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January 1979

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ABSTRACT

External exposure rate surveys from 1975 to 1977 on the islands Nam, Eneu and Bikini of Bikini Atoll gave average external exposure rates of 24, 5.7 and 32 μR/hr respectively. The exposure rate on Eneu Island is uniform, whereas those on Bikini and Nam range from 7.0 to 80. μR/hr. Based on an assumed living pattern at Bikini Island, the adult male Bikinian is estimated to be in the presence of an external radiation field corresponding to 16 μR/hr due to debris and fallout from the 1954 BRAVO incident. This corresponds to a 30 year dose equivalent of 2.8 rem.

INTRODUCTION

In April 1975, Brookhaven National Laboratory initiated an external survey of Bikini Atoll in order to obtain information concerning the ambient external radiation levels resulting from the mid 1950's weapons testing program and to make dose equivalent commitment determinations for the individuals living in the surveyed area. From 1975 to 1977, measurements were made to provide sufficient information on the external exposure received by the Marshallese people.

Most of the information concerning Bikini and Eneu Islands was obtained in April 1975, when environmental ionization chamber measurements were made. In addition, thermoluminescent dosimeters (TLDs) were placed in the field and exposed for six months at Bikini Island to verify the uniformity of the exposure. Other groups assisted in these surveys. The team from Lawrence Livermore Laboratory (UCRL) made a detailed survey of Bikini and Eneu Islands in June 1975[4,9], and they refer to the information presented in this report as BNL unpublished data. In general, their results are substantiated by the exposure and dose equivalent commitments calculated here.

The equipment used in 1975 consisted of a Reuter Stokes environmental radiation monitor model RSS-111 and a Baird-Atomic scintillation detector consisting of a sodium iodide detector (2.5 cm in diameter by 3.9 cm in length) connected to a ratemeter readout. Portable survey meters were used to help locate gross changes in the external exposure rate. Lithium fluoride thermoluminescent dosimeters were left on Bikini Island and retrieved in December 1975.

Environmental exposure levels were assessed via the RSS-111 and a NaI gamma spectrometer whose purpose was to determine the photon energy distribution and to compensate for the nonlinearity in the RSS-111 instrument response.

This report presents all of the external exposure data collected to date for Bikini Atoll by BNL. These data have been used to make external exposure estimates for the people living on Bikini Island, and the BNL data have been compared with UCRL data[9] for Bikini Atoll.

INSTRUMENTATION AND METHODS

A) Ion Chamber Measurements

All environmental exposure rate measurements were obtained with a Reuter Stokes environmental radiation monitor model RSS-111, which is designed to measure environmental radiation as low as 100 μR/yr. The RSS-111 consists of a spherical high pressure ion chamber filled with argon to a pressure of 25 atm. Incident radiation produces ion pairs within the active volume of the chamber which result in an ionization current. The current flow is measured by an electrometer and is directly related to the free air ionization rate[8].

The active volume of the stainless steel ionization chamber is known to ±1%. The ionization current produced in the chamber is a function of incident radiation from an external field, cosmic-ray response, and contamination present

in the stainless steel. The instrument response is energy dependent, and data from the manufacturer indicate an error of as much as 6 to 10% could result if energy corrections are not made to the gross readings[8].

The RSS-111s used in this study were calibrated at the factory against radium sources whose calibration is traceable to the National Bureau of Standards. The calibration of the instruments was also checked at the Environmental Monitoring Laboratory (formerly Health and Safety Laboratory) before and after field use.

In the report on external exposure for all other atolls surveyed by BNL[3], energy dependence corrections were calculated for data from Rongelap and Rongerik Atolls. The factors needed to compensate the RSS-111 response for energy dependence ranged from 1.01 to 1.05. The mean correction was approximately 1.02.

B) Thermoluminescent Survey

Lithium fluoride (LiF) thermoluminescent dosimeter chips 1/4-inch square were used[5], for several reasons. LiF is approximately a tissue equivalent material, and its response is essentially energy independent for photon energies greater than 20 keV up to several MeV. The system is precise to ±2% and has a long term retention of 5% loss at room temperature for one year. These qualities made the LiF ideal for use in the Marshall Islands.

All TLDs were cleaned with analytical grade methanol before departure for the Marshall Islands and prior to analysis. Prior to irradiation, the TLDs were annealed at 400°C for one hour and them at 100°C for 2 hr. After field exposure and before reading, the TLDs were annealed at 100°C for 10 min.

In addition to the TLDs exposed in the field at Bikini and Eneu, several sets of TLDs were assembled for use in correcting field measurements for background, fading and air transportation contributions. Several TLDs were annealed and then immediately stored in a lead pig in the BNL analytical counting area. An equal number of TLDs were irradiated to 100 mR and stored with the background TLDs to determine fading losses. Four other TLDs were sent to Kwajalein and stored there in a lead pig to determine in-transit contributions to the response. All TLD results have been corrected for these parameters.

The TLDs were calibrated at BNL with ^{137}Cs gamma and $^{90}Sr/^{90}Y$ betas. Results are directly related to the external exposure and beta absorbed dose that would be received by individuals living on Bikini and Eneu Islands.

Because the total response must be differentiated into beta and gamma components, a TLD holder was developed that would eliminate nearly 100% of the ^{90}Y beta of 2.27 MeV (Figure 1). Four TLDs are used per holder. Two are covered by 1100 mg/cm^2 of aluminum and Mylar which is of sufficient mass density thickness to eliminate beta response; these provide the gamma response. The two other TLDs are shielded by $\sim$ 15 mg/cm^2 Mylar to respond to the total gamma-beta contribution at one meter above the earth's surface. The difference between the

responses of the two TLD sets gives the beta response. TLDs placed in the field were positioned with the open windows facing the soil.

Because shielding part of the dosimeter may bias the data, an attempt was made to predict the resulting error by randomly placing four of the dosimeters (16 TLDs) together, open windows facing the soil, in a series of tests using ^{90}Sr-^{90}Y as a source, placed 30 cm from the TLDs. The open and closed windows were varied to cover all combinations of field positioning. The error using a point source and a source-to-detector distance of 30 cm was <2.5%. Because the field situation represents a distributed plane source, and the source-to-dosimeter distance was between 50 and 100 cm, the field situation should have a minimal positioning error associated with the results (Figure 2).

