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BETWEEN RESIDENCES

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NATURAL TERRESTRIAL BACKGROUND VARIATIONS BETWEEN RESIDENCES*

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ABSTRACT

Approximately 100 $\text{CaF}_2\text{:Dy}$ (TLD-200) dosimeters were placed in the homes of LRL employees as part of a program to determine the magnitude of natural terrestrial background variation. Dwellings were typically wood-frame structures with stucco exteriors. Measurements were made over two 3-month periods during the summer and fall of 1970. Essentially no difference was observed between the two sets of measurements. In both cases, the median dose rates were 9.6 mR per 3-month period; the ranges were from 8 to 19 mR and from 8 to 17 mR for the summer and fall months, respectively. Interior dose rates were, on the average, about 25% lower than those out of doors. Comparison of dose rates within individual homes showed an average summer-to-fall ratio of 0.973. Each dosimeter contained two chips. Average deviation in readings between chip pairs was about 2%.

Dosimeters were used without energy filters. To account for the phosphor's energy dependence below 100 keV, an energy weighted millirad/milliroentgen response factor was calculated. Such a calculation is practicable because the

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energy distribution within gamma spectra from natural terrestrial sources, particularly in the region of 100 keV and below, has been found to be relatively constant. Using the calculated response factor, dose rates made with unfiltered CaF_2 agree within about 15% with those determined with a 3-in. by 3-in. NaI(Tl) counter. Elimination of the energy filter provides additional sensitivity, as advantage can be taken of the enhanced response of CaF_2 below 100 keV, and simplifies packaging and handling requirements of these measurements.

INTRODUCTION

The Lawrence Radiation Laboratory (LRL) 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 terrestrial radiation background. As part of this study, we have completed measurements of radiation background variations between residences in the area. We are particularly interested in residential radiation background. 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. During a normal week, badges 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 is presumably due to 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 natural terrestrial background variations and the effect these variations have on personnel radiation dosimetry reporting when an "average" background dose rate is assigned.

Relatively few measurements of terrestrial 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 the dosimeters are small and unobtrusive, extended test periods can be employed without interfering with normal household activities. By integrating dose rates over these periods, possible fluctuations due to 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 LRL-Livermore volunteered to participate in the study. Their homes were surveyed during two consecutive 3-month test periods beginning in the summer

of 1970. All homes were within a 50-mile radius of LRL; 65% of the homes were in the City of Livermore. Thus, the study was conducted in a reasonably confined geographical area. Dwellings were of typically wood-frame, single-story construction with stucco exterior as shown in 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 $\text{CaF}_2:\text{Dy}$ (TLD-200). TLD-200 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, therefore, techniques to circumvent these factors had to be developed before this phosphor could be used in our study.

Signal Fading

Signal fading of $\text{CaF}_2:\text{Dy}$ 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. What we did was irradiate the control dosimeters used for calibration midway through each of the 3-month test periods. 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. Since the fading represents about 20% of the total dose, the error in this "correction" technique represents a very small contribution to the experimental errors.

Energy Dependence

The energy dependence of CaF_2 is illustrated by the millirad/milliroentgen versus energy response curve shown in Fig. 1. To use the CaF_2 as a dosimeter to measure natural terrestrial background requires that either (1) relative energy independence be achieved by using filters to flatten the energy response below 100 keV or, (2) the energy-weighted millirad response of the detector to the natural background gamma spectrum be known. We chose to investigate the latter. Elimination of filters also simplified packaging and handling requirements for these measurements while retaining the enhanced response of CaF_2 below 100 keV.

Natural background gamma spectral measurements were made at several locations in the Livermore Valley using a 3-in. by 3-in. NaI(Tl) detector. Based on previous surveys, the selected sites represented relatively high, low, and intermediate background levels. In addition, we obtained background spectra inside private homes. An example, typical of the spectra observed, is shown in Fig. 2.

