-positron linear accelerator). All radionuclides, with the exception of tritium, are short-lived. Comparative releases of radioactive effluents at Livermore during the five-year period 1975 through 1979, together with five-year averages are shown in Table 33. The decrease in ⁴¹Ar released in 1979 compared with that in 1978 is a result of the termination of LLL's participation in the National Uranium Resource Evaluation (NURE) program, and reduced use of the reactor, which is now scheduled for decommissioning in 1980. The linear accelerator (Building 194) was shut down for about 3 months in 1979, explaining the reduction in ¹³N₂-¹⁵O₂ from that of 1978.

Table 32 also contains estimated radiation doses to the public from these radioactive airborne effluents. Three dose reference points were used: 1) "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 man-rem dose within a radius of 80 km. The results indicate that the maximum estimated dose to the nearest resident was less than 1 mrem.

Dose calculations were made using a continuous point source computer code based on the Gaussian plume model.¹⁶ This code provides ratios of concentration to release rate (χ/Q) through 16, 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. This tower, located near the Laboratory's north site boundary, is equipped with sensors mounted at 10- and 40-m levels that measure wind direction, wind speed, and temperature. 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.¹⁷ 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. The release rate Q (in Ci/sec) was calculated from annual effluent data 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 nearest to the radioactivity release point, not nearest to the site boundary.) Dose estimates were based on the dose conversion factor in the U.S. NRC Regulatory Guide 1.109.¹⁰ In several cases, the estimated doses are somewhat higher than those reported in 1978, even though the radioactivity released was less. The reason for this apparent anomaly is that the computer code used in the present calculations adjusts for topography differences, whereas the code used in 1978 calculations did not.

Table 32 shows a combined population dose of man-rem from ⁴¹Ar, tritium, and activation products in Laboratory airborne effluents. This dose is based on a population of 4.8×10^6 within 80 km of the Laboratory. Using 100 mrem/y as a typical average radiation dose from natural sources, the comparable natural radiation dose the same group receives is 3.5 man-rem. By comparison, the man-rem from Laboratory operations is negligible.

Radioactive Liquid Effluents

Low-level radioactive liquid wastes are, within applicable health and safety standards, discharged into Livermore's sanitary sewer system. During 1979, the principal radionuclides released into the sewer system were 9.8×10^{-4} Ci of ²³⁹Pu and 7 Ci of HTO. Table 13 shows that the average annual concentration of these radionuclides represents $3.0 \times 10^{-3}\%$ and $2.0 \times 10^{-2}\%$ of the relevant standard, respectively. In addition, the average annual gross

beta activity of the LLL sewage effluent during 1979 was $3.4 \times 10^{-8} \mu\text{Ci}/\text{ml}$. It is assumed that this activity is caused by beta-gamma emitters, which are released into the sewer system in accordance with DOE MC 0524. Analyses of samples collected at the point of discharge show the presence of ^{134}Cs , ^{137}Cs , ^{65}Zn , ^{56}Mn , ^{60}Co , ^{95}Zr , ^{95}Nb , ^{125}Sb , and ^{110}Ag . However, even if one or more of these radionuclides were the sole source of the beta activity, none (as shown in Table 34) would account for over 0.01% of the CG value listed in DOE MC 0524.

Quality Assurance

During 1979, the Laboratory participated in the Environmental Protection Agency's interlaboratory Cross Check program and DOE's Sample Analysis Intercomparison program conducted for

DOE by the Environmental Measurements Laboratory (EML). The Laboratory also participated in the 4th International Intercomparison of Environmental Dosimeters and continued its quarterly intercomparison of thermoluminescence dosimetry measurements with EML.

A statistical summary is published annually by EML comparing the analytical performance of participating DOE contractors with measurements made by EML.¹⁸ Table 35 shows the comparison of analyses from LLL with EML for: ^{137}Cs in air, plutonium in air, soil, and water; and tritium in water. The analytical results are indicated by the ratio of LLL data to that of EML and the ratio of LLL data to the respective mean of all analyses reported.

A description of the sampling and analytical procedures used at LLL has been included as Appendix D in this report.

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APPENDIX A. TABLES

Error values that accompany individual measurements of radioactivity in the following tables are the result of counting statistics. Error values for groups of data like annual averages are calculated standard deviations of the mean (average). A 2σ error designates those errors from counting statistics, and the minimum detection limit is assumed reached when the 2σ error is $\pm 100\%$. Standard deviations of the mean are reported at the 95% confidence level.

Missing data values are indicated by NS (no sample collected) or by NA (not analyzed). Samples not analyzed were lost after collection, during processing, or before analysis. The missing values for TLD data are indicated by "lost" because the dosimeters were missing from the sampling locations at the time of collection.

TABLE 1. Gross alpha activity on air filters at the LLL perimeter and in the Livermore Valley during 1979.

	10 ⁻¹⁵ μCi/ml														
Location ^a	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average	error, %	% CG ^b
Perimeter															
01	1.0	0.6	0.7	0.6	0.4	1.3	0.6	0.7	0.8	1.3	0.6	1.9	0.9	28	4.5
02	0.9	0.8	0.7	0.7	0.5	2.0	0.6	0.7	0.8	1.6	1.0	2.8	1.1	37	5.5
12	1.3	0.5	0.9	0.7	0.6	1.4	0.9	0.6	0.9	1.7	1.3	2.7	1.1	32	5.5
13	1.0	0.6	0.5	0.5	0.4	1.0	0.5	0.6	0.6	1.2	0.9	1.8	0.8	29	4.0
14	1.3	0.4	0.3	0.6	0.4	1.2	0.5	0.6	1.2	1.6	1.1	2.9	1.0	41	5.0
15	0.9	0.5	0.6	0.5	0.4	1.0	0.5	0.7	0.9	1.2	1.0	2.0	0.8	34	4.0
Valley															
03	1.1	0.8	0.7	0.8	0.9	1.8	1.2	0.9	0.7	1.9	1.3	3.1	1.2	33	6.0
04	1.8	1.0	0.8	0.9	1.1	2.8	1.1	1.3	0.9	1.5	1.2	3.9	1.5	36	7.5
05	1.8	0.8	0.8	1.0	0.7	1.7	1.7	1.8	1.6	2.2	1.9	4.5	1.7	34	8.5
06	2.8	0.8	0.7	1.8	0.8	1.8	1.0	1.2	1.3	1.6	1.3	4.1	1.5	40	7.5
07	1.1	0.8	0.7	0.7	0.5	1.7	0.9	1.1	1.2	1.7	1.2	3.1	1.2	33	6.0
08	1.1	0.6	0.7	0.9	0.7	1.5	0.9	1.0	1.0	1.5	1.7	4.6	1.3	52	6.5
09	1.9	1.2	1.2	1.4	1.0	2.0	1.3	1.5	2.1	3.5	2.7	6.3	2.1	43	10.5
10	1.1	0.7	0.6	0.8	0.6	2.0	1.3	0.7	0.5	0.8	0.7	2.4	1.0	40	5.0
11	1.2	1.1	0.8	1.0	0.7	1.2	0.9	1.4	1.5	1.8	1.8	3.1	1.4	28	7.0
16	1.1	1.2	0.6	2.2	0.5	1.0	0.6	0.8	2.0	1.3	1.5	3.4	1.2	45	6.0
Annual average													1.2	10	6.0

^aSee Figs. 3 and 4 for sampling locations.^bConcentration guide (CG) = 2.0 E-14 $\mu\text{Ci/ml}$ for gross alpha activity in air.(All concentration guide values are from DOE MC 0524, *Standards for Radiation Protection*, unless otherwise stated.)

TABLE 2. Gross beta activity on air filters collected at the LLL perimeter and in the Livermore Valley during 1979.

	10 ⁻¹⁴ μCi/ml														
Location ^a	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average	error, %	%CG ^b
Perimeter															
01	3.3	1.8	1.9	1.7	2.0	2.4	1.3	1.3	1.9	1.8	2.3	3.1	1.7	27	1.7
02	2.5	1.9	2.7	2.0	2.3	2.5	1.6	1.5	2.2	2.3	2.2	3.3	2.4	27	2.4
12	3.2	1.7	2.3	1.8	2.2	2.2	1.3	1.5	2.0	1.9	2.5	3.7	2.2	18	2.2
13	2.8	1.7	2.1	1.6	1.9	1.8	1.2	1.1	1.6	1.7	2.0	2.7	1.9	16	1.9
14	4.0	1.7	1.8	2.0	2.2	2.4	1.6	1.4	1.9	1.9	2.9	3.8	2.3	21	2.3
15	3.0	1.7	1.9	1.6	1.5	1.9	1.3	1.3	1.6	1.7	2.2	2.9	1.9	17	1.9
Valley															
03	3.1	2.3	3.0	2.5	2.8	2.8	2.3	1.9	2.2	2.3	2.7	3.1	2.6	9	2.6
04	4.6	3.2	3.4	2.1	4.0	4.2	2.2	1.6	1.1	1.9	3.8	5.3	3.1	24	3.1
05	5.7	2.1	2.5	2.4	2.6	2.8	2.5	2.4	2.9	3.3	4.0	4.7	3.2	20	3.2
06	7.5	2.6	2.8	2.3	2.7	3.2	2.5	2.3	2.5	2.4	3.2	4.6	3.2	27	3.2
07	3.0	2.5	2.7	2.8	2.4	2.7	2.8	2.4	2.7	2.5	3.0	3.4	2.7	6	2.7
08	3.4	2.4	2.0	2.2	2.2	2.2	2.3	2.2	2.4	2.6	3.7	4.8	2.7	18	2.7
09	5.5	3.7	4.6	4.3	4.5	4.6	3.2	3.2	4.4	5.0	5.8	6.8	4.6	13	4.6
10	3.4	1.7	2.1	1.6	2.1	2.3	1.5	1.4	0.5	1.0	1.7	2.8	1.9	24	1.9
11	3.8	3.1	2.9	2.4	2.7	2.9	2.4	2.4	2.9	2.8	2.2	3.2	2.8	9	2.8
16	2.9	1.7	2.0	2.2	1.9	2.1	0.9	1.0	1.3	1.7	3.8	4.4	2.2	28	2.2
Annual average													2.6	5.0	2.6

^aSee Figs. 3 and 4 for sampling locations.^bCG = 1.0 E-12 for gross beta activity in air.

TABLE 3. Gross alpha activity on air filters at Site 300 during 1979.

Location ^a	10-15 $\mu\text{Ci}/\text{ml}$												Average	error, %	%CG ^b
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.			
01	1.1	0.4	0.7	0.3	0.6	2.1	0.7	1.3	0.9	1.2	1.4	3.5	1.2	43	6.0
02	1.0	0.5	0.7	0.4	0.4	1.2	0.6	1.2	0.9	1.9	1.8	2.6	1.1	37	5.5
03	1.1	0.7	0.8	0.9	0.7	1.3	0.9	1.6	1.3	1.4	1.2	2.6	1.2	25	6.0
04	1.2	0.5	0.6	0.7	0.6	1.4	0.8	1.2	1.7	1.3	1.7	2.7	1.2	31	6.0
05	1.0	0.4	0.6	0.6	0.6	1.2	0.6	0.5	0.8	1.2	1.5	2.3	1.0	33	5.0
07	1.3	0.5	0.7	0.5	0.5	1.1	0.6	0.8	0.7	1.0	1.5	2.0	0.9	30	4.5
08	1.1	0.5	0.8	0.5	0.4	1.3	0.6	0.6	0.9	1.4	1.4	2.1	1.0	31	5.0
09	1.1	0.6	0.6	0.9	0.9	1.1	0.6	1.5	1.3	1.4	1.8	2.5	1.2	27	6.0
10	1.1	0.5	0.6	0.5	0.6	1.5	1.0	0.7	0.8	1.6	1.4	2.7	1.1	34	5.5
11	1.4	0.5	0.7	0.5	0.6	1.0	0.6	1.1	0.6	1.3	1.3	3.3	1.1	41	5.5
Annual average													1.1	11	5.5

^aSee Fig. 5 for sampling locations.^bCG = 2.0 F-14 $\mu\text{Ci}/\text{ml}$ for gross alpha activity in air.

TABLE 4. Gross beta activity on air filters at Site 300 during 1979.

Location ^a	10-14 $\mu\text{Ci}/\text{ml}$												Average	error, %	%CG ^b
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.			
01	3.3	1.9	2.0	1.7	2.4	3.0	2.0	1.9	1.9	1.9	2.4	3.8	2.4	16	2.4
02	3.7	1.9	2.1	2.0	2.3	2.4	2.0	2.4	1.9	2.2	2.9	3.2	1.8	38	1.8
03	4.1	2.0	2.5	2.6	3.5	2.9	1.9	1.8	2.7	1.8	2.3	3.3	2.6	16	2.6
04	4.2	1.7	1.8	2.0	2.4	2.7	1.9	1.5	1.9	1.7	2.4	3.3	2.3	20	2.3
05	2.1	1.8	2.2	2.5	2.8	2.3	1.5	1.6	1.5	1.6	2.4	2.9	2.1	14	2.1
07	3.7	1.6	2.3	1.7	2.2	2.2	1.7	1.5	1.6	1.6	2.5	2.4	2.1	17	2.1
08	3.1	1.8	2.2	1.6	1.8	2.7	1.8	1.5	1.7	1.6	2.3	2.7	2.1	15	2.1
09	3.7	2.0	2.1	3.0	3.4	3.0	2.1	1.9	3.0	2.0	2.8	2.8	2.7	13	2.7
10	4.2	2.1	2.2	2.1	2.8	3.5	1.8	1.5	1.7	2.0	2.5	3.5	2.5	20	2.5
11	6.9	1.6	2.3	2.7	3.0	2.6	1.9	1.4	1.6	1.7	2.5	3.9	2.7	33	2.7
Annual average													2.3	7	2.3

^aSee Fig. 5 for sampling locations.^bCG = 1.0 F-12 $\mu\text{Ci}/\text{ml}$ for gross beta activity in air.

