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DOSIMETRY METHODS AND RESULTS FOR THE FORMER RESIDENTS OF BIKINI ATOLL*

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Abstract

The U.S. Government utilized Bikini and Enewetak Atolls in the northern Marshall Islands of Micronesia for atmospheric tests of nuclear explosives in the 1940's and 1950's. The original inhabitants of these atolls were relocated prior to the tests; and once the testing ceased in 1958, they petitioned the government to allow them to return. Radiological analyses of the Bikini environment in the 1960's indicated that with proper rehabilitation, the atoll could be reinhabited, and that the residents would receive acceptable doses from residual radioactivity. During the early 1970's, a small but growing population of Marshallese people reinhabited Bikini primarily to assist in government-sponsored cleanup and rehabitation programs. Environmental and personnel radiological monitoring programs were begun by Brookhaven National Laboratory in 1974 to ensure that doses and dose commitments received by Bikini residents remained within U.S. Federal Radiation Council guidelines. Dramatic increases were noted in ^{137}Cs body burdens among the inhabitants between April 1977 and 1978, and these observations may have played a significant role in the government decision to move the 140 Bikinians in residence at that time off of the atoll in August 1978.

The average ^{137}Cs body burden for the population was 2.3 uCi in April 1978, and subsequent whole body counts after the August departure indicate that this was close to the equilibrium value. Several individuals, however, exceeded the maximum permissible body burden of 3 uCi, and some approached 6 uCi. The resultant total dose commitment was less than 200 mrem for the average resident. The average total dose for the mean residence interval of ~ 4.5 years was about 1 rem.

The sources of exposure, the probable cause of the unexpected increase in ^{137}Cs body burdens, and the methods for calculating radionuclide intake and resultant doses are discussed in this paper. Suggestions are offered as to the implications of the most significant exposure pathways for the future inhabitation of Bikini and Enewetak.

Introduction

The United States tested nuclear explosives in the Pacific from 1946 to 1958. These tests had significant local environmental impacts on the two test sites, Bikini and Enewetak Atolls; and residual radioactivity from high level local fallout made these atolls uninhabitable for many years. The BRAVO test in March 1954 was probably responsible for most of the residual activity on Bikini Island, the traditional village island at Bikini Atoll (Fig. 1). BRAVO was also responsbile for significant personnel exposures and environmental contamination on the inhabited atolls, Rongelap, Rongerik, Ailinginae and Utirik, as a result of a wind shear which transported a large portion of the airborne debris to the east. Medical and environmental evaluations at Rongelap and Utirik Atolls have been undertaken periodically for the past 25 years [1-18].

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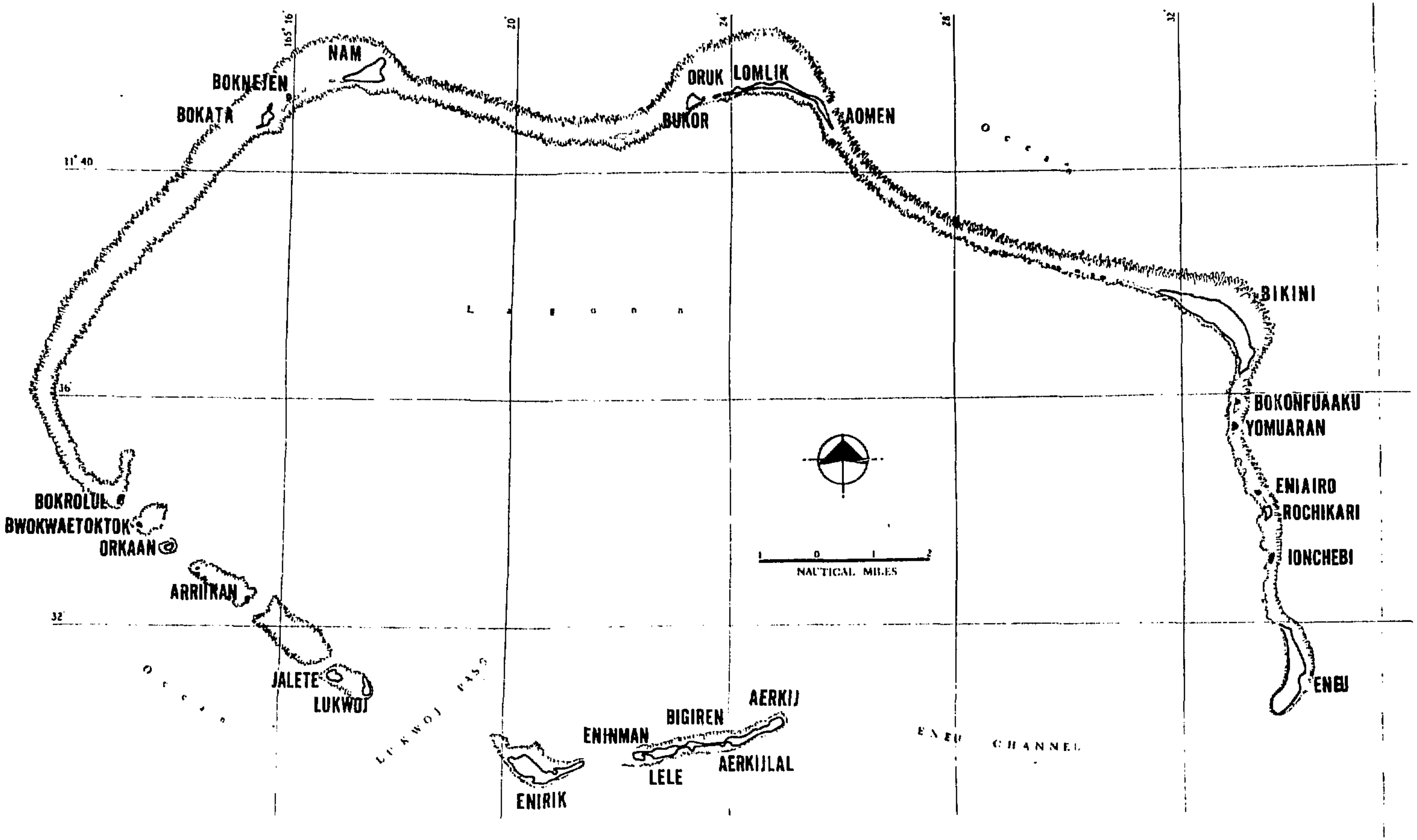

