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GEOGRAPHICAL VARIATIONS IN ENVIRONMENTAL
RADIATION BACKGROUND IN THE UNITED STATES*

C. L. Lindeken, K. R. Peterson, D. E. Jones, and R. E. McMillen

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GEOGRAPHICAL VARIATIONS IN ENVIRONMENTAL
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ABSTRACT

During the period from March 1 to June 1, 1971, the Lawrence Livermore Laboratory made simultaneous measurements of environmental radiation background at 107 weather stations throughout the United States. Measurements were made using $\text{CaF}_2:\text{Dy}$ thermoluminescent dosimeters (TLD-200). Freshly annealed dosimeters were mailed to the stations where they were exposed in the station's instrument shelter. At the end of the exposure period, the dosimeters were returned to Livermore for readout. Light output is proportional to the radiation dose received by the phosphor from the sum of terrestrial and cosmic sources. The cosmic component was estimated from the elevation and geomagnetic latitude of the station, and terrestrial radiation was obtained by difference.

Median environmental radiation exposure rate (terrestrial + cosmic) was 9.4 $\mu\text{R/hr}$ with a range from 3.7 to 19.9 $\mu\text{R/hr}$. The median terrestrial exposure rate was 5.5 $\mu\text{R/hr}$. Low backgrounds were found in the Hawaiian Islands, Northern Alaska, and Florida. High backgrounds in the Rocky Mountain

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States are due more to higher terrestrial radiation than to increased cosmic radiation. The thermoluminescent dosimetry procedure employed in this pilot study appears to be suitable for large-scale synoptic monitoring at costs which are modest compared with using portable instruments.

INTRODUCTION

The environmental impact of radiation arising from nuclear power operations within the United States is frequently compared with the radiation received by the population-at-large from natural sources. Such comparisons have prompted renewed interest in natural background, particularly with respect to its variation with geographical area. While a number of radiation background surveys have been conducted in the past, none of those involved simultaneous measurements over the entire nation in a geographically uniform manner. In 1957 Solon et al.¹ used an air-filled ion chamber to make a series of measurements covering an area from the East Coast to the Rocky Mountains. Later, Shambon et al.² made measurements with an argon-filled high-pressure ion chamber at a number of these same monitoring locations. In 1962, Lowder et al.³ developed a sodium iodide spectrometric system for similar measurements. Beck et al.,⁴ using a sodium iodide spectrometer, conducted a background survey during the summer of 1965 which covered a large portion of the United States. The advantage in using the spectrometer is that exposure rates from individual radioisotopes can be determined. The disadvantage is that the equipment is expensive, and trained personnel are required in the field for its operation and possible maintenance. Although not providing differential data, thermoluminescent

dosimetry provides a comparatively inexpensive means for making measurements of the total background. This paper describes a pilot study made by the Lawrence Livermore Laboratory (LLL) in the spring of 1971, in which simultaneous measurements of environmental gamma radiation background were made at 107 weather stations throughout the United States using $\text{CaF}_2:\text{Dy}$ (TLD-200) thermoluminescent dosimeters.

SELECTION OF MONITORING LOCATIONS

Through the cooperation of the National Oceanic and Atmospheric Administration (NOAA), it was possible to utilize the weather stations shown in Fig. 1. These stations were selected to provide a reasonably uniform geographical distribution. The dosimeter was placed in the rear center of the station's instrument shelter. Shelters are of similar design so that they provide essentially the same geometry for all measurements. About 70% of the shelters were located over grass; the balance were over a variety of material as indicated in Table I.

DOSIMETRY PROCEDURE

A total of 300 $\text{CaF}_2:\text{Dy}$ (TLD-200) chips and 150 LiF (TLD-100) chips were annealed at 425°C for 1-1/2 hr followed by a 16-hr post-annealing period at 80°C . After cooling to room temperature, the chips were loaded into LLL personnel dosimeter holders⁵ under subdued room lighting. Each holder contained two TLD-200 chips and one TLD-100 chip. One hundred and

twenty of these freshly annealed dosimeters were mailed to cooperating stations with instructions for conducting the test and a postcard for acknowledging receipt of the dosimeter and recording the date the dosimeter was placed in the shelter. To estimate radiation exposure during delivery, five geographically separated stations received an additional dosimeter with instructions for its immediate return by mail. All remaining dosimeters were placed in a 3-in.-thick lead storage container fitted with a cadmium and copper liner. This container provided a low background storage area for control and calibration dosimeters. The five dosimeters noted above were placed in this container after their round trip. At the end of six weeks, a group of the control dosimeters were irradiated using the 60-keV gamma flux from a 7-Ci ^{241}Am source. Six dosimeters were used to cover an ^{241}Am exposure range from 0.5 to 10 mR.