TABLE 5. Results of gamma-ray spectral measurements of LLL perimeter air filters during 1979.

Month	$10^{-13} \mu\text{Ci/ml} \cdot 2\sigma\%$			$10^{-16} \mu\text{Ci/ml} \cdot 2\sigma\%$		
	^7Be	^{40}K	^{106}Ru	^{125}Sb	^{137}Cs	^{144}Ce
Jan.	$1.0 \cdot 2$	$1.4 \cdot 100$	$20 \cdot 5$	$4.0 \cdot 15$	$6.9 \cdot 6$	$28 \cdot 10$
Feb.	$0.8 \cdot 2$	$1.6 \cdot 100$	$20 \cdot 16$	$4.1 \cdot 14$	$6.7 \cdot 6$	$27 \cdot 8$
Mar.	$0.8 \cdot 2$	$8.5 \cdot 19$	$24 \cdot 7$	$4.3 \cdot 11$	$8.6 \cdot 4$	$30 \cdot 6$
Apr.	$1.0 \cdot 2$	$4.0 \cdot 48$	$30 \cdot 5$	$5.9 \cdot 9$	$12.4 \cdot 4$	$37 \cdot 4$
May	$0.9 \cdot 2$	$3.0 \cdot 56$	$31 \cdot 5$	$6.5 \cdot 9$	$11.2 \cdot 4$	$34 \cdot 6$
June	$1.1 \cdot 2$	$7.0 \cdot 34$	$32 \cdot 10$	$6.9 \cdot 9$	$15.1 \cdot 5$	$41 \cdot 5$
July	$0.8 \cdot 2$	$4.0 \cdot 38$	$14 \cdot 13$	$2.9 \cdot 13$	$6.2 \cdot 5$	$16 \cdot 7$
Aug.	$0.8 \cdot 2$	$6.0 \cdot 44$	$11 \cdot 14$	$2.6 \cdot 20$	$6.1 \cdot 7$	$13 \cdot 13$
Sept.	$1.1 \cdot 2$	$5.0 \cdot 44$	$9 \cdot 15$	$2.3 \cdot 23$	$4.8 \cdot 7$	$10 \cdot 11$
Oct.	$1.0 \cdot 2$	$10.0 \cdot 18$	$8 \cdot 16$	$1.4 \cdot 26$	$3.3 \cdot 7$	$6 \cdot 16$
Nov.	$0.7 \cdot 2$	$1.7 \cdot 100$	$4 \cdot 27$	$0.7 \cdot 53$	$1.7 \cdot 23$	$3 \cdot 43$
Dec.	$1.1 \cdot 2$	$1.8 \cdot 100$	$5 \cdot 31$	$1.3 \cdot 38$	$3.3 \cdot 16$	$5 \cdot 25$
Annual average	$0.9 \text{ F-}13$	$4.5 \text{ F-}16$	$17 \text{ F-}16$	$3.6 \text{ F-}16$	$7.2 \text{ F-}16$	$21 \text{ F-}16$
error, %	8	37	34	33	32	37
CG	$4.0 \text{ F-}08$	$4.0 \text{ F-}09$	$2.0 \text{ F-}10$	$9.0 \text{ F-}10$	$5.0 \text{ F-}10$	$2.0 \text{ F-}10$
%CG	$2.3 \text{ F-}04$	$1.1 \text{ F-}05$	$8.5 \text{ F-}04$	$4.0 \text{ F-}03$	$1.4 \text{ F-}04$	$1.1 \text{ F-}03$

Note: During January, Zr-95, Ru-103, and Ce-141 were present at detectable levels; however for the remainder of the year these activity concentrations were less than the limits of sensitivity.

TABLE 6. Results of gamma-ray spectral measurements of Site 300 air filters during 1979.

Month	$10^{-13} \mu\text{Ci/ml} \cdot 2\sigma\%$			$10^{-16} \mu\text{Ci/ml} \cdot 2\sigma\%$		
	^7Be	^{40}K	^{106}Ru	^{125}Sb	^{137}Cs	^{144}Ce
Jan.	$1.1 \cdot 2$	$1.0 \cdot 100$	$28 \cdot 9$	$4.4 \cdot 11$	$8 \cdot 5$	$35 \cdot 5$
Feb.	$0.9 \cdot 2$	$0.9 \cdot 100$	$21 \cdot 6$	$4.1 \cdot 10$	$8 \cdot 4$	$29 \cdot 6$
Mar.	$1.0 \cdot 2$	$4.9 \cdot 24$	$28 \cdot 14$	$5.1 \cdot 9$	$11 \cdot 4$	$37 \cdot 4$
Apr.	$1.0 \cdot 2$	$1.6 \cdot 55$	$35 \cdot 3$	$7.1 \cdot 5$	$13 \cdot 3$	$42 \cdot 3$
May	$1.2 \cdot 2$	$2.1 \cdot 45$	$36 \cdot 3$	$7.3 \cdot 5$	$13 \cdot 3$	$41 \cdot 3$
June	$1.4 \cdot 2$	$6.0 \cdot 33$	$43 \cdot 6$	$9.6 \cdot 7$	$20 \cdot 3$	$56 \cdot 4$
July	$1.2 \cdot 2$	$3.0 \cdot 53$	$19 \cdot 10$	$4.1 \cdot 10$	$9 \cdot 4$	$23 \cdot 6$
Aug.	$1.0 \cdot 2$	$1.3 \cdot 70$	$14 \cdot 8$	$3.1 \cdot 18$	$7 \cdot 5$	$16 \cdot 11$
Sept.	$1.2 \cdot 2$	$4.0 \cdot 40$	$9 \cdot 10$	$2.3 \cdot 16$	$4 \cdot 6$	$10 \cdot 11$
Oct.	$1.0 \cdot 2$	$5.0 \cdot 20$	$7 \cdot 11$	$1.4 \cdot 19$	$3 \cdot 6$	$6 \cdot 13$
Nov.	$0.9 \cdot 2$	$1.0 \cdot 100$	$4 \cdot 26$	$0.9 \cdot 29$	$3 \cdot 8$	$5 \cdot 20$
Dec.	$0.9 \cdot 2$	$0.9 \cdot 100$	$5 \cdot 17$	$1.0 \cdot 28$	$3 \cdot 8$	$5 \cdot 18$
Annual average	$1.1 \text{ F-}13$	$2.6 \text{ F-}16$	$21 \text{ F-}16$	$4.2 \text{ F-}16$	$9 \text{ F-}16$	$25 \text{ F-}16$
error, %	9	41	37	38	35	39
CG	$4.0 \text{ F-}08$	$4.0 \text{ F-}09$	$2.0 \text{ F-}10$	$9.0 \text{ F-}10$	$5.0 \text{ F-}10$	$2.0 \text{ F-}10$
%CG	$2.8 \text{ F-}03$	$6.5 \text{ F-}06$	$1.1 \text{ F-}03$	$4.7 \text{ F-}05$	$1.8 \text{ F-}04$	$1.3 \text{ F-}03$

Note: During January, Ru-103 and Ce-141 were present at detectable levels; however for the remainder of the year these activity concentrations and Zr-95 activity concentrations were less than the limits of sensitivity.

TABLE 7. ^{239}Pu concentrations on air filters in the Livermore Valley during 1979.

Location ^a	10 ⁻¹⁷ $\mu\text{Ci}/\text{ml}$												Average	error, %	%CC ^b
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.			
04	1.5	1.3	1.3	1.4	2.4	4.0	1.2	1.1	0.8	0.6	0.4	0.3	1.4	43	2.3 E-02
10	1.5	1.2	1.1	1.9	1.6	2.7	1.3	0.7	0.4	0.3	0.2	0.4	1.1	39	1.9 E-02
16	1.4	0.9	1.2	1.5	1.8	1.9	0.7	1.4	0.9	0.4	0.4	1.1	1.1	25	1.9 E-02

^aSee Fig. 4 for sampling locations.^bCC = 6.0 E-14 $\mu\text{Ci}/\text{ml}$ for ^{239}Pu (soluble) activity in air.

TABLE 8. Plutonium, cesium, and uranium concentrations on LLL perimeter air filters during 1979.

Month	Location ^a	10 ⁻¹⁷ $\mu\text{Ci}/\text{ml}$ · 2 σ %	10 ⁻² · 2 σ %	10 ⁻¹⁵ $\mu\text{Ci}/\text{ml}$ · 2 σ %	10 ⁻² · 2 σ %	10 ⁻⁷ $\mu\text{g}/\text{m}^3$ · 2 σ %	10 ⁻⁵ $\mu\text{g}/\text{m}^3$ · 2 σ %	10 ⁻³ · 2 σ %
		^{239}Pu ^b	^{238}Pu / ^{239}Pu	^{137}Cs	^{239}Pu / ^{137}Cs	^{235}U	^{238}U	^{235}U / ^{238}U
Jan.	01	0.9 · 12	5.0 · 55	0.8 · 5	1.2 · 13	1.9 · 2	2.8 · 2	6.9 ± 1
	02	0.8 · 17	5.0 · 70	0.7 · 6	1.2 · 18	4.1 · 2	5.9 · 2	7.1 ± 1
	12	1.7 · 10	4.0 · 46	0.6 · 5	2.7 ± 11	3.7 · 2	5.5 · 2	6.7 ± 1
	13	2.6 · 9	1.4 · 65	0.5 · 5	5.0 ± 10	1.8 · 1	2.6 · 1	7.0 ± 1
	14	1.1 · 13	3.0 · 65	0.8 · 4	1.4 · 14	1.7 · 2	2.7 · 1	6.4 ± 2
	15	0.7 · 14	NA	0.6 · 5	1.1 · 15	1.8 · 1	2.6 · 1	7.0 ± 1
Feb.	01	0.9 · 12	4.0 · 55	0.7 · 6	1.4 · 13	1.7 · 1	2.5 · 1	6.8 ± 1
	02	0.8 · 13	2.0 · 85	0.7 · 6	1.2 · 14	4.0 · 1	5.7 · 1	7.0 ± 1
	12	1.1 · 12	4.0 · 60	0.6 · 5	1.8 · 13	4.0 · 1	6.1 · 1	6.6 ± 1
	13	0.9 · 12	7.0 · 46	0.6 · 6	1.5 · 13	1.8 · 1	2.6 · 1	6.9 ± 1
	14	0.9 · 14	6.0 · 57	0.7 · 6	1.3 · 15	1.4 · 2	2.2 · 1	6.2 ± 1
	15	0.7 · 14	3.0 · 90	0.6 · 5	1.2 · 15	1.6 · 1	2.4 · 1	6.7 ± 1
Mar.	01	0.8 · 15	5.0 · 65	0.7 · 4	1.1 · 16	1.5 · 2	2.2 · 1	6.9 ± 1
	02	1.1 · 16	8.0 · 60	0.9 · 4	1.2 · 16	2.8 · 2	4.0 · 2	7.2 ± 1
	12	1.1 · 15	3.0 · 85	0.8 · 4	1.3 · 16	5.3 · 2	7.7 · 2	7.0 ± 1
	13	0.9 · 16	4.0 · 80	0.7 · 4	1.4 · 16	1.5 · 2	2.1 · 2	7.2 ± 1
	14	1.0 · 17	4.0 · 90	0.7 · 4	1.4 · 17	1.3 · 1	1.9 · 1	6.5 ± 1
	15	0.8 · 14	5.0 · 60	0.7 · 4	1.1 · 15	1.9 · 2	2.8 · 1	7.0 ± 1
Apr.	01	1.8 · 18	NA	1.1 · 4	1.6 · 18	2.7 · 2	6.0 · 1	4.6 ± 1
	02	1.3 · 18	5.0 · 80	1.2 · 4	1.1 · 18	2.9 · 2	5.5 · 2	5.3 ± 1
	12	1.5 · 17	7.0 · 60	1.1 · 4	1.3 · 17	5.6 · 2	9.7 · 2	5.9 ± 1
	13	1.3 · 19	4.0 · 90	1.0 · 3	1.3 · 19	2.3 · 2	4.4 · 2	5.2 ± 1
	14	1.8 · 12	4.0 · 50	1.2 · 3	1.5 · 12	2.2 · 2	4.6 · 2	4.8 ± 1
	15	1.4 · 14	3.0 · 70	1.0 · 4	1.4 · 15	2.5 · 2	4.9 · 2	5.2 ± 1
May	01	1.5 · 10	5.0 · 44	1.1 · 3	1.4 · 10	3.7 · 2	5.1 · 2	7.3 ± 1
	02	1.4 · 10	2.0 · 70	1.3 · 3	1.1 · 10	4.0 · 2	5.6 · 1	7.2 ± 1
	12	1.3 · 10	3.0 · 60	1.2 · 3	1.1 · 10	6.5 · 1	9.3 · 1	7.1 ± 1
	13	1.3 · 10	1.1 · 90	1.1 · 3	1.2 · 10	2.5 · 2	3.6 · 2	7.2 ± 1
	14	1.9 · 7	6.0 · 26	1.2 · 3	1.6 · 8	2.6 · 2	3.7 · 1	7.1 ± 1
	15	1.3 · 9	1.1 · 80	1.1 · 3	1.2 · 9	3.3 · 2	4.7 · 2	7.2 ± 1
June	01	2.0 · 11	8.0 · 38	1.6 · 4	1.3 · 12	6.9 ± 1	9.6 ± 1	7.3 ± 1
	02	1.7 · 13	2.0 · 74	1.6 · 4	1.1 · 14	6.4 ± 1	9.1 ± 1	7.1 ± 1
	12	1.9 · 13	3.0 · 72	1.5 · 5	1.3 · 14	8.8 ± 2	13.1 ± 1	6.8 ± 1
	13	1.6 · 12	3.0 · 61	1.3 · 4	1.2 ± 13	4.3 ± 2	6.0 ± 1	7.2 ± 1
	14	6.0 · 7	9.0 · 18	1.5 · 3	4.0 ± 8	5.7 ± 2	8.0 ± 1	7.1 ± 1
	15	1.6 · 12	3.0 · 18	1.3 · 7	1.2 · 14	5.9 ± 2	8.2 ± 1	7.3 ± 1

TABLE 8. (Continued.)

