BNL20767

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MARSHALL ISLANDS RADIOLOGICAL FOLLOWUP*

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Abstract

In August, 1968, President Johnson announced that the people of Bikini Atoll would be able to return to their homeland. Thereafter, similar approval was given for the return of the peoples of Enewetak. These two regions, which comprised the Pacific Nuclear Testing Areas from 1946 to 1958, will probably be repopulated by the original inhabitants and their families within the next year. As part of its continuing responsibility to insure the public health and safety in connection with the nuclear programs under its sponsorship, ERDA (formerly AEC) has contracted Brookhaven National Laboratory to establish radiological safety and environmental monitoring programs for the returning Bikini and Enewetak peoples. These programs are described in the following paper. They are designed to define the external radiation environment, assess radiation doses from internal emitters in the human food chain, make long range predictions of total doses and dose commitments to individuals and to each population group, and to suggest actions which will minimize doses via the more significant pathways.

Introduction

The U.S. nuclear testing programs of the 1940s and 1950s had significant local environmental impacts on the coral atolls of Bikini and Enewetak in the Marshall Islands. The high level close-in fallout made these atolls uninhabitable for many years. Fallout from the BRAVO event, which took place at Bikini in 1954, was inadvertently deposited on the nearby atolls of Rongelap, Rongerik and Utirik. In all, some thirteen atolls in the northern Marshalls were probably affected to a greater or lesser extent by fallout from these nuclear tests. Of these, however, the most significant long term radiological impact was on the test atolls, Bikini and Enewetak, and on Rongelap Atoll.

In 1957, Rongelap was reoccupied by its original inhabitants who had been evacuated two days after BRAVO. During the past several years, definitive plans have been made to repatriate the original inhabitants of Bikini and Enewetak Atolls, and their families. It is hoped that their return can take place soon.

In order to identify radiological problems from residual radioactivity in the environment, and to provide a data base for dose predictions applicable to the returning populace, ERDA (and its predecessor, the AEC), has sponsored many radiological surveys in the Marshall Islands. These surveys began during test operations and have been conducted periodically up to the present time. Results of the surveys have been published in numerous reports and scientific journals. References 1 through 12 are published reports of AEC/ERDA supported surveys of these atolls. References 13 through 29 are a portion of the published reports on work with collected environmental samples supported by AEC/ERDA.

Evaluation of survey results for Bikini Atoll, the consideration of predicted exposures compared with applicable radiation standards, and the acknowledgement of the many benefits to the people if they could return, led to the decision to clean up and rehabilitate that atoll. The Department of Defense, Department of the Interior (DOI), and AEC (now ERDA) participated in a joint effort of clean up and rehabilitation of Bikini Atoll starting in February, 1969. Clean up was completed in the fall of that year. Agricultural rehabilitation and housing construction is being conducted by DOI.

The decision to return the Enewetakese to their atoll led to a comprehensive survey conducted at Enewetak in 1972-1973.[10] A regional survey planned for 1976 will provide baseline radiological data for future dose assessments throughout nearly all of the northern Marshall Islands which may have been affected by the testing program. Environmental evaluations at Rongelap and Utirik Atolls have been undertaken periodically in association with ERDA's medical evaluations program there over the past 20 years.[30-42]

From all of these earlier surveys, it became apparent that periodic environmental monitoring and dose assessments must be made for Bikini, Enewetak, Rongelap and perhaps other atolls in the northern Marshalls to maintain a current radiological data base and to provide current information on individual and population doses. This followup monitoring is being performed by Brookhaven National Laboratory at the request of the Division of Operational Safety, U.S. Energy Research and Development Administration.

*Research carried out at Brookhaven National Laboratory under the auspices of the U. S. Energy Research and Development Administration.

Radiological Concerns

The primary radiological problems are the result of residual fission and activation products in the terrestrial environment. They have been identified by previous environmental surveys as follows: 1) External radiation levels significantly higher on some islands in an atoll compared to levels on lightly contaminated islands. 2) Fission and activation product radioactivity in certain terrestrial food items now growing on islands of these atolls and the possibility that unacceptable levels of these radionuclides may appear in foods, plants and animals newly introduced into these atolls. 3) Radioactivity in the ground water, a possible source of drinking water and water for irrigation. 4) Plutonium and americium isotopes in the surface soil. These factors are illustrated by data in Tables 1 through 4 taken from previous radiological survey reports.

