were calculated. Included are estimates based on BEIR-I which we used since BEIR-III had not yet been accepted by the U.S. Government. In fact at the time we wrote the Bikini book only a type set copy of BEIR-III was available, which was not identical to the version eventually published. We used this type set version to calculate estimates based on BEIR-III for comparison purposes. This also is enclosed.

Because of your question about the origin of the values for the dose to the highest individual I've included a table in the appendix of actual dose data for individuals.

Also included is a copy of the Trust Territory of the Pacific Islands, Five Year Comprehensive Health Plan, dated February 1979. As I mentioned to you on the phone this was our only source of population data on the Marshallese people. The enclosure is all of the report that Dr. Wachholz received from Mr. Ted Mitchell, a lawyer who was with the Micronesian Legal Service and who represented the Enewetak people. You'll note that it appears incomplete. Also, there is a part which is labeled Chapter Four, VI Demography. I don't know whether this is a part of the Marshall Islands Five Year Plan or whether it is from another report. The data in this Chapter Four is not quite in agreement with the data in the Five Year Plan. For example, in Table IV-6, page 63 the annual growth rate for the Marshallese is given as 4.4%. From the data in Table III-1 of the Five Year Plan, the annual growth rate seemed to be less than 4%; we used 3.8%.

Please call if you have any questions.

Sincerely yours,

Bill

W. J. Bair, Ph.D.
Manager
Environment, Health and
Safety Research Program

WJB:lm

Enclosures as stated

cc: J. W. Healy
W. L. Robison
B. W. Wachholz

Called him 1-28-82. Report being reviewed by Healy.

action

EPIDEMIOLOGY RESOURCES, INC.

January 26, 1982

1203 Shattuck Avenue
Berkeley CA 94709
415-526-0141

RECEIVED
JAN 28 1982
W. J. BAIR

Dr. W. J. Bair
Environment, Health and Safety Research Program
Batelle Pacific Northwest Laboratories
Richland, WA 99352

Dear Dr. Bair:

In your letter of December 29th, you were good enough to say that you would send us a copy of a summary of the risk calculations, on the Bikini problem,

I wonder if that summary has been completed, and if so, could it be sent to us now. It would be very helpful, since we are being pressed to comment on them.

Very sincerely yours,

Henry I. Kohn

Henry I. Kohn M.D.

P.O. Box 57, Chestnut Hill, Massachusetts 02167 (617) 522-8234

"THE MEANING OF RADIATION AT BIKINI ATOLL"

I. ASSUMPTIONS

Estimates of cancer and birth defect risks for the Bikini populations were based on a number of assumptions. Some of these assumptions resulted from consultation with other scientists including members of the BEIR committees.

1. Risk coefficients from BEIR-I were used because BEIR-III had not been accepted by any U.S. government agency. We elected to use the values as given in BEIR-I rather than the revised values based on increased age of the population shown in Table V-4 of BEIR-III.

2. For estimates of cancer risk both the relative risk coefficient and the absolute risk coefficient were used to give a range of estimated risk. The absolute risk coefficient gives a lower value, is less variable with the population and is not dependent upon the spontaneous cancer incidence, which is not known for the Bikini population. The relative risk coefficient gives a high value, but since it is based on the spontaneous cancer incidences, which is unknown for the Bikini population, it is probably less reliable than the estimates calculated from the absolute risk coefficients.

3. For estimating increased cancer incidences, the bone marrow dose was used because it was slightly higher than the whole body dose. This probably introduced a small element of conservation.

4. For estimating birth defects neither BEIR-I or BEIR-III is very clear about what is meant by parental dose, thus it is not clear whether birth defects should be based on the dose to one parent or both parents. In the latter case, the 30-year whole body dose would be doubled. We assumed the BEIR-I risk of 0.2% rem was based on both parents being irradiated. Also because we believed the risk coefficient from BEIR-I