Figure 1

Map of Bikini Atoll

The Bikini Atoll environment was the recipient of many radiological evaluations both during and after the testing years. After the testing ceased in 1958, however, these studies were focused on establishing the habitability of Bikini from a radiological standpoint [19-25]. During the early post-testing years, the Bikini people, now living on Kili Island some 800 km to the south, had been working through government channels to be allowed to return to their home atoll. The environmental studies of the 1960's suggested that with proper rehabilitation, Bikini could be reinhabited. Considerations of predicted radiation exposures compared with applicable protection standards, and the acknowledgement of the many benefits to the people if they could return led to the presidential announcement in 1968 that the Bikinians would be allowed to return. The U.S. Department of Defense (DOD) and Interior (DOI), and the Atomic Energy Commission (AEC, now Department of Energy (DOE)) participated in a joint effort to clean up and rehabilitate Bikini Atoll beginning in February, 1969. Agricultural rehabilitation and house construction began after cleanup was completed in the fall of that year; and agricultural development programs continued into the late 1970's. During these years, a small but growing population of Bikinians and other Micronesians were employed by the government to assist with the rehabilitation efforts. They and their families lived at Bikini, subsisting largely on local fish and imported foods.

During the early 1970's, the decision was also made to allow the Enewetak people to return to their atoll. This decision led to a comprehensive radiological survey at Enewetak in 1972-1973 [26]. In 1978, a large-scale regional survey was conducted at Bikini, Enewetak, Rongelap, Utirik, and 7 additional atolls and 2 islands (not associated with atolls) in the Northern Marshalls which may have been affected by the testing programs. This survey is expected to provide environmental radiological data from which long-term predictive dose estimates will be made.

The results of the earlier surveys in the Northern Marshalls also suggested the need for periodic environmental and personnel monitoring and dose assessments at Bikini, Enewetak, Rongelap and Utirik to maintain a current radiological data base, and to provide continuing information on the status of individual and population doses with respect to the radiation protection standards. This followup monitoring has been performed by Brookhaven National Laboratory (BNL) since 1974 under the sponsorship of the U.S. Department of Energy.

BNL Program Description

The BNL Marshall Islands Radiological Safety Program (MIRSP) was established to provide routine environmental and personnel monitoring and dosimetry coverage for inhabited islands in the Marshalls which were significantly affected by Pacific tests. The scope of this paper, however, will be limited to those aspects of the program involving the people and environment of Bikini Atoll.

By 1974, the population of Bikini "caretakers" and their families had grown to about 40 persons. Bikini and Eneu Islands, the two largest islands in the atoll, had been recently planted with some 80,000 coconut trees; and 40 houses had been constructed near the lagoon side of Bikini Island. Most of the residents were living in a camp area near the south end of Bikini which had been established to support the nuclear test programs. At this time, there was little in the way of locally grown terrestrial foods except for small amounts of produce from a garden plot behind one of the houses. Staple arboreal foods such as coconut, breadfruit and pandanus were not yet available, because the trees, planted in 1970 to 1971, required an additional 3 to 4 years or more before they would bear fruit. Government-sponsored food subsidy programs provided canned foods, flour, sugar and other staples to supplement the local fish and provide an adequate diet for the Bikini residents.

During the early years, the MIRSP concentrated its efforts on characterizing the external radiation environment, and on evaluating the radionuclide content of soil, catchment and well water, wild vegetation, garden vegetable samples and the inedible parts of immature coconut, pandanus and breadfruit trees.

The Brookhaven Medical staff made a sick call stop at Bikini in April 1974 after completing its rounds at Utirik and Rongelap. Any Bikinians who wished to participate were counted in a trailer-mounted shadow shield whole body counter which had been carried on the field trip ship to provide personnel monitoring services at Utirik and Rongelap. Urine samples were also collected from Bikini volunteers for bioassay for ^{90}Sr/Y and other radionuclides.

In 1975, BNL participated in a multiagency survey of Bikini and Eneu Islands which provided a high resolution mapping of external exposure rates, and laid the ground work for long range predictive dose assessments for Bikini [27]. Following the publication of these reports in 1976 and 1977, the Brookhaven MIRSP began shifting its emphasis from environmental to personnel monitoring in order to provide actual dosimetric data to compare with the predictions. Systematic personnel monitoring programs were initiated in 1977, and included the following aspects:

1) whole body gamma spectroscopy to measure ^{137}Cs, ^{60}Co, ^{40}K and other gamma emitters;

2) 24-hour urine sampling to measure ^{90}Sr/Y excretion for internal dose estimates, and to measure excretion rates for gamma emitters as an independent check on whole body counting results; and

3) a program of interviews and observations to develop an understanding of local diet and living patterns. This was necessary to quantitatively understand the ingestion rates for radionuclides, and to estimate external doses since the Bikini residents did not wear dosimeters.