In all cases we observed the Compton continuum peak at about 80 keV. Although the counting rates varied according to location, the relative distribution of energy within the spectrum remained remarkably constant. These observations are in agreement with the results of a previous 1-year

study of natural gamma background in the energy region from 10 to 100 keV, in which we found the energy distribution to be reproducing to within about $\pm 5\%$.⁶ This apparent uniformity in energy distribution within natural terrestrial gamma background spectra makes it possible to calculate an energy-weighted millirad/milliroentgen response factor for CaF_2 to this radiation. At selected energy intervals the respective photons per minute were converted to equivalent milliroentgen values.⁷ These dose rates were summed over the energy range from 20 keV to 1.5 MeV. For each energy interval, the fractional contribution each made to the total was calculated. Then each fractional milliroentgen value was multiplied by the corresponding millirad/milliroentgen response of CaF_2 at that energy. Finally, the products thus obtained were summed to obtain the desired energy-weighted response to natural background radiation. We found this value to be 1.47 ± 0.03 millirad/mR.

The observed CaF_2 millirad dose of exposed test dosimeters was divided by the conversion factor to obtain the equivalent milliroentgen value. It should be noted that our conversion factor is based on the energy response of CaF_2 —not $\text{CaF}_2:\text{Dy}$ (TLD-200). Consequently, the effect of the dopant is not reflected. Recently we obtained experimentally determined energy response data for TLD-200. While as expected, the presence of dysprosium increases the response below 100 keV, recalculation of the factor over the same energy range (20 keV to 1.5 MeV) using the TLD-200 data increases this factor by only about 2%.

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 LRL personnel dosimeter holders⁸ (Fig. 3) under subdued room lighting. Each holder contained two TLD-200 chips. Approximately 100 of these dosimeters were distributed to participating LRL 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 ²⁴¹Am source.⁹ Six dosimeters were used in each calibration to cover a ²⁴¹Am dose rate 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 LRL automatic hot gas research reader.¹⁰

RESULTS AND DISCUSSION

Figures 4 and 5 are histograms showing the frequency distribution of the 3-month terrestrial dose rates observed during the summer and fall months of 1970. The median dose rate in both cases was 9.6 mR. Dose rates ranged from 8 to 19 mR for the summer months and from 8 to 17 mR for the fall months. Thus, essentially no difference was observed between the two periods.

We have no basis for evaluating our data with respect to the accuracy of the measurements made in individual homes. Rather we must rely on reasonableness of the numbers compared with those made by others and the precision observed in replicate measurements. Our data show a projected annual terrestrial dose rate range from 32 to 75 mR, which is in good agreement with Solon's range of 29 to 90 millirad.¹ Wollenberg et al.¹¹ have measured terrestrial radiation backgrounds in the San Francisco Bay Area using a 3-in. by 3-in. NaI(Tl) scintillation counter. The correlation between dose rates they observed and dose rates based on a 1-month exposure of TLD dosimeters at a number of outdoors monitoring locations is shown in Fig. 6. The solid line represents a least squares fit; and, based on this fit, the two methods agree to within about 15%. Dose rates observed by the TLD method are generally higher, and this is probably due to the response of CaF_2 to cosmic radiation.

Measuring integrated radiation dose rates from the natural environmental background poses a problem in the handling of control not common to 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 the lead shield. During the time dosimeters used for calibration irradiations were out of the lead storage container, 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.¹² 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. The TLD's used have a standard deviation of about 1.6%. The typical sensitivity in light output per millirad 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 nonradiation (dose equivalent) background. The results showed a radiation dose rate of $46 \pm 3 \mu\text{r}$ (CaF_2) per day in the storage container and a nonradiation background of 0.3 millirad equivalent. These factors also contribute to the light output of the calibration dosimeter and must be considered in dose assignment. The nonradiation response was due to 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.

The precision obtained with the TLD method based on data from 10 dosimeters that were exposed at the same outdoor location for a period of 1-month is shown in Table 2. A similar measure of precision is directly available from the two sets of home exposure data. As previously noted, each dosimeter contained two TLD-200 chips. Average deviation between chip pairs was 2.1% for the summer

data and 1.6% for the fall data. Credence in the validity of the observed dose rates is supported by a comparison of individual residences for the two periods, which showed an average ratio between summer and fall dose rates of 0.973. No systematic attempt was made to compare indoor and outdoor dose rates for the residences. However, based on a limited number of measurements, indoor dose rates averaged about 25% lower than those outdoors. These observations suggest that in woodframe construction, typical of most homes in the area studied, the shielding properties of the construction material outweighs the radiation source properties.

In about 19% 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 3 with respect to median observed dose rates during the two test periods. As expected, second-floor locations show lower median exposures. However, the differences are small and are at about the reproducibility limits of our method. As a result, the observations are probably of directional significance only.

