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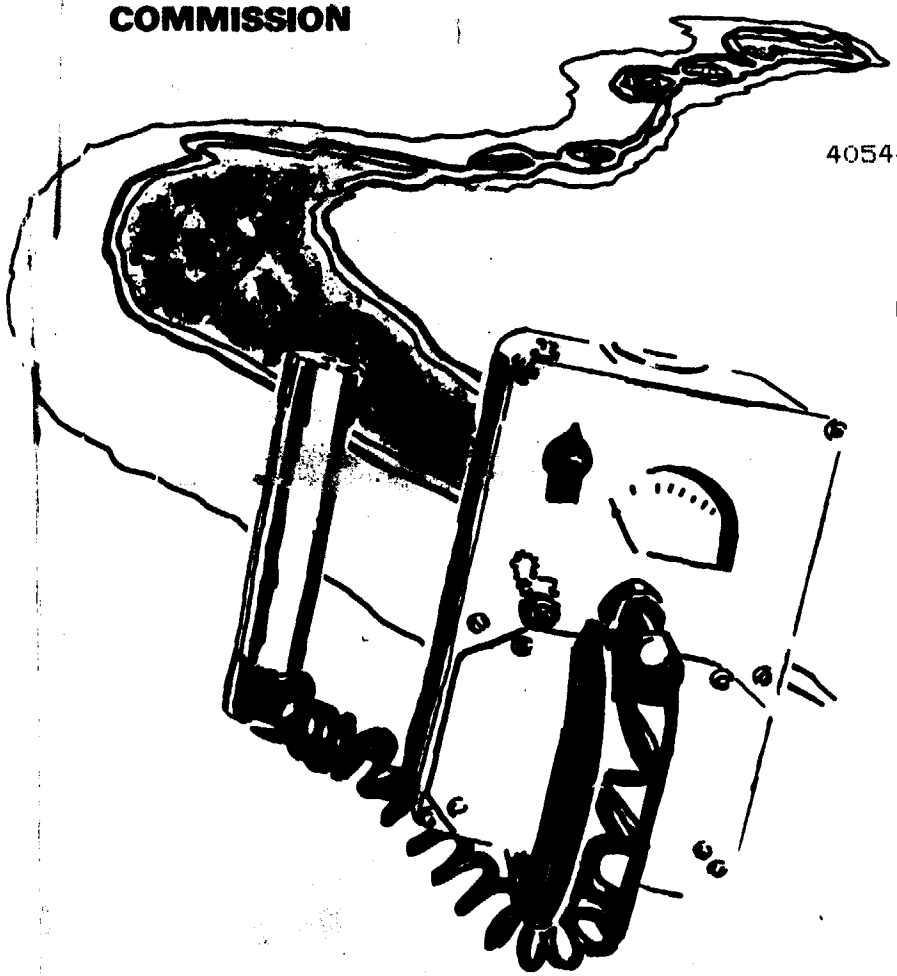
U.S. ATOMIC ENERGY COMMISSION



Levels of Environmental Radioactivity in Bikini Atoll

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LEVELS OF ENVIRONMENTAL RADIOACTIVITY IN BIKINI ATOLL

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Introduction

Bikini Atoll is located in the Western Pacific about 12° North of the Equator. Geographically the atoll consists of an oval shaped lagoon surrounded by a fringing reef with major and minor dimensions of 35 kilometers long and 21 kilometers wide. The total land area of the islands along the reef is 5.96 Km^2. The three largest islands, Bikini, Eneu, and Nam contain about 3.1 Km^2.

The Bikini people lived in their atoll for many generations in relative isolation from the rest of the world. In the recent past they have been under German, then Japanese, and now United States jurisdiction. At present, the Marshall Islands of which Bikini Atoll is a part are within the Trust Territory of the Pacific which is administered by the United States for the United Nations.

Early in 1946 it was determined that Bikini Atoll was a suitable site for nuclear weapons tests. The Bikini population, numbering 166, agreed to leave the atoll. After inspecting a number of possible resettlement areas and after living some time on Rongerik Atoll and Kwajalein Island, the Bikini people were relocated to Kili Island where they still live today. The Bikinians were promised the return of their atoll when it was no longer needed as a testing site.