Whole body counting results in 1977 demonstrated a dramatic increase in ^{137}Cs body burdens, a trend which continued in 1978. By April 1978, 15 Bikinians had exceeded the maximum permissible body burden (non-occupational) of 6.6 x 10^6 Bq (3 uCi); and six individuals approached twice that value. The 1977 and 1978 whole body counting results probably influenced the decision by DOI to move the Bikinians (now numbering about 140 persons) back to Kili

Island in August-September 1978. Several families have subsequently moved from Kili to Ejit Island, a former experimental agricultural station at Majuro Atoll, the Marshall Islands District Center. Followup personnel monitoring activities at Majuro and Kili in January and May 1979 have demonstrated that ^{137}Cs body burdens have declined predictably since the departure from Bikini in August 1978.

Summary of Body Burden Data

A. Methods

A trailer-mounted shadow shield whole body counter is used for in vivo gamma spectroscopy in the Marshall Islands. A large (28 cm diameter, 10 cm thick) NaI(Tl) scintillation detector is employed to minimize counting times. The amplified detector output is processed by a computer/pulse height analyzer (PHA) which stores the data on a magnetic disk. Body burden determinations are then computed in the field or at BNL using a matrix reduction, minimization of the sum of squares technique [28].

The system is calibrated with a phantom loaded with known amounts of ^{40}K, ^{60}Co, and ^{137}Cs. It provides a minimum detectable activity (MDA) at 95% confidence for ^{137}Cs and ^{60}Co in vivo of about 1 nCi, with 15 minute counting times in the field.

Estimates of ^{90}Sr/Y body burdens were derived from daily urinary excretion rates for these nuclides as determined by 24 hour urine bioassay. Constant continuous ingestion of radioactive material was assumed in a modified version [29] of the multicompartmental metabolic model used by the International Commission on Radiological Protection in its Publication 20 [30].

B. Results and Discussion

Average ^{137}Cs body burden data are presented in Table I for Bikini adults and children for the April field trips in residence years 1974, 1977 and 1978. Post-residence body burdens in January and May 1979 are listed in Table II.

The large increase in cesium body burdens between 1974 and 1977 is illustrated in Table I. These data represent an average increase by a factor of 13.3 for ^{137}Cs in males, for example. A further increase is noted from 1977 to 1978 by a factor of 1.8. After departure from Bikini in August 1979, the ingested intake rate of ^{137}Cs was reduced to the background amounts in foods from uncontaminated locations. As a result, the average body burden was reduced by a factor of 2.9 between 1978 and January 1979. A field trip in May 1979 afforded an opportunity to recount some of the January 1979 whole body counting subjects at Majuro, and to count some of the Bikinians at Kili who had not been monitored since the Bikini departure in 1978. The May 1979 data demonstrated a continued decline in cesium body burdens consistent with current models of excretion kinetics [31].

Table I

Summary of ^{137}Cs Body Burdens for Bikini Inhabitants, 1974 to 1979

Population	Number Counted 1974 (e)	Range of ^{137}Cs Results 1974 (e)	Mean ^{137}Cs Result 1974 (e)	Number Counted 1977 (e)	Range of ^{137}CS Results 1977 (e)	Mean ^{137}Cs Result 1977 (e)	Number Counted 1978	Range of ^{137}Cs Results 1978	Mean ^{137}Cs Result 1978	Number Counted 1979	Range of ^{137}Cs Results 1979	Mean ^{137}Cs Result 1979
Adult Male	18	1.6 kBq (0.043 µCi) to 15 kBq (0.40 µCi)	4.7 kBq (0.13 µCi) ± 3.4 kBq (0.0093 µCi)	22	21 kBq (0.57 µCi) to 120 kBq (3.2 µCi)	48 kBq (1.3 µCi) ± 27 kBq (0.73 µCi)	36 (a)	23 kBq (0.63 µCi) to 220 kBq (5.9 µCi)	90 kBq 2.4 µCi) ± 49 kBq 1.3 µCi)	17	12 kBq (0.32 µCi) to 89 kBq (2.4 µCi)	37 kBq (1.0 µCi) ± 19 kBq (0.51 µCi)
Adult Female	13	0.67 kBq (0.018 µCi) to 9.3 kBq (0.25 µCi)	2.7 kBq (0.073 µCi) ± 2.3 kBq (0.063 µCi)	20	20 kBq (0.53 µCi) to 83 kBq (2.2 µCi)	34 kBq (0.93 µCi) ± 17 kBq (0.47 µCi)	32	15 kBq (0.41 µCi) to 200 kBq (5.5 µCi)	62 kBq (1.7 µCi) ± 37 kBq (1.0 µCi)	16	2.2 kBq (0.060 µCi) to 36 kBq (0.98 µCi)	16 kBq (0.44 µCi) ± 8.9 kBq (0.24 µCi)
Male Children 11-15 yrs	0	ND	ND	3	24 kBq (0.65 µCi) to 39 kBq (1.0 µCi)	30 kBq (0.82 µCi) ± 7.6 kBq (0.21 µCi)	6 (b)	27 kBq (0.73 µCi) to 77 kBq (2.1 µCi)	53 kBq (1.4 µCi) ± 21 kBq (0.56 µCi)	4	2.0 kBq (0.055 µCi) to 28 kBq (0.76 µCi)	10 kBq (0.27 µCi) ± 12 kBq (0.33 µCi)
Female Children 11-15 yrs	0	ND	ND	3	20 kBq (0.56 µCi) to 35 kBq (0.94 µCi)	25 kBq (0.68 µCi) ± 8.5 kBq (0.23 µCi)	3	28 kBq (0.74 µCi) to 76 kBq (2.1 µCi)	46 kBq (1.3 µCi) ± 25 kBq (0.66 µCi)	2	5.6 kBq (0.15 µCi) to 10 kBq (0.27 µCi)	7.8 kBq (0.21 µCi) ± 3.1 kBq (0.080 µCi)
Male Children 5-10 yrs	0	ND	ND	0	ND	ND	8 (c)	37 kBq (1.0 µCi) to 64 kBq (1.7 µCi)	50 kBq (1.3 µCi) ± 7.6 kBq (0.21 µCi)	1	5.9 kBq (0.16 µCi)	5.9 kBq (0.16 µCi)
Female Children 5-10 yrs	0	ND	ND	0	ND	ND	14	20 kBq (54 µCi) to 92 kBq (2.4 µCi)	47 kBq (1.3 µCi) ± 21 kBq (0.56 µCi)	6	1.6 kBq (0.042 µCi) to 9.6 kBq (0.26 µCi)	4.4 kBq (0.12 µCi) ± 3.0 kBq (0.080 µCi)

