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Paul H. Gudiksen and Thomas R. Crites

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A COMPARISON OF GAMMA-RAY EXPOSURE RATE MEASUREMENTS AT BIKINI ATOLL*

Paul H. Gudiksen and Thomas R. Crites
Lawrence Livermore Laboratory, University of California
P. O. Box 808, Livermore, California, 94550

Abstract

A radiological survey of Bikini and Eneu Islands of the Bikini Atoll was conducted during June 1975 to assess the potential radiation doses that may be received by the returning Bikinians. Bikini Atoll was one of the U.S. nuclear weapons testing sites in the Pacific. An integral part of the survey included measurements of the gamma-ray exposure rates at 1 m above the ground with portable NaI instruments at nearly 2700 locations on the two islands. For comparison purposes, similar measurements were made with a pressurized ion chamber at approximately 200 locations, and with LiF and CaF_2:Dy thermoluminescent dosimeters (TLDs) at 80 locations. The results indicate that the NaI scintillators overresponded because of their nonlinear energy characteristics. The responses of the LiF dosimeters and the pressurized ion chamber agreed to within 13%. Attenuation studies with LiF TLDs indicated that roughly 25% of the total free air exposure rate at 1 m was due to beta radiation.

Introduction

With the objective of evaluating the potential external radiation doses that may be received by the returning Bikinians, during June 1975 a survey was conducted of the residual fission product radioactivity in the terrestrial environment on Bikini and Eneu Islands of Bikini Atoll. These are the largest islands and, therefore, the ones of primary importance for future habitation. The atoll is situated in the northern part of Micronesia in the Central Pacific ocean about 3600 km southwest of Honolulu, and consists of a number of small islands on an elliptical coral reef.

Several independent techniques were used to measure the gamma-ray exposure rates since each technique has its own set of limitations (i.e., nonlinear energy response, portability of equipment, and extent of geographic coverage). These techniques included making measurements with the use of portable, hand-held NaI scintillation detectors, a commercially available pressurized ion chamber, and two types of thermoluminescent dosimeters (TLDs).

Measurement Techniques

Measurements of the exposure rates at 1 m above the ground were made with NaI scintillators at about 2500 locations on a 30-m rectangular grid over the entire surface of Bikini Island, and at about 200 locations on a 100-m grid on Eneu Island. The portable scintillation detectors consisted of a 2.5-cm diam x 3.8-cm-long NaI crystal with rate meter readout. The instruments were calibrated in microroentgens per hour (µR/hr) in three ranges corresponding to 0 to 30, 0 to 300, and 0 to 3000 µR/hr against a ^{137}Cs point source on the primary calibration range of the National Environmental Research Center, Las Vegas, Nevada. Calibration was repeated on selected instruments following the survey. Since the response of this instrument is energy-dependent, it was expected to overrespond because of the distributed nature of the activity in soil. Instrument portability and the comparison of its response with the results of other techniques allowed measurements at many locations on a uniform grid of the islands. This detector is virtually insensitive to cosmic radiation.

Comparisons were performed by making duplicate measurements over the entire range of observed exposure rates, about 200 locations, with a high-pressure ion chamber. This instrument utilizes a stainless steel sphere filled with high-pressure ultra-pure argon. The current produced by the radiation-induced ionization within the chamber is measured by a sensitive electrometer with digital readout. The detector was calibrated by the manufacturer and verified by several ERDA laboratories. The instrument exhibits a relatively flat energy response over gamma-ray energies of interest to this survey. The chamber walls are sufficiently thick to make the detector insensitive to the beta radiation present in fallout fields. This instrument is sensitive to cosmic radiation.

