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External Radiation on Bikini Atoll

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Wide variations in external exposure rates and a large number of radionuclides were found contributing to the residual radiation fields on Bikini Atoll.

A SURVEY of the islands of Bikini Atoll has revealed several interesting features of the residual environmental radiation in an area of heavy local fallout several years after the initial deposition. Bikini Atoll is the former weapons test area in the mid-Pacific where more than twenty nuclear tests were conducted between 1946 and 1958. Our survey in May 1967 included measurements of the external radiation levels and determination of the principal isotopes contributing to the total external exposure rates on each island of the atoll. We were able to detect many long-lived fission and activation products which have not been detectable in previously surveyed fallout areas. The pattern of the residual radiation on the atoll can be related to the locations of the ground zeros of various tests, the meteorological conditions affecting local fallout at the time of the tests, and the subsequent weathering and radioactive decay.

Bikini Atoll consists of some fifteen islands and two

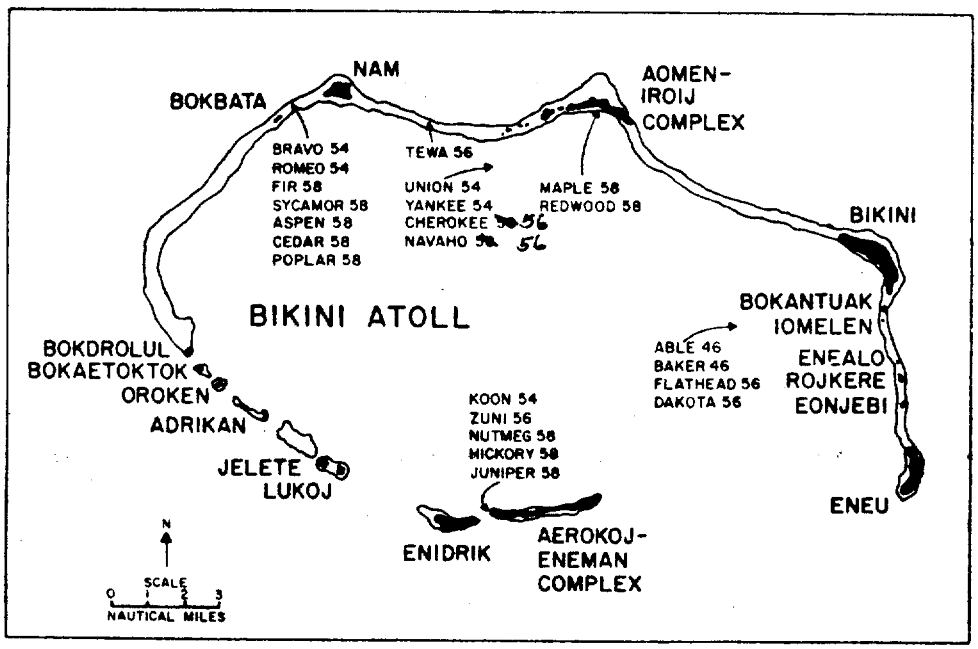

Fig. 1. Bikini Atoll showing locations with code names and years of nuclear weapons tests.

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island complexes, located on a coral rim surrounding a lagoon twenty-two miles long and thirteen miles wide (Fig. 1). Total land area of the atoll is 2·32 square miles. More than half the area is included in the three largest islands, Bikini, Eneu and Nam. The largest island, Bikini, is 2·5 miles long and 0·5 mile wide.

The survey techniques utilized were largely those developed by the Health and Safety Laboratory for detailed investigations of the properties of the external radiation environment in the United States[1-3]. The instrumentation included a high-pressure ionization chamber, an NaI(Tl) field spectrometer system for *in situ* γ-ray spectrometry, and a number of hand-held survey instruments (Geiger–Müller counters and scintillation detectors). Because of the number of islands to be surveyed and the difficult logistical problems and environmental conditions (difficult access, dense vegetation, high temperatures, humidity and so on), we restricted spectrometer and ionization chamber measurements to representative locations on the main islands of Bikini, Eneu and Nam.

or south-westerly direction, so the heavy fallout areas were primarily the islands of the south-western reef. There were exceptions to the normal wind pattern, however, most notably for shot Bravo in 1954 when unexpected high altitude winds carried fallout eastward over Bikini Island and on to the Marshallese natives of Rongelap Atoll. Thus non-blast, low fallout areas, which include the islands of Bikini, Eneu and the eastern half of the Aerokoj–Eneman Complex, experienced lesser but not insignificant amounts of local fallout. Eneu on the south-eastern rim of the atoll was the most favourably situated to avoid local fallout and exhibited some of the lowest exposure rates measured (3–7 μr./h).

