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EXTERNAL RADIATION SURVEY AND DOSE PREDICTIONS FOR RONGELAP, UTIRIK, RONGERIK, AILUK, AND WOTJE ATOLLS

N.A. Greenhouse and R.P. Miltenberger

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December 13, 1977

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A B S T R A C T

External radiation measurements were made at several atolls in the northern Marshall Islands, which are known or suspected to have been the recipients of tropospheric fallout during the Pacific Testing Programs. Sufficient data were available to ascertain realistic dose predictions for the inhabitants of Rongelap and Utirik Atolls where the 30 year integral doses from external sources exclusive of background radiation were 0.65 and 0.06 rem respectively. These estimates are based on realistic life-style models based on observations of each atoll community. Ailuk and Wotje Atolls were found to be representatives of regional background radiation levels.

Introduction

In 1976, Brookhaven National Laboratory initiated a program of external radiation survey for the Rongelap, Rongerik, Ailuk, Wotje and Utirik Atolls. The purpose of these surveys was to provide sufficient information concerning the ambient radiation levels resulting from the mid 1950's weapons testing program to make external dose calculations for the individuals living in the surveyed areas. During the last two years, sufficient measurements were made to provide external dose information for most of the populations in the region.

The data from Rongerik, Ailuk, Wotje, Rongelap and Utirik Atolls were acquired during trips in September 1976, May 1977 and October 1977. All the exposure rate information gathered from these atolls was obtained with a pressurized ion chamber.

The equipment used in these studies consisted of a Reuter Stokes Environmental Radiation Monitor, Model RSS-111 and a gamma spectroscopy system consisting of a sodium iodide detector coupled to a portable multichannel analyzer. Environmental exposure levels were assessed via the RSS-111, and the NaI gamma spectrometer was used to determine the energy dependence correction factors for the RSS-111 instrument.

The field trips were staffed by BNL personnel and guest scientists from other institutions. Participants are listed later in the report.

This report represents all of the external exposure data collected to date by BNL from these atolls. From these data, we have made external exposure estimates for the people living on Rongelap, Ailuk, Wotje and Utirik Atolls.

Instrumentation and Methods

A) Ion Chamber Measurements

All environmental exposure rate measurements were obtained using a Reuter Stokes environmental radiation monitor model RSS-111. The instrument is designed to measure environmental radiation as low as 100 μRad/year. The RSS-111 consists of a spherical high pressure ion chamber filled to 25 atmospheres of argon. Incident radiation produces ion pairs within the active volume of the chamber which result in a current flow. The current flow is measured by an electrometer and is directly related to the free air exposure rate (1).

The active volume of the stainless steel ionization chamber is known to ±01%. The current produced in the chamber is a function of incident radiation from an external field, cosmic ray-response and contamination found in the stainless steel. The equation relating instrument response to energy of the incident radiation is:

$$Rj = Kj\ Ij + R\alpha + Kc\ Ic$$

where

Rj = current produced in the chamber by the incident gamma field

Kj = proportionality constant stating the variability of instrument response to the energy of the incident gamma field

Ij = intensity of the gamma field in μR/hr

Rα = current produced by activity in the stainless steel

Kc = proportionality constant for cosmic rays

Ic = intensity of cosmic rays

For a given area, the values of Kc and Ic will be constant along with R_α. Since we measure R_T, the only unknown are Kj and Ij. The value of Kj can be determined once the ambient gamma spectrum is known. Data from the manufacturer indicates an error of as much as 6 to 10% could result if energy corrections are not made to the gross readings.

The RSS-111s used in this study were calibrated at the factory using radium sources whose calibration is traceable to the National Bureau of Standards. Calibration of the instruments were also checked by EML (formerly HASL) prior to field use.

Energy Dependence Corrections

In the 1977 surveys, BNL used a sodium iodide detector, whose output was coupled to a multichannel analyzer. The purpose was to enable the BNL team to acquire spectra of the terrestrial background radiation at one meter above the surface. This was done at the same height and in the same areas where the RSS-111 measurements were taken. Consequently, energy dependence factors could be calculated by examining the environmental gamma scan for the energies of those nuclides most predominant in the terrestrial environment.