Month	Location ^a	10 ⁻¹⁷ $\mu\text{Ci/ml}$ · 2 σ %	10 ⁻² · 2 σ %	10 ⁻¹⁵ $\mu\text{Ci/ml}$ · 2 σ %	10 ⁻² · 2 σ %	10 ⁻⁷ $\mu\text{g/m}^3$ · 2 σ %	10 ⁻⁵ $\mu\text{g/m}^3$ · 2 σ %	10 ⁻³ · 2 σ %
		²³⁹ Pu ^b	²³⁸ Pu/ ²³⁹ Pu	¹³⁷ Cs	²³⁹ Pu/ ¹³⁷ Cs	²³⁵ U	²³⁸ U	²³⁵ U/ ²³⁸ U
July	01	0.9 · 14	8.0 · 45	0.5 · 6	1.7 · 15	4.1 · 2	5.8 · 2	7.1 · 1
	02	0.8 · 14	2.0 · 85	0.6 · 4	1.3 · 14	3.8 · 2	5.3 · 1	7.2 · 1
	12	0.8 · 11	6.0 · 44	0.6 · 4	1.5 · 12	6.5 · 2	9.2 · 2	7.1 · 1
	13	0.6 · 13	4.0 · 60	0.6 · 4	1.1 · 14	3.1 · 2	4.4 · 2	7.2 · 1
	14	4.2 · 5	11.0 · 13	0.7 · 4	6.4 · 6	4.0 · 2	5.7 · 2	7.1 · 1
	15	0.7 · 11	5.0 · 47	0.6 · 6	1.2 · 13	4.5 · 2	6.4 · 2	7.1 · 1
Aug.	01	0.9 · 18	9.0 · 60	0.6 · 4	1.5 · 18	7.9 · 2	11.1 · 2	7.2 · 1
	02	0.8 · 18	· 1.0 · 100	0.7 · 4	1.1 · 18	4.0 · 2	5.6 · 2	7.2 · 1
	12	1.4 · 14	5.0 · 59	0.6 · 4	2.3 · 15	8.2 · 2	11.7 · 1	7.1 · 1
	13	0.6 · 21	· 2.0 · 100	0.5 · 8	1.2 · 22	2.7 · 2	3.8 · 2	7.3 · 1
	14	5.2 · 8	13.0 · 19	0.6 · 4	9.0 · 9	6.2 · 2	8.7 · 2	7.2 · 1
	15	0.5 · 23	· 1.0 · 100	0.6 · 5	0.9 · 24	4.8 · 2	6.8 · 2	7.1 · 1
Sept.	01	0.9 · 16	8.0 · 55	0.6 · 8	1.6 · 18	6.5 · 3	9.3 · 3	7.2 · 2
	02	0.6 · 25	· 4.0 · 100	0.7 · 14	0.8 · 29	5.1 · 2	7.1 · 2	7.3 · 1
	12	2.8 · 10	9.0 · 31	0.6 · 8	4.7 · 13	9.7 · 2	13.7 · 2	7.2 · 1
	13	0.5 · 22	7.0 · 82	0.5 · 6	1.0 · 23	3.9 · 2	5.4 · 2	7.2 · 1
	14	3.6 · 7	11.0 · 19	0.5 · 7	6.9 · 10	4.8 · 2	6.7 · 1	7.2 · 1
	15	0.6 · 18	· 2.0 · 100	0.5 · 7	1.3 · 19	4.4 · 2	6.2 · 2	7.2 · 1
Oct.	01	1.2 · 12	7.0 · 44	0.4 · 6	3.1 · 13	4.3 · 2	6.1 · 2	7.1 · 1
	02	0.5 · 18	4.0 · 91	0.5 · 7	1.2 · 19	5.2 · 2	7.4 · 2	7.2 · 1
	12	2.6 · 8	12.0 · 21	0.4 · 7	6.5 · 11	8.9 · 2	12.6 · 2	7.1 · 1
	13	0.5 · 18	4.0 · 93	0.4 · 6	1.1 · 19	3.7 · 2	5.1 · 2	7.3 · 1
	14	0.6 · 14	6.0 · 56	0.4 · 6	1.4 · 15	3.8 · 2	5.4 · 2	7.1 · 1
	15	2.1 · 9	11.0 · 24	0.4 · 5	5.1 · 10	3.5 · 2	4.9 · 2	7.2 · 1
Nov.	01	0.6 · 18	4.0 · 86	0.3 · 14	2.2 · 23	2.2 · 2	3.5 · 2	6.5 · 1
	02	0.6 · 23	· 3.0 · 100	0.3 · 10	2.4 · 25	3.2 · 4	4.8 · 3	6.7 · 3
	12	2.7 · 11	7.0 · 35	0.3 · 12	10.0 · 16	5.4 · 2	7.9 · 2	6.9 · 1
	13	2.4 · 30	NA	0.2 · 8	10.0 · 31	2.1 · 2	3.0 · 2	6.9 · 1
	14	0.7 · 16	12.0 · 47	0.4 · 9	1.6 · 18	2.3 · 2	3.5 · 2	6.7 · 1
	15	0.5 · 19	6.0 · 78	0.2 · 11	2.0 · 22	2.4 · 2	3.6 · 2	6.9 · 1
Dec.	01	0.8 · 16	5.0 · 74	0.4 · 7	1.9 · 17	2.6 · 2	3.9 · 2	6.9 · 1
	02	0.5 · 21	7.0 · 79	0.4 · 6	1.3 · 22	3.0 · 2	4.4 · 2	6.8 · 1
	12	1.8 · 11	11.0 · 32	0.5 · 5	4.0 · 12	6.9 · 2	10.3 · 2	6.8 · 1
	13	0.5 · 19	12.0 · 56	0.4 · 6	1.2 · 20	2.6 · 2	4.2 · 2	6.2 · 1
	14	0.5 · 21	22.0 · 47	0.4 · 2	1.6 · 21	2.5 · 2	3.7 · 2	6.8 · 1
	15	0.5 · 18	· 2.0 · 100	0.3 · 6	1.5 · 19	3.0 · 2	4.3 · 1	7.0 · 1

Annual averages

Location ^a	10 ⁻¹⁷ $\mu\text{Ci/ml}$			10 ⁻¹⁵ $\mu\text{Ci/ml}$			10 ⁻⁷ $\mu\text{g/m}^3$			10 ⁻⁵ $\mu\text{g/m}^3$		
	²³⁹ Pu ^b	· error, %	%CG ^c	¹³⁷ Cs	· error, %	%CG ^d	²³⁵ U	· error, %	%CG ^e	²³⁸ U	· error, %	%CG ^f
01	1.1	23	1.8 E-02	0.7	30	1.5 F-04	5.8	33	2.0 E-05	5.7	30	3.8 F-04
02	0.9	24	1.5 E-02	0.8	29	1.6 F-04	4.0	15	2.1 E-05	5.9	14	3.9 F-04
12	1.7	22	2.8 E-02	0.7	29	1.5 E-04	6.6	17	3.5 E-05	8.7	20	5.8 E-04
13	1.1	37	1.8 E-02	0.7	29	1.3 F-04	2.7	19	1.4 E-05	3.9	18	2.6 E-04
14	2.3	49	3.8 E-02	0.8	27	1.5 E-04	3.2	30	1.7 E-05	4.8	27	3.2 E-04
15	1.0	32	1.7 E-02	0.7	29	1.3 F-04	3.3	23	1.7 E-05	4.8	22	3.2 E-04

^aSee Fig. 3 for sampling locations.^bIn all tables, activity listed as ²³⁹Pu includes activity due to the ²⁴⁰Pu isotope.^cCG = 6.0 E-14 $\mu\text{Ci/ml}$ for ²³⁹Pu (soluble) activity in air.^dCG = 5.0 E-10 $\mu\text{Ci/ml}$ for ¹³⁷Cs (insoluble) activity in air.^eCG = 1.9 $\mu\text{g/m}^3$ for ²³⁵U (insoluble) activity in air.^fCG = 15.0 $\mu\text{g/m}^3$ for ²³⁸U (insoluble) activity in air.

TABLE 9. Plutonium, cesium, and uranium concentrations on air filters at Site 300 during 1979.

Month	10 ⁻¹⁷ $\mu\text{Ci}/\text{ml}$ · 2 $\sigma\%$	10 ⁻² · 2 $\sigma\%$	10 ⁻¹⁵ $\mu\text{Ci}/\text{ml}$ · 2 $\sigma\%$	10 ⁻² · 2 $\sigma\%$	10 ⁻⁷ $\mu\text{g}/\text{m}^3$ · 2 $\sigma\%$	10 ⁻⁵ $\mu\text{g}/\text{m}^3$ · 2 $\sigma\%$	10 ⁻³ · 2 $\sigma\%$
	239Pu	238Pu/239Pu	137Cs	239Pu/137Cs	235U	238U	235U/238U
Jan.	1.4 · 6	3.0 · 22	0.8 · 2	1.8 · 6	4.2 · 1	14.1 · 2	3.0 · 1
Feb.	1.1 · 7	2.6 · 28	0.7 · 1	1.6 · 7	1.9 · 2	4.9 · 2	3.8 · 1
Mar.	1.2 · 6	1.5 · 31	0.8 · 1	1.5 · 6	3.4 · 1	12.8 · 1	2.7 · 1
Apr.	1.7 · 6	1.8 · 23	1.3 · 1	1.3 · 6	3.4 · 1	9.2 · 1	3.7 · 1
May	2.0 · 3	2.5 · 12	1.4 · 2	1.4 · 4	3.4 · 1	5.8 · 1	5.9 · 1
June	2.4 · 6	2.7 · 21	1.6 · 1	1.5 · 6	6.1 · 1	11.8 · 1	5.2 · 1
July	1.1 · 5	2.2 · 23	0.8 · 2	1.4 · 5	4.3 · 1	7.1 · 1	6.0 · 1
Aug.	1.1 · 6	2.3 · 31	0.8 · 2	1.4 · 6	4.1 · 1	6.7 · 1	6.1 · 1
Sept.	0.7 · 7	2.2 · 34	0.5 · 3	1.6 · 8	5.9 · 1	11.2 · 1	5.3 · 1
Oct.	0.6 · 6	2.9 · 25	0.4 · 4	1.8 · 8	5.2 · 1	10.1 · 1	5.2 · 1
Nov.	0.7 · 7	2.2 · 35	2.5 · 2	2.6 · 7	3.8 · 1	10.0 · 1	3.9 · 1
Dec.	2.8 · 5	3.2 · 15	2.8 · 3	1.0 · 6	4.4 · 1	12.6 · 1	3.5 · 1
Annual average	1.4 E-17		0.8 E-15		4.2 E-07	9.7 E-05	
· error, %	28		33		16	18	
CG	6.0 E-14		5.0 E-10		1.9 E+00	1.5 E+01	
%CG	2.3 E-02		1.6 E-04		2.2 E-05	6.5 E-04	

TABLE 10. Tritium (HTO) in air at the LLL perimeter and in the Livermore Valley during 1979.