Further comparisons were made by means of LiF and CaF_2:Dy thermoluminescent dosimeters (TLDs) placed at 80 of the above locations. The LiF chip was used because of its energy linearity and its excellent thermal stability. The response of LiF is within approximately 1% of being air-equivalent for a typical environmental radiation field. The CaF_2:Dy TLDs have an enhanced energy response at low energies, and were used to detect possible low-energy radiation fields by comparison with the LiF readings. The LiF and CaF_2 chips (3.18 mm square x 0.89 mm and 1.02 mm thick respectively) were matched to 5% and 4% respectively within each batch. The TLDs were annealed on the atoll immediately before being placed on the two islands. Two Lawrence Livermore Laboratory (LLL) plastic personnel badges containing three LiF and three CaF_2 chips were placed at each field location. The TLD packets were attached to trees by nylon straps or placed on wooden stakes at a height of 1 m above the ground. The locations were carefully

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chosen to obtain exposures over the full range of gamma exposure rates observed by the portable instrument survey. After the three-month exposure period, the dosimeters were retrieved and handcarried (by air) in a lead container to Livermore for readout.

Calibration and signal fading studies were carried out by exposing separate sets of TLDs to a ^{137}Cs point source before and after the exposure period. A special low-scatter calibration fixture was constructed for field use which aided in obtaining uniform, reproducible exposures. The strength of the calibration source was determined by use of a NBS-calibrated Radocon chamber and TLD comparison to a NBS-calibrated ^{60}Co source. The calibration is believed to be known within ±3% at one standard deviation.

A set of control TLDs was stored in a lead pig on a "clean" island in the Marshalls during the exposure period for background determination. The background exposure was essentially all contributed by cosmic radiation during the three-month exposure period and during the aircraft flight to LLL. Additional TLDs were stored on the periphery of the storage container to identify possible inadvertent exposures. The average background exposure for the two types of TLDs was subtracted from all field measurements so that the results represent only the terrestrial radiation exposure rates. The effect of sunlight on this packaging arrangement was also studied and found to be negligible within the statistics of the data.

The beta contribution to the total exposure rate was studied at three locations. The experimental stands, 46 cm wide by 92 cm long and 46 cm high, were built of aluminum framework. Three pieces of aluminum bar stock, 1.3 cm thick and 5 cm wide, were bolted across the top of each stand, evenly spaced. These were each drilled to receive two sets of TLDs and various thicknesses of aluminum shielding. Thus six sets of TLDs were exposed at each location, shielded top and bottom by various thicknesses of aluminum. Aluminum shielding by the bar stock around the sides of the dosimeter package was not less than 0.6 cm. An attenuation plot is shown in the next section.

Comparison of Results

The correspondence between the results obtained with the NaI scintillator and the pressurized ion chamber is presented in Fig. 1. The ion chamber readings have been reduced by 3.3 μR/hr; the cosmic-ray contribution at that latitude. A review of the figure reveals the overresponse exhibited by the NaI scintillator due to its nonlinear energy characteristics. The discontinuity at about 30 μR/hr occurs at a range switching point on the scintillator. Three locations, were measured on both low and high range, and those results are shown in solid circles. On the scintillation instrument's low range of 0-30 μR/hr, a correspondence near 1:1 is observed. On the higher range, the correspondence, though linear, deviates more markedly from the 1:1 relationship.

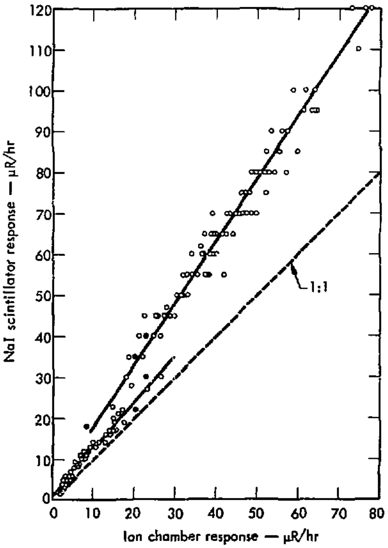

Fig. 1. Comparison of responses of NaI scintillator and ion chamber.