The equipment used to accomplish this part of the work was a computing Gamma Spectrometer, Model LEA 74-008 #11 built by Lawrence Livermore Laboratory (2). The system uses a Harshaw 5.08 cm diameter x 5.08 cm thick NaI(Tl) scintillation detector. The spectrometer can be operated from AC power or on internal batteries. Spectra are visually displayed on a CRT, and transferred to magnetic tape for storage. Using the math package with the system, each spectrum was examined in 100 KeV increments, and folded into the RSS-111 energy response curve to determine the energy dependence factors.

The range of factors needed to compensate the RSS-111 response due to energy

dependence was 1.01 to 1.05. The mean correction was approximately 1.02. Consequently, we felt no need to correct the remaining 1976 or 1977 data for the minor energy dependence encountered.

Results

A total of 112 RSS-111 measurements were taken on five atolls. Each data point is the average of at least 20 individual readings. This assures the precision of the value while the initial calibration guarantees accuracy. The one sigma error is on the mean exposure rate. All exposure rate values include natural background except where otherwise noted. Figure 1 graphically presents the data obtained at Eniwetak Island, Rongerik Atoll. On this island, random measurements were taken along a central northsouth transect. Table 1 presents the raw data collected with one sigma error. The average exposure rate for this island is 6.3 μR/hr. This is about 1.5 times higher than the cosmic/terrestrial date rate found on uncontaminated coral islands. Eniwetak was the island surveyed in the Rongerik Atoll due to presence of U. S. servicemen at the weather station there at the time of the BRAVO fallout incident.

Tables 2, 3, 4, 5 and 6 present the raw data from Rongelap Atoll. The islands surveyed were Kabelle, Naen, Eniaetok and Rongelap. Naen is located at the northwest corner of the atoll, and Kabelle at the northeast corner. Kabelle is a significant copra resource; and both of these islands may be used for brief visits, but neither of them is permanently inhabited. These islands received a significant amount of fallout debris and consequently, are still substantially more contaminated than the islands of Rongelap and Eniaetok, located in the southeast and eastern parts of the atoll. The current values for external exposure rates on these islands are listed below and in Table 14. The entire population presently

Island	Average Exposure Rate in μR/hr
Naen	43.1
Kabelle	21.7
Eniaetok	9.9
Rongelap	7.3

lives on Rongelap Island. The people obtain most of their food from Rongelap with occasional supplemental trips to Eniaetok and to other southern islands in the atoll. Little or no activities currently takes place on Naen or Kabelle, or other islands in the north.

Figure 2 is a graphic presentation of the measurement points and exposure rates along the main road of Rongelap Island. The exposure rate is fairly uniform averaging 7.3 μR/hr over the island. This is about twice the background radiation level of uncontaminated atolls in the Marshall Islands.

Tables 7, 8 and 9 present the data for the islands surveyed in the Utirik Atoll. These islands, Aon, Eorukku and Utirik, represent the major islands within the atoll. Aon, located in the southwest corner and Utirik located in the southeast corner of the atoll, are the major areas for living and food production. The external exposure rate for all these islands is about 4 μR/hr, i.e., very near the regional background level.

Tables 10, 11, 12 and 13 present the RSS-111 survey results for Wormej and Wotje Islands of Wotje Atoll and for Bigen and Ailuk Islands of Ailuk Atoll. These islands were surveyed to determine whether they were representative of baseline external exposure rates for the Marshall Islands. The individual island averages are found in Table 14, but range from 3.7 μR/hr to 3.9 μR/hr. These exposure rates are about the same as that for Kwajalein and other areas not exposed to gross contamination from fallout; we assumed them to be representative of ambient background radiation levels for the region.

Discussion of Results

The average exposure rate as measured for each island is listed in Table 14. In all areas, except for Rongelap Atoll and Rongerik Atoll where only Eniwetak Island was visited, there is essentially an uniform exposure rate within the islands of a given atoll. For hypothetical inhabitants of Eniwetak Island at Rongerik Atoll,

and for the people living at Utirik Atoll, external dose estimates were made, and the results are presented in Table 15. These dose estimates were made based upon the following assumptions or observations:

1) The exposure rate was relatively uniform throughout the atoll.
2) The average exposure rate represents the average for all islands within the atoll.
3) Wotje and Ailuk Atolls are representative of the natural background in the Northern Marshall Islands.