RESULTS

A total of 203 RSS-111 measurements were made on Bikini Atoll. Each data point is the average of at least 20 individual readings. This assures the precision of the value, and the initial calibration guarantees accuracy. The mean exposure rate is reported with one standard deviation calculated by assuming that the data obtained from a specific site follow a Gaussian distribution.

Tables 1 through 5 represent all data taken on Bikini Atoll. Table 2 lists the data from Nam Island, located at the northwest corner of the atoll, closest to ground zero of the BRAVO device. The average external exposure rate over the land areas monitored is $\sim$ 24 μR/hr. This is six times higher than the background levels at Wotje, Ailuk or Utirik Atolls[3]. This average value should not be interpreted as a true value for the Nam island average, since dense vegetation prevented a representative sample of readings over the whole island. Nam is uninhabited at present and is not used for food production. The exposure rate is non-uniform and varies significantly as a function of location.

Table 3 presents the data from Eneu Island, located south and west of Bikini Island. Eneu received the least fallout contamination as evinced from the average external radiation exposure rate of 5.7 μR/hr. This value is 1.5 times the natural background and is the lowest external exposure rate on any of the islands surveyed. Figure 3 shows the sample sites and the exposure rate measured at each site. These data demonstrate the uniformity of exposure rate on this island.

The external exposure rate on Bikini Island is a strong function of location (Figure 4A-E). It is the lowest in the areas closest to the lagoon and current housing*, highest in the center of the island and intermediate in other areas. The average exposure rate for the island, based on an average of all the data is 32.1 μR/hr. Table 4 lists exposure rate measurements made in the living areas of the available housing. Table 5 lists all other exposure rate measurements made at Bikini Island.

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*In 1978, the Department of Interior made the decision to relocate the inhabitants of Bikini Atoll to either Ejit Island, Majuro Atoll, or Kili Island. The relocation took place in August 1978.

The TLD data for Bikini Island (Table 1) agree with the RSS-111 measurements, but no constant relationship is seen between beta dose and gamma exposure. Non-uniform deposition of fallout material in the areas surveyed and translocation of material are major factors governing this result.

DISCUSSION OF RESULTS

The average exposure rate as measured for each island is listed in Table 6. Estimation of the dose equivalent for the inhabitants of Bikini Atoll is debatable due to the nonuniform distribution of radioactive material within given areas of the atoll. The exposure rates measured on Eneu Island are fairly uniform, but those on Bikini Island showed significant differences between areas (Table 5 along with Figure 4A - 4E). In the UCRL work[4], this problem was approached and a solution derived by estimating the fractions of an individual's time spent in various areas. These estimates[4] are used here (Table 7) to construct external exposure rate estimates for the various activities based on the measurements reported in Tables 2 through 5. The exposure rate for the lagoon was obtained by assuming that it would be less than or equal to that in the areas of continual habitation. The values for other islands were obtained by assuming that the Marshallese would spend an equal amount of time on each of the other islands surveyed. All other estimates were made by taking the average of all measurements made within the area of interest.

Table 8 shows the estimated exposure rate for each pattern of activity in Table 7 based on continuous occupancy of Bikini Atoll. Table 9 shows the estimated exposure rate for each age group as weighted by the percent of time spent in each area, for inhabitants of Bikini Atoll. Summation of the exposure rates in all the areas provides the average total-body exposure rate for each age group.

Using the average hourly exposure rate, the long term external dose equivalent was calculated (Table 10). The data were corrected for background (terrestrial and cosmic radiation) by using the average exposure rate on Wotje and Ailuk as representative samples of the normal Marshall Island environment[3]. These data for Bikini residents are lower than UCRL data[9] for living patterns 2 and 3, which give the estimated integral external gamma dose equivalent for 30 years as 4 rem, because the present estimates include the measured exposure rate for habitation of the newly constructed housing. These indoor values are 39% lower than those previously reported and their use reduces the total estimated reduction in the 30 year dose equivalent commitment by 32%.

The ICRP suggests[6] that population groups should not receive a 30-year dose equivalent of more than 5.0 rem to the whole body from sources other than medical equipment or natural background. For the external radiation component at Bikini Atoll, this requirement is met; the problem is that external radiation is not the sole source of radiation exposure to the Marshallese. The dietary pathway, based on UCRL data[9], could increase the 30-year total body dose equivalent commitment by a factor of 4.

Whole-body counting data taken in 1974[1], 1977[2] and 1978[7] indicate that the dietary pathway became the prime source of radiation exposure after January

1977. Current in vivo data indicate that the equilibrium body burdens for ^{137}Cs will range from 3 μCi to 30 μCi in the Bikini population. This corresponds to a 30-year internal dose equivalent that falls in the range of 11 to 110 rem. Bioassay data obtained from Bikinians during 1978 indicate that bone marrow dose equivalents for 30 years of habitation would be between 0.4 and 1.0 rem from ^{90}Sr-^{90}Y[10].

Reviewing the Bikini dose commitment in this light, one immediately realizes that the inhabitants would receive a total body dose equivalent exceeding the ICRP criteria[6]. Thus, for Bikini Atoll, we concur with the UCRL recommendation[9] that more must be done to lower the total body and bone marrow radiation exposures so that the Marshallese can live within the population dose equivalent recommendations.

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Table 1

Bikini Island TLD Exposure Survey (129 days), Dec. 7, 1974, to Apr. 15, 1975

Location	Total γ Exposure μR	Total β Dose, μrad
House 4 - inside	28400*	-
House 4 - outside 20 in. above ground	36200*	-
House 20 - inside	29900*	-
House 20 - outside mid backyard	27800*	-
House 38 - inside	48600*	-
House 38 - outside mid backyard	41000*	-
Big twin coconut trees, west side of tree near USGS well	194300*	-
Behind house 40, cookhouse at 18 in. off ground	26800	1500
Behind house 35, behind living area at 22 in. off ground	45300	25800
Behind house 30, behind living area at 20 in. off ground	32800	10300
East/west road by house 30 about 30 yd. north of bunker	35600	11000
Behind house 25 near banana and papaya patch, 22 in. off ground	54000	29800
Behind house 21, 20 in. off ground	26300	14700
Behind house 15	29900	4700
Behind house 10	73000	62800
Behind house 6	36200	8400
By USGS well and twin coconut trees	79100	85100
Control 1	2900	2400
Control 2	5100	0
Control 3	6300	0

*Total unshielded response.

