BIKINI ATOLL IONIZING RADIATION SURVEY--MAY 1985-MAY 1986

K. L. Shingleton, J. L. Cate, M. G. Trent, W. L. Robison
Lawrence Livermore National Laboratory

INTRODUCTION

Between 1946 and 1958, the United States conducted 23 nuclear tests at the Bikini Atoll in the Marshall Islands. The single largest detonation was the "Bravo" test, which resulted in extensive radioactive contamination of a number of islands and prevented the timely resettlement of the native population. Since 1958, many studies have been conducted to assess cleanup options and the internal and external radiation doses the Bikinians would likely receive, should they resettle the islands.

Although the external dose rates from β and γ radiation have been previously determined by aerial and ground measurement techniques, technical constraints limited the assessment of external β dose rates from the Cs-137 and Sr-90/Y-90 contamination on the islands. Now, because of the recent development of very thin thermoluminescent dosimeters (TLDs), these external β dose rates can be measured.

THE SURVEY

The purpose of this survey was to (1) determine the β dose rate at 7 mg/cm^2 and the deep dose rate (γ) on the two habitable islands in the atoll, Bikini and Eneu; (2) compare the dose rates at heights of 1 cm, 50 cm, and 100 cm; and (3) determine the effect of various ground covers on the β dose rate.

We conducted this survey in two 6-month phases, and based results on data from 800 Panasonic-802 dosimeters. Each dosimeter contains 4 elements (E1, E2, E3, and E4); E1 and E2 are $Li_2B_4O_7$:Cu and E3 and E4 are $CaSO_4$:Tm (hereafter referred to as Li or Ca). These dosimeters are normally exposed in their holders, which contain absorbers, but in this experiment, half of the dosimeters were exposed out of their holders so that both the Li and Ca chips measured the β radiation. We sealed each dosimeter in a Saran bag that was lined with aluminized mylar: the Saran (2 mg/cm^2) provided moisture protection and the reflective aluminized mylar (1 mg/cm^2) minimized heat buildup. Except where the bags were exposed to intense reflected light or got buried in the ground, this packaging configuration was successful. Bagged Panasonic dosimeters were placed between aluminum supports that were stapled to wood blocks. A layer of plastic tape was placed over the top and sides of the dosimeters to protect them from direct rain and sunlight.

We distributed the dosimeters among 102 monitoring sites, each consisting of 1 out-of-holder (O) and 1 in-holder (I) dosimeter at heights of 1 cm, 50 cm, and 100 cm; 11 β spectrometer arrays, used to assess the maximum and average energy of the β radiation; and 6 fade study stations, used to assess environmentally induced fading of the Panasonic dosimeters. Each β spectrometer array consisted of five out-of-holder dosimeters at heights of 1, 50, and 100 cm. At each level, one dosimeter was left bare, while the other four were covered with aluminum absorbers so that total absorber thicknesses were 14, 21, 48, 84, and 233 mg/cm^2, respectively. Each fade study site consisted of two out-of-holder dosimeters, sandwiched between thick aluminum absorbers and mounted in a holder equidistant from a 10 μCi Cs-137 source. Since any β response was eliminated by the aluminum absorbers, and both Li and Ca respond linearly to the 662 keV photons from Cs-137, any fading of the Li relative to the Ca would be evident by comparing the measured doses at the end of the experiment. Three fade study locations were selected, representing the full range of thermal environments: one in a house protected from direct rain and sunlight, one in a breezy, semi-shaded area, and one in the middle of the island with intense sunlight and little breeze.

We selected monitoring sites based on the Marshallese life style, giving emphasis to areas where people would likely spend the most time. To assess the effect of ground cover, many of the areas monitored included two adjacent sites, one cleared of plants and debris, and one left uncleared. We also evaluated the effect of coral gravel as a ground cover by placing a 1-m-radius pad of it in two highly contaminated areas on Bikini and putting a monitoring station in the center of each. Nearby, we established stations over cleared and uncleared soil.

Another area specifically evaluated was the Excavation Plot, an experimental garden established in the most contaminated area of Bikini. All plants and the top 40 cm of soil had been removed from this 2-acre plot, where different crops were then grown. The Control Plot, equal in size and adjacent to the Excavation Plot, was also stripped of plants and used as an experimental garden, but the topsoil was left essentially undisturbed. A 90-foot-wide Buffer Zone, left in its natural condition, separated the Excavation and Control Plots.

DATA ANALYSIS:

The dosimeters were shipped to Bikini in a lead box and the control dosimeters indicated the transportation dose was statistically indistinguishable from background. Therefore, we made no specific correction for transportation dose.

The cosmic ray background of 3.3 μR/hr had been previously assessed by various experimenters and data from Eneu corroborate this value. We subtracted a background of 3.3 μR/hr (29 mrem/yr) from the dose rates reported in this survey.

Li data from the six fade study sites were within two standard deviations of the respective Ca data, so we did not apply any fade correction to the Li data.

Because Ca significantly overresponds to low-energy photons, we compared data from E3(I) (Ca) and E2(I) (Li), both of which are covered with absorbers that attenuate only 4% of 30 keV photons. We found the dose on E3(I) exceeded that on E2(I) by more than 3 standard deviations only 3.9% of the time, indicating that low-energy photons made an insignificant contribution to the total radiation dose. Therefore, we did not make a correction for Ca overresponse.