Table 1 (Cont'd)

Population	Number Counted 1974(e)	Range of ^{137}Cs Results 1974(e)	Mean ^{137}Cs Result 1974(e)	Number Counted 1977(e)	Range of ^{137}Cs Results 1977(e)	Mean ^{137}Cs Result 1977(e)	Number Counted 1978	Range of ^{137}Cs Results 1978	Mean ^{137}Cs Result 1978	Number Counted 1979	Range of ^{137}Cs Results 1979	Mean ^{137}Cs Result 1979
All Adults	21	0.67 kBq (0.018 μCi) to 15 kBq (0.40 μCi)	3.9 kBq (0.11 μCi) ± 3.1 kBq (0.085 μCi)	42	20 kBq (0.53 μCi) to 120 kBq (3.2 μCi)	42 kBq (1.1 μCi) ± 24 kBq (0.64 μCi)	68	15 kBq (0.41 μCi) to 220 kBq (5.9 μCi)	77 kBq (2.1 μCi) ± 46 kBq (1.2 μCi)	33	2.2 kBq (0.060 μCi) to 89 kBq (2.4 μCi)	27 kBq (0.73 μCi) ± 18 kBq (0.49 μCi)
All Children$^{(d)}$	0	ND	ND	6	20 kBq (0.56 μCi) to 39 kBq (1.0 μCi)	28 kBq (0.75 μCi) ± 7.8 kBq (0.21 μCi)	31	20 kBq (0.54 μCi) to 92 kBq (2.3 μCi)	50 kBq (1.4 μCi) ± 18 kBq (0.49 μCi)	13	1.6 kBq (0.042 μCi) to 28 kBq (0.76 μCi)	8.3 kBq (0.22 μCi) ± 7.8 kBq (0.21 μCi)
Total Average	21	0.67 kBq (0.018 μCi) to 15 kBq (0.40 μCi)	3.9 kBq (0.11 μCi) ± 3.1 kBq (0.085 μCi)	48	20 kBq (0.53 μCi) to 120 kBq (3.2 μCi)	40 kBq (1.1 μCi) ± 22 kBq (0.61 μCi)	99	15 kBq (0.41 μCi) to 220 kBq (5.9 μCi)	68 kBq (1.8 μCi) ± 38 kBq (1.0 μCi)	46	1.6 kBq (0.042 μCi) to 89 kBq (2.4 μCi)	22 kBq (0.59 μCi) ± 18 kBq (0.49 μCi)

ND - No Data available for the specific column.

(a) One adult, counted at Bikini, was a visitor from Rongelap Atoll. He remained on ship with the BNL staff while at Bikini. His body count was not used in this table.

(b) One male child in this age group was counted twice to determine what effect showering prior to the body count had on the final result. Only one result was used for this individual since both results were similar.

(c) A six month old child's data has not been included in this table and category due to the difference in geometry between a baby and our calibration phantom.

(d) The 1978 mean value for all individual counts includes the 5-10 year age group while the 1977 mean value has no representation in this sample section and the 1974 mean value has no child representation at all.

(e) The 1974 and 1977 ^{137}Cs body burden data were obtained from S. Cohn, Brookhaven National Laboratory, Medical Department.

Since approximately 4 months elapsed between the last personnel monitoring effort at Bikini in April 1978, and the departure of the Bikinians at the end of August 1978, some inferences had to be made as to whether the April 1978 cesium body burdens were at equilibrium with the then current ingestion rate. Comparisons of the observed reduction in body burdens from April 25, 1978 to January 24, 1979 with the predicted reduction in body burdens from September 1, 1978 to January 24, 1979 yield almost identical results for the adult male and female groups shown in Table II. The implication is that the Bikini adult population was essentially at equilibrium, and therefore, that the body burdens at the time of their departure were not significantly different from those measured some 4 months earlier. The data for children do not agree as well with the expected value; however, the difference is within the range of excretion half-times listed in NCRP Report 52 [31].

Estimates of ^{90}Sr/Y body burdens were hampered somewhat by the difficulty in obtaining a good 24 hour urine sample. The body burden estimates in Table III were derived from "good" samples obtained in April 1978. The September 1978 post-departure body burden estimates were calculated from the April 1978 excretion data by assuming a constant continuous ingestion rate for ^{90}Sr. Equilibrium was not assumed because of the long (4000 day) half-time compartment in the strontium metabolic model. Body burdens were calculated utilizing the mean residence (^{90}Sr intake) intervals in Table III which were obtained through interviews with the subjects.

Assessment of Doses

A. Methods

The external component of dose during Bikini residence period was estimated by applying the averages of measured exposure rates at Bikini Atoll to an assumed living pattern [32,33]. The living pattern, based on interviews and observations of Bikini residents, is a breakdown of times spent in various locations during typical daily activities. Exposure rate data are presented in Tables IV and V [33]. The highest average exposure rate, 20.2 uR/hr, is for adult males. This computes to an annual dose of about 177 mrem per year, which includes a natural background component of about 35 mrem per year.