Table 2

Nam Island, Bikini Atoll, RSS-111 Exposure Survey, April 1976

Location	μR/hr
West Transect - 200 meters from soil pit	33.4 ± 0.6
West Transect - 100 meters from soil pit	16.7 ± 0.4
East Transect - 200 meters from soil pit	17.6 ± 0.5
East Transect - 100 meters from soil pit	15.2 ± 0.4
East Transect - 245 meters north of lagoon beach	44.9 ± 0.7
East Transect - 150 meters north of lagoon beach	23.1 ± 0.5

Table 3

ENEU ISLAND RSS-111 EXPOSURE SURVEY APRIL 1975

Location	μR/hr
South road to ocean near middle of island	7.2 ± 0.62
2nd coconut row, ocean side of runway adjacent to marker 4	5.6 ± 0.25
2nd coconut row, ocean side of runway adjacent to marker 1	4.2 ± 0.17
2nd coconut row, ocean side of runway adjacent to marker 2	4.9 ± 0.37
2nd coconut row, ocean side of runway adjacent to marker 3	8.2 ± 0.10
1st coconut row, ocean side of runway adjacent to marker 1	5.3 ± 0.16
Midway north of runway apron and coconut row	6.1 ± 0.32
5th coconut row up the road from north corner of runway apron	8.7 ± 0.23
16th coconut row by 2nd large nature tour	6.1 ± 0.14
Group of old buildings, south of church, ocean side of road	6.9 ± 0.12
West bend in road just north of old church, ocean side	8.1 ± 0.31
North 1/3 way up road to Camp Blandy, ocean side	4.9 ± 0.30
North 2/3 way up road to Camp Blandy, ocean side	6.5 ± 0.20
Blandy area just south of soil pit 3, 100 yd from lagoon beach	6.1 ± 0.15
Blandy area just south of soil pit 3, 100 yd from ocean beach	5.6 ± 0.31
North end of Camp Blandy near middle of the island	5.9 ± 0.29
North end of Camp Blandy near lagoon road, ocean side	6.0 ± 0.21
Lagoon road south of Camp Blandy, 100 yd west of church	5.7 ± 0.15
Lagoon road about 150 yd north of Camp Blandy	5.0 ± 0.35
Bunker near dock	5.0 ± 0.22
Old bldg. frame work due west of runway marker 1	6.1 ± 0.27

Table 4

Measured Exposure Rates Within Permanent Housing Constructed on Bikini Island

Location	Exposure rate μR/hr	Location	Exposure rate μR/hr
House 21	6.6 ± 0.13	House 4	7.5 ± 0.15
House 22	7.3 ± 0.37	House 6	7.8 ± 0.28
House 23	7.2 ± 0.10	House 7	10.5 ± 0.28
House 25	7.3 ± 0.28	Outside house 7	
House 26	7.3 ± 0.25	north side on gravel	12.9 ± 0.20
School		House 9	10.7 ± 0.16
middle of the room	7.2 ± 0.10	House 10	11.1 ± 0.25
House 30	8.4 ± 0.14	House 11	9.3 ± 0.23
House 31	8.9 ± 0.10	House 12	9.7 ± 0.49
House 32	10.0 ± 0.37	House 13	13.3 ± 0.19
House 33	9.6 ± 0.45	House 15	11.6 ± 0.23
House 35	15.8 ± 0.19	House 16	11.5 ± 0.60
House 36	13.1 ± 0.17	House 18	8.2 ± 0.17
House 37	11.9 ± 0.30	House 19	7.8 ± 0.26
House 40	11.1 ± 0.15	House 20	7.2 ± 0.13

Table 5

Bikini Island RSS-111 Exposure Survey, April 1975

Location	μR/hr
Column 1, due east of house 30	57.3 ± 0.2
Column 10, due west of bunker	31.8 ± 0.4
Column 20	50.0 ± 0.4
Column 30	46.6 ± 0.4
Column 40	26.4 ± 0.1
Column 50, due west of twin coconut trees	36.6 ± 0.2
Column 58-59, intersection with 1st baseline south	44.5 ± 0.3
North/south transect between 1st baseline south and 2nd baseline south	
Column 1	59.5 ± 0.3
Column 10	78.4 ± 0.5
Column 20	64.7 ± 0.2
Column 30	49.2 ± 0.3
Column 40	45.0 ± 0.2
Column 50	53.8 ± 0.1
Column 60	48.0 ± 0.1
Column 70	48.9 ± 0.4
North/south transect from 2nd to 1st baseline north	
Column 2, 10 yd due south of soil pit A	47.7 ± 0.2
Column 10	54.2 ± 0.6
Column 20	41.2 ± 0.3
Column 30	39.1 ± 0.2
Column 40	55.1 ± 0.2
Column 50	41.3 ± 0.7
Column 60	53.4 ± 0.4
Column 70	82.1 ± 0.5
Column 77, 2 rows due east of soil pit E	31.6 ± 0.3
South/north transect north from 1st baseline north (continuation of USGS-bunker rd.)	
Column 1	52.7 ± 0.1
Column 10	43.2 ± 0.1
Column 20	44.0 ± 0.3
Column 30	58.2 ± 0.2
Column 40	46.6 ± 0.2
Column 50	34.3 ± 0.3
Column 60, due west of small bunker on ocean rd.	31.6 ± 0.3
Column 70	31.2 ± 0.3
Column 77, and intersection of 2nd baseline north	26.6 ± 0.2
40 yards north of 1st baseline north	22.3 ± 1.4
Across lagoon road from house 37	20.0 ± 0.7
Across lagoon road from house 38	24.0 ± 1.1

Table 5 (Cont'd)