Location ^a	10 ⁻¹¹ μ Ci/ml												Average	error, %	%CG ^b	Calculated ^c adult whole body dose, mrem
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.				
Perimeter																
01	3.7	3.9	4.0	3.2	3.9	3.0	4.9	4.7	3.4	2.0	2.7	10.0	3.8	19	1.9 E-02	4.8 E-02
02	6.9	5.9	3.8	3.1	5.1	4.1	2.7	3.4	3.7	2.5	7.4	7.2	4.6	19	2.3 E-02	5.8 E-02
12	6.5	5.8	5.0	4.5	9.4	8.1	6.8	4.3	5.5	5.0	6.0	4.6	6.1	17	3.0 E-02	7.7 E-02
13	12.0	9.9	3.4	2.3	2.2	2.8	2.5	2.1	3.3	1.7	3.3	4.8	3.8	34	1.9 E-02	4.8 E-02
14	3.3	5.5	4.5	3.8	4.5	7.7	6.9	3.3	5.2	3.4	5.3	3.8	4.8	14	2.4 E-02	6.1 E-02
15	3.2	5.7	4.0	3.2	3.1	3.8	3.8	2.6	3.1	2.1	4.3	3.7	3.4	19	1.7 E-02	4.3 E-02
Valley																
S1	3.0	2.6	2.3	2.4	3.0	2.5	4.8	3.3	2.6	0.6	2.2	2.7	2.6	17	1.3 E-02	3.3 E-02
S2	3.6	3.5	3.5	2.6	3.0	4.1	2.9	1.5	2.9	1.3	3.1	NS	2.8	18	1.4 E-02	3.5 E-02
Annual average													4.0	8	2.0 E-02	5.1 E-02

^aSee Figs. 3 and 4 for sampling locations.^bCG = 2.0 E-07 $\mu\text{Ci}/\text{ml}$ for tritium (HTO) in air.^cDoses are calculated using the methods in U.S. NRC Regulatory Guide 1.109 unless otherwise stated.

TABLE 11. Concentrations of various radionuclides in the Livermore Valley soil samples during 1979.

Location ^a	Sampling depth, cm	$\mu\text{Ci/dry g} \pm 2\sigma$			$\mu\text{g/dry g} \pm 2\sigma$	
		²³⁹ Pu (10-9)	⁴⁰ K (10-3)	¹³⁷ Cs (10-7)	²³² Th	²³⁸ U
726	0-5	11.3 · 7	1.3 · 7	0.7 · 19	6.4 · 11	2.0 · 70
727	0-5	2.6 · 11	0.9 · 13	0.5 · 13	7.5 · 9	1.7 · 37
728	0-5	2.7 · 11	1.4 · 12	2.3 · 7	7.3 · 10	3.8 · 26
729	0-5	6.7 · 7	1.2 · 10	4.4 · 4	4.9 · 10	2.4 · 37
730 ^h	0-5	1.5 · 12	1.1 · 9	0.3 · 24	3.9 · 10	2.4 · 21
731	0-5	9.5 · 6	1.1 · 10	0.7 · 14	6.1 · 9	3.9 · 19
732	0-5	3.0 · 9	1.0 · 9	0.6 · 17	5.5 · 15	2.1 · 42
733	0-5	8.5 · 6	1.7 · 10	4.9 · 5	5.3 · 13	2.6 · 25
734	0-5	7.6 · 6	1.4 · 9	3.6 · 5	6.0 · 11	2.5 · 36
735	0-5	2.8 · 9	1.1 · 12	1.3 · 10	4.8 · 13	2.0 · 100
736	0-5	3.3 · 9	1.7 · 9	1.8 · 8	7.0 · 8	2.9 · 22
737	0-5	3.5 · 9	0.8 · 10	2.0 · 7	4.0 · 12	2.1 · 32
738 ^b	0-5	2.8 · 9	0.9 · 13	1.6 · 8	4.5 · 12	1.7 · 25
739	0-5	2.4 · 8	0.6 · 9	1.9 · 7	3.7 · 15	1.0 · 41
740	0-5	2.2 · 8	0.9 · 9	0.8 · 14	4.8 · 15	2.0 · 53
741	0-5	15.5 · 4	1.4 · 7	7.7 · 4	6.0 · 11	3.0 · 90
742	0-5	3.0 · 6	1.2 · 6	1.8 · 22	6.0 · 11	2.1 · 41
743	0-5	1.8 · 7	1.6 · 7	1.1 · 14	6.7 · 13	3.0 · 66
744	0-5	0.5 ± 24	1.8 · 7	0.4 · 34	6.5 · 12	3.0 · 56
745	0-5	3.9 · 6	1.0 · 8	1.6 · 9	5.0 · 15	1.6 · 41
746 ^h	0-5	2.3 · 8	1.0 · 6	1.0 · 12	5.7 · 13	2.0 · 60
747	0-5	1.1 · 11	1.2 · 12	0.5 · 20	6.0 · 15	0.9 · 100
748	0-5	5.6 · 6	1.2 · 16	2.8 · 7	6.7 · 14	2.0 · 38
779 ^c	0-5	0.7 ± 18	1.4 · 16	0.5 · 18	5.3 · 12	2.3 · 33
780 ^c	0-5	6.2 · 8	1.7 · 4	3.6 · 5	6.1 · 9	3.0 · 98
781 ^c	0-5	1.8 · 13	1.2 · 18	1.0 · 12	5.9 · 11	2.5 · 25

^aSee Fig. 7 for sampling locations.^bReplicate ²³⁹Pu analysis results from aliquots of these samples are as follows:

730A 1.4 E-09 · 12%

738A 2.7 E-09 · 9%

746A 2.8 E-09 · 11%.

^cThese samples represent a resampling of the Patterson Pass region.

TABLE 12. Plutonium, cesium, and uranium concentration in Site 300 soil samples during 1979.

Location ^a	Sampling depth, cm	$\mu\text{Ci/dry g} \pm 2\sigma$		$\mu\text{g/dry g} \pm 2\sigma$	
		²³⁹ Pu (10-9)	¹³⁷ Cs (10-7)	²³⁵ U (10-2)	²³⁸ U
749	0-5	3.6 ± 6	2.0 · 8	1.5 · 2	2.1 · 2
750	0-5	6.0 ± 5	3.5 · 7	1.2 · 2	1.7 · 2
751	0-5	7.1 · 7	3.7 · 6	1.2 · 2	1.7 · 2
752	0-5	0.3 · 32	0.2 · 67	1.8 · 2	2.9 · 2
753	0-5	3.2 · 10	1.4 · 10	3.7 · 1	14.0 · 2
754 ^b	0-5	2.0 ± 12	1.2 · 10	1.7 · 2	2.4 · 1
755	0-5	4.3 · 9	2.2 · 7	1.3 · 2	2.0 · 1
756	0-5	5.1 · 9	2.6 · 7	1.3 · 2	1.9 · 1
757	0-5	4.4 · 11	3.1 · 7	37.6 · 1	195.0 · 2
758	0-5	4.3 · 8	2.4 · 6	1.5 · 2	2.2 · 2
759	0-5	7.1 · 7	4.3 · 5	1.3 · 2	2.0 · 1
778 ^b	0-5	40.0 ± 4	5.3 · 4	1.4 · 2	2.7 · 2
782 ^c	0-5	11.8 · 7	4.0 · 5	1.4 · 2	2.5 · 2

^aSee Fig. 8 for sampling locations.^bReplicate ²³⁹Pu analysis results from aliquots of these samples are as follows:

754A 1.9 E-09 · 12%

778A 37.0 E-09 · 5%.

^cSample 782 is a replicate sample taken from the same location as sample 778.

TABLE 13. Comparison of various radionuclides
in LLL and Livermore Water Reclamation Plant effluents during 1979.

	HTO, $\mu\text{Ci/ml}$		^{137}Cs , $\mu\text{Ci/ml} \cdot 2\sigma\%$		^{239}Pu , $\mu\text{Ci/ml} \cdot 2\sigma\%$	
	10-5	10-6	10-10	10-11	10-9	10-12
Month	LLL	LWRP	LLL	LWRP	LLL	LWRP
Jan.	0.5	0.8	15.1 $\cdot$ 4	2.0 $\cdot$ 86	17.9 $\cdot$ 6	17.0 $\cdot$ 9
Feb.	0.3	0.7	3.4 $\cdot$ 8	2.0 $\cdot$ 85	1.8 $\cdot$ 4	4.8 $\cdot$ 17
Mar.	0.4	0.6	7.7 $\cdot$ 5	7.0 $\cdot$ 28	2.2 $\cdot$ 7	5.0 $\cdot$ 23
Apr.	0.7	0.8	7.4 $\cdot$ 6	6.0 $\cdot$ 30	5.9 $\cdot$ 6	1.2 $\cdot$ 36
May	1.1	1.4	NA	10.0 $\cdot$ 47	0.9 $\cdot$ 5	0.5 $\cdot$ 60
June	2.2	2.2	NA	7.0 $\cdot$ 25	1.6 $\cdot$ 6	33.0 $\cdot$ 10
July	0.5	0.9	6.7 $\cdot$ 7	7.0 $\cdot$ 18	2.5 $\cdot$ 5	1.9 $\cdot$ 16
Aug.	2.3	3.6	5.1 $\cdot$ 12	7.0 $\cdot$ 23	0.8 $\cdot$ 5	1.3 $\cdot$ 23
Sept.	3.5	1.7	3.3 $\cdot$ 8	6.0 $\cdot$ 19	0.4 $\cdot$ 4	1.7 $\cdot$ 19
Oct.	0.9	4.7	5.6 $\cdot$ 4	7.0 $\cdot$ 20	0.7 $\cdot$ 5	0.7 $\cdot$ 43
Nov.	8.9	6.0	11.7 $\cdot$ 3	17.0 $\cdot$ 12	1.1 $\cdot$ 6	3.3 $\cdot$ 18
Dec.	3.0	2.5	5.7 $\cdot$ 6	16.0 $\cdot$ 14	0.3 $\cdot$ 5	2.8 $\cdot$ 22
Annual average	2.0 E-05	2.2 E-06	7.2 E-10	7.8 E-11	3.0 E-09	6.1 E-12
$\cdot$ error, %	69	47	33	34	95	91
CG	1.0 E-01	3.0 E-03	4.0 E-04	2.0 E-05	1.0 E-04	5.0 E-06
%CG	2.0 E-02	7.3 E-02	1.8 E-04	3.9 E-04	3.0 E-03	1.2 E-04

TABLE 14. Gross alpha activity in water samples from the Livermore Valley during 1979.

Location ^a	Number of samples	10 ⁻⁹ μ Ci/ml			$\pm$ error, %	%CG ^b
		Maximum	Minimum	Average		
11	4	3.3	0.3	2.0	65	6.8
13	6	2.5	0.3	1.3	55	4.3
15	4	2.1	0.3	1.2	79	4.1
16	4	4.5	0.3	1.8	106	5.9
19	4	2.3	0.3	1.0	87	3.5
20	3	5.0	0.3	1.9	175	6.5
24	4	3.6	0.4	1.8	92	5.9
26	4	1.9	0.3	0.9	71	3.1
29	4	1.9	0.1	0.6	138	2.1

^aSee Fig. 4 for sampling locations.^bCG = 3.0 E-08 μ Ci/ml for gross alpha in water.

TABLE 15. Gross alpha activity in water samples from Site 300 during 1979.

Location ^a	Number of samples	10 ⁻⁹ μ Ci/ml			$\pm$ error, %	%CG ^b
		Maximum	Minimum	Average		
01	4	3.9	0.4	2.3	71	7.7
02	4	5.3	0.7	3.0	72	10.0
03	4	11.2	0.2	3.9	129	13.0
04 ^c	3	80.2	2.6	32.3	150	108.0 ^c
05	4	4.5	0.5	2.6	63	8.7
06	4	4.5	0.2	1.7	119	5.7
07	4	5.0	0.2	2.5	105	8.3
11	3	5.2	0.4	2.3	130	7.7
14	2	7.0	0.2	3.6	200	12.0
20	2	2.2	1.0	1.6	79	5.3
21	2	0.7	0.3	0.5	91	1.7

^aSee Figs. 5 and 6 for sampling locations.^bCG = 3.0 E-08 μ Ci/ml for gross alpha activity in water.^cSpecific analyses of these samples demonstrate that all the activity is due to naturally occurring uranium, for which the concentration guide value is 2.0 E-05 μ Ci/ml.

TABLE 16. Gross beta activity in water samples from the Livermore Valley during 1979.

Location ^a	Number of samples	10 ⁻⁹ μ Ci/ml			± error, %	%CG ^b
		Maximum	Minimum	Average		
11	4	12.0	2.6	6.7	66	2.2
13	5	6.2	0.9	2.7	71	0.9
15	4	7.0	0.3	3.9	71	1.3
16	4	14.2	4.8	8.5	50	2.8
19	4	5.0	0.8	3.6	53	1.2
20	3	21.3	1.2	8.0	168	2.7
24	4	8.4	5.1	6.5	23	2.2
26	4	15.1	3.2	7.8	72	2.6
29	4	8.0	2.1	5.1	58	1.7

^aSee Fig. 4 for sampling locations.^bCG = 3.0 E-07 μ Ci/ml for gross beta activity in water. The CG for ⁹⁰Sr is used for these analyses.