In addition to this general pattern of radiation levels around the atoll, we found considerable variation on individual islands, similar to that shown in Fig. 2 of a typical radiation profile across the middle of Bikini Island. The lowest levels were measured near the shores where the vegetation was sparse and the soil very sandy, conducive to weathering and deeper penetration of

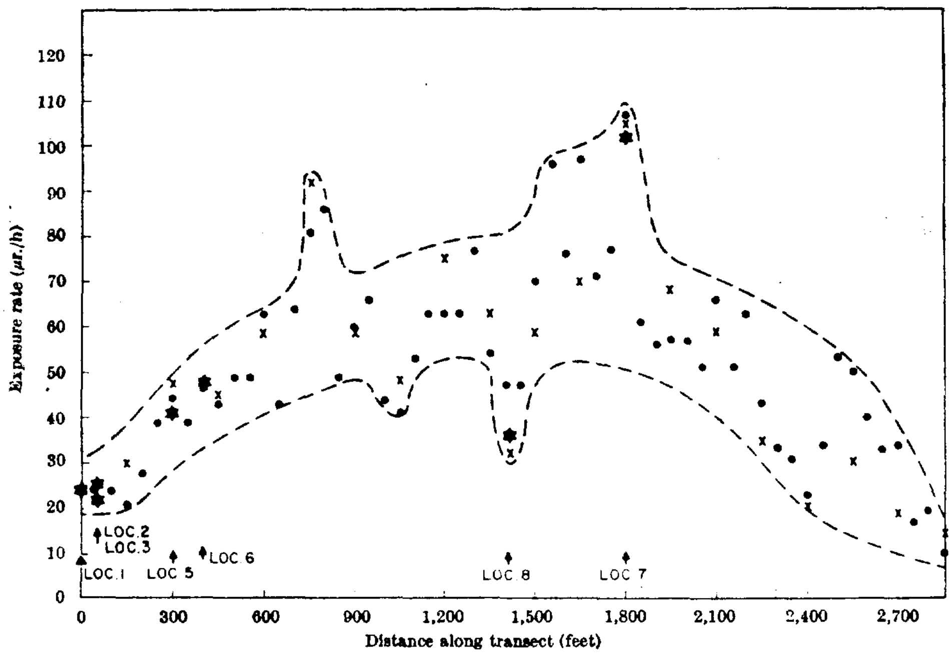

Fig. 2. Exposure rate profile of a survey transect across central Bikini Island from the lagoon shore to the ocean beach. The dotted lines enclose the various measurements with the scintillation detector (●), the Geiger-Müller counter (×) and the ionization chamber (★).

The hand-held survey meters were used to extend the survey throughout the atoll so that variations in radiation levels from island to island and on individual islands could be studied in some detail.

Pattern of Radiation Distribution

The external γ-radiation levels were found to vary considerably from island to island around the atoll. We can, however, roughly classify most islands into three general areas, characterized by the relative exposure rates and also the composition of the radiation fields: blast areas immediately surrounding the ground zeros of tests where the highest exposure rates were measured, heavy fallout areas down-wind from the blast areas with intermediate exposure rates, and non-blast, low fallout areas with the lowest exposure rates.

The location, code name and year of each announced nuclear weapons test[4] are indicated on the map in Fig. 1. It can be seen that the blast areas include the western tip of Eneman, Lomilik near the centre of the Aomen–Iroij Complex, and the north-western reef near Nam. The prevailing winds in the area are generally in a westerly

fallout. Other significantly low exposure rate levels could be associated with weathered areas, such as former roadways. Higher levels were recorded in the central parts of the islands, where the vegetation was much more dense and where increased amounts of organic matter in the soil apparently influenced the retention of fallout near the surface of the ground.