Bikini Island RSS-111 Exposure Survey, April 1975

Location	μR/hr
Across lagoon road from house 39	22.9 ± 0.6
10 columns north of house 40	28.5 ± 0.6
South on ocean beach road from 2nd baseline north	
Column 1	23.6 ± 1.0
Column 10	38.3 ± 1.3
Column 20, 3 columns south of small bunker	25.9 ± 0.4
Column 30, 3 rows east of ocean beach road	22.4 ± 1.1
Column 40, 6 rows east of ocean beach road	49.4 ± 0.8
Column 50, 1 row in from ocean beach road	33.4 ± 0.4
Column 60, 3 rows in from ocean beach road	33.4 ± 0.3
Column 70, 1 row in from ocean beach road	37.0 ± 0.7
Column 78, at intersection of ocean beach road and 1st baseline north	33.2 ± 0.5
North/south transect along road separating (1972 designation of rows) rows 24 & 25 from center baseline to 1st baseline north	
Column 1	22.6 ± 0.3
Column 10	62.0 ± 0.2
Column 20	26.7 ± 0.4
Column 30	52.9 ± 1.1
Column 40	42.6 ± 0.3
Column 49 and the intersection of 1st baseline north	48.0 ± 0.3
North/south transect along breadfruit row starting at 2nd baseline north	
Column 4 of older plantings behind house 40	49.2 ± 0.9
Breadfruit planting east of house 39	59.0 ± 0.4
Breadfruit planting east of house 38	40.9 ± 0.5
Breadfruit planting near small bunker between houses 37 & 38	29.9 ± 0.5
Breadfruit east of house 37	28.0 ± 0.8
2 columns of coconut trees north of 1st baseline north	23.0 ± 0.3
1st breadfruit south of 1st baseline north by soil pit D	42.0 ± 0.7
5th breadfruit east of house 36	33.1 ± 0.6
9th breadfruit near banana garden, house 35	34.1 ± 0.6
12th breadfruit east of Japanese memorial and house 34	38.8 ± 0.3
15th breadfruit north of center baseline and east of house 31	22.4 ± 0.2
North/south transect along breadfruit row from center baseline	
Due east and house 30	18.4 ± 0.2
Breadfruit near house 26 and 30 yards east of papaya patch	26.2 ± 0.3
Breadfruit 8 near house 4 and main garden	48.4 ± 0.5
Due east of houses 20 and 21	19.2 ± 0.3
Due east of house 17	25.6 ± 0.5
Due east of house 16 just north of center baseline and soil pit	30.3 ± 0.2

Table 5 (Cont'd)

Bikini Island RSS-111 Exposure Survey, April 1975

Location	μR/hr
Due east of house 14	32.4 ± 0.2
Due east between houses 12 & 13	40.3 ± 0.6
Due east and between house 10 and breadfruit row	24.7 ± 0.3
Due east of house 8 next to breadfruit row	46.4 ± 0.4
Due east of houses 7 & 8 near vegetation depression	16.3 ± 0.2
Due east of houses 5 & 6	34.5 ± 0.5
Due east of houses 3 & 4	7.7 ± 0.4
North/south transect between 2nd baseline north (pit B) and 1st baseline north (pit D)	
Column 2, 15 yd due south of soil pit B	44.5 ± 0.4
Column 10	52.3 ± 0.3
Column 20 due east of house 39	56.9 ± 0.4
Column 30	66.8 ± 0.2
Column 40	41.5 ± 0.4
Column 50	33.2 ± 0.4
Column 60 due east of house 36	42.5 ± 0.3
Column 70	32.8 ± 0.4
Column 77	45.1 ± 0.4
North/south transect between 1st baseline north and center baseline, sample locations proceed due south	
Column 1	28.5 ± 0.2
Column 10	41.0 ± 0.3
Column 20	41.8 ± 0.4
Column 30	56.6 ± 0.2
Column 40	61.5 ± 0.2
Column 48 (last column before crossing center baseline)	15.2 ± 0.2
Row 20	50.9 ± 2.1
Row 30	60.1 ± 1.4
Row 40	46.7 ± 2.2
Row 50	55.1 ± 2.4
Ocean road just behind row 59	34.4 ± 2.0
South on ocean beach road from 2nd baseline south, measurements taken on lagoon side of road	
Column 10	36.9 ± 0.6
Column 20	38.0 ± 0.4
Column 30	29.2 ± 0.5
Column 40	19.6 ± 0.6
Column 50, about 100 yd from ocean	27.7 ± 0.6
Column 60, about 150 yd from ocean	27.8 ± 0.7
Column 67	16.2 ± 0.4

Table 5 (Cont'd)

Bikini Island RSS-111 Exposure Survey, April 1975

Location	μR/hr
Camp area	
Bldg. 1	12.2 ± 0.2
Bldg. 3	13.8 ± 1.0
Near church on northward bend of road halfway between equipment shed and house 1 (ocean side of road)	17.3 ± 0.3 26.3 ± 0.5
Lagoon road north, measurements taken on ocean side of road	
Open area between houses 3 and 4	16.0 ± 0.1
Open area between houses 5 and 6	18.5 ± 0.4
Open area between houses 7 and 8	28.4 ± 0.6
Open area between houses 9 and 10	23.9 ± 0.3
Open area between houses 12 and 13	24.9 ± 0.3
Open area between houses 14 and 15	37.8 ± 1.8
Open area between houses 16 and 17	28.1 ± 1.6
Open area between houses 34 and 35	13.9 ± 0.9
Open area between houses 35 and 36	14.0 ± 0.3
75 yd north of house 36	23.0 ± 2.0
3rd baseline north starting at the lagoon road	
Row 1	30.9 ± 0.1
Row 5	40.4 ± 0.3
Row 10	44.7 ± 0.4
Lagoon road	
100 yd south of north beach	19.6 ± 0.3
Near house 40 - ocean side of road	13.5 ± 0.5
Near house 38 - lagoon side of road	17.0 ± 0.3
50 yd south of house 37	20.4 ± 0.4
Near house 35 - lagoon side	31.6 ± 0.4
Village center - near intersection of lagoon road and center baseline	9.4 ± 0.4
Soil pit G	22.5 ± 0.4
Near house 25 - lagoon side	18.5 ± 0.1
Near house 20 - lagoon side	18.2 ± 0.2
Near house 15 - lagoon side	24.7 ± 0.2
Near intersection of 1st baseline and lagoon road	
Near house 10 - lagoon side	17.5 ± 0.2
Near house 5 - lagoon side	26.0 ± 0.3
Near house 1 - lagoon side	11.8 ± 0.1
Second baseline south starting behind house 7	
Behind house 7, breadfruit row ↷10 yd to row 1	27.0 ± 0.9
Row 10	54.9 ± 1.7
Row 20	50.5 ± 1.4
Row 30	54.0 ± 1.8

Table 5 (Cont'd)