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, Rojkere, Eonjebi	.003-.010	**
Aerokoj-Emenman 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	**

*See ref. 9.

**No soil sample or field spectra measurements.

In some cases, the predicted doses and dose commitments derived from survey information for Bikini and Enewetak Atolls approach or even exceed national and international radiation protection standards for certain living and dietary patterns. Corrective actions or restrictions must be placed on use of these atolls and their resources to assure that the applicable radiation standards are not exceeded. Herein lies the primary justification for the continuing environmental followup surveys sponsored by ERDA.

Environmental Monitoring

The most important sources of exposure to people living on Rongelap and to future residents of Bikini and Enewetak Atolls are from internal deposition of radioisotopes from certain elements in the human diet, and from the long term occupancy of islands having external radiation dose rates higher than natural background. Aside from periodic re-evaluations to establish trends in external dose rate reduction, external radiation monitoring will assume less significance, compared to monitoring of the food chain, as time passes. At present, annual visits are being made to identify and collect representative samples of local diets for laboratory analysis and dose commitment updates. New locally grown food items are becoming available in small quantities on Bikini Island as a result of the experimental agricultural practices of a small group of caretaker families living there. Neither Bikini Atoll, where radiological cleanup has been completed, nor Enewetak Atoll where clean up has not yet begun, have a subsistence agriculture resource in being which is sufficient to support the anticipated populations which will one day live there (though such crops are currently being developed or planned).

Table 2. Concentrations of ^{40}K, ^{60}Co, ^{90}Sr, and ^{137}Cs in Food Plants Collected on Bikini Island in November 1971 and March 1972*

Plant type	Tissue	Collection date	pCi/g, dry+ ^{40}K	^{60}Co	^{137}Cs	^{90}Sr
Lettuce	Entire	March 1972	7.1±6.1	NS†	1860±10	320 ±25
Papaya #1	Seeds	March 1972	17 ±2	0.13±0.12	140± 1	NAδ
"	Fruit	March 1972	31 ±3	NS	160± 1	72 ± 3
Papaya #2	Seeds	March 1972	14 ±4	NS	270± 2	NA
"	Fruit	March 1972	23 ±3	NS	290± 1	69 ± 4
Pandanus	Fruit (edible)	November 1971	7.5±0.6	0.05±0.03	82± 0.4	56 ± 0.6
"	Fruit (fibrous)	November 1971	12 ±2	NS	200± 1	220 ± 2.2
"	Leaves	November 1971	3.4±1.5	NS	71± 0.4	190 ± 1.9
Coconut #1	Meat	November 1971	1.6±1.3	NS	93± 0.5	NA
"	Milk	November 1971	3.9±1.9	NS	110± 0.7	NA
Coconut #2	Meat	November 1971	4.4±2.1	NS	110± 1	0.88± 0.04
"	Milk	November 1971	4.3±2.5	NS	100± 1	< .22
Coconut #3	Meat	November 1971	11 ±4	NS	147± 1	NA
Coconut #4	Meat	November 1971	2.5±2.0	NS	100± 0.8	NA
"	Milk	November 1971	3.0±1.8	NS	77± 0.6	NA
Coconut #5	Meat	November 1971	15 ±6	NS	270± 2	NA
"	Milk	November 1971	2.1±1.3	NS	33± 0.3	NA
Coconut	Fronds (old)	November 1971	7.0±5.0	NS	310± 3	NA
	Fronds (new)	November 1971	14 ±5	NS	220± 2	NA

*See ref. 11.
+The error terms for ^{40}K, ^{60}Co, and ^{137}Cs are two-sigma, propagated, counting errors. The errors for ^{90}Sr are one-sigma, propagated, counting errors.
†NS = not significant. The net sample count is less than the two-sigma, propagated, counting error.
δNA = not analyzed.