Although highly sensitive, CaF_2 is characterized by strong signal fading, which is most pronounced during the first 24 hr after irradiation. About 10% of the signal is lost during this period. Thereafter, fading proceeds at a much slower rate; at the end of three months, losses of about 30% may be expected. We made no attempt to apply fading corrections per se. Rather, we irradiated control dosimeters used for calibration midway through the three-month test period, and calibration and test dosimeters were both read out at the end of the test period. After six weeks, the extent of signal fading of the calibration dosimeters approximated that of the test dosimeters.

The survey was conducted during the period March 1 to June 1, 1971. At the end of May, recall notices were sent out. Those five stations previously receiving dosimeters to detect radiation exposure during delivery

were again sent dosimeters with instructions to return both this dosimeter and the one from their shelter in the same envelope. We estimated the average round-trip transportation dose from these two sets of dosimeters. We received 110 of the 120 dosimeters initially issued. However, we found that three of the stations returning dosimeters used shelters mounted on rooftops. Accordingly, our survey was based on 107 monitoring locations. All dosimeters were read in the LLL automatic hot gas research reader.⁶ After subtracting the average transportation dose (1.71 mrad) and normalizing to a 90-day exposure period, the CaF_2 mrad dose data were converted to $\mu\text{R/hr}$ exposure rates using the conversion factor 0.853, the rad/R response of CaF_2 at 1 MeV.

Dosimeters were used without energy filters. Because of the energy dependence of CaF_2 below about 200 keV, as shown in Fig. 2, energy filters are normally incorporated in the dosimeter to flatten the phosphor's response. However, as Becker⁷ has recently reported, we find that low-energy photons contribute a negligibly small fraction of the total dose from natural-occurring terrestrial sources. Such information is obtained from the ratio of respective light outputs of the $\text{CaF}_2\text{:Dy}$ and the LiF in our dosimeter package. In no case did we see any increase in this ratio above the normal sensitivity ratio expected at energies exceeding the energy-dependent region of CaF_2 . Elimination of energy filters greatly simplifies packaging and handling requirements of these measurements.

As noted, CaF_2 dose rates were converted to exposure rates using the rad/R response of CaF_2 at 1 MeV (0.853). Figure 2 shows that this phosphor's rad/R response is essentially constant at energies above 300 keV, so the

numerical value of exposure rates is not significantly affected by choice of response in this energy region. Use of the rad/R response at 1 MeV serves merely as a convenient reference.

Natural terrestrial and cosmic radiation are at present the principal sources of environmental radiation, and the $\mu\text{R/hr}$ value obtained above represents the sum of the two sources. The data of Lowder and Beck⁸ relating cosmic radiation and elevation were used to obtain the cosmic ray exposure rate at each station surveyed. Corrections were made for geomagnetic latitude departures from 50°N , which was the reference latitude used by these authors. Calculated cosmic radiation exposure rates were then subtracted from the CaF_2 data to obtain terrestrial radiation exposure rates.

RESULTS AND DISCUSSION

Data obtained from the survey are shown in Table I. In this table, stations are listed in ascending order of their postal ZIP code which permits general grouping according to geographical area, moving from east to west. Although backgrounds vary widely, it is possible to categorize certain areas. The Hawaiian Islands, Florida, and Northern Alaska have lower than average backgrounds. The Hawaiian Islands, being formed by volcanic action, have soils of a predominantly basaltic origin.⁹ Such soils are usually low in uranium, thorium, and potassium. Much of Florida's soil is of a sedimentary marine origin. Mahdavi¹⁰ found extremely low radioactivity levels along the Gulf beaches east of the Mississippi River. However, the data for Florida illustrate the difficulties that can be encountered in attempting to

characterize any area by a limited number of sampling locations, since Osmond has shown that there are several areas in Florida containing elevated concentrations of natural radioisotopes.¹¹ Snow cover may explain the low background observed in Northern Alaska. A high background in Georgia and South Carolina may be due to the granite outcropping characteristic of this area. As expected, the Rocky Mountain States have the highest average background of any region.

