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ENVIRONMENTAL RADIATION BACKGROUND VARIATIONS BETWEEN RESIDENCES*

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Abstract—Environmental background radiation exposure measurements made in approximately 100 residences in the vicinity of Livermore, California, show variations in annual exposure from 52 to 130 mR. Measurements were made with CaF_2:Dy (TLD-200) dosimeters at quarterly intervals for a period of 1 yr. Dwellings were typically wood-frame structures with stucco exteriors. Interior exposure rates were, on the average, about 25% lower than those out of doors. Dosimeters were used without energy filters, since it appears photons with energies less than 100 keV contribute little to the total dose from natural radiation sources. Elimination of energy filters materially simplifies packaging and handling requirements for these measurements.

INTRODUCTION

THE Lawrence Livermore Laboratory (LLL) at Livermore, California, is currently engaged in a program to determine environmental levels of radioactivity in the area surrounding the Laboratory. Included in the program are measurements of the natural radiation background. As a part of this study, we have determined radiation background variations between residences in the area. We are particularly interested in residential radiation background because at the Laboratory, personnel dosimeters (TLD) are attached to the security pass badge, which the employee wears while at work. These badges are taken home and, during a normal week, are in the employees' homes over three times as long as they are at the Laboratory. For those whose assignments do not bring them in contact with work-related radiation, it follows that accumulated radiation registered by the dosimeter presumably is the result of natural background, most of which probably reflects a home exposure. At present, our Dosimetry Section is reviewing the appropriateness of the background value now used in dosimetry reporting. Measurements of home exposures were undertaken to determine the magnitude of background variations and the effect these variations have on personnel radiation dosimetry reporting when an "average" background exposure rate is assigned.

Relatively few measurements of environmental radiation have been made inside buildings.[1–5] The work of SOLON *et al.*,[1] using an ion chamber to measure the dose rate within 17 houses in the New York area probably represents the most frequently referenced study in the United States. One deterrent to such investigations, particularly in private dwellings, is the inconvenience involved in setting up and operating the detection equipment. Our measurements were made with thermoluminescent dosimeters. Because these dosimeters are small and unobtrusive, extended test periods can be employed without interfering with normal household activities. By integrating exposure rates over extended periods, possible fluctuations as a result of meteorological changes are minimized. Finally, as the detector package is relatively inexpensive, a large number of locations can be monitored simultaneously.

EXPERIMENTAL

Description of residences studied

One hundred and ten members of the Hazards Control Department at LLL volunteered to participate in the study. Their homes were surveyed during four consecutive 3-month test periods beginning in the summer of 1970. All homes were within a 50-mile radius of LLL; 65% of the homes were in the city

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Table 1. *Information concerning residences studied*

	Number	percentage
Construction		
Wood-frame with stucco exterior	78	70.9
Wood-frame with wood and stucco	20	18.2
Wood-frame with wood exterior	8	7.3
Concrete block	2	1.8
Other	2	1.8
Location of personnel dosimeter		
Bedroom	77	70.0
Kitchen	14	12.7
Dining room	7	6.4
Living room	6	5.5
Family room	3	2.7
Entry closet	2	1.8
Bathroom	1	0.9
Elevation of bedroom		
Ground floor	89	80.9
Second floor	21	19.1

of Livermore. Thus, the study was conducted in a reasonably confined geographical area. Dwellings were of typically wood-frame, single-story construction with stucco exteriors (Table 1). Prior to the test, a questionnaire was sent to the participants to determine the usual location of the personnel dosimeter badge when not at work. Most employees keep it in a bedroom, as indicated in Table 1. Accordingly, the test dosimeters were placed in this room usually in a closet or dresser drawer.

Detection

Measurements were made using CaF_2:Dy (TLD-200), which was selected for its greater sensitivity compared with LiF (TLD-100). Increased sensitivity of CaF_2 is partially offset by signal fading and energy dependence; these factors had to be considered before this phosphor could be used in our study.