Since their relocation, the Bikini population has increased in size. There is a continuing strong desire on the part of a significant fraction of the group to return to their home atoll. With its scarcity, these island dwellers have a great love for the land and have an extreme reluctance to give up or sell land. Except for the sea, there are few other natural resources available in the atoll environment.

The Bikini Test Site

Following resettlement of the population, preparation of the atoll for upcoming tests was begun. These field operations and test activities occurred periodically from 1946 through 1958. During this time, areas of the islands were cleared for camp sites and there was construction of housing, docks, towers and instrument bunkers. An aircraft runway and parking ramp were built on Eneu and another runway was constructed on a string of islands connected by man-made causeways along the southern rim of the reef.

A total of 23 devices of both fission and thermonuclear types were detonated during 1946, 1954, 1956, and 1958. The islands of Bikini Atoll received fallout from these tests to varying degrees. The largest islands, Bikini and Eneu, located at the Eastern end of the atoll, were generally upwind of the detonation sites and thus received lesser amounts of fallout debris than some of the other islands. The relative locations of the islands of Bikini Atoll and the test sites are shown in Figure 1 with the number of tests indicated in the circle.

Radiological Survey and Monitoring Activities

An assessment of the impact of test activities on the environment at Bikini Atoll was begun shortly after the first two detonations were conducted in 1946. Survey teams have revisited the atoll between testing periods and since testing was concluded to obtain samples of marine life, land plants and animals, soil, water and to spot-check the external radiation levels within the atoll. (1)

In 1964, a survey team visit to Bikini Atoll produced a sizeable quantity of data on the radionuclide content of foods (marine and terrestrial) that would be available to a returning population. In December 1966, the USAEC in responding to a request from the Secretary of the U.S. Department of the Interior, agreed to make a determination on whether Bikini and its lagoon were safe for continued habitation and whether the Bikinians could have hazard-free use of the resources of the atoll and its adjacent water areas. Subsequently, it was determined that the available survey data were not yet complete and that another team visit was needed to conduct a more extensive survey of external radiation levels in Bikini Atoll. Also needed, for projections into the future, was a determination of which radionuclides contributed to this radiation field.

1967 Survey

Planning for a major survey effort by the staff of the USAEC Division of Biology and Medicine (now the Division of Biomedical and Environmental Research, DBER) began early in 1967. The emphasis was on delineation of the external radiation fields particularly on islands and at locations of past and future habitation and to obtaining more measurements on all islands including the smaller islands near test locations. Dr. Edward Held, who at that time was at the University of Washington, Laboratory of Radiation Ecology, Seattle, Washington, was appointed survey team leader. Team membership included personnel from USAEC, USAEC contractors, U.S. Trust Territory, and the U.S. Naval Radiological Defense Laboratory. Four native workers were added to the team in Kwajalein.

The survey team spent 16 days at the atoll in April-May 1967. Except for Adrikon, a very small island in the Southwest corner of the atoll, all fourteen islands and the two complexes of islands joined by man-made causeways were surveyed. Seven days were spent with studies on Bikini Island.

Instrumentation

To provide cross-checks on measurements and flexibility sufficient that detailed data could be obtained for certain locations with rapid coverage of other areas, several types of semiportable and portable instruments were used. The Health and Safety Laboratory (HASL) of the USAEC provided two semiportable instruments, a high pressure ionization chamber and an X-ray spectrometer, plus a small portable scintillation counter survey meter and thermoluminescent dosimeters (TLD's). The U.S. Naval Radiological Defense Laboratory (USNRDL)