Figures 3 through 5 are histograms showing exposure rate frequency distributions for terrestrial, cosmic and total (terrestrial plus cosmic) radiation background, respectively. Terrestrial radiation is assumed to be from natural sources; however, since the values are obtained by difference (subtracting the cosmic from the total) any fission product fallout radiation would be included as natural terrestrial. At present, ¹³⁷Cs is the major source of terrestrial gamma radiation from residual global fallout. Beck's⁵ survey in 1965 showed an average exposure rate of 0.4 μ R/hr from ¹³⁷Cs. Exposure rates calculated from the ¹³⁷Cs content of Livermore soils collected during 1971 average about 0.1 μ R/hr.¹² Fallout deposition rates are roughly proportional to annual rainfall. Livermore is a semi-arid area so that lower than average global fallout levels can be expected in this region. It is clear, however, that today residual fallout contributes less than about 5% of the total environmental radiation background.

The median terrestrial exposure rate, 5.5 μ R/hr, when projected to an annual dose, is equivalent to 42 mrem/yr. This is somewhat lower than expected, but as previously noted, the value may merely reflect contributions from many lower than average background locations not included in previous surveys.

The median cosmic-ray exposure rate was 3.9 $\mu\text{R/hr}$, equivalent to an annual dose rate of 30 mrem per year. The accuracy of the terrestrial exposure rate data depends on the response efficiency of CaF_2 to the energetic cosmic radiation since, as previously noted, the terrestrial values were obtained by difference. Subsequent to the national survey, cosmic-ray response measurements were made at three different elevations in California (Mt. Hamilton, 4202 ft; Mt. Diablo, 3849 ft; and Livermore, 600 ft). To exclude the less energetic terrestrial radiation, the CaF_2 dosimeters were placed in 3-in.-thick lead shields. The exposure period was 18 days. A comparison of the CaF_2 mrad dose observed with the cosmic air dose calculated is shown in Table II. The observed/calculated ratio is in reasonable agreement with the 0.7 hard-to-total cosmic-ray flux ratio at sea level observed by Lowder and Beck.⁷ This agreement suggests that $\text{CaF}_2\text{:Dy}$ gives an essentially full "air equivalent" response to cosmic radiation.

Median total background radiation was 9.4 $\mu\text{R/hr}$ with a range from 3.7 to 19.9 $\mu\text{R/hr}$. Total background distribution projected as an annual mrem dose is shown in Fig. 6, indicating a range of from 28 to 151 mrem/yr.

It is generally recognized that environmental radiation backgrounds are higher in mountainous regions than at lower elevations. Table III lists the ten stations from the survey with the highest elevations. It is interesting to note that, based on the average terrestrial and cosmic exposure rates for this group, those stations with the highest total backgrounds show much higher increases in the terrestrial component than in the cosmic. Thus with few exceptions, in the Rocky Mountains States, increased environmental radiation appears to be due more to higher concentrations of

naturally occurring radioisotopes in the soil than to increases in cosmic radiation. The standard deviations in terrestrial and cosmic radiation exposure rates in Table I are 2.78 and 0.84, respectively, clearly showing that variations in environmental radiation are due predominantly to variations in the terrestrial component.

Measurement of integrated radiation exposure from the natural environmental background poses a problem in the handling of control dosimeters, which is not common in normal radiation dosimetry. Normally, the net dose delivered over a short exposure period from a specific source is determined by comparison with a control that has had negligible exposure. In environmental background measurements involving three-month exposure periods, the exposure to the control dosimeters is certainly not negligible. We have attempted to reduce this exposure by storing all controls in a lead shield. During the time dosimeters used for calibration irradiations were out of the lead storage containers, they were accompanied by additional controls to assure that no undetected exposure occurred.