It is difficult to estimate an external dose for the inhabitants of Rongelap Atoll apart from typical residents who spend most of their time on Rongelap Island. The reason lies in the nonuniform distribution of radioactive material from island to island within the atoll. While the southern islands of Rongelap were determined to have uniform exposure rates on a per island basis, there were significant differences in the exposure rates between islands and substantial heterogeneity in exposure rates on any given island in the northern sector.

In UCRL 51879 Rev. 1 (3,4), this problem was approached by estimating the fraction of the time that an individual spends on various activities. This estimate is reprinted here as Table 16. Using this as a basic assumption, we have constructed external exposure rate estimates for the various living activities based upon our measurements reported in Tables 1-13. The value for the lagoon exposure rate was assumed to be the same as that for uncontaminated atolls in the region (~3.7 μR/hr). The value for "other islands" was obtained by assuming that the Marshallese would spend an equal amount of time on each of the other islands which we surveyed. All other estimates are made by taking the average of all measurements made within the area of interest.

Table 17 represents the exposure rate at each pattern of activity as listed in Table 16 calculated assuming 100% occupancy for Rongelap Atoll. Table 18 presents an estimate of the exposure rate for each age group, weighted by the percent of time spent in each area for inhabitants of Rongelap Atoll based on the Lawrence Livermore lifestyle Model (3,4). Summation of the exposure rates in each area provides the average exposure rates to the Rongelapese.

Using the average hourly exposure rates, the long term external dose was calculated. These data, presented in Table 9 for Rongelap Atoll, have been corrected for background (terrestrial and cosmic) radiation by using the average exposure rate of Wotje and Ailuk Atolls as a representative sample of the normal (unexposed) Marshall Island environment.

We feel that this is a very conservative estimate for Rongelap Atoll since the people rately visit the more heavily contaminated islands in the north, and tend to restrict their "other islands" visits to the southern sector where exposure rates are similar to that on Rongelap Island itself. This observation was supported by an independent living pattern assessment from which data became available in the fall of 1977 (5).

Specific living pattern information for Rongelap was obtained on a field trip in October 1977 (5). This information is presented in Table 20. It should be noted that as previously mentioned, the Rongelap "lifestyle" involves very little time away from Rongelap Island where a constant exposure rate of 7.3 μR/hr is assumed. Revised external dose predictions based on the observed Rongelap living pattern are given in Tables 21, 22 and 23. These doses include corrections for physical decay for ^{137}Cs and ^{60}Co which are responsible for >99% of the total external exposure rate above background. The cesium and cobalt ratios were obtained using the averages of soil sample activities from analyses by BNL (6) and the University of Washington (LRE) (7). It was assumed for this assessment that no radionuclide loss mechanisms are operative other than physical decay.

ICRP #9 suggests that in 30 years, the general public should receive a dose of less than 5.0 rem from total body sources other than medical or natural background (8). In all cases examined here, this requirement is met. The problem arises that the external gamma radiation is only one source of exposure to the Marshallese. The dietary pathway could contribute a substantial increment as an internal dose commitment.

Reviewing all atoll dose commitments in this light, we feel that inhabitants of Rongelap Atoll may have difficulty meeting the ICRP #9 criterion of 5 rem in 30 years, but should be within the 0.5 rem/year standard for individuals. The interal dose assessment for the people of Rongelap will be the subject of a separate report. At this time, we do not recommend any remedial action until a complete dose commitment can be determined by means of examining the external, dietary and whole body counting data available to date.

The other islands and atolls surveyed are well within the ICRP recommended levels. As such, little more than minimal followup should be done on these atolls. The main task of the environmental programs should be one of detecting significant changes in the environment or lifestyle which might warrant a reassessment of these dose predictions.

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Table 1

ENIWETAK ISLAND - RONGERIK ATOLL
RSS-111
EXPOSURE SURVEY
May 1977

Location	Exposure Rate in μR/HR
Cross Island transect, 100 m from the ocean in a sandy open area	5.26±0.28
Cross Island transect, 120 m from the ocean in a wooded grove	6.47±0.22
Cross Island transect, 170 m from the ocean in a sandy area	6.85±0.22
Cross Island transect, near center of the island near the lone standing pole	8.33±0.36
Cross Island transect, 50 m from lagoon on top of organic debris	8.42±0.25
Cross Island transect, 20 m from lagoon in clearing	4.8 ±0.25
Cross Island transect, 20 m from lagoon under shrubbery	5.11±0.42