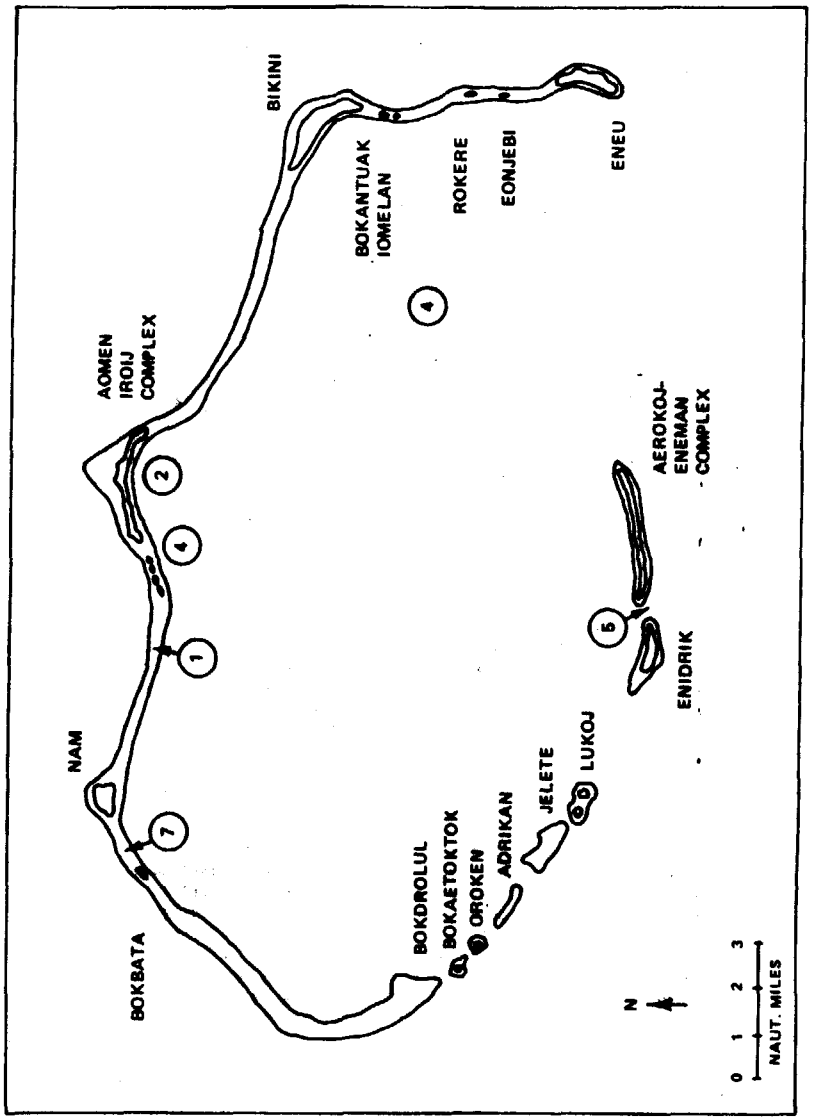


Figure 1. BIKINI ATOLL

supplied a number of portable G-M counter survey meters plus a large number of TLD's. These instruments and their calibration are described in HASL-190.[2]

Field Operations

The base of operations for the team was the M.S. Militobi, a U.S. Trust Territory ship. Under the conditions for this survey, the monitoring instruments and equipment were transported repeatedly from the ship in small boats, through the surf on foot, and back again. The portable instruments were checked daily using a small button source. Team members plus workers who cut trails through the heavy vegetation went ashore with their equipment in the early morning. Except for a mid-day rest period, work continued until dark. A daily log of each team members activity was prepared and the evening critique and planning session developed the schedule for the following day. In this way the impact of the time consuming and strenuous trail cutting operation was minimized and the TLD's would be emplaced for an exposure time of maximum duration. Segments of the shore party carried portable two-way radio equipment and there was a base station operator on duty in the ships communication room throughout the day.

External Radiation Measurement Results

Bikini

This the largest island in the atoll is about 4 kilometers long and 0.8 kilometers wide. It is heavily overgrown with scrub vegetation, primarily scaevola. This vegetation is quite impenetrable having a height of about three meters. The former Bikini village site is located mid-island and a short distance inland along the lagoon shore. While somewhat overgrown, the village road was passable and the initial gamma and beta-gamma measurements, gamma spectra determination, and TLD emplacements were made here while other team members and workers cut the first trail across the island from the lagoon to the ocean shore. This trail, which took one whole day to complete, was known as the 0 Transect. As to the level of monitoring effort, portable scintillation counter readings were made every 15 meters along the 0 Transect. Geiger counter readings were made and TLD's emplaced every 45 meters. At each location, four measurements of gamma and four of beta-gamma were made around a point at a height of about 1 meter and again at ground level. These values were averaged to obtain the gamma and beta-gamma level at one meter and at the surface for that location.