The TLD results indicated that the CaF_2 measurements were approximately 21% higher than those of LiF. This is consistent with similar studies made at Eniwetok Atoll(1) and with environmental monitoring performed by LLL in the U.S. This ratio corresponds to an average gamma energy of about 500 keV, and is reasonable based on the CaF_2 enhanced low-energy response and the predominance of ^{137}Cs activities distributed in the soil. Fading studies indicate a 5.5% signal decrease during the three-month exposure period for LiF and 34% for CaF_2. These figures are similar to previous results at LLL with these materials. Overall accuracy of exposure assessment from the TLD data appears to be within ±6% at 1σ for the range 30 μR/hr to 90 μR/hr.

To assess the beta contribution to the LiF exposure rates, the beta attenuation curve is shown in Fig. 2 for one of the three locations. The measurements at the other two locations were similar in shape, though differing in intensity. A feather analysis of the beta curves gives a beta energy between 1.5 and 2.2 MeV. Given the distributed nature of the activity in the soil and the known predominance of ^{90}Sr-^{90}Y beta activities, this energy range is consistent with the 2.27-MeV ^{90}Y beta radiation. Previous(2) soil sample analysis indicates a fairly uniform mixing of radioisotopes in the top 25 cm of soil, with the gamma activity largely due to ^{137}Cs. The ^{90}Sr/^{137}Cs ratio was found to be approximately 0.6 in the top few centimeters of soil.

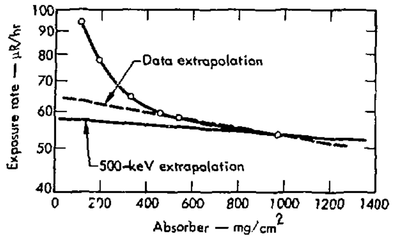

Fig. 2. Beta attenuation.

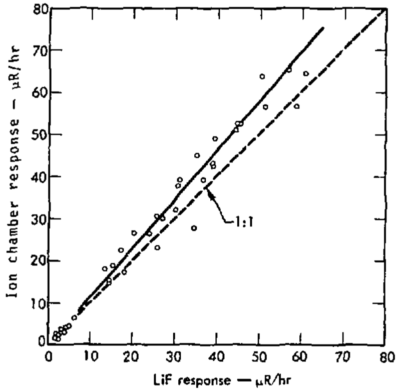

Fig. 3. Comparison of responses of ion chamber with LiF.

Two gamma-ray extraction lines are shown in Fig. 2. One is based on extrapolation of the last few data points on the curve, the other on the observed 0.50 MeV average energy attenuation in aluminum. This extraction was made for each of the three locations measured and an average gamma-to-gamma plus beta ratio of 0.73 determined for a height of 1 m. Thus, the total free air exposure rates measured by the LiF dosimeters were reduced by the factor 0.73 to obtain the gamma-ray exposure rates.

The comparison between the ion chamber results and the LiF gamma-ray exposure rates is presented in Fig. 3. The scintillator data differ widely (up to 75%) from either of the other two measurements, and are not shown in this plot. The ion chamber readings also differ somewhat from the LiF results. A linear regression of the two data sets gives agreement of about 13% between the two methods. One also finds that the correlation of points in Fig. 3 is not as good as that in Fig. 1. This difference is most likely due to the beta contribution to the LiF results, which may vary throughout the islands, causing spread in the data. Departure from the 1:1 relationship in Fig. 3 may be due to an over-correction of the TLD data for beta response or to insufficient consideration of the ion chamber data for energy dependence. Calibration of the pressurized ion chamber against a point ^{226}Ra source, the method used with the instrument in this study, leads to a 3% overestimate in the measurement of "typical" environmental fields in this country.[3] If a similar correction were made to these data, the agreement of the two independent exposure-rate determinations would be within 10%.

Summary

The survey performed at the Bikini Atoll in June 1975 included, as one part, the determination of the external exposure rates at points about the primary islands of the atoll. The beta contribution to the free-air exposure rate was found to be significant, and must be considered. The importance of instrument calibration for the type of exposure field to be measured was reinforced. General agreement of two independent exposure-rate assessment techniques (ion chamber and TLD), after correction for known energy and beta effects, lends confidence to the final exposure results.

Acknowledgments

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