Table 2

KABELLE ISLAND - RONGELAP ATOLL
RSS-111
EXPOSURE SURVEY
September 1976

Location	Exposure Rate in μR/hr
Cross Island transect beginning at the water catchment	
Innermost penetration along this transect 220 m from lagoon	13.0±0.3
30 m west of innermost penetration	16.3±0.3
65 m west of innermost penetration	18.1±0.3
90 m west of innermost penetration	12.9±0.4
115 m west of innermost penetration by water catchment	22.1±0.3
125 m west of innermost penetration in area of sand and scaveola scrub	34.0±0.3
20 m south of water catchment	29.7±0.4
170 m west of innermost penetration	31.3±0.3
Second transect 275 m south of Cross Island transect	
First level messerschmidia canopy	18.2±0.2
Scaveola clearing	20.3±0.3
Scaveola clearing ~30 m to the lagoon beach	26.9±0.4

Table 3

ENIAETOK ISLAND - RONGELAP ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
Eastwest cross island transect - Middle Island	
50 m due west of Ocean Beach	5.6±0.4
85 m due west of Ocean Beach - clearing south of path	11.4±0.3
85 m due west of Ocean Beach - clearing north of path	12.4±0.2
135 m due west of Ocean Beach	11.7±0.5
175 m due west of Ocean Beach	11.5±0.3
215 m due west of Ocean Beach near cluster of three houses. Area has patchy coral gravel.	8.6±0.2
265 m west of Ocean Beach: 40 m from Lagoon Beach	5.8±0.4
Second transect: 250 m due north of Middle Island transect	
70 m due east of lagoon	11.5±0.3
Adjacent clearing returning toward Lagoon Beach	12.0±0.4
Third transect near south end of the island	
80 m due east of the lagoon	12.0±0.3
30 m from Lagoon Beach near a house: some gravel present	6.7±0.4

Table 4

NAEN ISLAND - RONGELAP ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
First transect due west to northwest from near southeast corner of the island	
clearing 40 m in from the beach	22.5±0.4
150 m inland due west to northwest	55.3±0.6
returning to beach due southeast, 25 m to next clearing	42.1±0.5
southeast ~40 m to next clearing	40.6±0.5
Midisland second transect due north from the lagoon center of island	62.2±0.7
25 m south of center island towards the lagoon	45.5±0.7
60 m south of center island towards the lagoon	44.7±0.5
90 m south of center island towards the lagoon	59.0±0.6
120 m south of center island towards the lagoon	33.1±0.5
150 m south of center island towards the lagoon	70.7±3.4
sandy head land on southeast corner of the island	6.0±0.6

Table 5

RONGELAP ISLAND - RONGELAP ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
Cross Island transect on path near church	
70 m from Ocean Beach	6.8±0.6
140 m north from Ocean Beach	7.0±0.3
200 m nortn from Ocean Beach	8.5±0.3
270 m north from Ocean Beach	8.5±0.2
350 m north from Ocean Beach	9.1±0.5
420 m north from Ocean Beach	7.7±0.4
500 m north from Ocean Beach	7.5±0.3
570 m north from Ocean Beach	4.9±0.4
Village road transect starting at western end of the village	
100 m west of first house in the village	8.2±0.3
front of first house: lagoon site of the road	7.8±0.4
100 m due east of first house	7.3±0.4
200 m due east of first house: past houses 3, 4 and 5	8.9±0.3
300 m due east of first house: near houses 6, 7, 8 and 9 (area covered with crushed coral)	5.9±0.4
100 m part church	7.1±0.3
200 m past church near co-op	6.7±0.3
in front of Jerry Knight's house	6.0±0.3
in front of 2 houses near the dock	5.8±0.4
100 m east of the bock	6.6±0.4
170 m east of the dock	6.6±0.7
Observation tower at west end of the island in open field	5.1±0.3
0.5 km east near main road in clearing	9.6±0.3
1.0 km east near main road about 50 m from the lagoon	8.5±0.3
1.5 km east near main road in the middle of the road	5.8±0.3
in coconut grove about 1.2 km east of observation tower	8.1±0.2
1.9 km east near main road on lagoon side of the road	7.8±0.2
2.4 km east near main road, lagoon side on grass covered coral	6.3±0.3
2.9 km east near main road, lagoon side of grassy area	7.1±0.2
3.4 km east near main road, grassy area on the ocean side	8.8±0.4
3.8 km east near main road, grassy area on the ocean side	8.3±0.4
4.3 km east near main road, grassy near trees lagoon side	7.1±0.3
4.8 km east near main road, grassy area on ocean side	6.1±0.4
5.3 km east near main road, grassy area on lagoon side	7.4±0.2
5.8 km east near main road, a grassy area with Pandanus at edge of village	6.6±0.3
6.3 km east near main road in the village by the school and cemetery	5.0±0.2
along side church in mil village	8.9±0.4
6.7 km east near main road, east of village in grassy area beneath coconut trees, ocean side of the road	6.6±0.2
8.3 km east near main road near Japanese cistern	7.9±0.2
8.8 km northeast beneath Guettarda grove, ocean side	7.5±0.2
9.3 km northeast approaching north end of island	9.5±0.4
9.8 km northeast on main road, ocean side in a coconut grove	9.5±0.5
10.2 km northeast near end of island in grassy area and scaveola trees	6.0±0.4