II. POPULATION ESTIMATES

To estimate the number of births, deaths and the magnitude of the Bikini population after 30 years, information was used from the final draft of the Marshall Islands Five Year Health Plan prepared by the Trust Territories' Department of Health Services' Office of Health Planning and the Resources Department. The document is undated, but the presence of data from 1976 indicates that it must have been prepared in the period of 1977 to 1979 when we received it. It was noted that there are apparent inconsistencies among several of the different tables. For example, Table III-1 gives data for the Marshall Islands for the period 1955-1975 and Table III-5 gives data for the infant mortality rate for 1976. In Table III-1, the infant death rate per 1000 births for 1970 through 1975 is given as 28.3, 33.6, 25.4, 46.4, 21.1 and 37.0. However, Table III-5 indicates the infant mortality rate to be only 17.04. We used the data of Table III-1 in the following estimates; because it is more complete and it provides a self-consistent set of data. However, in view of the discrepancies, the results can only be considered as approximations. This probably makes little real difference in view of the uncertainties in the risk coefficients that were used. There is also a bias built into the data because of the inclusion of Ebye and Majuro in the overall Marshall Island rates. This arises from the different death rates (particularly infants) at these two locations. In many respects the population of Ebye and Majuro are quite dissimilar from the Bikini population because they have the advantages and disadvantages of a more technical environment.

For the estimates the last 5 or 6 year average of the data were used because they are probably the most representative of current conditions. From this, the following were obtained:

1. Rate of increase of the population has been about 3.8%/year.
2. Infant death rate is about 3.2% per birth.
3. Overall death rate is 0.54% per year.
4. Birth rate is 4.2% per year.

summing. This gave 8949 rads for the total population including the original 550. The total dose received by the original 550, assuming that all live for the 30 years, is

$$P' = \frac{550}{\lambda}(1 - e^{-\lambda t}) = 11{,}902 \text{ rads}$$

For those born after the return, the population would be the difference between the total population in 30 years, the number of deaths and the original 550 people or 1134. Thus, the per capita dose for this group is 8949/1134 = 7.9 rads. For the original 550, the per capita dose is 11,902/550 = 22 rads. The ratio of these two to give an estimate of the fraction of the full 30 year dose received by the children is 0.36.

The assumption of no deaths in the original 550 returning was made for simplicity and the lack of good death rate data.

We also compared the age characteristics of the Marshallese from Table IV-3 and the U.S. population in 1970. This comparison is given in the attached curve. The slopes are similar above age 35 but the magnitudes are distorted by the high birth rate in the Marshall Islands. However, in terms of the relative risk the similar slopes suggest that if the natural cancer rates in the two populations are similar, the relative risk for people above 35 in both populations would be similar because most of the cancer occurs at ages from about 40 and above. However, the magnitude of the relative risk in the U.S. used for the Marshallese will be high by a factor of somewhere around 2-3 because of the distortion caused by the very high proportion of young people who have a relatively low natural cancer incidence.

Using the preceding calculations for a population of 550, calculations were made for other population sizes. For a population of 550 (from preceding):

Deaths in 30 years = $164 \approx 160$
Births in 30 years = $1277 \approx 1300$

For a population of 140 (the number that returned to Bikini):

A population of 550 was assumed for the one that might move back permanently to Bikini Atoll. Values for other initial populations were obtained by ratios of the results.

The total population at the end of 30 years is given by the compounding equation:

$$P_{30} = 550\ (1 + 0.038)^{30} = 1684$$

The number of births in 30 years are given by:

$$B = 0.042 \times 550 \int_0^{30} (1.038)^x\, dx$$

where x is the time between 0 and 30. This gives

$$B = \frac{0.042 \times 550}{\ln 1.038}\ [1.038^{30} - 1] = 1277$$

Similarly, the number of deaths in the 30 year period would be:

$$\text{Deaths} = 0.0054 \times 550 \int_0^{30} (1.038)^x\, dx$$

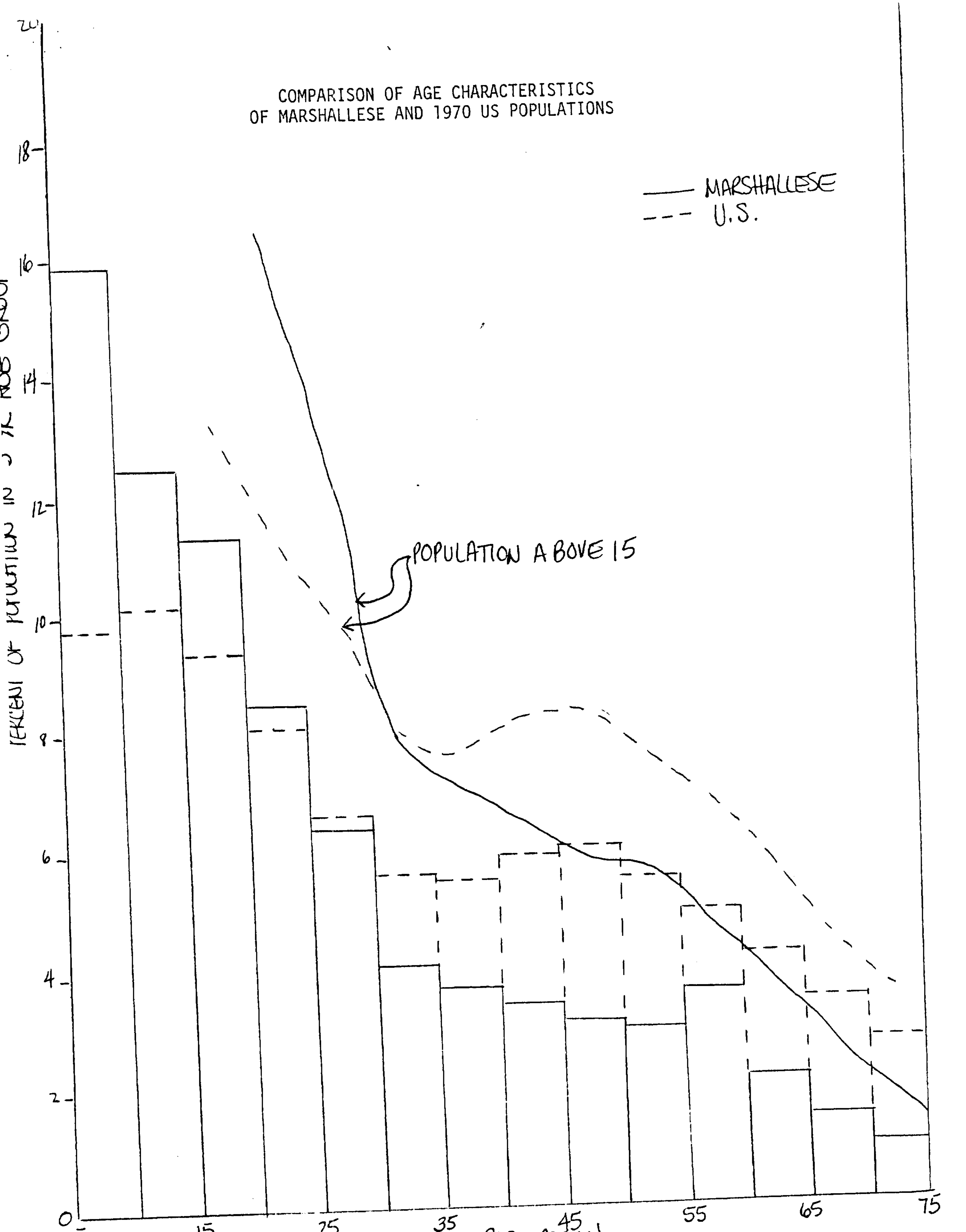
$$\text{Deaths} = \frac{0.0054 \times 550}{\ln 1.038}\ [1.038^{30} - 1] = 164$$

One other datum needed is the reduction in 30 year dose to those born after the return because of the decrease in radiation levels and the smaller amount of time in the 30 year period that is spent on the island. For this, the total population dose for those born after returning assuming an initial dose rate of 1 rad/year is given by:

$$P = 550\ D_1 \int_0^{30} e^{-\lambda x}\ (1.038^x)\ dx$$

λ is the half-life of decrease of the radiation dose, taken here as 30 years.