The internal component was evaluated from whole body counting and urine bioassay data on body burdens of ^{137}Cs/^{137m}Ba, and ^{90}Sr/Y. The only other fallout-derived radionuclide which was detected in personnel monitoring was ^{60}Co. Since this nuclide contributed less than one percent of the internal dose, it was omitted from further consideration in this paper.

Internal doses were determined by applying the appropriate MIRD values [34] to cumulated activity data calculated over the average residence period for adult males, adult females, and children. Dose commitments received from body burdens existent at the time of departure from Bikini were also calculated. The primary considerations were: (1) whole body doses and dose commitments from ^{137}Cs/^{137m}Ba, and (2) bone marrow doses and dose commitments from ^{90}Sr/^{90}Y.

Table II

Summary of ^{137}Cs Body Burdens for Bikinians Relocated in 1978

Present Location	Sex	April 1978	Jaunary 1979	May 1979
Majuro	Male	1.93 µCi ± 0.97 µCi N = 17	0.94 µCi ± 0.53 µCi N = 18	0.49 µCi ± 0.26 µCi N = 8
	Female	1.4 µCi ± 0.7 µCi N = 16	0.44 µCi ± 0.24 µCi N = 16	0.21 µCi ± 0.15 µCi N = 12
	Children	1.2 µCi ± 0.47 µCi N = 12	0.13 µCi ± 0.24 µCi N = 19	0.016 µCi ± 0.020 µCi N - 23
Kili	Male	3.16 µCi ± 2.36 µCi N = 5	-	0.33 µCi ± 0.17 µCi N = 6
	Female	2.55 µCi ± 1.21 µCi N = 3	-	0.18 µCi ± 0.11 µCi N = 3
	Children	1.2 µCi ± 0.47 µCi N = 12	-	0.01 µ ± 0.007 µCi N = 6

Table III

Summary of Calculated $^{90}Sr/^{90}Y$ Body Burdens

Group	Group Size	Mean 4-78 Result[a] nCi ± 1σ (Range)	Mean 9-78 Result[a] nCi ± 1σ (Range)	Mean Uptake Interval, Years
Male	19	2.2 ± 2.3 (.23 - 7.8)	2.7 ± 2.8 (.27 - 9.0)	4.2
Female	15	1.4 ± 1.2 (.16 - 3.5)	1.5 ± 1.3 (.22 - 3.8)	4.3
Male Child	3	4.4 ± 5.2 (.96 - 10.)	4.7 ± 5.5 (.99 - 11)	5.3

(a) Calculated from April 1978 urine activity concentration values.

Table IV
Assumed Exposure Rate for Each Living Pattern

Pattern	Bikini Atoll μ/hr
Inside home	9.7
Within 10 m of home	15.8
Elsewhere in village	25.3
Beach	15.8
Interior Island	44.9
Lagoon	15.8 (a)
Other Islands	15.5 (b)

(a) Value assumed to be less than or equal to value for beach.

(b) Based on assumption that equal amounts of time are spent on other islands within the Atoll.

Table V

Exposure Rate Estimates for Bikini Inhabitants

Description	Infants 0-4 yrs	Children 5-19 yrs	Men 20+ yrs	Women 20+ yrs
Fraction of population	16%	41%	22%	21%
Effective exposure rate (μR/hr) [a]				
Inside Home	4.85	2.91	2.91	2.91
Within 10 m of home	2.37	1.58	0.79	1.58
Elsewhere in village	1.27	2.53	1.27	2.53
Beach	0.79	0.79	0.79	0.79
Interior Island	2.25	6.74	8.98	6.74
Lagoon	0.00	1.58	1.58	0.79
Other Islands	3.10	3.10	3.88	3.88
Total (μR/hr)	14.63	19.23	20.20	19.22

(a) The product of average measured exposure rate in a given area, and the fraction of time spent each day in the area listed.

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Elsewhere in village	1.27	2.53	1.27	2.53
Beach	0.79	0.79	0.79	0.79
Interior Island	2.25	6.74	8.98	6.74
Lagoon	0.00	1.58	1.58	0.79
Other Islands	3.10	3.10	3.88	3.88
Total (μR/hr)	14.63	19.23	20.20	19.22

[a] The product of average measured exposure rate in a given area, and the fraction of time spent each day in the area listed.

B. Results and Discussion

Table VI depicits the external dose equivalent resulting from living on Bikini Island. The dose equivalent during the residency interval varies for subgroups within the population according to the assumed living pattern selected. Since these values were obtained from ion chamber measurements and hypothetical living patterns, no range of results has been provided. In this report, one Roentgen is assumed equal to one Rem.

Table VII presents the average whole body doses due to the ingestion of ^{137}Cs. Data were derived from whole body counts made in 1974, 1977 and 1978. Constant continuous uptake of ^{137}Cs in the diet was not assumed. For these calculations, the uptake period was divided into three intervals during which the ^{137}Cs activity ingestion rate for a given interval remained constant, but increased stepwise with time to account for observed increases in ^{137}Cs body burdens.

Table VIII represents the bone marrow mean doses and ranges in mRem which were the result of ingesting ^{90}Sr/^{90}Y during the residency interval. These data were derived from measured urine activity concentrations during the uptake period. Constant continuous ingestion of activity was assumed in the models used to calculate the doses and dose commitments.