Table 6

RONGELAP ISLAND - RONGELAP ATOLL
RSS-111
EXPOSURE SURVEY

October 1977

Location	Exposure Rate in μR/hr
Cross Island transect on path behind Tarbud's (Jerry Knight's) house shrub line, ocean side	3.9±0.3
39 m lagoonward (scaveola grove)	4.6±0.2
80 m lagoonward (edge of coconut grove)	4.9±0.3
118 m lagoonward	5.8±0.2
158 m lagoonward	5.8±0.4
197 m lagoonward	5.9±0.3
237 m lagoonward	6.1±0.2
276 m lagoonward	6.4±0.1
316 m lagoonward	7.0±0.1
355 m lagoonward	6.2±0.3
395 m lagoonward	7.3±0.4
434 m lagoonward	7.8±0.3
474 m lagoonward	7.5±0.4
513 m lagoonward (near rear of Tarbud's house)	5.9±0.3
Main island road, front of Tarbud's house	5.5±0.3
Lagoon Beach near Boas' house	4.2±0.2

Table 7

AON ISLAND - UTIRIK ATOLL
RSS-111
ESPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
100 m from the Ocean Beach	4.1±0.3
200 m from the Ocean Beach	4.2±0.3
30 m from Lagoon Beach near middle of the island	4.1±0.3

Table 8

EORUKKU ISLAND - UTIRIK ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
Middle Island	4.3±0.5
Southwest	4.1±0.4

Table 9

UTIRIK ISLAND - UTIRIK ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
Eastwest transect across island near south end of village	
60 m west of Ocean Beach	3.7±0.3
150 m west of Ocean Beach	4.3±0.3
10 m east of village road	4.1±0.8
100 m west of ocean near the middle of the village	4.1±0.2
200 m west of ocean near the middle of the village	4.2±0.2
300 m west of ocean near large hollow and taro patch	4.5±0.9
100 m from large hollow and taro patch	4.5±0.4
200 m from large hollow and taro patch near the middle of village	3.9±0.7
village road by the cemetery	4.0±0.2

Table 10

WORMEJ ISLAND - WOTJE ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
Middle of the village	3.9±0.3
transect due north ~150 m north of the church	3.7±0.3
transect due north ~250 m north of village	3.6±0.3
transect due north ~350 m north of village	3.8±0.3
transect due north ~450 m north of village	3.7±0.2
transect due north ~550 m north of village and ~30 m south of of Ocean Beach	3.9±0.2

Table 11

WOTJE ISLAND - WOTJE ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
northsouth air strip, 2/3 of the distance from the lagoon to the ocean	3.7±0.2
100 m west of air strip	3.7±0.2
200 m west of air strip	3.8±0.3
300 m west of air strip	3.8±0.3

Table 12

BIGEN ISLAND - AILUK ATOLL
RSS-111
EXPOSURE SURVEY

April 1976

Location	Exposure Rate in μR/hr
150 m from the Lagoon Beach, north end of the island North end Lagoon Beach	4.2±0.3