Bikini Island RSS-111 Exposure Survey, April 1975

Location	μR/hr
Row 40	
Soil pit between rows 42 & 43	47.3 ± 0.2
Row 50, 100 yds from ocean beach	40.8 ± 1.4
Row 60, 30 yds from ocean beach	50.8 ± 5.1
Pandanus 118 behind house 15	25.0 ± 0.3
Behind agriculture area	27.4 ± 1.4
Row 1	
Row 10	
North face of bunker	44.5 ± 1.9
North-south road midway between bunker and USGS well	51.5 ± 1.9
North-south road, column 5 from 1st baseline south	21.5 ± 0.5
North-south road, column 15 from 1st baseline south	66.5 ± 0.2
North-south road, column 25 from 1st baseline south	56.8 ± 1.1
North-south road, column 35 from 1st baseline south	43.4 ± 0.3
North-south road, column 45 from 1st baseline south	32.7 ± 0.6
Lagoon road, end of center baseline behind house 30	58.0 ± 1.1
Row 10, south side of baseline	27.2 ± 0.3
Row 20, 30 yd from fork to bunker	18.7 ± 0.3
Row 30, 50 yd north of bunker	25.0 ± 0.2
Row 40	20.4 ± 0.8
Row 50	20.1 ± 0.4
Row 60	12.3 ± 0.2
Row 69-70	30.8 ± 0.6
East-west transect	29.5 ± 0.3
Lagoon road and 1st baseline north	18.4 ± 0.4
Soil Pit D	
Row 10, east from lagoon road	44.4 ± 0.2
Row 20	40.3 ± 0.3
Row 30	36.3 ± 0.5
Row 40	38.3 ± 0.4
Row 50	35.7 ± 0.2
Row 60	42.3 ± 0.4
North side of 2nd baseline north (near house 40)	58.1 ± 0.6
Row 1	41.8 ± 0.1
Row 10	
Row 20, near soil pit B	17.5 ± 0.2
Row 30	30.6 ± 0.3
Row 36-37, near soil pit A	35.9 ± 0.3
Row 40	28.9 ± 0.3
Row 50	23.3 ± 0.3
	29.6 ± 0.2
	30.6 ± 0.2

Table 6

Average Exposure Rate Corrected for Decay to May 1977

Island	No. of Observations	Av. exposure rate μR/hr
Nam	6	23.5 ± 11.0
Eneu	21	5.7 ± 1.1
Bikini	203	32.1 ± 16.3

Table 7

Population Breakdown by Age and Geographical Living Patterns[5]

	Infants and small children	Children and adolescents	Men	Women
Age, yr	0-4	5-19	20+	20+
Percent of population	16	41	22	21
Percent of time spent in following 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 8

Assumed Mean Exposure Rate for Each Activity Area

Pattern	Bikini Atoll μR/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*
Other islands	15.5**

*Value assumed to be less than or equal to value for beach.

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

Table 9

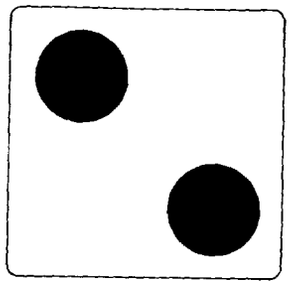
Exposure Rate Estimates for Bikini Atoll Inhabitants

	Infants 0-4 yr	Children 5-19 yr	Men 20+ yr	Women 20+ yr
Percent of population	16%	41%	22%	21%
Exposure rate (μR/hr) during time within following areas:				
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	14.63	19.23	20.20	19.22

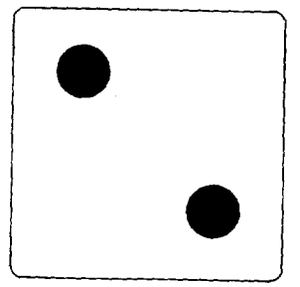
Table 10

External Dose Equivalent to Inhabitants of Bikini Atoll

Age Group	Net ext. exposure rate, μR/hr, May '77	Ext. integrated dose equiv., rem (background subtracted)		
		10 yr	30 yr	50 yr
Infants (0-4)	10.27	0.80	1.90	2.59
Children (5-19)	14.60	1.12	2.69	3.66
Men (20+)	15.52	1.20	2.85	3.88
Women (20+)	14.60	1.12	2.69	3.66

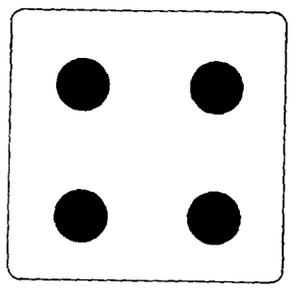


FRONT SIDE WITH 1.6 cm OUTER DIAMETER TAPPERED CUT-OUTS.

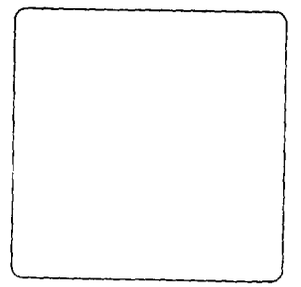


REAR SIDE WITH 1.1 cm INNER DIAMETER AND COVERED WITH A THIN LAYER OF MYLAR.

FRONT PANEL



FRONT SIDE WITH 1 cm DIAMETER INSETS TO HOLD TLDS.

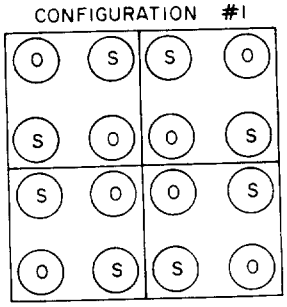


REAR SIDE, SOLID ALUMINUM.

REAR PANEL

Figure 1. Aluminum TLD holder.

CONFIGURATION #1



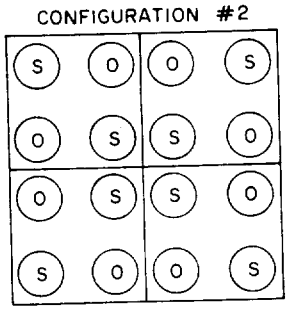
$^{90}Sr/^{90}Y$ SOURCE PLACED 12 INCHES FROM THE MIDLINE OF THE TLD HOLDER.

S – INDICATES TLD LOCATED BENEATH 3.48 mm OF ALUMINUM

O – INDICATES TLD WASN'T SHIELDED

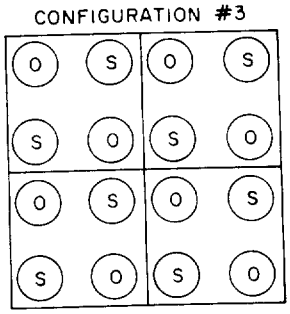
CALIBRATION FACTOR = 0.1458 RADS/NANOCOULOMB

CONFIGURATION #2



CALIBRATION FACTOR = 0.1414 RADS/NANOCOULOMB

CONFIGURATION #3



CALIBRATION FACTOR = 0.1464 RADS/NANOCOULOMB

AVERAGE CALIBRATION FACTOR = 0.1445 ± 0.00273 RADS/NANOCOULOMB

Figure 2. Determination of Beta calibration factor.