Table IX summarizes the total body dose equivalent during the residency period from internal ^{137}Cs and man-made external radiation, and the total body dose equivalent commitment upon departure from Bikini Atoll in August 1978. A standard deviation for these quantities of approximately ± 40% of the mean was observed in adult subgroups. Internal dose equivalent distributions in Figures 2, 3 and 4 were constructed by first calculating mean daily activity ingestion rates for different subgroups of the Bikini Island population based on the individual measurement data from which Tables VII and VIII were derived. Secondly, these mean activity ingestion rates and individual residence interval values were used as input data to mathematical models applied to inhabitants who did not participate in the personnel monitoring programs. The models describe various regimes for the uptake, retention and excretion of internally deposited radionuclides. Finally, dosimetric models which allow for constant continuous uptake of ^{90}Sr and stepwise increasing uptake for ^{137}Cs were chosen to determine the internal dose equivalent and dose equivalent commitment for all inhabitants. Thus, for residence periods between the years 1969 and 1978, these calculations demonstrate a maximally exposed person receiving a whole body dose equivalent and commitment of 3 rem, and a population average dose equivalent and commitment of 1.2 rem from man-made radioactivity on Bikini Island.

Conclusions

Personnel monitoring and dosimetry efforts at Bikini have demonstrated that internally deposited ^{137}Cs is the most significant contributor to the total dose received by Bikini residents. Observations of the availability of locally grown terrestrial foods indicate that coconut and traditional foods derived from coconut are the most likely sources of cesium intake. The significant increase in ^{137}Cs body burdens observed in 1977 coincides with

TABLE VI

External Total Body Dosimetric Average for Bikinians

Population Description	Number of Persons	Mean Residence Interval, Years	Dose Equivalent During Residence Interval, mRem
			Mean
Adult males	17	4.9	600
Adult females	16	4.3	500
Children (5-14 years)	12	4.4	500

TABLE VII

^{137}Cs-^{137m}Ba Total Body Dosimetric Averages for Bikinians

Population Description	Number of Persons	Mean Residence Interval, Years	Dose Equivalent During Residence Interval, mRem			Dose Equivalent Commitment, mRem		
				Range			Range	
			Mean	High	Low	Mean	High	Low
Adult males	17	4.9	470	810	120	110	200	43
Adult females	16	4.3	330	770	91	85	190	29
Children (5-14 years of age)	12	4.4	670	920	270	140	270	57

TABLE VIII

^{90}Sr--^{90}Y Bone Marrow Dosimetric Averages for Bikinans

			Dose Equivalent During Residence Interval, mRem			Dose Equivalent Commitment, mRem		
				Range			Range	
Population Description	Number of Persons	Mean Residence Interval, Years	Mean	High	Low	Mean	High	Low
Adult males	19	4.2	27	120	.57	61	210	6.7
Adult females	15	4.1	14	41	.34	38	98	5.3
Male children (11-15 years of age)	3	5.3	47	120	13	120	290	26

TABLE IX

Total Body Dosimetric Average for External Plus Internal Sources for Former Bikini Residents

Population Description	Number of Persons	Mean Residence Interval, Years	Dose Equivalent During Residence Interval, mRem	Dose Equivalent Commitment, mRem
Adult males	17	4.9	1100	110
Adult females	16	4.3	830	85
Children (5-14 years)	12	4.4	1200	140