Signal fading

Signal fading of CaF_2:Dy is most pronounced during the first 24 hr following irradiation. About 10% of the signal is lost during this period. Thereafter, fading proceeds at a much slower rate. However, at the end of 3 months, losses of about 30% may be expected. We made no attempt to apply fading corrections *per se*. We did irradiate the control dosimeters used for calibration midway through each 3-month test period. Control and test dosimeters were all read at the end of the test period. After 6 weeks, the extent of signal fading of the calibration dosimeters approximated that of the test dosimeters.

Energy dependence

Figure 1, which represents the calculated rad/R response at the energies shown, illustrates the energy dependence of CaF_2. Relative energy independence can be achieved by using filters to flatten the response below 100 keV. However, it appears that a negligible fraction of the radiation dose from natural background results from photons with energies less than 100 keV. We find that dosimeters containing both CaF_2 and LiF, the latter being comparatively energy independent, when exposed to natural background show a CaF_2 to LiF response ratio equivalent to the approximate sensitivity ratio of the two phosphors at energies exceeding the energy-dependent region of CaF_2. The absence of appreciable low-energy contribution permits the use of unfiltered CaF_2:Dy dosimeters for natural environmental radiation background measurements. Elimination of the energy response filters simplified packaging and handling requirements for these measurements.

Control dosimeters

Measurement of integrated radiation exposure from the natural environmental background poses a problem in the handling of

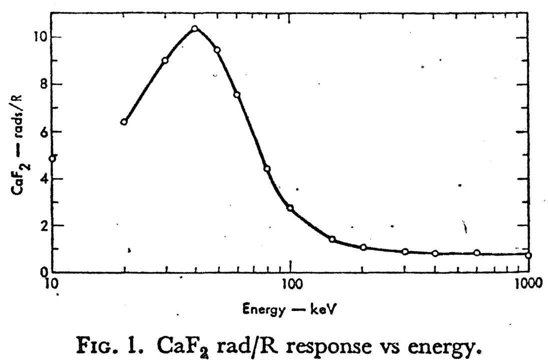

FIG. 1. CaF_2 rad/R response vs energy.

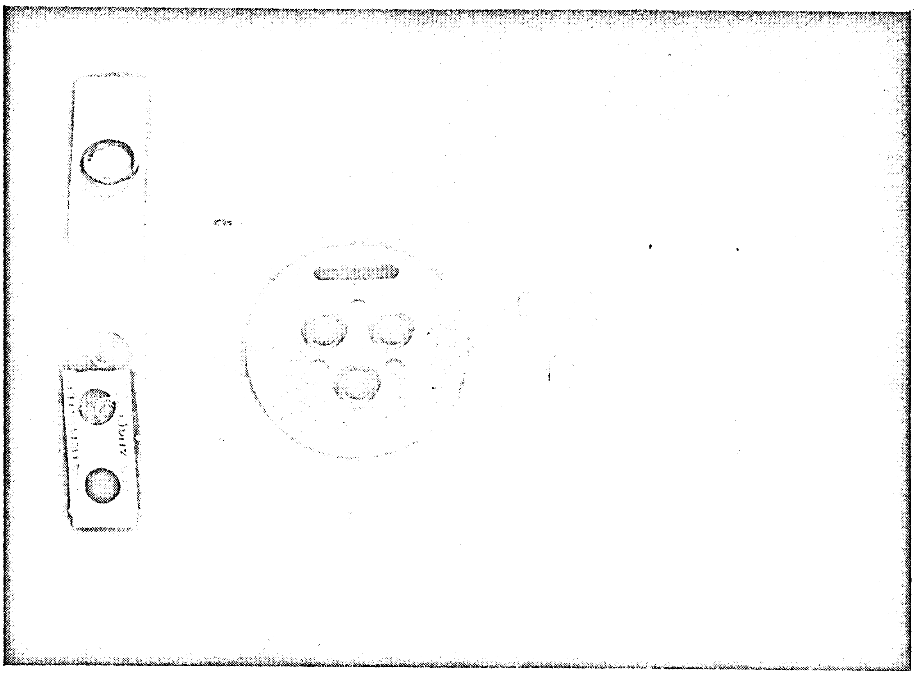

FIG. 2. LLL personnel dosimeter holder.