TABLE 17. Gross beta activity in water samples from Site 300 during 1979.

Location ^a	Number of samples	10 ⁻⁹ μ Ci/ml			± error, %	%CG ^b
		Maximum	Minimum	Average		
01	4	6.3	5.2	5.7	9	1.9
02	4	10.6	3.5	8.2	40	2.7
03	4	30.0	9.0	14.7	69	4.9
04	3	29.4	16.7	21.0	40	7.0
05	4	11.8	7.1	10.0	21	3.3
06	4	6.5	4.2	5.7	18	1.9
07	4	20.4	8.5	12.0	47	4.0
11	3	9.9	2.9	7.0	60	2.3
14	2	9.7	6.0	7.9	47	2.6
20	2	6.0	5.5	5.8	10	1.9
21	2	15.2	12.0	13.6	24	4.5

^aSee Figs. 5 and 6 for sampling locations.^bCG = 3.0 E-07 μ Ci/ml for gross activity in water. The CG for ⁹⁰Sr is used for these analyses.

TABLE 18. Tritium (HTO) in water samples from the Livermore Valley during 1979.

Location ^a	Number of samples	10 ⁻⁷ $\mu\text{Ci}/\text{ml}$			error, %	%CG ^b	Calculated adult whole body dose, mrem
		Maximum	Minimum	Average			
11	4	1.4	1.2	1.3	7	4.3 E-03	1.0 E-02
15	4	1.4	1.2	1.4	8	4.7 E-03	1.0 E-02
16	4	3.0	1.7	2.3	27	7.7 E-03	1.8 E-02
19	4	1.3	0.3	0.9	48	3.0 E-03	6.9 E-03
20	6	25.6	3.0	11.6	57	3.9 E-02	8.9 E-02
24	4	2.7	1.9	2.4	15	8.0 E-03	1.8 E-02
26	4	3.1	2.9	3.0	4	1.0 E-02	2.3 E-02
29	4	1.3	1.1	1.2	7	4.0 E-03	9.2 E-03
30	10	1.6	1.2	1.4	5	4.7 E-03	1.1 E-02

^aSee Fig. 4 for sampling location.^bCG = 3.0 E-03 $\mu\text{Ci}/\text{ml}$ for tritium (HTO) in water.

TABLE 19. Tritium (HTO) in water samples from Site 300 during 1979.

Location ^a	Number of samples	10 ⁻⁸ $\mu\text{Ci}/\text{ml}$			error, %	%CG ^b	Calculated adult whole body dose, mrem
		Maximum	Minimum	Average			
01	4	4.5	2.6	3.4	25	1.1 E-03	2.6 E-02
02	3	5.5	4.1	4.8	17	1.6 E-03	3.6 E-02
03	4	4.0	2.5	3.2	23	1.1 E-03	2.4 E-02
04	3	4.8	3.1	3.9	26	1.3 E-03	3.0 E-02
05	4	6.5	4.0	5.4	20	1.8 E-03	4.2 E-02
06	4	4.5	1.2	3.1	45	1.0 E-03	2.4 E-02
07	4	5.2	3.1	4.6	22	1.5 E-03	3.5 E-02
11	3	6.4	4.5	5.5	20	1.8 E-03	4.2 E-02
14	2	12.0	7.5	9.8	46	3.3 E-03	7.5 E-02
20	6	22.5	0.8	8.3	78	2.8 E-03	6.3 E-02
21	2	4.2	4.2	4.2	1	1.4 E-03	3.2 E-02

^aSee Figs. 5 and 6 for sampling locations.^bCG = 3.0 E-03 $\mu\text{Ci}/\text{ml}$ for tritium (HTO) in water.

TABLE 20. Tritium (HTO) in groundwater samples from the Livermore Valley during 1979.

Location ^a	Well identification	Well depth, m	Activity [9-6 $\mu\text{Ci/ml}$]	%CG ^b
1	3S/1E-01P2	15	3.12	1.0 E-01
2	3S/1E-02P3	116	0.04	1.3 E-03
3	3S/1E-02R1	10	2.74	9.1 E-02
4	3S/1E-07B2	46	0.02	6.5 E-04
5	3S/1E-09G1	49	0.67	2.2 E-02
6	3S/1E-10A2	27	1.29	4.3 E-02
7	3S/1E-11J1	63	0.55	1.8 E-02
8	3S/1E-11H1	92	0.11	3.7 E-03
9	3S/1E-12C1	82	0.16	5.3 E-03
10	3S/1E-12D2	14	2.25	7.5 E-02
11	3S/1E-12G1	27	1.05	3.5 E-02
12	3S/1E-12H1	104	0.19	6.3 E-03
13	3S/1E-14F1	82	0.30	1.0 E-02
14	3S/1E-16H2	29	0.16	5.3 E-03
15	3S/1E-22D2	22	0.05	1.7 E-03
16	3S/2E-01P2	44	0.07	2.3 E-03
17	3S/2E-03K3	18	0.09	3.0 E-03
18	3S/2E-10Q1	13	0.20	6.7 E-03
19	3S/2E-11A1	20	0.18	6.0 E-03
20	3S/2E-14A1	36	0.18	6.0 E-03
21	3S/2E-14B4	79	0.07	2.3 E-03
22	3S/2E-22B1	17	0.25	8.3 E-03

^aSee Fig. 10 for sampling locations.

^bCG = 3.0 E-03 $\mu\text{Ci/ml}$ for tritium (HTO) in water.

TABLE 21. Tritium (HTO) in vegetation samples collected in the Livermore Valley during 1979.

Location ^a	Number of samples	10 ⁻⁶ μ Ci/ml, water recovered			error, %	Calculated adult whole body dose, mrem
		Maximum	Minimum	Average		
04	10	1.5	0.5	0.9	23	8.0 E-02
15	12	3.0	1.2	1.7	25	1.5 E-01
16	10	0.9	0.2	0.7	17	6.0 E-02
20	9	3.4	0.8	1.4	36	1.3 E-01
21	10	1.7	0.9	1.2	13	1.1 E-01
22	12	2.8	0.7	1.5	27	1.3 E-01
23	5	17.8	1.7	5.8	104	5.2 E-01
29	11	4.5	0.7	2.3	30	2.0 E-01
30	12	2.1	0.7	1.3	19	1.1 E-01
31	12	3.8	0.8	1.9	27	1.7 E-01

^aSee Fig. 4 for sampling locations.

TABLE 22. Tritium (HTO) in vegetation samples collected from Site 300 during 1979.

Location ^a	Number of samples	10 ⁻⁷ μ Ci/ml, water recovered			error, %	Calculated whole body dose, mrem
		Maximum	Minimum	Average		
01	11	12.3	4.1	6.8	20	6.1 E-02
02	10	7.0	3.5	5.0	18	4.5 E-02
03	12	7.8	2.9	5.8	14	5.2 E-02
05	9	16.1	2.0	6.7	40	6.0 E-02
06	10	26.8	4.9	10.1	39	9.0 E-02
11	5	6.1	1.0	4.4	41	3.9 E-02
12	12	17.5	1.9	7.3	31	6.5 E-02
13	5	230.0	3.3	51.9	172	4.6 E-01

^aSee Figs. 5 and 6 for sampling locations.

TABLE 23. Tritium (HTO) in wine samples.^a

Location	Number of samples	10 ⁻⁶ μ Ci/ml, water recovered			+ error, %
		Maximum	Minimum	Average	
Livermore Valley	16	0.69	0.10	0.42	16
California ^b	11	0.16	0.07	0.11	16
Europe	8	2.67	0.11	1.11	69

^aSamples represent vintages ranging from 1967 to 1978.^bExcluding the Livermore Valley region.TABLE 24. Tritium (HTO) concentration in honey samples collected in the Livermore Valley.^a

Number of samples	10 ⁻⁶ μ Ci/ml, water recovered			+ error, %
	Maximum	Minimum	Average	
7	0.79	0.31	0.48	28

^aThe samples include honey from 1978 and 1979 production years, and include the following varieties: mixed flower, starthistle, cream of wildflower, safflower, mustard, eucalyptus, and fall wildflower.

TABLE 25. Concentration of various radionuclides in milk samples from the Livermore Valley during 1979.

	10 ⁻⁷ μ Ci/ml	10 ⁻⁶ μ Ci/ml	10 ⁻⁹ μ Ci/ml
	HTO	40K	137Cs
Number of samples	31	31	31
Maximum	9.3	2.1	7.1
Minimum	2.1	1.3	0.8
Average	5.4	1.6	3.6
+ error, %	10	4	14
Calculated adult whole body dose, mrem	1.8 E-02	20.3	8.0 E-02

TABLE 26. Environmental radiation measurements (TLD) at the LLL perimeter during 1979.

Location ^a	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Annual ^b
1	15	17	15	13	60
2	16	15	16	14	61
3	16	15	15	15	61
4	15	16	15	15	61
5 ^c	36	23	23	14	96
6	15	16	16	15	62
7	14	15	14	13	56
8	13	15	14	14	56
9	14	16	15	13	58
10	16	16	17	16	65
11	18	18	17	15	68
12	18	16	18	15	67
Average	15.5	15.9	15.6	14.4	61.4

^aSee Fig. 3 for sampling locations.

^bTLD measurements in the off-site vicinity of the Laboratory (Fig. 11) have a median annual background of 59 mrem. However, subtracting this value from the data above to estimate the contribution from Laboratory operations yields several negative contributions; thus, demonstrating that background levels at various perimeter locations cannot be represented by a single value.

^cNeutron dose measurements at location 5 indicate an additional annual dose of 80 mrem. The seven other neutron monitoring locations (see Fig. 3) indicate an annual average neutron dose of 12 mrem.

TABLE 27. Concentration of beryllium on air filters at the LLL perimeter during 1979.

Location ^a	10 ⁻⁵ µg/m ³												Average	error, %
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		
01	1.3	1.7	1.6	1.7	3.8	3.6	2.7	1.7	4.9	1.3	1.6	1.8	2.3	29
02	1.9	1.6	1.8	1.5	2.4	3.1	2.4	1.5	3.0	1.5	2.3	2.2	2.1	15
12	1.5	1.8	1.8	1.6	2.9	3.3	5.3	3.3	5.3	5.4	1.7	5.5	3.3	30
13	1.4	1.6	1.6	1.6	1.2	1.7	2.5	1.5	1.7	1.4	1.7	1.8	1.6	11
14	1.5	1.9	1.8	1.3	1.1	2.8	3.7	2.8	4.2	1.2	2.4	2.4	2.3	25
15	1.4	1.5	1.5	1.5	1.2	3.1	2.6	1.6	3.2	1.2	1.6	1.8	1.8	22
Average	1.5	1.7	1.7	1.5	2.1	2.9	3.2	2.1	3.7	2.0	1.9	2.6	2.2	12
error, %	11	6	6	7	44	19	30	32	30	68	16	46		
% standard ^b	0.15	0.17	0.17	0.15	0.21	0.29	0.32	0.21	0.37	0.20	0.19	0.26	0.22	

^aSee Fig. 3 for sampling locations.^bEmission standard is 0.01 µg/m³, Federal Register, April 6, 1973.

TABLE 28. Concentration of beryllium on air filters at Site 300 during 1979.

Location ^a	10 ⁻⁵ µg/m ³												Average	error, %
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		
01	1.1	1.1	1.1	0.9	1.2	2.0	1.2	1.7	1.4	3.0	1.3	1.7	1.5	23
02	1.1	1.2	1.1	1.0	1.2	2.9	2.4	2.0	1.3	3.6	1.5	1.4	1.7	28
03	2.0	2.2	2.1	1.9	2.2	2.5	3.8	2.4	3.4	3.2	2.4	2.6	2.6	14
04	2.6	2.1	2.7	1.5	2.2	2.6	2.1	2.5	3.1	1.8	2.2	2.3	2.3	11
05	1.4	1.5	1.3	1.3	4.5	5.5	4.4	2.3	3.4	3.8	1.5	1.5	2.7	33
07	1.5	1.5	1.6	1.3	1.7	1.8	1.6	1.9	1.8	1.5	1.8	1.8	1.6	6
08	1.4	1.6	1.9	1.3	1.4	2.0	1.4	1.5	1.8	1.4	1.8	1.7	1.6	8
09	1.9	2.1	2.0	1.6	2.5	1.9	1.3	2.9	3.5	1.6	1.5	1.4	2.0	19
10	1.9	1.6	3.3	2.9	1.9	6.9	2.3	2.1	5.4	1.6	1.9	1.8	2.8	35
11	6.3	1.6	1.5	1.3	3.2	4.1	1.6	1.9	1.8	1.6	2.0	2.1	2.4	35
Average	2.1	1.7	1.9	1.5	2.0	3.2	2.2	2.1	2.7	2.3	1.8	1.8	2.1	9
error, %	46	15	24	24	38	34	32	2	30	27	13	14		
% standard ^b	0.21	0.17	0.19	0.15	0.20	0.32	0.22	0.21	0.27	0.23	0.18	0.15	0.21	

^aSee Fig. 5 for sampling locations.^bEmission standard is 0.01 µg/m³, Federal Register, April 6, 1973.