Table 3. Some Radionuclides in Water Samples Collected with a Large Volume Filter Sorption Bed from Bikini Atoll, May 1972*

Collection location	Fraction	Liters Sampled	Radionuclide concentration in pCi/m³+ ^{60}Co	^{137}Cs	^{155}Eu	^{207}Bi	^{241}Am
Bravo Crater (bottom)	Particulate†	3785	51 ±3	12 ±1	97 ±4	27 ± 2	70 ±5
	Solubleδ	3785	28 ±8	<14 ±	<20	160 ±11	<30
Bravo Crater (surface)	Particulate	3785	6.5±1.4	NSΔ	9.6±1.3	0.5± 0.3	8.2±1.4
	Soluble	3785	<10	< 6	<16	<12	<22
Bokdrolul Pass (ebb tide)	Particulate	4088	6.0±7.3	NS	6.4±1.2	NS	5.4±1.1
	Soluble	4088	1.4±0.6	<1.0	<2.3	3.0± 0.5	<2.9
Bokdrolul Pass (flood tide)	Particulate	4921	2.1±0.7	NS	1.5±0.8	NS	1.8±0.9
	Soluble	4921	NS	NS	NS	2.5± 1.7	NS
Bikini Island (seaward reef)	Particulate	1620	1.5±1.5	NS	NS	2.0± 0.8	NS
	Soluble	1620	6.2±5.4	NS	NS	NS	NS
Bikini Island (lagoon)	Particulate	2271	5.6±1.0	NS	NS	0.76± 0.38	1.1±1.1
	Soluble	2271	9.2±6.6	NS	NS	NS	NS
Ocean between Bikini and Enewetakθ	Particulate	4898	NS	7.7±1.0	NS	NS	NS
	Soluble	4898	NS	NS	NS	NS	NS
Bikini Island (freshwater well)	Particulate	1893	21 ±3	21 ±1	14 ±3.7	NS	NS
	Soluble	1893	54 ±9	990 ±60	<2	<7	34 ±0

*See ref. 11.
+Errors are two-sigma, propagated, counting errors.
†Particulate--that portion retained by the 0.3 u filter.
δSoluble--that portion which passes through the 0.3 u filter and is sorbed by the Al_2O_3 beds.
ΔNS--not significant. The net sample count is less than the two-sigma, propagated counting error.
θThis sample was collected over a 6 hr period between the following positions: 11°29'5" by 164°58'0" E to 11°24'5" N by 164°18'0" E.

Table 4. $^{239,240}Pu$, ^{238}Pu and ^{241}Am in Surface Soil Samples Collected at Bikini Atoll in 1972, activities in pCi/g ± 1-.*

Location	$^{239,240}Pu$	^{238}Pu	^{241}Am	$^{239,240}Pu/^{238}Pu$	$^{239,240}Pu/^{241}Am$
Isl-29, Ourukaen	16.3 ±0.5	5.7 ±0.2	3.6 ±0.3	2.86	4.53
Isl-30, Bokoatokutoku	15.1 ±0.7	3.9 ±0.3	4.3 ±0.42	3.87	3.51
Isl-30, Bokoaetokutoku Pisonia Grove	22.2 ±0.5	6.7 ±0.2	7.0 ±0.30	3.31	3.17
Boro Bokororyruru, Isl-31 down center of island	36.4 ±2.8	7.2 ±0.8	13.0 ±1.1	5.05	2.75
Namu, west end + 150 yds	24.0 ±0.1	00.28±0.02	14.0 ±0.4	85.7	1.68
Namu, 200 yds SW of bunker 300 yds E of west tip	20.1 ±0.3	0.24±0.02	11.0 ±0.7	83.8	1.76
Namu, top of bunker center of island	22.9 ±0.7	0.31±0.04	15.0 ±0.05	73.9	1.57
Namu, 200 yds E of bunker, center of island	17.4 ±0.6	0.57±0.11	10.0 ±0.5	30.5	1.68
Bikini, Row 24 center BL to 1st BLN	3.3 ±0.1	0.45±0.04	2.2 ±0.3	7.33	1.50
Bikini, N corner of ctr. BL and Lagoon Beach Rd.	3.41±0.36	N.R.†	.87±0.12	--	4.01
Bikini, Row 34 center BL to 1st BL	3.0 ±0.2	0.06±0.04	2.1 ±0.2	50.0	1.42
Bikini, Row 38 2nd BLN to Lagoon Beach Rd.	2.5 ±0.2	0.07±0.04	1.2 ±0.2	35.7	2.08
Bikini, Row 25 or 26 sand-pile sample, 100 yds S of 2nd BLN	0.50±0.05	N.S.δ	--	--	--
Bikini, Row 34 ctr BL to 1st BLS	10.8 ±0.04	N.R.	3.3 ±0.3	--	3.27
Bikini, Row 24 ctr BL to 1st BLS	13.2 ±0.3	N.R.	8.4 ±0.55	--	1.58
Bikini, Row 24, 1st BLN to Lagoon Beach Rd.	9.3 ±0.4	0.39±0.07	4.1 ±0.2	23.8	2.27
Bikini, Row 34, 1st BLS to 2nd BLS	11.6 ±0.4	0.09±0.02	5.3 ±0.4	128.0	2.18
Bikini, Row 24, 1st BLN to 2nd BLN	7.8 ±0.2	0.20±0.03	3.5 ±0.3	39.0	2.23
Eneman, NW end of island 500-700 mR/hr area	209.2 ±9.0	97.6 ±4.3	24.0 ±1.5	2.14	8.57
Eneman, 500-700 mR/hr area	360.9 ±5.9	174.3 ±2.8	45.0 ±1.0	2.07	8.05