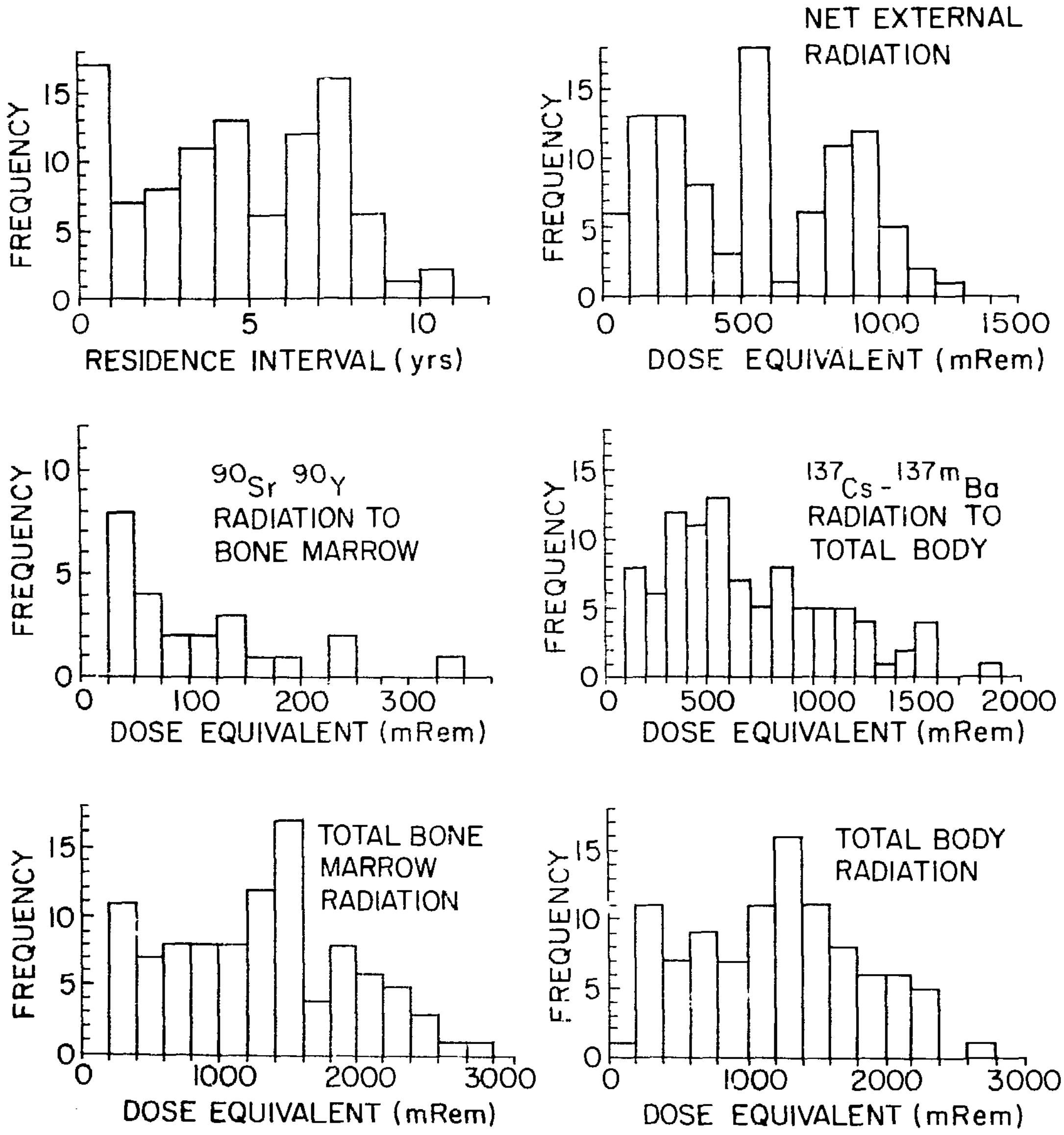

Fig. 2 TOTAL MALE AND FEMALE DISTRIBUTION OF DOSE EQUIVALENT (DURING AND POST RESIDENCE) OR RESIDENCE INTERVAL FOR INHABITANTS OF BIKINI ISLAND, BIKINI ATOLL

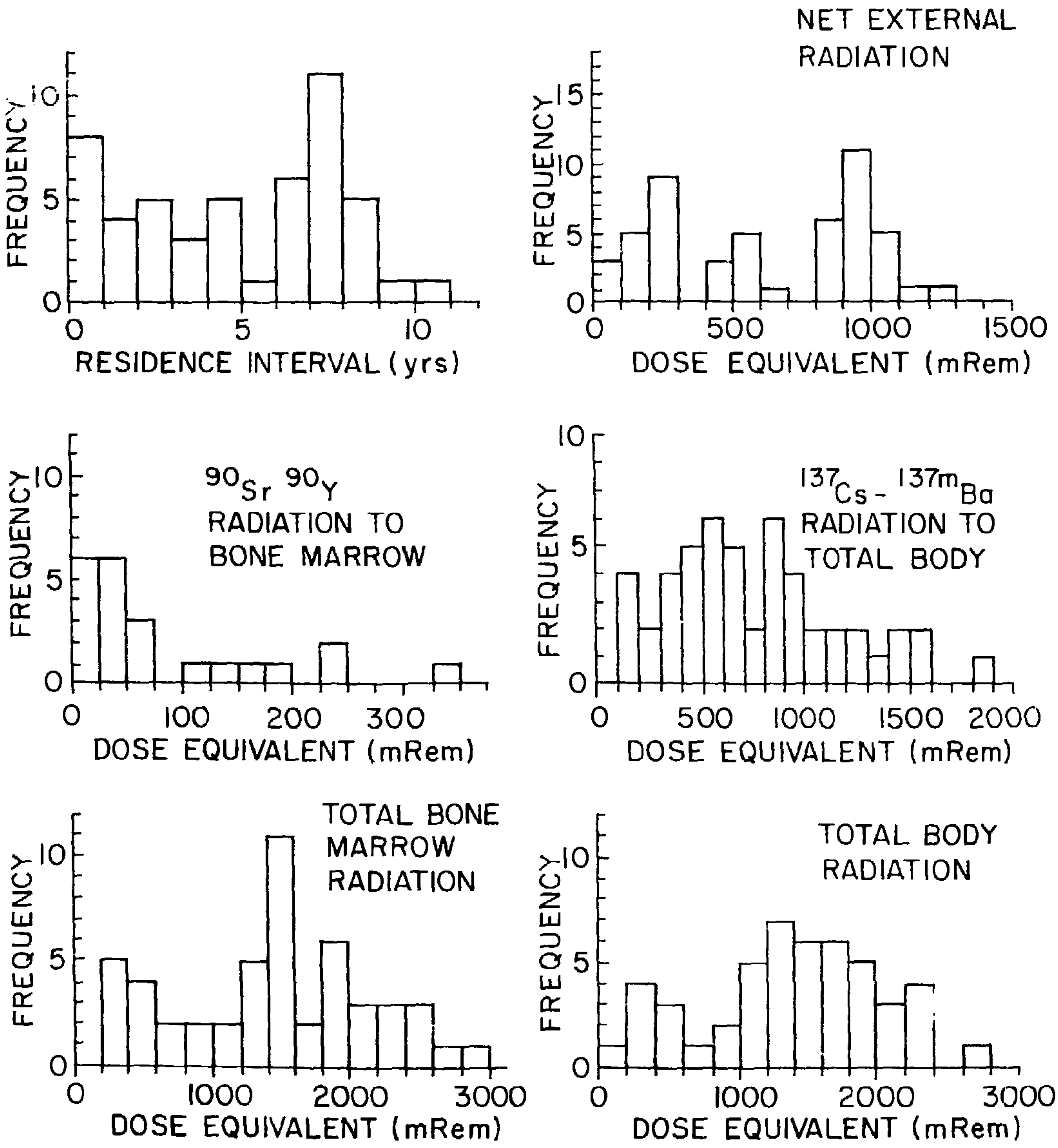

Fig. 3 TOTAL MALE DISTRIBUTION OF DOSE EQUIVALENT (DURING AND POST RESIDENCE) OR RESIDENCE INTERVAL FOR INHABITANTS OF BIKINI ISLAND, BIKINI ATOLL