The dose rate received by the dosimeters in the lead container was determined using control and calibration readings from six sets of data.¹³ Steps in this calculation were as follows:

- The overall TLD and reader sensitivity were determined for each set of data by successive differences in the calibration readings. Data from the TLD's used had a standard deviation of about 1.6%. The typical sensitivity in light output per mrad was found to have a standard deviation of about 4%.

- Each data set was evaluated to find a total dose equivalent background. The calibration data were weighted according to the ratio of control light output to sample light output in this calculation.

• The six total background values were used with the time in the container to estimate the dose rate and the "nonradiation" (dose equivalent) background from all sources other than ionizing radiations. The results showed a radiation dose rate of $46 \pm 3 \text{ } \mu\text{rad (CaF}_2\text{) per day}$ in the storage container and a nonradiation background of 0.3 mrad equivalent. These factors contribute to the light output of the calibration dosimeter and must be considered in dose assignment. The nonradiation response was the result of photomultiplier tube dark current, thermal "glow," and nonradiation-induced thermoluminescence. It is assumed that radiation self-dose for the $\text{CaF}_2\text{:Dy}$ is negligible for these artificially grown crystals, since potassium should be volatilized at the high temperatures maintained during crystal production.

As noted, radiation dose to the dosimeters during delivery and release was approximated by averaging the doses received by two extra sets of dosimeters. The average dose received by these "transit" dosimeters was somewhat less than 10% of the average test exposure dose. This technique is applicable only when the test exposure is relatively long, or more properly, when the ratio of transit dose to test exposure dose is low. Otherwise, errors inherent in the transit dose approximation would result in serious errors in assigning test exposure doses.

No corrections were made for the shielding effect of the instrument shelter in which the dosimeter was placed. Such a correction would be difficult to derive, as no information is presently available on the relative abundance of uranium, thorium and potassium in the soil at the sites monitored. It may be assumed that the shelters provided sufficient low-energy attenuation to eliminate the characteristic enhanced response

of $\text{CaF}_2\text{:Dy}$ at energies less than 100 keV. However, at Livermore, direct exposure of $\text{CaF}_2\text{:Dy}$ dosimeters shows no enhanced response suggesting, as previously noted, that perhaps low-energy photons do not contribute significantly to the total natural background radiation dose. In this pilot study, photon attenuation by the shelter is considered balanced by the relatively uniform geometry provided. Indeed, without access to these instrument shelters, execution of this survey would have been much more difficult.

While the data in Table 1 are not accompanied by error terms, we consider that at the median exposure rate the precision of our method is about $\pm 5\%$. Light output data from the two chips of $\text{CaF}_2\text{:Dy}$ in each dosimeter deviated from the average by less than 2%. Residual uncertainty is due to inherent errors of the calibration procedure.

SUMMARY

Based on a pilot TLD study conducted in the spring of 1971, environmental radiation background measurements made at 107 weather stations throughout the United States showed a median exposure rate of 9.4 $\mu\text{R/hr}$, with a range from 3.7 to 19.9 $\mu\text{R/hr}$. Measurements were made by mailing freshly annealed $\text{CaF}_2\text{:Dy}$ (TLD-200) dosimeters to the stations where they were exposed in the station's instrument shelter. Following a three-month exposure, the dosimeters were returned to Livermore for readout.

We believe that this pilot survey adequately demonstrates the capability of the procedure for large-scale synoptic background monitoring. Measurements can be made at little expense, and only modest field effort is involved. Indeed, the number of simultaneous measurements made in this

survey would be patently impractical using portable instruments. Continuation of these quarterly measurements over a multi-year period would detect any systematic change in nationwide background, as well as provide a unified surveillance network to delineate the effect of a major nuclear accident within the United States.

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Table I. Environmental radiation background exposure rates within the United States, March - June 1971, TLD survey.