The primary objectives of this study were to determine (1) the magnitude of natural terrestrial background variations between residences and (2) the effect these variations would have on personnel radiation dosimetry reporting, if an "average background" dose rate term were assigned. From measurements based on two consecutive 3-month test periods in a reasonably confined geographical area in California, we found the projected annual median residential radiation dose to be 38 mR with a variation (upward) of about the same magnitude. Thus, it would appear impractical to assign much significance to an "average background" dose determined for this population. We suspect that similar studies in other areas would demonstrate that this observation is the rule rather than the exception.

It may be of interest to point out that this home exposure study reflects terrestrial radiation dose rates to the "population-at-large." Under present standards,¹³ recommended radiation exposures to this population is limited to 170 mrem/yr from other than medical or natural radiation. If recommended exposure to other than medical and natural sources were lowered by an order of magnitude, as some have suggested,¹⁴ our data show that such action would result in a standard that is exceeded by the observed variation in the natural terrestrial background. At these low rates, the state-of-the-art of personnel dosimetry cannot accurately distinguish between radiation sources. As a result, measurements of background, even in relatively confined geographical areas, would indicate a significant number of "over exposures" traceable to natural source variations, if we were to use an assigned "average background."

SUMMARY

Natural terrestrial background radiation dose rate measurements made in approximately 100 residences in the vicinity of Livermore, California, using $\text{CaF}_2:\text{Dy}$ (TLD-200) dosimeters show variations in projected annual dose rates from 32 to 75 mR. Measurements were in good agreement with those made in the New York area using an ion chamber. Dose rates measured at several outdoor locations agreed within about 15% of those made using a $\text{NaI}(\text{Tl})$ scintillation counter. Based on replicate measurements, the TLD method shows a reproducibility within $\pm 5\%$.

The $\text{CaF}_2:\text{Dy}$ dosimeters were used without energy filters. To account for the phosphor's energy dependence below 100 keV, an energy-weighted millirad/milliroentgen response was calculated. Elimination of filters

simplified packaging and handling requirements of these measurements while retaining the enhanced response of CaF_2 below 100 keV.

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TABLE 1
INFORMATION CONCERNING RESIDENCES STUDIED

	Number	Percentage
<u>Construction</u>		
Wood-frame with stucco exterior	78	70.9
Wood-frame with rustic and stucco	20	18.2
Wood-frame with rustic	8	7.3
Concrete block	2	1.8
Other	2	1.8
<u>Location of Personnel Dosimeter</u>		
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
<u>Elevation of Bedroom</u>		
Ground floor	89	80.9
Second floor	21	19.1

TABLE 2
REPLICATE MEASUREMENTS—EAST PERIMETER
LRL-LIVERMORE

Dosimeter	$\mu\text{R/hr}^*$
1	5.83
2	6.10
3	6.18
4	6.05
5	6.08
6	5.92
7	6.02
8	6.02
9	6.26
10	6.26
Average = $6.07 \pm 0.14 \mu\text{R/hr}$	

*Based on a 32-day exposure (768 hr). Light output values from the two TL0-200 chips were averaged.

TABLE 3
COMPARISON OF GROUND FLOOR AND SECOND FLOOR
RADIATION BACKGROUNDS

Test Period	Median Dose, mR	
	Ground Floor	Second Floor
Summer	9.6	8.9
Fall	9.6	9.1

FIGURE CAPTIONS

- Fig. 1.** CaF_2 millirads/milliroentgen vs energy.
- Fig. 2.** Natural background spectrum vs energy for the 3-in. by 3-in. NaI detector—Livermore Valley, August 1970.
- Fig. 3.** LRL personnel dosimeter holder.
- Fig. 4.** Distribution of natural terrestrial radiation backgrounds—Livermore Valley residences, summer 1970.
- Fig. 5.** Distribution of natural terrestrial radiation backgrounds—Livermore Valley residences, fall 1970.
- Fig. 6.** Comparison of natural terrestrial radiation dose rate measurements—NaI scintillation counter ¹² and $\text{CaF}_2\text{:Dy}$ TLD.

Lindeken - Fig. 1

Lindeken - Fig. 2

Lindeken - Fig. 3

Lindeken - Fig. 4

Lindeken - Fig. 5

Lindeken - Fig. 6