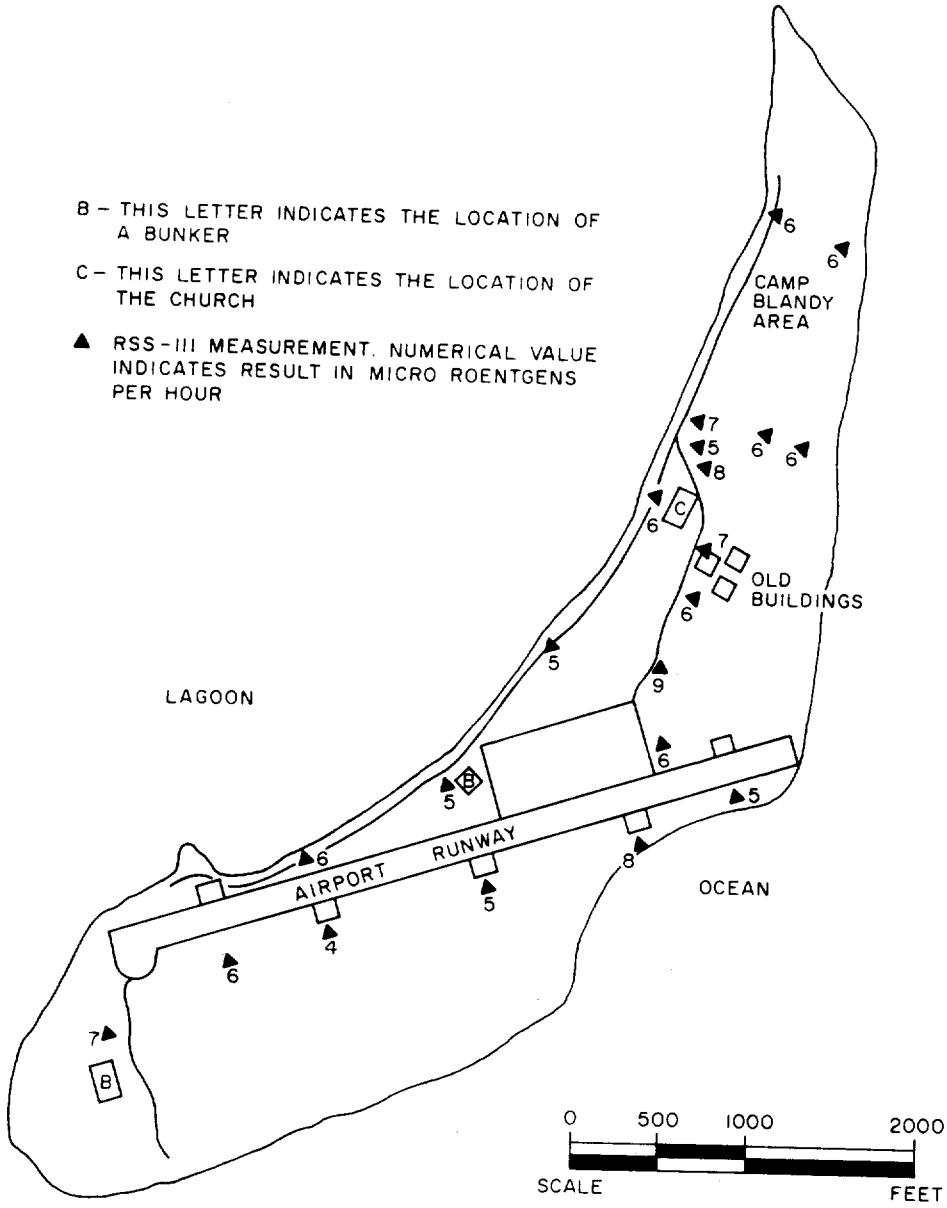


Figure 3. Eneu Island external exposure survey, April 1975.

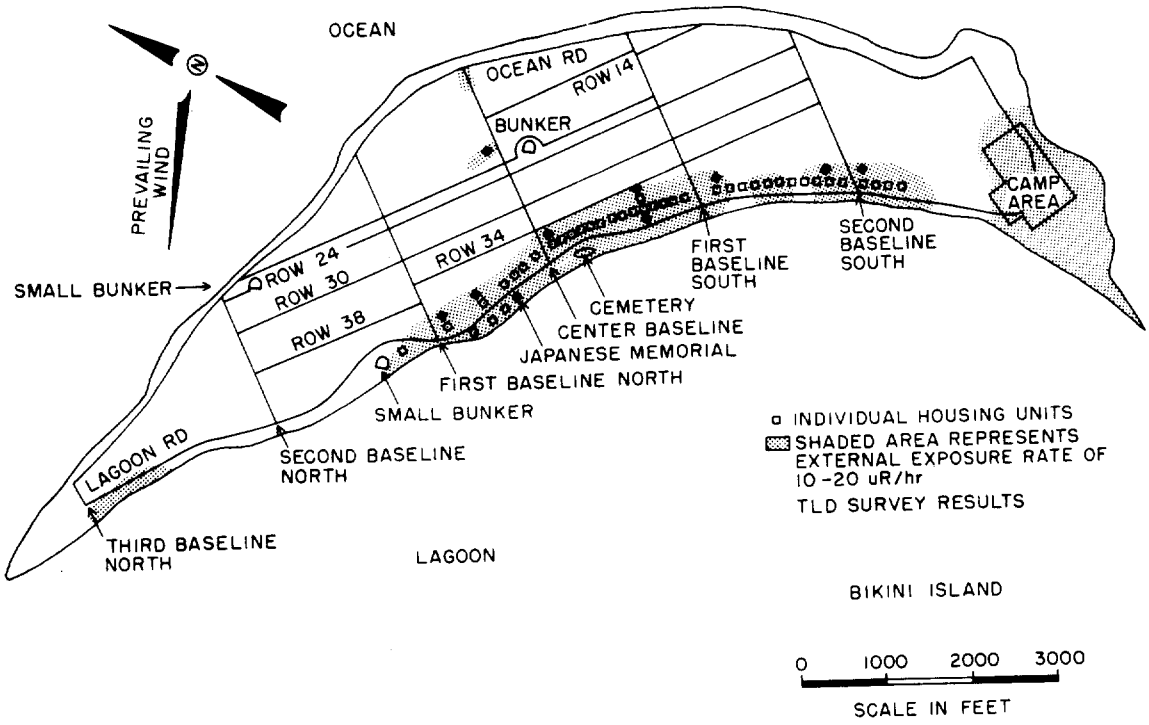


Figure 4A.