Exposure Rates and Isotopic Contributors

Representative exposure rates in air 1 m above the ground from γ-ray emitters in the soil obtained from the analysis of the field spectra and ionization chamber measurements on Bikini, Eneu and Nam are given (Table 1). Exposure rates from cosmic radiation (3·4 μr./h) are not included. More detailed data on the measurement of the radiation fields on Bikini Atoll are given in ref. 5.

The exposure rates for Bikini Island were in general 20–40 μr./h near the shore, 50–80 μr./h in the interior, and up to 120 μr./h at scattered hot spots. The field spectrometer measurements showed the exposure rate levels on Bikini Island to be due primarily to three radionuclides, with about 75 per cent of the exposure rate at a given

Table 1. EXTERNAL γ-RAY EXPOSURE RATES AND MAJOR CONTRIBUTORS TO THE RADIATION FIELDS AT REPRESENTATIVE LOCATIONS ON BIKINI, ENEU AND NAM

Location	Exposure rates (μr./h) Components ^{137}Cs	^{60}Co	^{125}Sb	Total Field spectrometer	Ionization chamber
Bikini					
1 Near lagoon shore	19·0 (77)	3·0 (12)	2·8 (11)	24·8	24·0
2 50 feet along transect	17·8 (78)	2·4 (10)	2·7 (12)	22·9	22·8
3 50 feet along transect (in brush)	18·9 (78)	2·1 (9)	3·3 (14)	24·3	25·0
5 300 feet	22·8 (61)	11·3 (30)	3·5 (9)	37·6	41·2
6 400 feet	27·2 (62)	12·5 (29)	4·0 (9)	43·7	47·5
7 1,800 feet	83·6 (74)	19·5 (17)	10·3 (9)	113·4	103·2
8 1,410 feet	28·1 (76)	4·9 (13)	3·8 (10)	36·8	36·1
Eneu					
1 800 feet inland—mid-island	3·1 (78)	0·5 (12)	0·4 (10)	4·0	4·1
2 1,200 feet north of 1	3·0 (63)	1·5 (31)	0·3 (6)	4·8	5·1
Nam					
1 Near lagoon shore	18·1 (50)	17·2 (48)	0·6 (2)	35·9	34·1
2 Island centre	25·8 (39)	39·4 (59)	1·1 (2)	66·3	75·5
3 Near NE corner	60·6 (33)	119·5 (66)	2·0 (1)	182·1	204·0

The sums of the component exposure rates, obtained with the field spectrometer, are compared with the total exposure rates obtained with the ionization chamber (percentages within parentheses).

site due to ^{137}Cs, 15 per cent to ^{60}Co and 10 per cent to ^{125}Sb. Natural emitters (uranium, thorium and potassium) were almost entirely undetectable in the field spectra. The composition of the radiation field on Eneu was quite similar to that of Bikini, that is, predominantly ^{137}Cs with some ^{60}Co and ^{125}Sb, even though the exposure rate levels were much lower. Nam, however, because of its proximity to several test sites, had several properties of blast areas, including high exposure rates and increased amounts of ^{60}Co and ^{125}Sb in the soil relative to ^{137}Cs.

The maximum exposure rates measured on Bikini Atoll in 1967 were in blast areas very near the ground zeros of tests. At one isolated area on West Eneman near the ground zero for two surface tests we measured an exposure rate just over 500 μr./h. Vegetation in the blast areas is generally sparse and the organic content of the soils quite low, so weathering may accelerate the reduction of radiation levels in these areas compared with the more densely vegetated areas. Also the greater proportional contribution of the shorter-lived ^{60}Co and ^{125}Sb relative to ^{137}Cs to the exposure rates in these areas will also cause these radiation levels to decrease more rapidly with time.