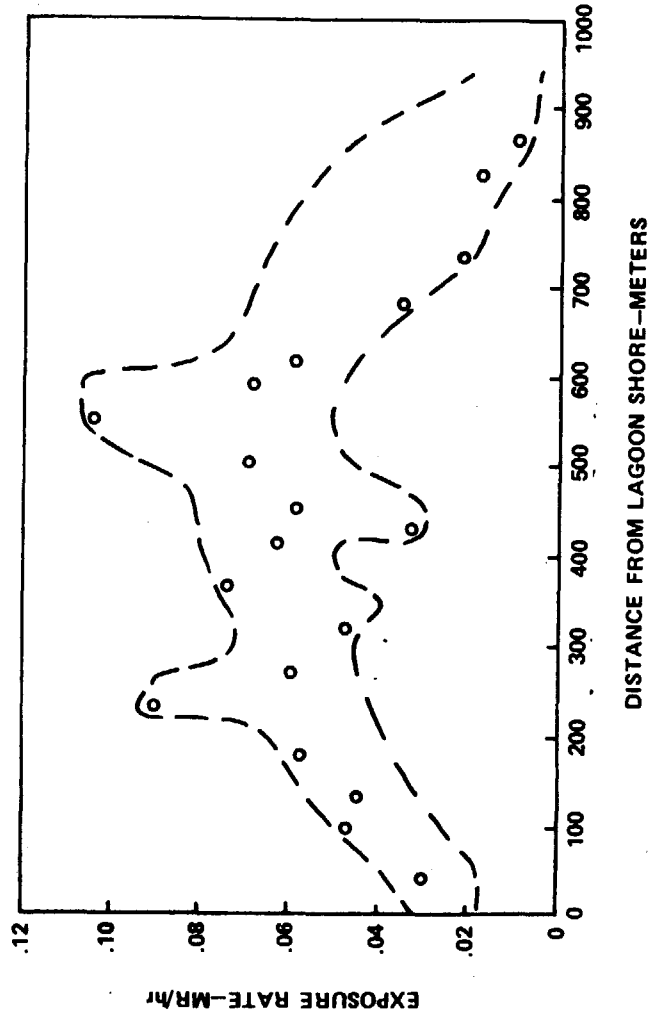
Similar measurements at increments of 45 meters were made and TLD's emplaced along 640 meters of the village road, along the 869 meters of a second lagoon to ocean trail known as the 1 Transect, and along the much shorter North End and South End Transects.

Ionization chamber and spectrometer measurement were made at locations on the 0 Transect and on the village road.

Figure 2 shows a plot of the average of G-M counter gamma measurements made along the 0 Transect. The scintillation detector and spectrometer measurements show a comparable picture, namely, low levels near the lagoon and ocean shores and higher levels in the interior. The dashed lines enclose most of the measurements. The levels along the 1 Transect show a similar pattern.

The spectrometric results as developed by HASL staff indicated that the predominant gamma emitter in Bikini soil was ^{137}Cs with lesser amounts of

Figure 2. EXPOSURE RATE ON "O" TRANSECT GM COUNTER



^{60}Co and ^{125}Sb. Of these three isotopes, ^{137}Cs contributed 76 to 78 percent of the total exposure rate and ^{60}Co and ^{125}Sb each contributed about 10 to 12 percent. These results were in agreement with gamma field estimates derived from soil sampling data. Also identified at levels too low to significantly contribute to the total exposure rate were ^{155}Eu, ^{152}Eu, ^{241}Am, and possibly ^{106}Rh.

The TLD results on the O Transect showed the same trend as in Figure 2, although these values are slightly higher on the average.