TABLE 29. Monthly average concentrations of various elements in the LLL liquid effluent during 1979.

Month	Cd	Cr	Cu	Fe	Pb	Ni	Ag	Zn	F
Jan.	0.02	0.36	3.6	7.3	0.04	0.12	0.22	0.98	0.12
Feb.	0.01	0.16	1.0	2.0	0.06	0.02	0.12	0.29	0.18
Mar.	0.02	0.65	3.7	4.5	0.05	0.09	0.35	0.84	NA
Apr.	0.01	0.60	2.3	3.3	0.03	0.07	0.25	0.56	0.13
May	0.01	0.47	2.6	3.1	0.16	0.09	0.01	0.64	0.12
June	0.01	0.35	2.1	1.9	0.10	0.07	0.01	0.67	0.10
July	0.01	0.28	2.3	2.5	0.05	0.06	0.01	1.16	0.11
Aug.	0.01	0.28	4.7	2.1	0.03	0.12	0.02	0.71	0.11
Sept.	0.01	0.16	3.6	1.7	0.22	0.08	0.23	0.60	0.10
Oct.	0.01	0.19	3.4	2.8	0.10	0.13	0.05	0.70	0.04
Nov.	0.01	0.33	2.5	1.9	0.07	0.09	0.01	0.57	0.07
Dec.	0.01	0.28	0.90	0.45	0.08	0.02	0.01	0.41	0.12
Average	0.01	0.34	2.7	2.8	0.08	0.08	0.14	0.68	0.11
± error, %	19	27	24	36	40	25	60	20	19

TABLE 30. Results of physical and chemical examinations of LLL sewage effluent during 1979.

Analysis	mg/l					
	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Average	± error,
BOD	NA ^a	54	49	102	63	49
COD	NA	208	187	267	221	22
Total nitrogen (as N)	36	27	32	39	34	15
Ammonia nitrogen (as N)	28	21	27	31	27	16
Nitrate nitrogen (as N)	NA	0.07	0.01	0.04	0.04	87
Nitrite nitrogen (as N)	0.02	0.002	0.01	0.01	0.01	71
Oil and grease (T.M.)	5	11	10	9	9	30
Sulfate	67	41	73	87	67	29
Arsenic	0.002	0.002	0.002	0.0005	0.002	45
Boron	0.9	0.72	1.0	0.9	0.9	17
Cyanide	NA	0.97	0.19	0.28	0.5	99
Mercury	0.12	0.001	0.001	0.002	0.03	198
Selenium	0.0005	0.0005	0.0005	0.0005	0.0005	
Total alkalinity	128	96	110	116	113	12
Total phosphorus (as P)	5.9	3.0	4.3	5.2	4.6	27
Chloride	30	37	32	94	48	64
Phenols	NA	0.007	0.031	0.056	0.031	91
Calcium	11	10	16	15	13	25
Magnesium	1.5	1.2	1.8	5.1	2.4	75
Sodium	32	35	28	72	42	48
Potassium	19	16	17	27	20	25
Sodium (as % of cations)	55	60	47	63	56	12
Total solids	221	323	288	452	321	30
Dissolved solids	NA	234	211	376	274	38
Suspended solids	NA	104	66	89	86	26
Volatile solids	62	167	119	170	130	39
Settleable solids (ml./hr.)	NA	3.0	3.5	5	3.8	32
Identifiable chlorinated hydrocarbons	1.0S	1.0S	1.0S ^b	1.0S ^b		-
PCB (ppb)	0.10	0.2	0.10	0.4	0.2	71

^aSample analyses for BOD, COD, nitrate nitrogen, cyanide, phenols, and dissolved, suspended, and settleable solids were inadvertently not performed.

^bException is 0.6 ppb of technical chlordane (1.0S ± 0.05 ppb).

TABLE 31. Results of physical and chemical examinations of the Site 300 sewage pond influent during 1979.

Analysis	mg/l					error, %
	Jan.-Mar. ^a	Apr.-June ^a	July-Sept. ^a	Oct.-Dec. ^a	Average	
BOD	113	1076	762	17	492	134
COD	262	15600	10838	249	6737	115
Total nitrogen (as N)	17	364	213	15	152	111
Ammonia nitrogen (as N)	13	44	25	5.1	22	77
Nitrate nitrogen (as N)	0.5	0.1	0.1	0.04	0.19	111
Oil and grease (F&M)	32	515	1615	5	542	139
Sulfate	148	140	23	440	188	94
Arsenic	0.002	0.033	0.004	0.0068	0.011	132
Boron	1.6	1.3	1.9	6.2	2.8	84
Cyanide	0.012	0.01	0.001	0.001	0.006	97
Mercury	0.005	0.008	0.001	0.0001	0.004	92
Selenium	0.0005	0.0005	0.0005	0.0005	0.0005	
Total alkalinity	123	617	480	993	553	65
Total phosphorus	5.1	55.2	44	8.6	28	90
Chloride	102	132	84	365	171	77
Phenols	0.11	0.12	0.12	0.01	0.09	60
Total solids	883	7547	10407	2682	5380	81
Dissolved solids	753	1100	1110	2527	1373	57
Suspended solids	73	3440	9943	50	3377	138
Volatile solids	200	5809	8128	420	3639	109
Settleable solids (ml 1 hr)	0.1	486	680	0.1	292	118
Copper	0.03	1.9	0.72	0.01	0.67	132
Nickel	0.05	0.21	0.15	0.07	0.12	62
Zinc	0.21	5.9	2.0	0.01	2.0	135
Chromium	0.02	0.5	0.45	0.04	0.25	103

^aSamples were collected immediately upstream from the oxidation pond inlet. Waste concentrations are elevated because of improper mixing at point of collection.

TABLE 32. Estimated radiation dose to the public from LLL airborne effluents during 1979.

Nuclide	Facility	Curies	Dose at ^a site boundary, mrem	Dose to nearest ^a resident, mrem	Dose within ^a 80-km radius of LLL, man-rem
⁴¹ Ar	Livermore pool type reactor	383	3.0	0.61	3.72
³ H	Tritium facility	4069	0.72	0.57	2.4
³ H	Insulating core transfer accelerator	436	0.37	0.31	0.25
¹³ N- ¹⁵ O	Electron-positron linear accelerator	829	1.05	0.28	0.08
Total annual dose, man-rem					3.45

^aDoses were calculated using CPS, the atmospheric diffusion code, with a correction for topography. The 1979 annual arithmetic average λ , Q values and the calculational methods in the U.S. NRC Regulatory Guide 1.109 were used to determine the doses to the public.

TABLE 33. Radioactive effluent releases from LLL from 1975 through 1979.

Year	Airborne effluents, Ci			Liquid effluents, Ci	
	⁴¹ Ar	³ H	¹³ N- ¹⁵ O	HTO	²³⁹ Pu
1975	595	3384	1185	38	2.1 E-04
1976	470	3991	1035	10	1.5 E-04
1977	380	5210	990	13	3.6 E-04
1978	766	5362	1445	9	8.6 E-04
1979	383	4517	829	7	9.8 E-04
Average	519	4492	1095	15	5.1 E-04

TABLE 34. Percent of concentration guide of radio-nuclides detected in discharges to Livermore's sanitary sewer system.

Nuclide ^a	Concentration guide, ^b μ Ci/ml	CG
¹³⁴ Cs	3 E-04	1.1 E-02
¹³⁷ Cs	4 E-04	8.5 E-03
¹¹⁰ Ag	9 E-04	3.8 E-03
¹²⁵ Sb	3 E-03	1.1 E-03
⁹⁵ Nb	3 E-03	1.1 E-03
⁵⁶ Mn	4 E-03	8.5 E-04
⁶⁵ Zn	3 E-03	1.1 E-04
⁹⁵ Zr	2 E-03	1.8 E-04
⁶⁰ Co	1 E-03	3.4 E-04

^aAssuming each nuclide was the sole source of the annual average gross beta activity of 3.4 E-08 μ Ci/ml in the discharges.

^bFrom DOE Manual Chapter 0524, Annex A, Table L Col. 2.

TABLE 35. Summary of various analyses for the Quality Assurance Program during 1979.^a

Isotope	Media	Quarter	LLL	EML	All ^b	LLL/EML	LLL/All
¹³⁷ Cs	Air	1	NS	NS	NS		
		2	1.60	1.32	1.31	1.21	1.22
		3	3.15	3.47	3.24	0.91	0.97
		4	1.68	1.30	1.41	1.29	1.19
²³⁹ Pu	Air	1	5.50	5.30	5.76	1.04	0.95
		2	6.50	6.40	6.78	1.02	0.96
		3	2.75	2.43	2.67	1.13	1.03
		4	5.95	6.00	6.16	0.99	0.97
²³⁹ Pu	Soil	1	7.10	8.10	7.10	0.88	1.00
		2	1.80	1.88	1.80	0.96	1.00
		3	4.60	6.00	5.49	0.77	0.84
		4	1.50	1.35	1.42	1.11	1.06
³ H	Water	1	1.34	1.24	1.24	1.08	1.08
		2	2.49	2.45	2.40	1.02	1.04
		3	3.16	3.04	3.07	1.04	1.03
		4	1.39	1.34	1.46	1.04	0.95
²³⁹ Pu	Water	1	1.85	2.30	1.85	0.80	1.00
		2	5.40	9.00	5.84	0.60	0.92
		3	7.70	8.10	8.10	0.95	0.95
		4	NS	NS	NS		

^aAll of the values shown are relative, i.e. the exponents are not included, and therefore do not indicate total activity or concentration levels.

^bThe "All" designation refers to all participating laboratories (including LLL and EML) which performed similar analyses, excluding only those values considered by EML to be statistical outliers.

APPENDIX B. DISCHARGE LIMITS TO THE SANITARY SEWER SYSTEM OF THE CITY OF LIVERMORE

Sections 18.63 and 18.66 of the Code of the City of Livermore (1959) state the discharge limits for Livermore's sanitary sewer system. These limits are as follows:

Section 18.63

No person shall discharge, or cause to be discharged, except for salt waste discharge from water softener units of any kind or description installed and in operation on or before January 31, 1966, which are regenerated by the owner thereof at the place of use of such units, any of the following described water or wastes to any public sewer unless the customer obtains a permit from the city in accordance with Section 18.65.

- (a) Any liquor or vapor having a temperature higher than one hundred fifty degrees Fahrenheit.
- (b) Any waters or wastes which contain more than two hundred ppm of fat, oil or grease that is petroleum ether soluble.
- (c) Any gasoline, benzene, naphtha, fuel oil or other inflammable or explosive liquid, solid or gas.
- (d) Any garbage, except properly ground with a mechanical garbage grinder. 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.
- (e) Any ashes, cinders, sand, mud, straw, shavings, metal, glass, rags, feathers, tar, coal tar, asphalt, cement, plastics, woods, paunch manure or any other solid viscous substance capable of causing obstruction to the flow in sewers or other interferences with the proper economical operation of the sewage works.
- (f) Any wastes or water with a pH lower than six and eight-tenths or higher than eight.
- (g) Any waters or wastes containing total dissolved solid increments greater than three hundred and twenty-five ppm, nor chloride increments greater than seventy-five ppm, increase during a single cycle use of the water supply.
- (h) Any water or wastes having a B.O.D. greater than three hundred ppm (the average B.O.D. for residential users).
- (i) Any waters or wastes containing more than three hundred ppm of suspended solids (the average suspended solids for residential users).
- (j) Any waters intended to be used or used to dilute waste discharge to avoid violation of the above limitation (Order No. 586, paragraph I).

Section 18.66

No person shall discharge or cause to be discharged any radioactive wastes into any public sewers, except where:

A. The waste is discharged in strict conformity with current Atomic Energy Commission recommendations for safe disposal of radioactive wastes.

B. The discharging of radioactive waste will not cause injury to personnel or damage to the sewer works. Any person discharging a radioactive waste to a public sewer in accordance with the provisions of the preceding paragraph shall submit to the council such report as the council may deem necessary.

In the event of an accidental spill of any radioactive material into the public sewer, the person responsible shall (a) immediately notify the plant superintendent, and (b) render such technical or other assistance to the department of public works within his power to prevent the sewage works from becoming contaminated with radioactivity.