To complement our field spectrometry and to characterize the composition of the radiation field on islands where we were unable to obtain field spectra, a large number of soil samples were collected from throughout the atoll. These samples, usually obtained in several depth increments, were analysed quantitatively by laboratory NaI(Tl) γ-spectrometry and also qualitatively by Ge(Li) spectrometry. We found that in high activity areas most of the activity (two-thirds or more) was usually in the top 2 or 3 inches of soil. Because of large local variations in soil activity on all the islands, we could not calculate accurate exposure rates in air from the one or two soil samples obtained per site. The soil samples proved very useful, however, for identifying and determining relative activities of the isotopes present, which were then used to estimate the relative contributions of these isotopes to the exposure rates at the various sites[5]. The relative exposure rate values obtained for the same sites with the spectrometer-ionization chamber system and from soil sample analysis agreed quite well. Because the field spectrometer and ionization chamber "see" large areas (approximately 30 feet in diameter), local variations are averaged out and these measurements are very reliable.

The composition of the radiation field on Lukoj, a densely vegetated heavy fallout area, where exposure rates varied from 60 to 200 μr./h, is indicated by the Ge(Li) spectrum (Fig. 3). Approximately 60 per cent of the exposure rate at the soil sampling site in the high activity interior of the island was from ^{60}Co, 30 per cent from ^{125}Sb and ^{102m}Rh and the remainder principally from