Table 1 shows a summary of the range of exposure rates on Bikini, the levels applicable to various locations, and the major contributor to the gamma radiation levels. A separate value is not given for the beta-gamma measurements since even at ground level the gamma and beta-gamma values were essentially the same. One exception was an area near the mid-point of the 1 Transect where the beta-gamma levels were consistently higher but not significantly greater.

Bikini vegetation clearing experiment

The planned clearing of scrub vegetation on Bikini to make space for planting coconut trees and other food plants could have some effect on population exposures if radionuclides in plants contribute significantly to the external radiation field. A vegetation clearing experiment was planned and conducted on Bikini. The area chosen for the experiment was near the center of the island. The dense vegetation at this location, mainly scaevola, was about three meters high. At a point marked by a stake a complete set of spectrometer, ionization chamber, and portable instrument measurements were made before any clearing began. These measurements were repeated as a circular area was cleared to 3 meters, 6 meters, and 9 meters radius. The radiation levels changed very little as the area was cleared.

At the request of the Trust Territory District Agriculturist, vegetation removed during the vegetation clearing experiment was separated as to type, weighed, and data recorded. These results give an indication of potential agricultural productivity. The amount of vegetation removed from this small area was very large amounting to almost 2,500 kilograms.

The results of the experiment indicate that clearing vegetation has little immediate effect on total exposure rate. However, subsequent weathering of cleared areas and termination of cycling of radionuclides through scrub plants could lead to lower radiation levels. The cleared area was resurveyed two weeks later upon return to Bikini. The radiation level was found to be about the same as before.

Eneu

Eneu is the second largest island in the atoll. It contains many buildings and several steel towers and is less heavily overgrown with scrub vegetation than Bikini. There was easy access to the interior of the island and a road along the lagoon shore was quite visible. Portable instrument measurements were made along this road and along a path parallel to the ocean shore on the other side of the island. Spectrometer and ionization chamber measurements were made at two places on the lagoon side of the island. TLD's were placed along the lagoon road to remain about two weeks.

Table 1

Gamma Radiation Rates in Bikini Atoll

mR/hr

Island	Exposure Rate Range	Major Contributors
Bikini	.010-.120	^{137}Cs
Weathered Areas	.010-.030	
Close-to-Shore	.020-.040	
Island Center	.050-.080	
Hot Spots	.080-.120+	
Eneu	.002-.010	^{137}Cs
Nam	.010-.330	^{60}Co, ^{137}Cs
Outer Edge	.010-.030	
Island Center	.015-.150	
N.E. Corner	.110-.330	
Bokantuak, Iomelan,	.003-.010	*
Rojkere, Eonjebi		
Aerokoj-Eneman Complex:		
Aerokoj, Aerokojlol	.001-.010	*
Bikdrin, Lele	.006-.010	*
Eneman	.001-.570	^{60}Co, ^{125}Sb, ^{102m}Rh
East Eneman	.001-.010	
West Eneman	.020-.570	
Enidrik	.003-.235	^{60}Co, ^{125}Sb, ^{102m}Rh
East Enidrik	.003-.030	
West Enidrik	.010-.235	
Lukoj	.060-.200	^{60}Co, ^{125}Sb, ^{102m}Rh
Jelete	.060-.130	*
Oroken	.015-.045	*
Bokaetoktok	.010-.035	*
Bokdrolul	.020-.050	
Bokbata	.010-.030	^{60}Co, ^{137}Cs
Aomen-Iroij Complex:		
Aomen	.005-.020	*
Lomilik	.020-.330	^{60}Co, ^{125}Sb
Odrik, Iroij	.010-.040	*

*No soil sample or field spectra measurements.

External radiation levels on Eneu were among the lowest found in the atoll ranging from 0.002 mR/hr to 0.01 mR/hr (see Table 1). This is lower than the U.S. average.

Nam

The third largest island, Nam, contains large open areas covered with fimbrisytlis and ipomea vines. A full set of ionization chamber, spectrometer, and portable instrument measurements were made on Nam. The monitoring paths passed around the island and across it in several places.