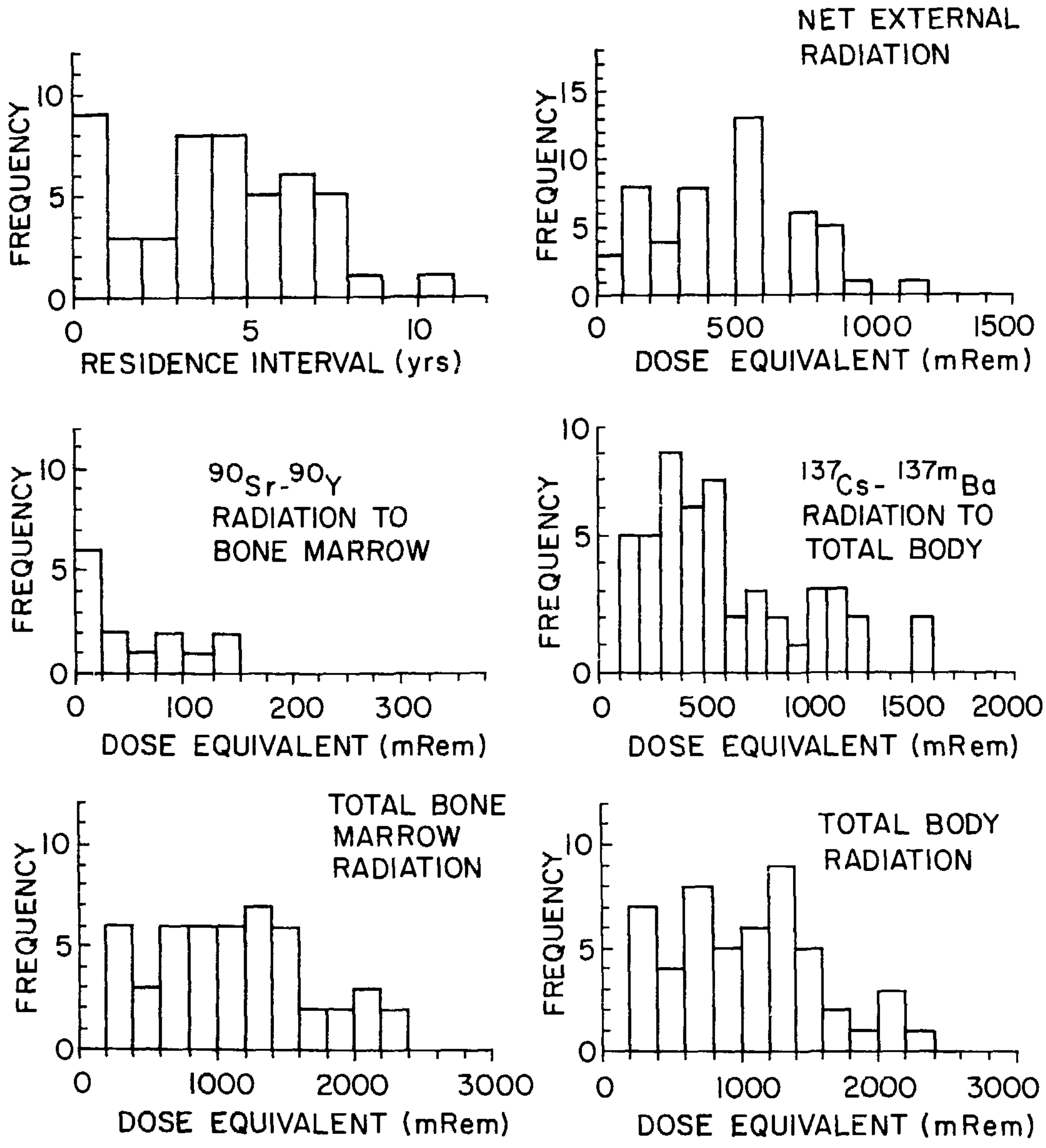

Fig. 4 TOTAL FEMALE DISTRIBUTION OF DOSE EQUIVALENT (DURING AND POST RESIDENCE) OR RESIDENCE INTERVAL FOR INHABITANTS OF BIKINI ISLAND, BIKINI ATOLL

the availability of coconuts from maturing trees which were planted in the early 1970's. Pandanus and breadfruit plantings were made in the same time frame; but the plants were far fewer in number, and appear to take significantly longer to mature than did the coconut trees. Therefore, even though pandanus and breadfruit are traditional staples, they were not available in sufficient quantity in the mid to late 1970's to contribute a significant fraction of the total radionuclide content in the Bikini diet.

A predictive dose assessment for Bikini, published in 1977 [27] includes a dose estimate for the terrestrial food chain on Bikini Island, minus pandanus and breadfruit. The 10 year integral whole body dose from ^{137}Cs is estimated to be 5.1 rem, or an average of approximately 0.5 rem per year if equilibrium is assumed. In comparing this estimate with the average doses presented in Table IX it should be noted that equilibrium was probably not established until late 1977 or early 1978. Also, during the residence years prior to 1976-1977, the doses from internal ^{137}Cs were quite low because of the unavailability of significant terrestrial food items from Bikini. Therefore, the large majority of the dose was received in 1977 and 1978, and the dosimetric findings from personnel monitoring are in reasonably good agreement with the predicted value.

List of Figure Captions

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Figure 4: Total Female Distribution of Dose Equivalent (During and Post Residence) or Residence Interval for Inhabitants of Bikini Island, Bikini Atoll.

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