Location	Background radiation ($\mu\text{R/hr}$)			Geomagnetic Lat ($^{\circ}\text{N}$)	Elevation (ft)	Nature of soil under dosimeter ^a
	Terrestrial	Cosmic	Total			
San Juan, Puerto Rico 00912	3.4	3.2	6.6	29.9	60	?
Warwick, Rhode Island 02886	6.7	3.7	10.4	53.2	60	G
Portland, Maine 04102	7.5	3.8	11.3	55.1	60	G
Caribou, Maine 04736	4.9	4.0	8.9	58.3	631	G
Bennington, Vermont 05201	8.0	4.0	12.0	54.3	820	G
Barre, Vermont 05601	10.4	4.1	14.5	55.6	1120	C
Millville, New Jersey 08333	7.7	3.7	11.4	50.8	80	B, D, G
New York, New York 10020	8.4	3.7	12.1	52.2	90	?
North Syracuse, New York 13212	6.4	3.8	10.2	54.5	410	G
Buffalo, New York 14225	5.0	3.9	8.9	54.2	710	G
Pittsburgh, Pennsylvania 15231	8.5	3.9	12.4	51.9	720	G
Montoursville, Pennsylvania 17754	5.4	3.8	9.2	52.6	530	G
Starling, Virginia 22170	7.4	3.7	11.1	50.3	320	G
Norfolk, Virginia 23518	5.1	3.6	8.7	48.3	30	G
Beckley, West Virginia 25801	4.3	4.4	8.7	48.9	2510	G
Greensboro, North Carolina 27420	4.7	3.8	8.5	47.3	890	G
Buxton, North Carolina 27920	1.9	3.5	5.4	46.6	10	S
Charleston, South Carolina 29401	6.1	3.5	9.6	44.1	50	G
West Columbia, South Carolina 29169	9.8	3.6	13.4	45.1	230	G
Atlanta, Georgia 30220	10.7	3.8	14.5	44.6	1030	?
Augusta, Georgia 30906	7.0	3.5	10.5	44.5	150	G
Albany, Georgia 31702	4.4	3.5	7.9	42.5	190	G
Jacksonville, Florida 32229	5.0	3.4	8.4	41.6	30	C, G, S

^aG = grass, D = dirt, S = sand, C = concrete, A = asphalt, R = crushed rock, W = wood chips.

Table I. (continued)

Location	<u>Background radiation ($\mu\text{R/hr}$)</u>			Geomagnetic Lat ($^{\circ}\text{N}$)	Elevation (ft)	Nature of soil under dosimeter ^a
	Terrestrial	Cosmic	Total			
Apalachicola, Florida 32320	2.2	3.4	5.6	40.7	40	G
Key West, Florida 33040	1.2	3.3	4.5	35.7	10	G, R
Miami, Florida 33159	1.9	3.3	5.2	37.0	10	G
Tampa, Florida 33607	1.7	3.4	5.1	39.1	10	G
Memphis, Tennessee 38130	5.8	3.6	9.4	45.6	280	D, G
Meridian, Mississippi 39301	3.7	3.5	7.2	43.0	310	G
Lexington, Kentucky 40504	5.9	3.9	9.8	49.0	990	G, C, A
Dayton, Ohio 45424	6.8	3.9	10.7	50.9	980	G
Indianapolis, Indiana 46241	7.6	3.8	11.4	50.6	810	G
Marquette, Michigan 49855	4.4	4.2	8.6	57.3	1430	G
Cedar Falls, Iowa 50613	5.2	3.9	9.1	52.9	880	G
Milwaukee, Wisconsin 53207	4.9	3.9	8.8	53.7	690	G
Duluth, Minnesota 55811	4.6	4.2	8.8	57.1	1420	G
Rochester, Minnesota 55901	6.1	4.1	10.2	54.2	1320	G
International Falls, Minnesota 56649	4.3	4.1	8.4	58.7	1180	G
Huron, South Dakota 57350	5.5	4.1	9.6	54.1	1290	G
Rapid City, South Dakota 57705	5.6	4.8	10.4	53.1	3170	C, G
Fargo, North Dakota 58102	6.3	4.0	10.3	56.7	900	G
Bismarck, North Dakota 58501	5.0	4.3	9.3	56.1	1660	G
Williston, North Dakota 58801	6.1	4.4	10.5	57.1	1910	G
Miles City, Montana 59301	6.4	4.6	11.0	55.1	2630	D

Table I. (continued)