Radiation levels varied widely and Nam contained a considerable quantity of radioactive scrap metal. The radionuclide identified with the metal scrap and the major contributor to the external radiation field was ^{60}Co. ^{137}Cs was another lesser contributor and ^{125}Sb was found in small amounts. A summary of results for Nam is given in Table 1.

Bilantuak, Iomelen, Rojkere, Eonjebi

These very small islands located between Bikini and Eneu were monitored with G-M counters only. The observed levels were quite low and uniform (see Table 1).

Aerokoj-Eneman Complex

This three kilometer long complex of five narrow islands interconnected by man-made causeways lies along the southern rim of the atoll. From east to west these are Aerokoj, Aerokojlol, Bikdrin, Lele, and Eneman. An aircraft runway was constructed on Aerokoj and Aerokojlol which are almost indistinguishable as separate islands. These islands have scattered vegetation and the grass covered ground was used by a considerable number of nesting birds. Survey measurements with the scintillation counter and G-M counter were made along a route down the center of these islands with spot measurements nearer the ocean and lagoon shores. Readings were quite low and uniform with a range for the G-M counter of 0.003 to 0.01 mR/hr and for the scintillation counter of 0.001 to 0.003 mR/hr. The western tip of Aerokojlol is connected to the next island Bikdrin by a long causeway. Bikdrin plus the next island, Lele, are wide places in the causeway. Except for some pieces of scrap metal on the causeway showing higher radiation levels, the measured values were low and uniform along the causeways and islands. The scintillation counter showed 0.006 to 0.008 mR/hr and the G-M counter about 0.010 mR/hr.

Eneman is the largest and western-most island in the string. The eastern and central portions contain thick vegetation. This becomes less dense toward the west until at the western tip there are low depressions covered by black algae and almost no vegetation.

Wide variation in radiation levels were found on Eneman. The eastern end was similar to the other four islands, 0.001 to 0.01 mR/hr. Toward the west along the island, levels increased to 0.020 to 0.060 mR/hr. The algae covered depressions which had been near test locations showed 0.100 to over 0.500 mR/hr. The highest value in the atoll, 0.570 mR/hr, was measured in this western end of Eneman.

The western end of Eneman contained quantities of radioactive scrap metal in the form of steel cables and pieces of reinforcing rods embedded in concrete fragments. Soil samples from this area indicated primarily ^{60}Co activity with considerable ^{125}Sb, ^{155}Eu, and ^{102}Rh activity. There was little ^{137}Cs activity. As determined from soil sampling, ^{60}Co accounts for 83 to 87 percent of the

total exposure rate.

Endrik

Endrik is the largest island on the southern rim of the reef and the fourth largest in the atoll. It is about one kilometer west of Eneman. Except for the eastern tip, Endrik is heavily vegetated with dense undergrowth in the interior. There were stands of cardia and pisonia trees and several pandanas trees. Several transects from lagoon to ocean shores were surveyed in the eastern part of the island but survey of the wider western portion was less sytematic due to heavy vegetation.

G-M counter readings on the eastern part of the island generally ranged from 0.003 to 0.010 mR/hr with one area near the eastern end reading 0.030 mR/hr. Some radioactive scrap metal was found on the eastern end. The western part showed variations in levels similar to Bikini - low levels near the shore and higher levels inland. A transect near the center showed values ranging from 0.003 mR/hr near the shore up to 0.019 mR/hr in the interior. Another transect west of center showed 0.009 mR/hr near shore to 0.235 mR/hr in the interior. Black algae-covered depressions near the western end gave G-M counter reading ranging from 0.11 to 0.22 mR/hr. Analysis of soil samples from the western end indicated that ^{60}Co, ^{120m}Rh, and ^{125}Sb contributed about 85 percent of the total exposure rate with ^{137}Cs contributing about 12 percent.

Lukoj-Jelete

These two islands in the southwest part of the atoll are about one kilometer apart and are similar in appearance. They are small with shore areas covered with ipomea vines and have densely vegetated interiors. Monitoring coverage was obtained by cutting two transects on Lukoj and by circling Jelete and pushing inland about 30 meters at every 90 meters of circular path.