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 3-month exposure periods, the exposure to the control dosimeters is not precisely known, but it 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.[6] 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 have 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 ± 3 μrad (CaF_2) per day in the storage container and a nonradiation background of 0.3 mrad equivalent. These factors also 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 CaF_2:Dy is negligible for these artificially grown crystals, since potassium should be volatilized at the high temperatures maintained during crystal production.

PROCEDURE

Three hundred chips of TLD-200 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 holders[7] (Fig. 2) under subdued room lighting. Each holder contained two TLD-200 chips. Approximately 100 of these dosimeters were distributed to participating LLL employees, who were instructed to take the dosimeters home the day they were issued and to place them in a bedroom closet or dresser drawer. The 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. At the end of 6 weeks, a group of the control dosimeters was irradiated using the 60-keV gamma flux from a 7-Ci ^{241}Am source.[8] Six dosimeters were used in each calibration to cover a ^{241}Am exposure range from 0.5 to 10 mR. At the end of 3 months, the test dosimeters were recalled, and all dosimeters were read in the LLL automatic hot gas research reader.[9] Observed CaF_2 mrad doses from the two chips in each dosimeter were averaged and this average was converted to an equivalent mR exposure by dividing by 0.853, the rad/R response of CaF_2 at 1 MeV. Data for each seasonal exposure were normalized to the exposure period of the summer measurements.

RESULTS AND DISCUSSION

Figure 3 is a histogram showing the frequency distribution of 3-month exposure rates for each of the seasons studied. As indicated, median exposure rates during winter and spring are somewhat lower than those during summer and fall. In California, most of the annual rainfall occurs between November and April. The observed decrease in median exposure may reflect increased soil moisture, which in turn tends to reduce emanation rates of radon and thoron from the soil.

The range of exposure rates—nearly a factor of 3—and the discontinuity of the histograms at higher exposure rates is due to the radiation

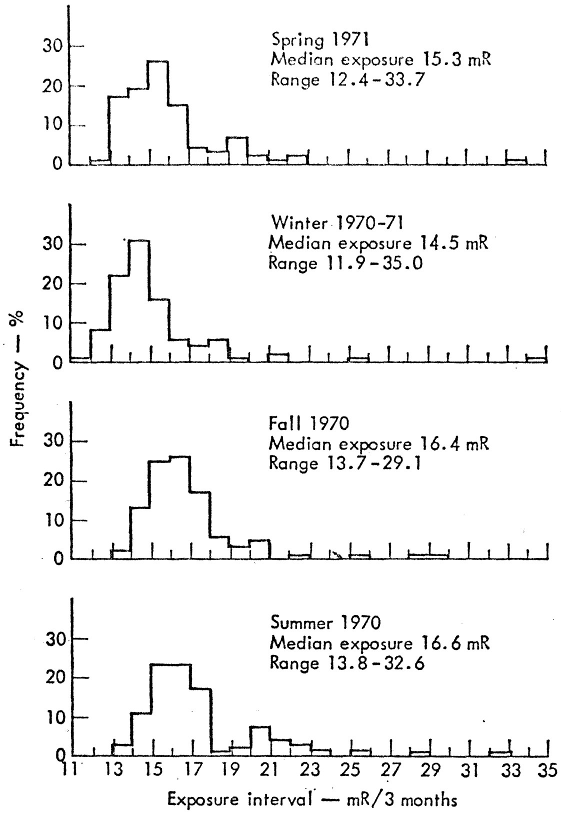

FIG. 3. Frequency distributions by residential background radiation by seasons.