*Single sample error values are one-sigma, propagated, counting errors. See ref. 29.
†N.R. Not resolved by alpha spectroscopy.
δN.S. Not significant.

As a result, some of the dietary items likely to have the higher radionuclides content, e.g. pandanus and breadfruit, are not actual problems to date. They may or may not be of concern in the future as the plantings mature and the fruit becomes available in quantity. Thus, the diets of people living in these two atolls are expected to change over the coming years reflecting the relative influences of imported and locally grown food items. Allowance has been made for this in development of radiation dose estimates. Experimental studies at Enewetak may yield techniques to interrupt or break the recycling of radionuclides through the vegetation, soil, and ground water systems, and thereby reduce the radioactivity content of some important dietary items. All of the aforementioned factors will necessitate continuing monitoring of the diet for many years. Periodic sampling and analysis of soil and ground water will be necessary in order to establish trends in the changes of radioactivity content of these media.

In the northern Marshalls, drinking water is obtained primarily from rain water catchments. While the radionuclide content of collected rain water will not be zero, this source is not expected to contribute significantly to the radiation exposure picture for future Bikini, Enewetak, and Rongelap Atoll residents. However, rain water which drains from the windward side of building rooftops may provide useful data on resuspension of radioactivity in the soil. The collection of rain water by future Bikini and Enewetak residents is being facilitated by including gutters and water storage tanks in plans for houses and community structures. Some of the larger islands have fresh ground water located only a few feet below the surface. Analysis of this water for its radionuclide content has been limited to date and the capacity of this resource to serve the needs of island residents is not well defined. More study of this water is being supported by ERDA.

Personnel Monitoring

Dose predictions for Bikini and Enewetak Atoll residents derived from environmental data have been deliberately conservative, and establish probable upper limits on doses to be expected for individuals.

Reliable assessments of actual doses must be determined through personnel monitoring. External radiation dosimeters do not appear to be a practical means of personnel monitoring for individual external dose measurements, although certain individuals within given populations may be relied upon to wear them. A "lifestyle model" which includes estimates of occupancy factors for various locations in a given atoll has been coupled with environmental monitoring data to estimate average external radiation doses to individuals. This model will be revised as needed so that it closely approximates the actual lifestyle of the people.

The more important internal pathway can be monitored directly by conventional techniques of bioassay and whole body counting of individuals. A portable shadow shield whole body counter has been constructed and mounted in a shipboard trailer for use in the Marshall Islands. It is capable of quantitative detection of very small quantities of certain radionuclides in the body such as ^{137}Cs and ^{60}Co, the primary environmental gamma emitters at Bikini, Enewetak and Rongelap Atolls. The system clearly identifies individuals in the Rongelap population who are not following the recommended dietary restrictions on eating coconut crabs from certain locations.(42,43) Body burdens of $^{90}Sr/^{90}Y$, $^{239,240}Pu$ and ^{241}Am are estimated by the radiochemical analysis of urine samples. Urine sample collections and whole body counting will be performed every one to two years at Bikini and Enewetak Atolls when the people return, and every two to three years at Rongelap Atoll until the results warrant less frequent measurement intervals.

Summary

Marshall Islands Radiological Followup has consisted of intensive environmental studies at Bikini, Enewetak, and Rongelap Atolls to gather radiological data on the external radiation environment and on radioactivity in food chains. Radiation and radioactivity levels in these atolls are being reduced with time. These changes are monitored in annual or biannual environmental surveys. Updated information is used to make conservative estimates of population doses and dose commitments. When people have returned, actual internal doses to individuals are determined for whole body counting and bioassay data. These results are combined with environmental data on the external radiation environment to complete the total dose assessment picture.

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