On Lukoj, a range of values on one transect showed 0.061 mR/hr to 0.104 by scintillation counter and 0.063 to 0.130 mR/hr by G-M counter. On the next transect near mid-island the ranges were 0.100 to 0.171 mR/hr and 0.083 to 0.197 mR/hr. A soil sample taken near island center indicated that 60 percent of the exposure rate was due to ^{60}Co, 30 percent to ^{125}Sb and ^{102m}Rh, and the rest primarily to ^{137}Cs.

On Jelete the levels measured along the circular path ranged from 0.063 to 0.130 mR/hr. No soil samples were obtained.

Oroken-Bokaetoktok-Bokdrolul

These three islands near the western end of the lagoon are very small and are similar in appearance. Each has a densely vegetated interior and there are many nesting birds.

Radiation levels on Oroken ranged from 0.017 to about 0.040 mR/hr. Values on Bokaetoktok ranged from 0.010 to 0.030 mR/hr. In each case the higher levels were found in the interior of the islands. Bokdrolul showed less variability with levels away from the shore line ranging from 0.024 to 0.036 for both scintillation and G-M counters. There was one G-M counter reading of 0.050 mR/hr. No soil samples were taken.

Bokbata

All that remains of Bokbata is a small sand island containing zero vegetation. This sand island is located southwest of the Bravo Crater. The radia-

tion levels along the center of the sand island were observed to be about 0.015 mR/hr.

Samples of sand from the island and bottom sediments from Bravo Crater were collected. The sand contained ^{60}Co, ^{137}Cs, and ^{125}Sb. ^{60}Co was responsible for about 60 percent and ^{137}Cs responsible for about 30 percent of the exposure rate on the sand island. The bottom sediments contained ^{207}Bi in addition to the above but ^{60}Co was the predominant radionuclide.

Aomen-Iroij Complex

The northern rim of the atoll contains a long string of four narrow causeway-connected islands. From east to west these are Aomen, Lomilik, Odrik, and Iroij. Vegetation is sparse along this string of islands. Since two tests had been conducted near the center of this complex (see Figure 1), the radiation levels along the string of islands were quite variable and there were considerable quantities of radioactive scrap metal. The survey route passed down the center of the islands and causeways. Measurements ranged from 0.005 to 0.020 mR/hr on Aomen, 0.020 to 0.330 mR/hr on Lomilik, 0.010 to 0.040 mR/hr on Iroij, and 0.003 to 0.007 mR/hr on the causeways. The higher levels on Lomilik were in depressed areas with clay-like soil.

A soil sample taken from the area of highest radiation level indicated ^{60}Co contributed more than 75 percent of the total exposure rate. Traces of ^{106}Rh, ^{101}Rh, ^{144}Ce, ^{155}Eu, and ^{241}Am (and thus ^{239}Pu) were also detected.

Sample Analysis and Data Evaluation

The analysis of collected environmental samples such as marine life, coconut, arrowroot, pandanus, birds, land crabs, and soil and the calibration and development of correction factors for instruments continued in 1967. The next significant step was taken by Dr. Philip F. Gustafson of the Division of Biomedical and Environmental Research, USAEC,* who collected and summarized the data from all past surveys. Included in this material were reports from the Trust Territory District Agriculturist and from the Trust Territory District Anthropologist. Dr. Gustafson prepared estimates of potential exposures, both internal and external, for a returning population having living habits and diet that are expected to apply to the Bikinians. Also prepared were tentative recommendations with regard to the basic question of whether from a radiation exposure viewpoint the Bikinians should be allowed to return.**

In April 1968, the Division of Biology and Medicine, USAEC, appointed an Ad Hoc Committee of eight expert consultants to consider the question of return of the Bikinians. The Committee members reviewed the survey data, Dr. Gustafson's reports, and consulted with the team members of the 1967 survey. Following this review, the Committee stated that on the basis of information provided, the exposures to radiation resulting from the repatriation of Bikini people would not offer a significant threat to their health and safety.(3) Key recommendations for actions to further reduce exposures were restriction of rehabilitation for the present to the Bikini-Eneu Complex, removal of radioactive scrap, reduction of land crab population, a dietary supplement of calcium. The Committee also recommended periodic resurveys of the atoll. There were other recommendations for agricultural and village construction activities expected to reduce the radionuclide content of pandanus and reduce external radiation levels in village and dwelling sites.