Table 13

AILUK ISLAND - AILUK ATOLL
RSS-111
EXPOSURE SURVEY

September 1976

Location	Exposure Rate in μR/hr
50 m from Ocean Beach	4.0±0.4
150 m due west of Ocean Beach	3.7±0.3
350 m due west of Ocean Beach	3.9±0.5
450 m due west of Ocean Beach, ~100 m from village	3.7±0.4
Ailuk village near intersection of village road and Cross Island road	3.7±0.4

Table 14

Average Exposure Rates (May 1977)

Island	Atoll	n	Average Exposure Rate +1σ error
Kabelle	Rongelap	11	21.7 μR/hr ± 7.3 μR/hr
Naen	Rongelap	11	43.1 μR/hr ±18.6 μR/hr
Eniaetok	Rongelap	11	9.9 μR/hr ± 2.7 μR/hr
Rongelap	Rongelap	57	7.3 μR/hr ± 1.5 μR/hr
Aon	Utirik	3	4.0 μR/hr ± 0.3 μR/hr
Eorukku	Utirik	2	4.1 μR/hr ± 0.1 μR/hr
Utirik	Utirik	9	4.1 μR/hr ± 0.3 μR/hr
Bigen	Ailuk	2	3.9 μR/hr ± 0.3 μR/hr
Ailuk	Ailuk	5	3.7 μR/hr ± 0.1 μR/hr
Wormej	Wotje	6	3.7 μR/hr ± 0.1 μR/hr
Wotje	Wotje	4	3.7 μR/hr ± 0.1 μR/hr
Eniwetak	Rongerik	7	6.3 μR/hr ± 1.7 μR/hr

*Corrected for energy dependence of RSS-111. (Typical spectral correction factor was 1.05).

Table 15

External Exposure Rates and Dose Predictions
Persons Living on Surveyed Atolls [1,2]
(Exclusive of Rongelap Atoll)

Atoll	Ave. Gross Exposure Rate April 1977	Net Exposure Rate[3] April 1977	10 yr. Integral[3] Dose in Rem	30 yr. Integral[3] Dose in Rem	50 yr. Integral[3] Dose in Rem
Utirik[4]	4.07 μR/hr	0.32 μR/hr	0.024	0.056	0.077
Ailuk	3.80 μR/hr	-	-	-	-
Wotje	3.70 μR/hr	-	-	-	-
Rongerik[5]	6.30 μR/hr	2.55 μR/hr	0.199	0.484	0.663
ICRP 9 Population Dose Limit		-	1.700	5.000	8.300

1. Doses were calculated from average exposure rates for each atoll.
2. Multiple year dose calculations were made on the background substracted exposure rate. Background was assumed to be the average of exposure rates detected at Ailuk and Wotje Atolls.
3. Dose represents increase over background.
4. Conservatively assumes 100 percent of time spent on Utirik Island.
5. Based on a superficial survey of Eniwetak Island only.

Table 16

Population Breakdown by Age and Geographical Living Patterns
(Ref. 6)

	Infants and small children	Children and adolescents	Men	Women
Age Bracket (years)	0-4	5-19	20+	20+
Fraction of population (%)	16	41	22	21
Fraction of time spent in respective areas (%):				
Inside Home	50	30	30	30
Within 10 m of home	15	10	5	10
Elsewhere in village	5	10	5	10
Beach	5	5	5	5
Interior of island	5	15	20	15
Lagoon	0	10	10	5
Other Islands	20	20	25	25

Table 17

Assumed Exposure Rate for
Each Living Pattern*

Pattern	Rongelap Atoll μR/hr
Inside home	7.3
Within 10 m of home	7.3
Elsewhere in village	7.3
Beach	7.3
Interior Island	7.3
Lagoon**	3.7
Other Islands***	24.9

* Values listed are mean exposure rates.

** Lagoon value is assumed to be the same as regional background at uncontaminated atolls.

*** Values used for other islands assumed equal distribution of time spent on other islands within the atoll.

Table 18

Rongelap Exposure Rates Based on Living Pattern Assumed for Bikini [3,4]

Description	Infants 0-4 yrs	Children 5-19 yrs	Men 20+ yrs	Women 20+ yrs
Fraction of population	16%	41%	22%	21%
Dose rate due to Time spent within these areas (μR/hr)				
Inside Home	3.65	2.19	2.19	2.19
Within 10 m of home	1.10	0.73	0.37	0.73
Elsewhere in village	0.37	0.73	0.37	0.73
Beach	0.37	0.37	0.37	0.37
Interior Island	0.37	1.10	1.46	1.10
Lagoon	0.00	0.37	0.37	0.19
Other Islands	4.98	4.98	6.23	6.23
Total (μR/hr) (incl bkgd)	10.84	10.47	11.36	11.54