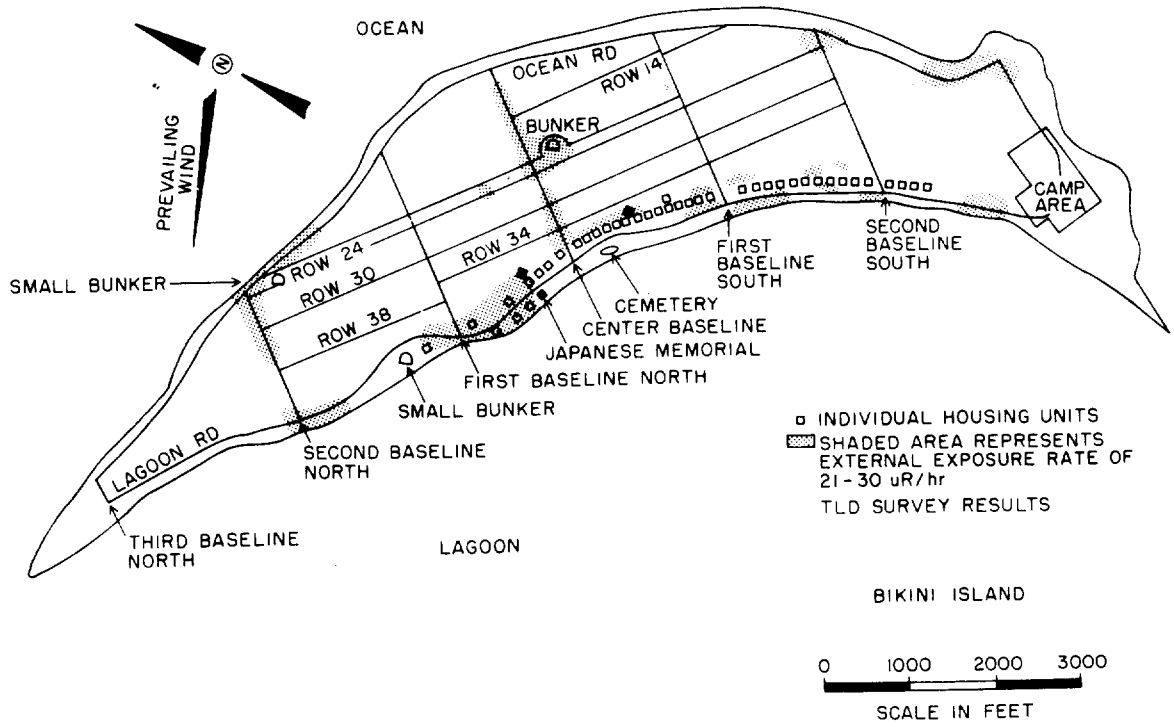


Figure 4B.

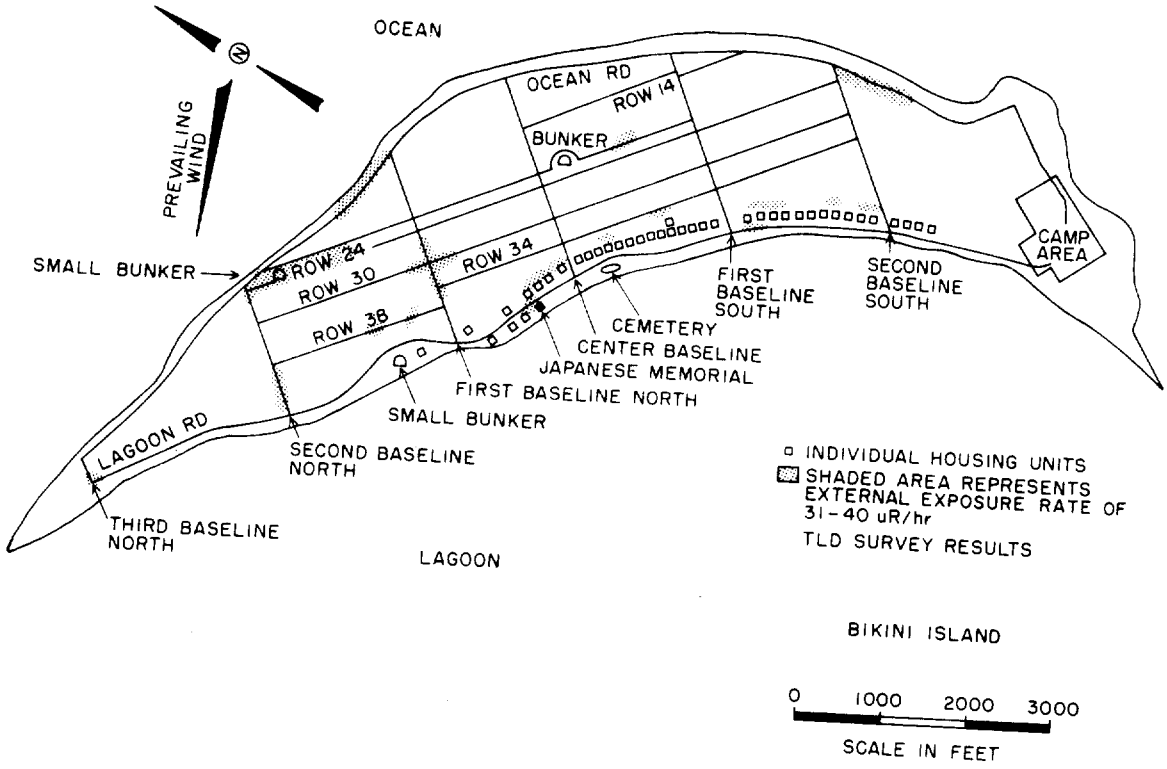


Figure 4C.