*Now at Argonne National Laboratory, Argonne, Illinois, USA

**Copies of the technical data are available for examination at the Public Document Room in USAEC's Washington, D.C. Office at 1717 H. St.

On August 12, 1968, the decision was announced that the Bikinians were to be returned to their atoll.(3) The USAEC and United States Department of Defense (DOD) were requested to work with the Department of the Interior in planning and carrying out a comprehensive program for returning the Bikinians to their home islands. To begin the planning, High Commissioner W. R. Norwood of the Trust Territory of the Pacific Islands led a part of Trust Territory officials, nine Bikini natives, USAEC and DOD representatives, and members of the press, back to Bikini in late August 1968.

Cleanup and Followup, 1969-1970

The first units of the atoll cleanup force arrived at Bikini Atoll in February 1969. The DOD directed the cleanup phase of the rehabilitation project which lasted about eight months. The Department of the Interior is managing the agricultural restoration and housing construction phases of the project. The AEC provided radiological safety and monitoring support for cleanup operations and is conducting followup surveys.

Additional information was obtained on radiological conditions during cleanup. Clearing of scrub vegetation provided easy access to island areas. Additional soil and food samples were collected and analyzed and many radiation measurements made with portable instruments. Results of analysis of soil taken from the location having the highest external gamma level in the atoll (from Eneman, an island where houses are not to be built and where replanting of coconut trees is restricted), showed a level of ^{239}Pu in dry soil of 410 pCi/g.(4) Analysis of food items collected during cleanup indicated mean concentrations of ^{137}Cs and ^{90}Sr that were essentially in agreement with those obtained in 1967. For 1969 and 1970 collections, there were no striking differences between average values for edible foods of marine origin, including the sea birds, compared with values reported in 1967.(5) Internal dose estimates performed for the 1967 sample collections appeared to be valid for the 1969 data as well. External gamma surveys during cleanup confirmed the earlier measurements. Estimates of total exposure for children for the 1967 and 1969 data are as follows:

	Total whole body gamma exposure (Rads)	
Time (years)	1967	1969
5	1.16	0.75
30	5.32	5.28
70	9.74	9.36

1970 Survey

Sampling for ^{239}Pu in air at Bikini and Eneu Islands was conducted during May-June 1970. For Bikini the results ranged from 0.6×10^{-4} to 5.4×10^{-4} pCi/m^3. Results for Eneu were 0.4×10^{-4} pCi/m^3. These concentrations are comparable to those found in the U.S. and are lower than the Federal Radiation Council, FRC, guides for soluble plutonium in air (6×10^{-2} pCi/m^3 for individuals and 2×10^{-2} pCi/m^3 for population groups) by about two orders of magnitude.

1972 Survey

Additional followup monitoring at Bikini Atoll was conducted in May 1972, by the AEC Division of Operational Safety, with support from staff of the AEC Nevada Operations Office, the University of Washington, and the Western Environmental Research Laboratory of the Environmental Protection Agency. Soil, water and food items were collected and sampling was conducted for determining the radionuclide content of air. Reports of results are being prepared by the principal investigators.

Conclusion

Radiation and radioactivity levels and the radionuclides contributing to those levels were determined for the Bikini Atoll environment through a detailed survey in April-May 1967, and by additional survey activities in 1969, 1970, and 1972. External radiation levels were found to vary considerably from island to island and from place to place on the same island. On islands more remote from testing activities such as Eneu and Bikini, the major contributor to the external gamma field is ^{137}Cs. The levels on Bikini were observed to be highest in the more heavily vegetated interior and lowest along the shore where there has been more weathering. On near test islands, the major contributor to the external gamma field was observed to be ^{60}Co. Quantities of scrap metal containing ^{60}Co were found on these islands. These were removed during cleanup operations in 1970. The information obtained since 1968 would not require any significant change in the estimates of potential exposures for the returning population.

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