Location	Background radiation ($\mu\text{R/hr}$)			Geomagnetic Lat ($^{\circ}\text{N}$)	Elevation (ft)	Nature of soil under dosimeter ^a
	Terrestrial	Cosmic	Total			
Havre, Montana 59501	7.0	4.7	11.7	56.6	2600	G
Helena, Montana 59601	11.0	5.2	16.2	54.3	3900	?
Peori, Illinois 61607	6.1	3.8	9.9	51.2	660	G
Salem, Illinois 62881	6.5	3.8	10.3	49.3	580	G
Monett, Missouri 65708	7.1	3.9	11.0	47.2	1280	G
Topeka, Kansas 66616	7.6	3.8	11.4	49.1	890	G
Norfolk, Nebraska 68701	6.9	4.1	11.0	51.8	1550	G, S
New Orleans, Louisiana 70013	3.5	3.4	6.9	40.1	10	G
Shreveport, Louisiana 71109	5.8	3.5	9.3	42.7	160	G
Fort Smith, Arkansas 72901	6.4	3.6	10.0	45.5	460	G
Oklahoma City, Oklahoma 73159	5.9	3.8	9.7	45.2	1300	G
Waco, Texas 76708	5.6	3.5	9.1	41.5	510	G
Houston, Texas 77014	2.8	3.4	6.2	40.1	110	G
San Antonio, Texas 77014	2.7	3.6	6.3	39.3	790	G
Brownsville, Texas 78520	5.5	3.3	8.8	35.8	20	G
Del Rio, Texas 78840	3.3	3.6	6.9	38.9	1030	G
Childress, Texas 79201	4.9	4.0	8.9	44.0	1950	G
Abilene, Texas 79601	4.7	3.9	8.6	42.1	1750	G
Midland, Texas 79705	4.1	4.3	8.4	41.3	2860	D, G
Marfa, Texas 79843	11.4	5.3	16.7	39.5	4860	D
El Paso, Texas 79925	4.4	4.8	9.2	40.6	3920	S, D

Table I. (continued)

Location	Background radiation ($\mu\text{R/hr}$)			Geomagnetic Lat ($^{\circ}\text{N}$)	Elevation (ft)	Nature of soil under dosimeter ^a
	Terrestrial	Cosmic	Total			
Colorado Springs, Colorado 80901	12.3	6.6	18.9	48.7	6170	S
Grand Junction, Colorado 81501	8.9	5.6	14.5	47.5	4840	D
Cheyenne, Wyoming 82001	11.5	6.7	18.2	50.0	6140	G
Lander, Wyoming 82520	8.3	6.2	14.5	51.1	5580	G
Pocatello, Idaho 83201	6.3	5.4	11.7	50.6	4480	D
Boise, Idaho 83701	9.2	4.6	13.8	50.1	2870	R
Salt Lake City, Utah 84116	5.6	5.2	10.8	48.6	4230	G
Milford, Utah 84751	12.0	5.6	17.6	46.0	5030	R
Tucson, Arizona 85706	8.7	4.1	12.8	40.3	2560	R
Flagstaff, Arizona 86001	4.8	7.2	12.0	43.1	7020	G
Albuquerque, New Mexico 87101	6.7	5.7	12.4	43.8	5310	D
Clayton, New Mexico 88415	7.4	5.6	13.0	45.6	4970	G
Las Vegas, Nevada 89109	2.5	4.1	6.6	43.5	2180	C, A
Ely, Nevada 89301	5.8	6.6	12.4	46.7	6260	R
Elko, Nevada 89801	6.9	5.7	12.6	48.1	5050	A
Reno, Nevada 89502	6.1	5.2	11.3	46.1	4400	D, S
Rosemead, California 91769	7.4	3.6	11.0	41.1	860	G
San Diego, California 92123	7.0	3.5	10.5	40.0	410	C
Santa Maria, California 93454	6.8	3.5	10.3	41.5	240	?
Bishop, California 93514	14.9	5.0	19.9	44.3	4150	S
Oakland, California 94614	3.0	3.5	6.5	44.0	20	G, A
Hawaiian Islands						
Keowakapu Beach, Maui 96753	0.7	3.0	3.7	20.8	20	G
Maalehu, Hawaii 96772	1.2	3.1	4.3	19.4	680	?
Waimanalo, Oahu 96795	1.6	3.0	4.6	21.2	60	G