Table 19

Exposure Rates and Dose Predictions for Persons Living on Rongelap Atoll Based on Assumed Bikini Living Pattern

Age Group	Net Weighted Rate in μR/hr May 1977	External Integral Dose in Rem (Bkgd Subt) 10 yr.	30 yr.	50 yr.
Infants (0-4 yrs)	7.09	0.56	1.35	1.84
Children (5-19 yrs)	6.72	0.52	1.27	1.75
Men (20 yrs+)	7.61	0.60	1.44	1.97
Women (20 yrs+)	7.79	0.62	1.49	2.03

Table 20

Living Pattern Model for Rongelap
(October 1977)

	Infants & Small Children	Children & Adolescents	Men	Women	Old People
Age Bracket (yrs)	0-4	5-19	20-59	20-59	60+
Fraction of time spent in respective areas(%)					
In village (including inside home)	100	84	77	94	100
Interior of island	-	8	13	4	-
Beach	-	8		2	-
Lagoon	-	-	4	-	-
Other islands	-	-	6	-	-

Table 21

Rongelap Exposure Rates Based on Observed Living Pattern (5)

Description	Infants 0-4 yrs	Children 5-19 yrs	Men 20-59 yrs	Women 20-59 yrs	Old People >60 yrs
Dose rate due to time spent within these areas (μR/hr)					
In village (including home)	7.3	6.13	5.62	6.86	7.3
Beach	-	0.58	-	0.15	-
Interior Island	-	0.58	0.95	0.29	-
Lagoon	-	-	0.15	-	-
Other islands	-	-	1.49	-	-
Total μR/hr (incl bkgd)	7.3	7.3	8.21	7.3	7.3

Table 22

Average Exposure Rates and Dose Predictions for Persons Living on Rongelap Atoll Based on Rongelap Living Pattern (1977)

Age Group	Weighted Net Exposure Rate in μR/hr	Net Integral External Dose in Rem 10 yr	30 yr	50 yr
Infants (0-9)	3.6	0.27	0.65	0.90
Children (5-19)	3.6	"	"	"
Men (20-59)	4.5	0.34	0.82	1.12
Women (20-59)	3.6	0.27	0.65	0.90
Old People (60+)	3.6	"	"	"
Additional Contribution From Background Radiation	3.7	0.32	0.97	1.62

Table 23

Total Doses Including Background Based on Rongelap Living Pattern (1977)

Group	Weighted Total Exposure Rate μR/hr	Total Integral Dose in Rem 10 yr	30 yr	50 yr
Rongelap Men (ages 20-54)	8.3	0.66	1.79	2.74
All others (Rongelap)	7.3	0.59	1.62	2.54
Utirik, all residents*	4.1	0.34	1.03	1.70

*Assumes (conservatively) 100% occupancy on-island.

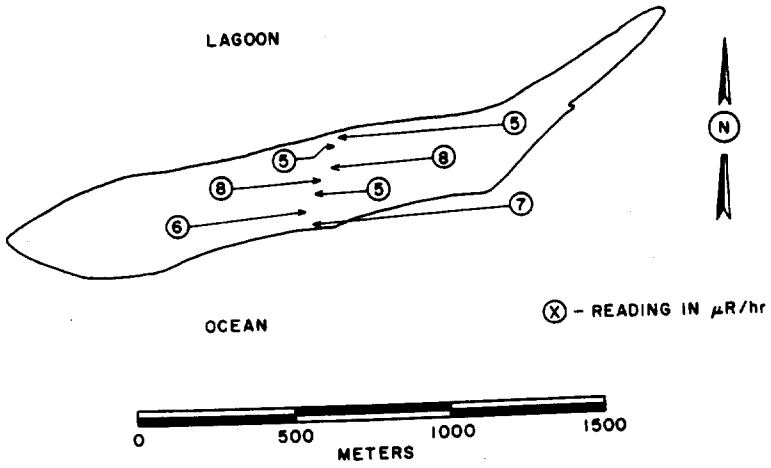

Figure 1. Eniwetak Island Rongerik Atoll.