levels in a relatively few homes. High readings were quite consistent. Figure 4, which is a season-by-season comparison of exposure rate in individual homes, shows remarkedly good agreement. In this comparison, all data were referred to fall measurements because returns were most nearly complete during that period. The purpose of the present work was to document the magnitude of background variations. The sources of the higher exposure rates are the subject of a separate investigation. Prior to each dosimeter distribution, participants were cautioned not to place their dosimeter near ceramic pottery pieces or luminescent dial watches or clocks. Similarities of construction make it unlikely that the differences observed are related to different construction materials. As a matter of interest, the highest reading was in a wood-frame home not discernibly different from the majority of the residences studied.

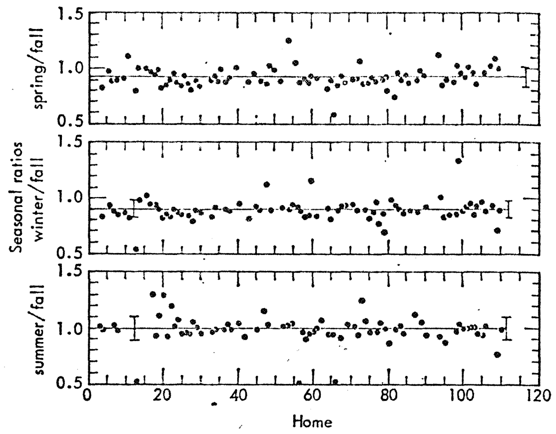

FIG. 4. Seasonal ratios from TLD readings in employees' homes. Top curve is spring 1971 to fall 1970 ratio. Center curve is winter 1970–1971 to fall 1970 ratio. Bottom curve is summer 1970 to fall 1970 ratio. Solid line is the average ratio; the error bars represent the standard deviation of a single reading.

No systematic attempt was made to compare indoor and outdoor exposure rates at each residence. However, based on a limited number of measurements, indoor values averaged about 25% lower than those outdoors. These observations suggest that in wood-frame construction, typical of most homes in the area studied, shielding effects of the construction material outweigh the radiation source effects.

In about 20% of the residences surveyed, the dosimeters were exposed in a second-floor bedroom (Table 1). Ground level and second-floor locations are compared in Table 2 with respect to median observed exposure rates during the four test periods. As expected, second-floor locations show lower median exposures but the difference is near the precision limits of these measurements.

Table 2. Comparison of ground floor and second floor radiation background

Test period	Median exposure, mR Ground floor	Second floor
Summer	16.7	15.9
Fall	16.4	15.7
Winter	14.7	13.9
Spring	15.5	15.0

Table 3. CaF_2:Dy *response to cosmic radiation.* (*TLD readings are in effective* CaF_2 mrad *based on* ^{60}Co *for* 18-day *exposures in spherical lead shields*)

Location	Calculated cosmic air dose, mrad	Observed dose, mrad	Ratio observed/calculated
Livermore	1.36	0.96 $\pm$ 0.03	0.71
Mt. Diablo	1.82	1.24 $\pm$ 0.04	0.68
Mt. Hamilton	1.89	1.19 $\pm$ 0.03	0.63