APPENDIX C. ENVIRONMENTAL ACTIVITY CONCENTRATION—GUIDE LEVELS

The standards for Radiation Protection (DOE Manual Chapter 0524, issued March 3, 1977) 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)	$6 \times 10^{-12} \mu\text{Ci/ml}$
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 the Laboratory. Chapter 0524 of the ERDA Manual 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 D

Lawrence Livermore Laboratory

SAMPLING AND ANALYTICAL PROCEDURES FOR
ENVIRONMENTAL MONITORING AT LAWRENCE
LIVERMORE LABORATORY

C. L. Lindeken, K. M. Wong, G. L. Seibel,
and K. S. Griggs

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This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the laboratory. Prepared for U. S. Department of Energy under contract No. W-7405 Eng-48

CONTENTS

Abstract	D-5
Introduction	D-5
Air Sampling	D-5
Collection	D-6
Identification	D-6
Replication	D-7
Soil Sampling	D-7
Collection	D-7
Identification	D-7
Replication	D-8
Water Sampling	D-8
Collection	D-8
Identification	D-8
Replication	D-8
Sewage Sampling	D-8
Collection	D-9
Identification	D-9
Replication	D-9
Vegetation Sampling	D-9
Collection	D-10
Identification	D-10
Replication	D-10
Milk Sampling	D-10
Air Analysis	D-10
Gross Alpha and Beta Counting	D-10
Gamma Counting	D-11
^{238}Pu , ^{239}Pu	D-11
^{137}Cs	D-12
^{235}U , ^{238}U	D-12
HTO	D-12
Beryllium	D-13
Soil Analysis	D-13
Gamma Counting	D-13

238Pu, 239Pu	D-14
235U, 238U	D-14
Water Analysis	D-14
Gross Alpha and Beta Activity	D-14
HTO	D-15
Sewage Analysis	D-15
Gross Alpha and Beta Radioactivity	D-15
Tritium	D-15
239Pu, 137Cs, and 90Sr	D-15
Nonradioactive Metals and Fluorides	D-17
Fluoride Measurements	D-18
Vegetation Analysis	D-16
References	D-19

SAMPLING AND ANALYTICAL PROCEDURES FOR ENVIRONMENTAL MONITORING AT LAWRENCE LIVERMORE LABORATORY

ABSTRACT

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

INTRODUCTION

Written procedures have been prepared for each environmental monitoring activity at Livermore as part of the quality assurance program developed for environmental monitoring at Lawrence Livermore Laboratory (LLL). 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 of this report describe the sampling procedures used for each sample medium monitored. A general description of each medium is usually provided. This is followed by the collection procedure used, provisions for sample identification, and a schedule for sample replication.

The "Analysis" sections of this report cover sample analysis. 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 LLL to measure the concentration of airborne particulate radioactivity, beryllium, and tritiated water. Samplers placed at 6 perimeter locations at LLF and at 10 locations at Site 300 measure particulate radioactivity and beryllium. Particulate radioactivity is also measured at 10 off-site locations near the

Laboratory. Tritiated water samplers are operated at the six LLL perimeter locations and at two off-site locations. In all cases, samplers are so placed as to provide reasonable assurance that any significant concentration of effluents from Laboratory operations would be detected regardless of local meteorology.

Collection

Particulates

LLL perimeter and Site 300 particulate samples are collected on 5.2- x 10⁻² m² Whatman filters, using average flow rates of 700 l/min. Off-site samplers in the Livermore Valley use 4.6- x 10⁻³ m² Flanders F-700 glassfiber filters operated at a flow rate of 80 l/min. Particulate sample flow rates are calibrated with a spirometer that has been calibrated against an immersion unit certified by the National Bureau of Standards. Flow rates of Hi-vol air samplers are verified at monthly intervals with a portable field-calibration unit.

Tritiated Water

Samples of tritiated water vapor are collected by drawing air through silica-gel-packed columns at flow rates of about 0.5 l/min. Columns are exchanged weekly.

Identification

Particulates

Particulate samplers are run continuously, and sample filters are exchanged weekly. Each filter is identified by location, date on, date off, elapsed sampling time, and flow rate. Filter samples are placed in glassine envelopes and are transported to the laboratory, where this information is transferred to log sheets and each sample is given a serial number that accompanies it during analysis. Half of each LLL perimeter and Site 300 filter is used for beryllium analysis; the other half is retained for radioactivity measurements.

Tritiated Water

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

Replication

Particulates

At bimonthly intervals, a particulate air sampler is operated in parallel with the permanent sampler at one of the six LLL perimeter locations. This parallel operation is continued for one month, filters are changed weekly, and both filters are submitted for analysis in the usual manner. Bimonthly rotation of the extra sampler among the six locations ensures 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 LLL 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 analysis of these samples serves to document any changes that may have occurred during the year. Increases in radioactivity that may result from Laboratory operations are brought to the public's attention through annual monitoring reports.

Collection

Sampling sites are selected in reasonably level areas that represent undisturbed soil. A 2-m square is marked off with each such area, and an 8.25-cm-diam coring tool designed at LLL is used to collect 5-cm-deep samples at the corners and center of the square.¹

Identification

The 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 analysis and in the annual monitoring report.

Replication

During each annual collection of soil samples, at least 10% of the sites are sampled in duplicate. In such collections, two adjacent 5-cm-deep cores 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 various 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 such surface sources as ponds, creeks, and reservoirs are obtained with a tethered plastic pail. The samples are transferred to 4-l plastic containers to which 6.5 ml of concentrated HCl has been added. For tritium analyses, a 1-l sample is collected in an airbone-flushed glass container fitted with a ground-glass stopper.

Identification

As samples are collected in the field, they are tagged with 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 the Laboratory 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 LLL effluent and from the treated effluent of the Livermore Water Reclamation Plant (LWRP). Quarterly samples are also collected from the Site 300 sewage-oxidation pond.

Collection

ILL Effluent

A 24-hr composite of ILL sewage effluent is collected daily by a motorized proportional sampler. Aliquots of this composite are transported to the laboratory in 500-ml, wide-mouth polyethylene bottles.

LWRP Effluent

Daily composites of treated effluent from the LWRP are also collected by a proportional sampler. Aliquots of these composites are placed in 500-ml polyethylene bottles and are retained for weekly collection by ILL.

Site 300 Sewage-Oxidation Pond

Grab samples of the Site 300 sewage-oxidation pond are collected quarterly in 1.78-l polyethylene containers.

Identification

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

Replication

ILL Effluent

Every Wednesday, one replicate sample of ILL effluent is taken for tritium, alpha, beta, and tritium. For one month each year, duplicate samples of ILL effluent are taken each day to permit preparation of duplicate monthly composites.

LWRP Effluent

One replicate sample of LWRP effluent is taken every Wednesday and is analyzed for tritium, alpha, beta, and tritium. For one month each year, duplicate samples are taken each day to permit preparation of duplicate monthly composites.

VEGETATION SAMPLING

At monthly intervals, samples of vegetation (usually native grasses) are collected throughout the Livermore Valley, at Site 300, and at the 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 l. As each sample is collected, it is placed in a plastic bag and frozen in a dry-ice chest to minimize water loss on the bag 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 tagged according to sample type and location. In the laboratory, each sample is assigned a number that accompanies it until the measurement is reported. Measurement data are permanently retained on computer cards.

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 measurement data.

MILK SAMPLING

Milk samples are obtained at monthly intervals from two goat farms located about 5 km south and 5 southeast of the Laboratory. A 3-l portion of each milk sample is vacuum distilled, and the tritium content of the distilled water is determined by liquid scintillation. Each 3-l sample is then concentrated by evaporation and gamma counted.

AIR ANALYSIS

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

Gross Alpha and Beta Counting

After a four-day delay to allow for decay of the radon-thoron daughters, all environmental-radioactivity air filters are counted for alpha and beta activity. Counting is done in a Sharp gas-proportional counter using 20-min counting periods. Normally, this counter is used only for environmental samples 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 convoluted planchets are used for determining alpha and beta counting efficiencies, respectively. These standards are traceable to NBS or to equivalent certified sources. Counting efficiency measurements are made with each set of filters counted, and a background count is taken at the beginning of each run and between each set of 10 samples. Records are kept of background and counting efficiency variations in the Sharp counter.

Gamma Counting

Monthly composites of Laboratory perimeter and Site 300 filters are analyzed for specific gamma-emitting radionuclides. These filters are sealed in 210-cm³, thin-walled aluminum cans and are counted for nominal 1000-min periods. Counting is done with an 80-cm³, low-background Ge(Li) spectrometer that is equipped with a background-suppression system.²

Standards and Calibration

Low-level uranium-ore (New Brunswick) and NBS river-sediment standards are used periodically to check counting system response. Efficiency calibration checks are made with calibrated sources supplied by the International Association of Environmental Analysts (IAEA), the Environmental Monitoring Laboratory (EML), or NBS.

^{238}Pu , ^{239}Pu

Following gamma counting, the monthly composite of Laboratory perimeter filters is divided according to sampling location. This composite and that from Site 300 are dry ashed in a 450°C muffle furnace. Ashed samples are then dissolved with a $\text{HNO}_3\text{-HF-H}_2\text{O}_2$ mixture and are equilibrated with a standardized cesium carrier and tracer amounts of ^{242}Pu and ^{233}U . This solution is made 8N with HNO_3 , the plutonium is oxidized to Pu^{+4} with NaNO_2 , and the plutonium, cesium, and uranium radionuclides are separated by anion-exchange techniques.

The ^{137}Cs is collected first in the 8N fraction. Then the plutonium is eluted with a mixture of concentrated $\text{HCl-NH}_4\text{I}$, and the uranium fraction is eluted with 0.1N HCl .

The plutonium fraction is purified by a second anion-exchange separation and is electrodeposited on a platinum disc. Then, ^{238}Pu and ^{239}Pu are determined by alpha spectrometry.

Standards and Calibration

The LLL Heavy Element Group purifies and calibrates internal tracer ^{242}Pu by means of mass spectrometry.³ Alpha spectrometry is also used to periodically calibrate ^{242}Pu against ^{236}Pu and ^{239}Pu standards from EML.

^{137}Cs

The cesium fraction collected in the plutonium separation is heated to evaporate excess acid. After it is diluted with water, sodium hydroxide (NaOH) is added to bring the pH to 2-3 and the cesium is extracted with ammonium molybdophosphate. The cesium is further purified by ion exchange with a Bio-Rex 40 cation-exchange resin and is then precipitated as Cs_2PtCl_6 for yield correction. The precipitate is mounted for ^{137}Cs determination and is counted in a low-background beta counter.

Standards and Calibration

Standard solutions of ^{137}Cs from EML, LLL, and commercial laboratories are used to prepare efficiency and self-absorption counting standards to calibrate low-background beta detectors.

^{235}U , ^{238}U

The uranium fraction from plutonium separation is converted to sulfate by evaporating to dryness and by fuming with H_2SO_4 . Further purification is obtained with anion exchange in sulfate form. Then ^{235}U and ^{238}U are determined with isotopic-dilution mass spectrometry.⁴

Standards and Calibration

The mass spectrometer is calibrated with NBS uranium sources containing certified quantities of ^{235}U , the balance being ^{238}U . Mass values are, as noted, based on the use, of ^{233}U , and semiannual alpha spectrometry measurements are employed to verify its purity.

HTO

Water vapor samples are collected biweekly at LLL perimeter locations by silica-gel samplers operated at flow rates of about 0.5 l/min. The collected water is recovered by vacuum drying at 150°C , and the HTO is measured by liquid scintillation counting.

Standards and Calibration

A primary HTO standard is obtained from NBS. The calibration curve for each counting set is made from eight replicate measurements of a dilution of this primary standard, and the background is determined from eight replicate measurements of a deep-well water sample.

Beryllium

Every month, half of each weekly LLL 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 1-2 ml, taking care not to allow samples to bake dry. After the samples are diluted with water, they are filtered, any residues are discarded, and the filtrates are diluted to 25 ml with demineralized water.

Standards and Calibration

Beryllium standards are prepared with 0.5 and 1- μ g of beryllium per 25 ml of solution. The recorder readout of the Model 306 Perkin Elmer atomic absorption spectrophotometer is set at 30 $\times$ absorbance expansion, and the spectrophotometer is zeroed while aspirating deionized water into the flame. Instrument responses from the 0.5- and 1- μ g beryllium standards are then recorded. Following these calculations, the response of each monthly composite is recorded and its beryllium content is calculated from the calibration data.

SOIL ANALYSIS

Each soil sample collected in accordance with the "Gamma Counting" section below is dried to constant weight at 110°C, is pulverized in a mechanical grinder, and is screened through a 32-mesh screen to remove pebbles and dry vegetation. The sample is then blended, and aliquots are taken for various analyses.

Gamma Counting

Approximately 300 g of the pulverized and blended soil sample is sealed in a 210-cm³, thin-walled aluminum can. It is then counted for a nominal 1000 min in the low-background gamma counter for gamma emitters and ²³⁸U.²

Standards and Calibration

Low-level uranium-ore (New Brunswick) and NBS river-sediment standards are used periodically to check counting system response. Efficiency calibration checks are made with calibrated sources supplied by IAEA, EML, or NBS.

Tracer ^{242}Pu is added to a 100- to 500-g aliquot of soil sample prepared as previously indicated in the first paragraph of the "Soil Analysis" section of this paper. The sample is then acid leached with $\text{HNO}_3\text{-HCl}$ acid, using the EML soil-leach method.⁵ Plutonium isotopes are separated, purified, and analyzed in accordance with the "Air Analysis" section on ^{238}Pu and ^{239}Pu .

In addition to the ^{238}U data obtained from gamma measurement ("Soil Analysis" section on gamma counting), natural isotopic content and depleted uranium concentration are also determined by isotopic-dilution mass spectrometry in certain selected samples. These samples are analyzed in a manner similar to the procedure given in the "Air Analysis" section on ^{238}Pu and ^{239}Pu and on ^{235}U and ^{238}U .