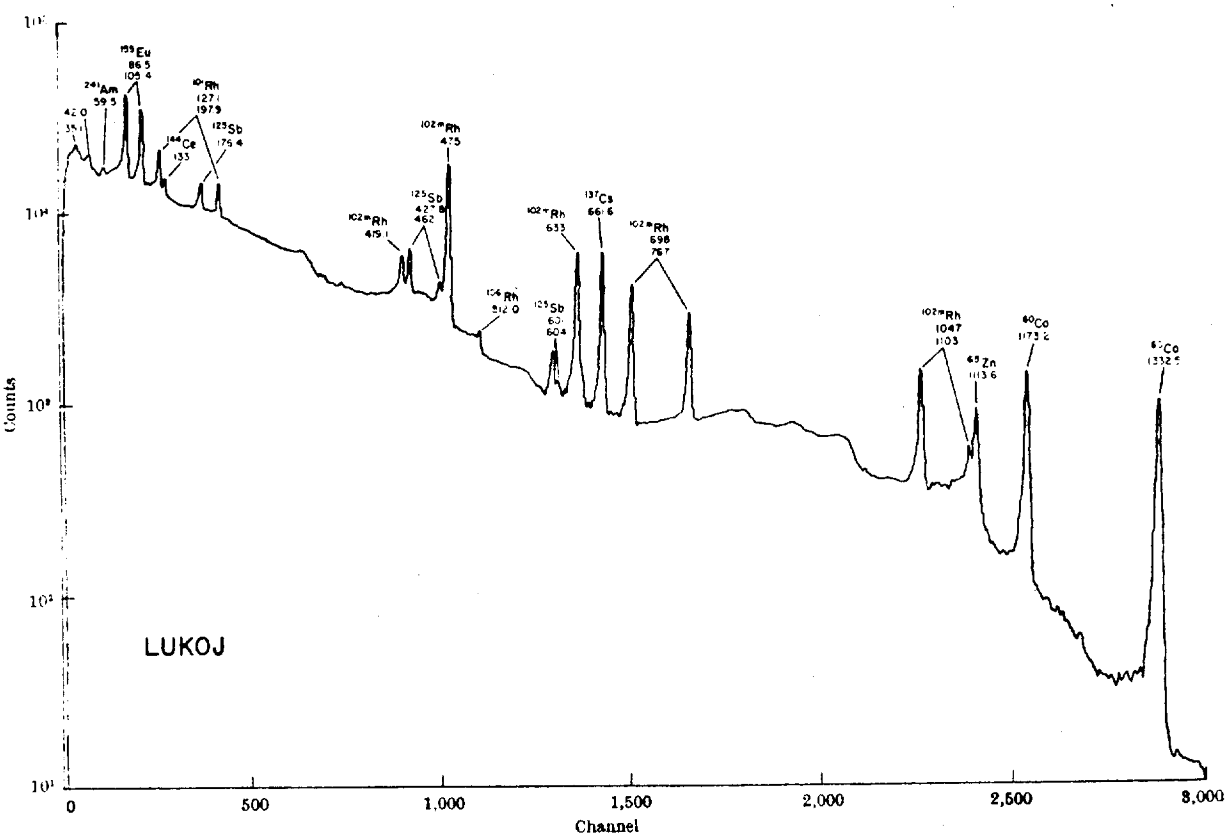

Fig. 3. Ge(Li) spectrum with peak identification and approximate energies in keV of a soil sample taken from Lukoj Island, a heavy fallout area on the south-western rim of the atoll.

^{137}Cs. The relatively large ^{60}Co and ^{125}Sb activities relative to ^{137}Cs contrast with the Bikini Island situation. The peaks characteristic of the recently identified[6] long-lived isomer (2·9 yr) of rhodium, which we have designated ^{102m}Rh, are quite prominent (Fig. 3) along with the ^{60}Co, ^{125}Sb and ^{137}Cs peaks. Also easily identifiable are ^{241}Am, ^{155}Eu, ^{101}Rh, ^{102}Rh, ^{144}Ce and ^{65}Zn.

All of the isotopes identified in Fig. 3 along with ^{152}Eu and ^{54}Mn were present in spectra of soil samples from blast areas. In soils from non-blast, low fallout areas we usually found only trace amounts of ^{241}Am, ^{152}Eu and ^{155}Eu along with the major contributors, ^{137}Cs, ^{60}Co and ^{125}Sb. We also detected ^{207}Bi in a soil sample from the Bravo crater on the north-western reef and have tentatively identified ^{133}Ba in a soil sample from Nam Island.

Although most of the isotopes which we found contributing to the radiation fields on the atoll are familiar long-lived fission products, such as ^{137}Cs (30 yr), ^{125}Sb (2·7 yr), ^{106}Ru-Rh (367 days) and ^{144}Ce (284 days) or frequently observed activation products such as ^{54}Mn (303 days) and ^{65}Zn (245 days), other isotopes such as ^{60}Co, ^{207}Bi, ^{152}Eu, ^{155}Eu and ^{102m}Rh are rarely detected with such prominence in environmental samples. Many of the weapons tests were conducted on barges, and the resulting activation of ^{59}Co and ^{60}Ni in the steel of the barges accounts for the large amount of ^{60}Co activity. ^{152}Eu (12·7 yr), an apparent activation product, has been found previously[7] in trinitite, an artificial mineral produced in the first nuclear explosion in New Mexico in 1945. ^{101}Rh (3 yr) and ^{102}Rh (206 days) are also activation products. ^{102}Rh is known to have been used as a tracer material in several weapons tests. ^{241}Am indicated the expected presence of plutonium isotopes.

The measured external exposure rates along with the fractional contributions due to various short and long-lived components were used in estimating time integrated doses from external radiation to a returning population. Account was taken of the time breakdown of inhabitation of various areas of the islands. Because of the low cosmic-ray and negligible natural radioactivity levels, and the radioactive decay of the large fraction of short-lived components, these estimates rapidly become comparable with or, in some cases, as for Eneu Island, much lower than integrated doses from natural radiation in the United States.

In addition to our measurements of external radiation at Bikini, intensive sampling by other investigators of flora, fauna, marine life, birds, soils and ground water was carried out in 1964 as well as in 1967. All these data were considered carefully by government officials and a special scientific committee of consultants in arriving at the recent decision to allow resettlement of certain islands of the atoll.

The radiation situation on Bikini Atoll provided a unique opportunity for investigating an aged, relatively intense fallout field. We were able to relate exposure rates on the atoll to test locations and environmental conditions at and subsequent to the times of the tests. A large number of radionuclides, including several unusual for environmental samples, were found contributing to the wide range of external γ-radiation levels. Utilization of the combination of ionization chamber and field spectrometric measurements with laboratory Ge(Li) spectrometry of soil samples proved to be a very effective method of analysing this complex radiation environment.

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