We also compared E1(O) and E2(O) (Li) to E3(O) and E4(O) (Ca) and found that in 85% of the cases, the average of the dose on the Li chips fell within three standard deviations of the average on the Ca chips. In 7% of the cases, the Li chips read higher than the Ca, and in 8% of the cases, the Li chips read lower. After extensive evaluation, we found that Li TLDs were adversely affected by moisture, heat, and light, and had limited accuracy at low doses. Ca TLDs did not have these limitations, and since there was no low-energy Ca overresponse to contend with, we used only the Ca data (E3 and E4) to calculate dose rates.

Analysis of the β spectrometer arrays indicated that the average energy of the β spectrum was somewhere between that of Y-90 and Tl-204. At 7 mg/cm^2, the efficiency of the Ca TLDs to Y-90 was 85%, and to Tl-204 was 72%. We chose a calibration factor of 79% and then determined the β dose rates at 7 mg/cm^2 by averaging the E3(O) and E4(O) data, subtracting the corresponding E4(I) data, and dividing by 0.79.

We used E4(I) data to assess the exposure rate in air from penetrating γ radiation, and Kerr's conversion factor for the testes (0.75 rads in tissue/R in air, at 662 keV) to convert to dose in tissue.

Published conversion factors for photon dose to the skin range from 0.685 to 0.78 rads in tissue/R in air. We chose to use 0.75 because it was conservative and the same conversion factor used to calculate dose in the testes. Shallow dose rates were then calculated by adding the photon dose rate to the skin to the respective β dose rate.

After measuring the precision and accuracy of the dosimeters, we calculated a total experimental error of $\pm$15% on the raw data, and propagated the errors to report the 95% confidence interval of the reported dose rates. We assumed that the background value of 3.3 μR/hr and the conversion of 0.75 rad in tissue/R in air were constants.

DISCUSSION OF RESULTS

The mean deep dose rate on Eneu was approximately 18 mrem/yr, and the mean β dose rate varied from 23 mrem/yr 1 cm off the ground to 6 mrem/yr 100 cm off the ground. The highest β dose rate measured on the island was 90 mrem/yr at 1 cm, and 42 mrem/yr at 100 cm. The highest measured deep dose rate was 88 mrem/yr, but there were only three areas on the island where the measured deep dose rate exceeded 30 mrem/yr. Natural ground cover had no measurable effect on the dose rates.

Bikini's radiation profile was more complicated than Eneu's. Since there were many unique areas to be evaluated, data from Bikini Island was divided into subgroups. In general, the highest

β dose rate measured in each subgroup was 1.5-2.5 times the mean, and the highest deep dose rate was 1.5-2 times the mean. Exceptions to this generalization existed where the dose rates varied little between sites.

IN HOUSES: The mean deep dose rate in the houses was about 37 mrem/yr. In a house with concrete made with reef aggregate, no β radiation was detected, but in the houses made from island aggregate, β radiation averaged 116 mrem/yr at 1 cm, and 46 mrem/yr at 1 m.

AROUND HOUSES: The mean deep dose rate around houses was about 110 mrem/yr. The mean β dose rate ranged from 301 mrem/yr at 1 cm to 165 mrem/year at 100 cm.

GENERAL AREAS: The mean deep dose rate was about 200 mrem/yr, and the mean β dose rate ranged from 550 mrem/yr at 1 cm to 192 mrem/yr at 100 cm. These values are higher than the true island average, though, since a disproportionate number of sites were selected in highly contaminated areas.

EXCAVATION EXPERIMENT: Both the β and deep dose rates varied greatly in the Buffer Zone and the Control Plot, probably as a result of soil disturbances that occurred during excavation and planting. In these areas, deep doses ranged from about 100 mrem/yr to 536 mrem/yr, and β dose rates ranged from 173 to 1886 mrem/yr at 1 cm, and from 100 to 500 mrem/yr at 1 m.

The dose rates in the Excavation Plot were consistently low: the mean deep dose rate was 47 mrem/yr at 1 m, and the mean β dose rate was 88 mrem/yr at 1 cm and 54 mrem/yr at 100 cm. Removing the top 40 cm of soil reduced the β dose rate between 80% and 94% at 1 cm, and between 72% and 87% at 1 m.

VARIATION OF DOSE RATE WITH HEIGHT: In heavily contaminated areas, the mean β dose rate at 1 cm was about 2.5 times the respective mean deep dose rate; at 50 cm, it was 1.5 times the mean deep dose rate, and at 100 cm, it about equaled the mean deep dose rate. In lightly contaminated areas the β dose rates more closely paralleled the deep dose rates at all heights.

EFFECT OF GROUND COVER ON β DOSE RATES: A comparison of data from cleared and uncleared areas showed that ground cover did not consistently enhance or degrade the β dose rates. Presumably, the large variations in the β dose rate that existed within small geographical areas overwhelmed the small botanical differences we were trying to measure.

Coral gravel reduced the 1 cm β dose rate from 1,015 to 110 mrem/yr (89%) in one area, and from 346 to 79 mrem/yr (77%) in the other.

A full report on this survey, including raw data and references, can be obtained from the author by requesting report UCRL-553798.