Table I. (continued)

Location	<u>Background radiation ($\mu\text{R/hr}$)</u>			Geomagnetic Lat ($^{\circ}\text{N}$)	Elevation (ft)	Nature of soil under dosimeter ^a
	Terrestrial	Cosmic	Total			
Salem, Oregon 97302	4.4	3.7	8.1	50.8	200	G
Madford, Oregon 97501	4.0	3.9	7.9	48.4	1330	R, D
Burns, Oregon 97720	4.2	5.2	9.4	50.2	4170	G
Pendleton, Oregon 97801	4.9	4.1	9.0	52.3	1500	G
Forks, Washington 98331	2.8	3.7	6.5	51.5	210	W
Easton, Washington 98925	0.3	5.2	5.5	53.4	3970	D
Spokane, Washington 99219	7.6	4.5	12.1	54.4	2370	G, D
Anchorage, Alaska 99502	2.6	3.8	6.4	60.9	90	G
Bethel, Alaska 99559	4.2	3.8	8.0	58.3	150	D
Cold Bay, Alaska 99571	4.8	3.7	8.5	52.9	100	G
King Salmon, Alaska 99613	1.4	3.8	5.2	57.3	50	G
McGrath, Alaska 99627	2.7	3.9	6.6	61.5	340	Snow
Unalakleet, Alaska 99684	3.5	3.8	7.3	61.3	20	S
Yakutat, Alaska 99689	3.0	3.8	6.8	61.4	30	R, C
Fairbanks, Alaska 99701A	0.7	3.8	4.5	70.0	50	Snow
Barrow, Alaska 99723	0.3	3.8	4.1	68.6	10	Snow
Kotzebue, Alaska 99752	1.1	3.8	4.9	63.7	20	Snow
Annette, Alaska 99920	2.9	3.8	6.7	58.8	110	G

Table II. $\text{CaF}_2:\text{Dy}$ response to cosmic radiation-TLD readings (in effective CaF_2 mrad based on ^{60}Co) for 18-day exposures in spherical lead shields

Location	Elevation (ft)	Calculated cosmic air dose (mrad)	Observed dose (mrad)	Ratio observed/calculated
Livermore	600	1.36	0.96 ± 0.03	0.71
Mt. Diablo	3849	1.82	1.24 ± 0.04	0.68
Mt. Hamilton	4202	1.89	1.19 ± 0.03	0.63

Table III. Relative contribution of terrestrial and cosmic radiation at stations with highest elevations.

Location	Elevation (ft)	Geomagnetic Lat. ($^{\circ}$ N)	Radiation background (μ R/hr)		
			Terrestrial	Cosmic	Total
Flagstaff, Ariz.	7020	43.1	4.8	7.2	12.0
Ely, Nevada	6260	46.7	5.8	6.6	12.4
Colorado Springs, Colorado	6170	48.7	12.3	6.6	18.9
Cheyenne, Wyo.	6140	50.0	11.5	6.7	18.2
Lander, Wyo.	5560	51.1	8.3	6.2	14.5
Albuquerque, N.M.	5310	43.8	6.7	5.7	12.4
Milford, Utah	5030	46.2	12.0	5.6	17.6
Clayton, N. M.	4970	45.6	7.4	5.6	13.0
Grand Junction, Colorado	4840	47.5	8.9	5.6	14.5
Reno, Nevada	4400	46.1	6.1	5.2	11.3
Average			8.4	6.1	14.5

FIGURE CAPTIONS

- Fig. 1. National weather service stations selected for LLL environmental radiation background survey.
- Fig. 2. Rad/R response of CaF_2 versus energy.
- Fig. 3. Frequency distribution of terrestrial radiation versus exposure rate interval.
- Fig. 4. Frequency distribution of cosmic radiation versus exposure rate interval.
- Fig. 5. Frequency distribution of total environmental radiation background radiation versus exposure rate interval.
- Fig. 6. Projected annual environmental radiation background frequency distribution.

Lindeken - Fig. 1

Lindeken - Fig. 2

Lindeken - Fig. 3

Lindeken - Fig. 4

Lindeken - Fig. 5

Lindeman - Fig. 6

NOTICE

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