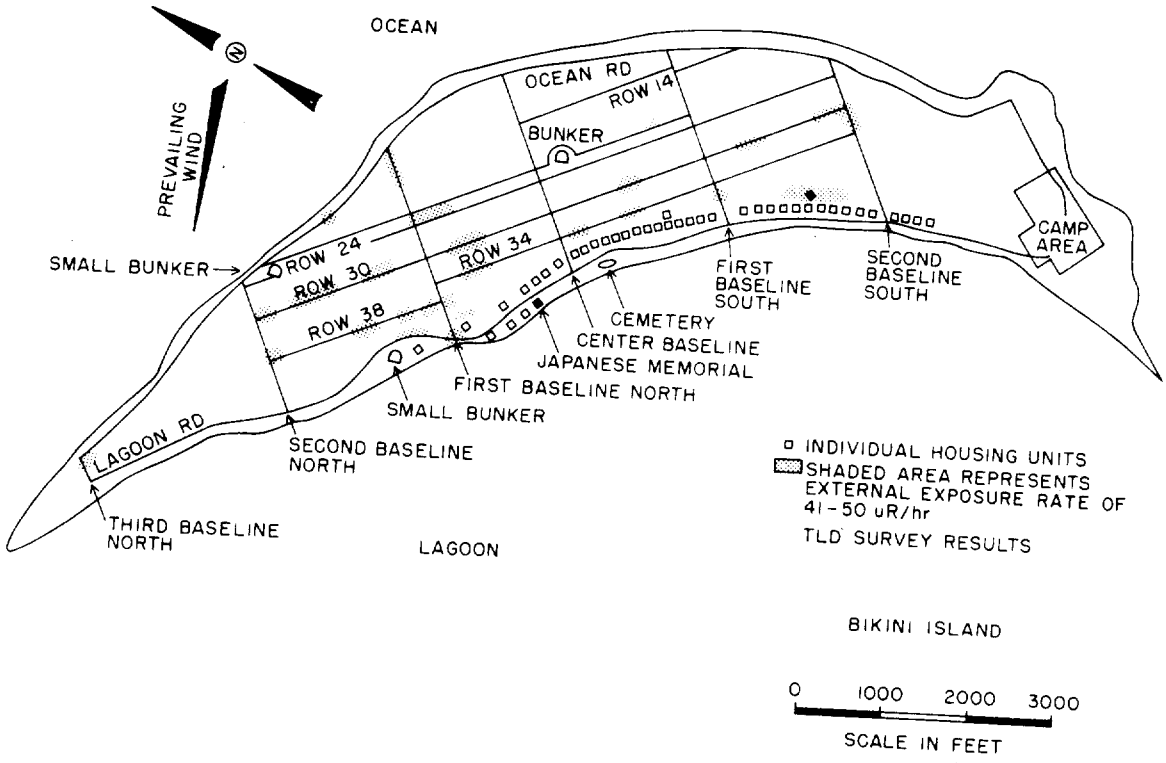


Figure 4D.

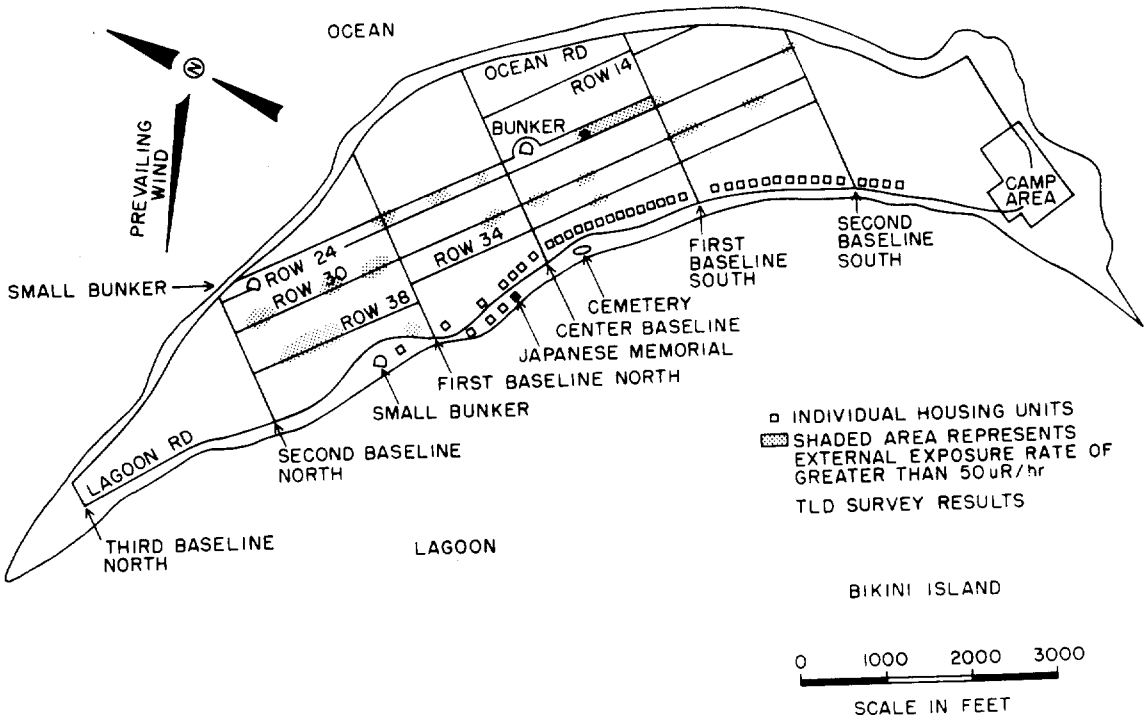

OCEAN
OCEAN RD
ROW 14
BUNKER
PREVAILING WIND
CAMP AREA
SMALL BUNKER
ROW 24
ROW 30
ROW 34
ROW 38
FIRST BASELINE SOUTH
SECOND BASELINE SOUTH
CEMETERY
CENTER BASELINE
JAPANESE MEMORIAL
FIRST BASELINE NORTH
SMALL BUNKER
LAGOON RD
SECOND BASELINE NORTH
THIRD BASELINE NORTH
LAGOON
INDIVIDUAL HOUSING UNITS
SHADED AREA REPRESENTS EXTERNAL EXPOSURE RATE OF GREATER THAN 50 uR/hr
TLD SURVEY RESULTS
BIKINI ISLAND
0 1000 2000 3000
SCALE IN FEET

Figure 4E.