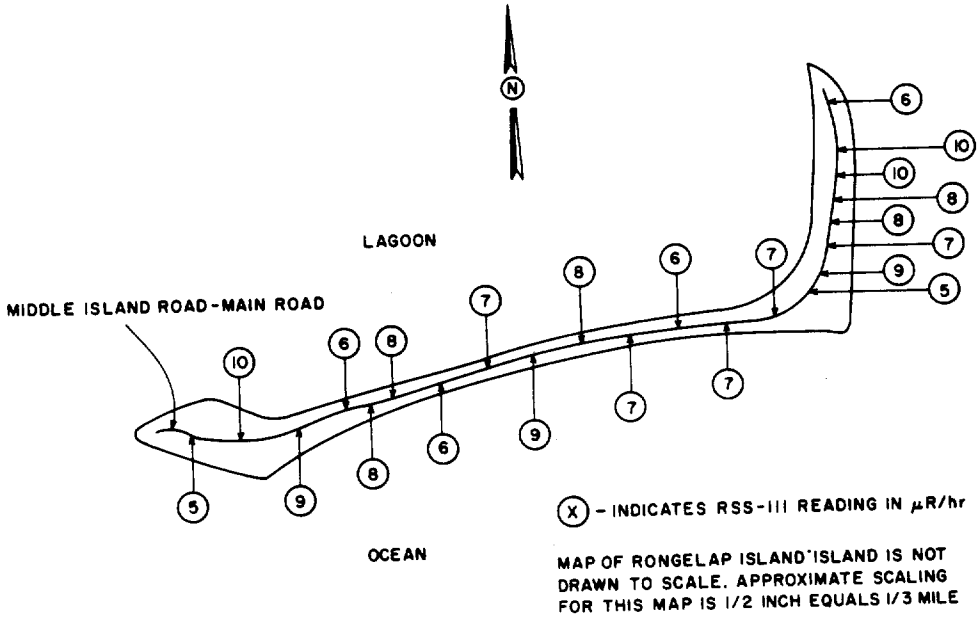

Figure 2. Rongelap Island.

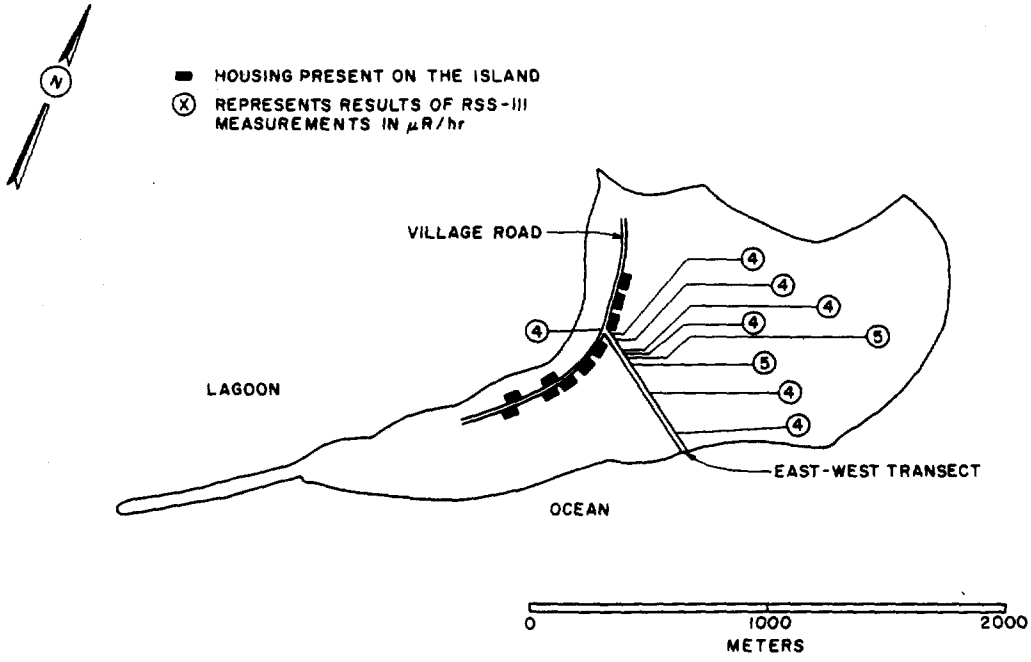

Figure 3. Utirik Island.