Natural terrestrial and cosmic radiation are at present the principal sources of environmental background. To determine how well CaF_2:Dy responds to the high-energy cosmic component, we measured its response at three different elevations (Mt. Hamilton, 4202 ft; Mt. Diablo, 3849 ft; and Livermore (LLL), 600 ft). In these measurements the phosphors were placed in 3-in.-thick lead shields to exclude the less energetic terrestrial radiation. The exposure period was 18 days. Table 3 compares the observed CaF_2 mrad dose with the cosmic air dose calculated for each location. The data of LOWDER and BECK[10] relating cosmic radiation and elevation were used for these calculations. Corrections were made for geomagnetic latitude of each location. The ratio of observed to calculated dose is in good agreement with the 0.7 hard-to-total cosmic ray flux and ionization ratio observed by Lowder and Beck at sea level at 50°N geomagnetic latitude. This agreement also indicates that the response of CaF_2:Dy to the hard component is approximately "air equivalent". Since the CaF_2 mrad dose data from the residential measurements also indicated a near "air equivalence", it would appear that there are no response anomalies in the natural background energy spectrum. As noted, CaF_2 dose data were converted to mR using 0.853, the rad/R response to CaF_2 at 1 MeV. Figure 1 shows little change in rad/R response above 200 keV so that in this energy region exposure rates are not materially affected by the choice of conversion factor.

From measurements based on four consecutive 3-month test periods in a reasonably confined geographical area in California, we found the projected annual median residential radiation exposure to be 63 mR with a range from 52 to 130 mR. Variations of a factor of 2 or more in radiation background between different geographical areas are well recognized, but it appears that similar variations may exist within a given area. As previously noted, 65% of the residences studied were within the city of Livermore; the range in observed backgrounds within Livermore residences approximates that of the group as a whole.

The "average background" used by our Dosimetry Section is equivalent to about 15 mR/3 months, which is in good agreement with the median exposure rate for the same period observed in the residential study. However, because of the range in residential backgrounds, it is doubtful that any assigned average background has much real utility.

SUMMARY

Environmental radiation background measurements made in approximately 100 residences in the vicinity of Livermore, California, show a median annual exposure rate of 63 mR with a range from 52 to 130 mR. While the median exposure rate is in good agreement with the 60 mR "average background" used by our Dosimetry Section in assigning occupational exposures, the range in observed residential background makes the use of any average background questionable.

Measurements were made with CaF_2:Dy (TLD-200) thermoluminescent dosimeters. Dosimeters were used without the energy response filters commonly employed to flatten the phosphor's energy response below 100 keV, because it was found that low-energy photons contribute a negligible fraction of the total dose from natural radiation sources.

REFERENCES

1. L. R. SOLON, W. M. LOWDER, A. SHAMBON and H. BLATZ, *Science* **131**, 903 (1960).
2. B. HULTQUIST, *Kgl. Sv. Vetenskapskad Handl* **6**, Ser. 4 (1956).

3. Physikalish-Technische Pruefaustalt fuer Radiologie and Elektromedizin, Radiological data; v.e. United Nations document A/AC.82/G/R. 102.
4. T. Doke, Y. Takami and A. Nakamoto, *Measurements of Radiation Doses due to Background Gamma Rays by Plastic Scintillators*, United Nations document A/AC.82/G/L. 397 (1960).
5. F. W. Spiers, *Strahlentherapie Sonderb* **111**, 65 (1960).
6. D. E. Jones, Low-Level Dose Measurement with TLD, in: *Hazards Control Progress Report No.* 39, Lawrence Livermore Laboratory, Livermore, Rept. UCRL-50007-71-1 (1971).
7. D. E. Jones, K. F. Petrock, B. G. Samardzich and E. G. Shapiro, *Thermoluminescence Dosimeter System for Personnel Monitoring*, Lawrence Livermore Laboratory, Livermore, Rept. UCRL-73084 (1971).
8. J. V. Boggs, *A Portable Low-Energy Photon Calibration Source*, Lawrence Livermore Laboratory, Livermore Rept. UCRL-72737, Rev. 1 (1971).
9. K. F. Petrock and D. E. Jones, Hot Nitrogen Gas for Heating Thermoluminescent Dosimeters, in: *Proc. 2nd Int. Conf. Luminescence Dosimetry*, p. 652, Gatlinburg, Tenn., 23–26 September (1968).
10. W. M. Lowder and H. L. Beck, *J. Geophys. Res.* **71**, 4661 (1966).