WATER ANALYSIS

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

Gross Alpha and Beta Activity

Each 500-ml water sample is acidified with HNO_3 . Then 30% H_2O_2 is added, and the sample is evaporated to near dryness and transferred to 5-cm-diam planchets of convoluted stainless steel. After drying and flaming, the sample is counted for 30 min in a Nuclear-Chicago proportional counter.

Standards and Calibration

The ^{239}Pu and ^{90}Sr standards are used with every sample set (see the "Soil Analysis" section on standards and calibration). Instrument background measurements are made between every 10 sample-counting measurements.

HTO

Samples collected in argon-flushed glass bottles are distilled under argon. A 250-ml aliquot of sample is electrolytically enriched, using the enrichment technique described by Ostlund.⁶ Following enrichment, the HTO content of the sample is determined with either liquid-scintillation or internal gas-proportional counting.

Standards and Calibration

Each enrichment set contains duplicate aliquots of the secondary HTO standard to verify the enrichment factors. See the "Standards and Calibration" section of "Air Analysis" on HTO for scintillation counter standards and calibration. For internal gas-proportional counter standardization, replicate samples of a secondary HTO standard are reduced to HT and are counted after 10 unknown samples are run.

SEWAGE ANALYSIS

Except for tritium analyses, all sewage samples are wet digested with a mixture of 20% HClO₄ and 80% HNO₃. Those sewage samples for tritium analysis are distilled to reduce self absorption before counting.

Gross Alpha and Beta Radioactivity

A 100-ml quantity of LWRP effluent is wet digested, and the residue is transferred to 5-cm-diam planchets and is counted in accordance with the procedures in the "Water Analysis" section on HTO. Aliquots of 500 ml are taken for all other gross alpha and beta measurements.

Tritium

A 1-ml aliquot of sewage sample is added to 10 ml of Packard Insta-Gel in a 25-ml screw-cap glass bottle. Then, 1 ml of tap water 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 2-hr temperature-equilibration period prior to counting. The sample and background are each counted for 100 min.

²³⁹Pu, ¹³⁷Cs, and ⁹⁰Sr

Nuclear Chemistry analyzes monthly composites of Laboratory sewage effluent and treated effluent from LWRP for ²³⁹Pu and ¹³⁷Cs. Duplicate composites are prepared by Hazards Control and are analyzed for ²³⁹Pu and ⁹⁰Sr.

Procedure

Daily samples of sewage effluent are combined for the monthly composite, are acidified with $3N$ HCl, and ^{242}Pu and cesium carrier are added. Ten milliliters of saturated KMnO_4 are added to the mixture, and the pH is adjusted to 8-10 with $3N$ NaOH. Then, 150 ml of MnCl_2 are added, and the plutonium coprecipitates with the MnO_2 .⁷ Each sample is later filtered through a 1- μm cotton filter cartridge, which is then dried and ashed at 475°C . The filtrate is acidified to pH 1-3 with $3N$ HCl, and the cesium is extracted with 5 g of AMP. The sample is then refiltered, and the cartridge is dried and ashed.

The plutonium filter is heated with 100 ml of concentrated HNO_3 , and the MnO_2 is dissolved with 30% H_2O_2 . The volume of solution is then reduced to about 50 ml, and the sample is filtered through 934-AH glass-fiber filter paper. The plutonium is oxidized with NaNO_2 purified by anion exchange, is electroplated, and is counted by solid-state alpha spectrometry.

The ashed cesium filter is dissolved in acid, excess ammonia is evaporated with NaOH, and the cesium is reextracted with 1 g of AMP. Further purification is carried out as outlined in the "Air Analysis" section on ^{137}Cs .

Radiochemical Separations

The procedure outlined in the "Air Analysis" section on ^{238}Pu and ^{239}Pu is used to purify ^{239}Pu . The purified ^{239}Pu is then electro-deposited and is counted by solid-state alpha spectrometry.

The Sr-Y is washed from the anion column (used in plutonium separation) with $8N$ HNO_3 . The combined washings are then evaporated and are converted to chloride by repeated HCl additions followed by evaporation. Residue is taken up in $8N$ HCl, transferred to a freshly prepared Dowex 1 column, and the column is washed with $8N$ HCl. The washings are later collected and evaporated to near dryness. Water is added, and the solution is adjusted to pH 1.5 with NH_4OH . This solution is extracted twice with 20% 2,2-diethyl hexyl phosphoric acid, and the organic phase is washed twice with $0.5N$ HCl and $1N$ HCl. The Y is then back extracted with three 20-ml portions of HCl, the solution is evaporated to about 10 ml, and the Y is precipitated by adding HF. The YF_3 is dissolved and precipitated as hydroxide; then it

is redissolved with HCl. The Y is then precipitated as oxalate and is filtered and converted to oxide in a muffler furnace set at 900°C for 1 hr. The ash is weighed, dissolved in HNO₃, transferred to a 5-cm-diam planchet, and dried. After drying, the ash is beta counted.

Nonradioactive Metals and Fluorides

Monthly composites of LLL sewage effluent are analyzed for copper and chromium with a Model 306 Perkin Elmer atomic-absorption spectrophotometer. Aliquots of these composites are also analyzed for cadmium, iron, lead, nickel, silver, zinc, and fluoride.

A monthly composite of Laboratory sewage effluent is prepared by combining 500-ml daily samples. Following each 500-ml addition, the solution is evaporated with HNO₃ to approximately 100 ml. After compositing is complete and organic matter has been destroyed by HClO₄ and HNO₃ treatments, the sample is evaporated to near dryness. The residue is taken up in about 30 ml of deionized water, is filtered through a sintered glass funnel, and any filter residue is discarded. The filtrate is made up to 100 ml in a volumetric flask.

Standards and Calibration

The atomic-absorption spectrophotometer is calibrated with solutions of the metals or compounds of the metal of interest. This spectrophotometer is zeroed with deionized water and is calibrated with standards. Dilution of stock solutions and the monthly composite may be necessary to obtain readings within the spectrophotometer's linear response region. Following calibration, the monthly composite sample is aspirated into the flame, and concentrations are read out directly.

Precision Checks. The monthly composite sample is used to prepare four dilutions. The first dilution provides a concentration near the limit of sensitivity; two dilutions provide intermediate concentrations; and the fourth provides a concentration near the upper limit of the spectrophotometer's linear response region. To reflect maximum interference, they are analyzed in order of highest concentration, lowest concentration, and then by the two intermediate concentrations. This set of measurements is repeated seven times, and the average and standard deviation for each concentration are recorded.

Accuracy Checks. Using the monthly composite, accuracy checks are performed by adding known amounts of the metal of interest to the low and intermediate concentrations. The amount of metal added to the low concentration is designed to double in concentration, and the amount of metal added to the intermediate concentrations is sufficient to result in concentrations that are within 25% of the upper limit of the spectrophotometer's linear response region. As in the precision measurements, seven replicate determinations are made at each concentration, and accuracy is expressed as percent recovery based on the average recovery of the seven replicates.

Fluoride Measurements

Fluorides in LLL sewage effluent are determined with a specific ion-electrode measurement. Daily additions of 100-ml aliquots of sewage effluent are used to prepare a monthly composite sample. This composite sample is stored in a plastic bottle, and no chemical treatment or evaporation is employed. At the end of the month, an aliquot of the composite sample is analyzed for fluorides with an Orion Model 401 specific ion meter equipped with a lanthanum fluoride electrode. Precision and accuracy measurements are conducted quarterly in a manner similar to those described for metals in the "Nonradioactive Metals and Fluorides" section on precision and accuracy checks above.

VEGETATION ANALYSIS

Frozen vegetation is transferred to freeze-drying equipment, and a 10- μ m vacuum is established. Recovered water is collected in a receiver chilled with dry ice and Dowanol (dipropylene methyl ether). The vacuum is checked periodically, and dry ice is added as needed over a four-day period. Liquid scintillation counting is then used to analyze an aliquot of the recovered water for tritium content.

Standards and Calibration

See the "Air Analysis" section on standards and calibration for HTO.

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APPENDIX E. 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, "Calculating Annual Doses to Man from Routine Releases of Reactor Effluent." 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/l,

U_w = intake rate, l/yr,

= 730 l/yr for maximum exposed individual,

D_w = dose factor, mrem/pCi,

= 1.05×10^{-7} mrem/pCi for the whole body ingestion pathway for an adult.

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

ANNUAL DOSE FROM FORAGE—COW—MILK PATHWAY FOR TRITIUM IN VEGETATION

Assuming that all the 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/yr, = 64 kg/yr, for maximum exposed individual,

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

D_{HTO} = dose factor, mrem/pCi = 1.05×10^{-17} mrem/pCi for ^3H
for the adult whole body ingestion pathway.

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

where

$$\begin{aligned} U_{\text{meat}} &= 110 \text{ kg/yr.} \\ D_{\text{HTO}} &= 1.05 \times 10^{-7} \text{ mrem/pCi.} \\ C_{\text{meat}} &= (F_f)(Q_f)(C_{\text{veg}}) \exp(-\lambda_1 t_c) \cdot \\ F_f &= \text{fraction of daily intake of nuclide per kg of animal/fish, days/kg.} \\ Q_f &= \text{amount of feed consumed, kg/day.} \\ C_{\text{meat}} &= \left(1.2 \times 10^{-2} \frac{\text{day}}{\text{kg}}\right) \left(50 \frac{\text{kg}}{\text{day}}\right) \left(3 \times 10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/ml}}\right) \\ &\quad \times \exp[-4.5 \times 10^{-3}(20)] = 1.5 \times 10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/ml}} \times C_{\text{veg}} \frac{\mu\text{Ci}}{\text{ml}} \text{ (measured).} \\ C_{\text{veg}} &= \text{same as above.} \\ \lambda_1 &= \text{radiological decay constant, day}^{-1}. \\ t_c &= \text{time between slaughter to consumption, days.} \end{aligned}$$

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

where

$$\begin{aligned} U_{\text{milk}} &= 310 \text{ l/yr.} \\ D_{\text{HTO}} &= 1.05 \times 10^{-7} \text{ mrem/pCi,} \\ C_{\text{milk}} &= F_m Q_f C_{\text{veg}} \exp(-\lambda_1 t_f) \cdot \\ F_m &= \text{fraction of daily intake of nuclide per litre of milk, day /litre).} \\ Q_f &= \text{amount of feed consumed, kg/day.} \\ C_{\text{veg}} &= \text{same as above.} \\ \lambda_1 &= \text{radiological decay constant, days}^{-1}. \\ t_f &= \text{transport time from the feed to milk receptor.} \\ C_{\text{milk}} &= \left(1.0 \times 10^{-2} \frac{\text{day}}{\text{l}}\right) \left(50 \frac{\text{kg}}{\text{d}}\right) \left(3 \times 10^9 \frac{\text{pCi/kg}}{\mu\text{Ci/ml}}\right) \\ &\quad \times \exp[-4.5 \times 10^{-3}(2)] = 1.5 \times 10^9 \frac{\text{pCi/l}}{\mu\text{Ci/ml}} \times C_{\text{veg}} \frac{\mu\text{Ci}}{\text{ml}} \text{ (measured).} \\ D_{\text{total}} &= \left(2.04 \times 10^4 \frac{\text{mrem}}{\mu\text{Ci/ml}}\right) \text{veg} + \left(2.07 \times 10^4 \frac{\text{mrem}}{\mu\text{Ci/ml}}\right) \text{meat} \\ &\quad + \left(4.88 \times 10^4 \frac{\text{mrem}}{\mu\text{Ci/ml}}\right) \text{milk} = 8.96 \times 10^4 \frac{\text{mrem}}{\mu\text{Ci/ml}} \times C_{\text{veg}} \frac{\mu\text{Ci}}{\text{ml}} \text{ (measured).} \end{aligned}$$

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.

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

where

χ/Q = diffusion parameter, sec/m³ .

Q = release rate, Ci/yr,

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

C_{downwind} = concentration downwind, pCi/m³

$$D_{\text{max individual}}^{-1} = C_{\text{downwind}} \cdot D \quad (4)$$

where

U = intake rate, m³/yr = 8000 m³/yr, inhalation rate
for adult maximum exposed individual

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

D = dose factor, mrem/pCi .

$$\text{for } ^3\text{H}, D = 1.58 \times 10^{-5} \text{ mrem} / \frac{\text{pCi}}{\text{Ci}} .$$

$$\text{for } ^{41}\text{Ar}, D = 8.84 \times 10^{-5} \text{ mrem} / \frac{\text{pCi}}{\text{Ci}} \cdot \text{yr} .$$

(Inhalation rate is included in the dose factor.)

$$\text{for } ^{135}\text{I}, D = D(^{41}\text{Ar}) \cdot \frac{1.74}{1.2}$$

$$\text{for } ^{135}\text{Xe}, D = D(^{41}\text{Ar})$$

$$D_{\text{max individual}} = \text{mrem/yr}$$

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

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

where

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

Q = release rate, Ci/yr .

U = inhalation rate, average individual (adult) .

D = dose factor, rem/pCi .

Dose = man-rem .