Because this integral cannot be solved analytical, an approximate solution was obtained by calculating this function for each of 30 years and


COMPARISON OF AGE CHARACTERISTICS
OF MARSHALLESE AND 1970 US POPULATIONS
MARSHALLESE
U.S.
POPULATION ABOVE 15
18
16
14
12
10
8
6
4
2
0
15
25
35
45
55
65
75

Deaths in 30 years $\frac{164}{550} = \frac{x}{140}$, $x = 41.7 \approx 40$

Births in 30 years $\frac{1277}{550} = \frac{x}{140}$, $x = 325. \approx 300$

For a population of 235:

Deaths in 30 years $\frac{164}{550} = \frac{x}{235}$, $x = 70.07 \approx 70$

Births in 30 years $\frac{1277}{550} = \frac{x}{235}$, $x = 545.62 \approx 550$

For a population of 350:

Deaths in 30 years $\frac{164}{550} = \frac{x}{350}$, $x = 104.36 \approx 100$

Births in 30 years $\frac{1277}{550} = \frac{x}{350}$, $x = 812.63 \approx 800$

III. RISK COEFFICIENTS

At the time the Bikini book was prepared no agency in the U.S. government had accepted the risk coefficients in BEIR-III. Thus we were constrained to use risk coefficients from BEIR-I. While not included in the printed book, risk estimates based on BEIR-III were calculated for comparison purposes. The following gives the origin of the risk coefficients used.

A. BEIR-I

1. Cancer (Tables 3-3 and 3-4)

	Cancer deaths/year in U.S. from 0.1 rem/year (pop = 197,863,000)		Derived Cancer deaths/10^6 person rem	
	Absolute	Relative	Absolute	Relative
Leukemia	516	738	26	37
Other Cancers				
30 year elevated risk	1210	2436	61	123
lifetime elevated risk	1485	8340	75	421

Range	1726-2001	3174-9078	87-101	160-458

From the above the minimum estimate of cancer risk would be given by a risk coefficient of $87/10^6$ person rem and the maximum by $458/10^6$ person rem. Thus, these two risk coefficients were used to define a range of estimated cancer deaths.

2. Genetic Effects (from Page 1 & 2 BEIR-I)

a. Based on specific defects 5 rem/30 year reproductive generation would cause in the first generation 100-1800 cases of dominant diseases and defects per year (3.6 million births/year) or 5 times this amount at equilibrium. The 1800 cases represent an increase of 0.05% incidences per year first generation and 0.25% at equilibrium. In addition there would be a few chromosomal defects and recessive diseases and a few congenial defects due to a single gene defect and chromosome aberrations.

The total incidence at equilibrium is 1100 to 27,000/year. These at equilibrium, the maximum would be 0.75% or 0.15% in the first generation.

These are equivalent to 0.15% per rem at equilibrium and 0.03%/rem in the first generation.

b. Based on overall ill health. Overall ill health: 5% - 50% of ill health is proportional to the mutation rate using 20% and doubling dose of 20 rem, 5 rem per generation would eventually lead to a 5% increase in ill health.

Thus the rate of overall ill health is 1%/rem at equilibrium or 0.2%/rem in first generation.

For estimating the potential genetic derived health defects in the Bikini population it was decided to use a risk coefficient of 0.2% per rem in the first generation recognizing that it was probably very conservative.

B. BEIR-III

1. Cancer (Table V-4 of Typescript Edition)

Lifetime Risk of Cancer Death

(deaths/10^6/rad)

Model	Single exposure to 10 rad: Absolute	Relative	Continous xposure to 1 rad/yr: Absolute	Relative
L-Q, $\overline{\text{LQ-L}}$	77	226	67	182*
L-L, $\overline{\text{L-L}}$	167	501	158	430*
Q-L, $\overline{\text{Q-L}}$	10	28	---	---

* In printed version these were 169 and 403, respectively. We used the risk coefficients that were derived for continuous exposure.

2. Birth Defects--pages 166-169 (mean parental age = 30 years) 1 rem per generation (1 rem parental exposure) per 10^6 live off-spring 5 to 75 birth defects, this is 0.0005--0.0075%--First generation.

   Since the spontaneous rate is given as 10.7%, in the U.S. population, 1 rem will increase the rate from 10.7% to 10.7005--10.7075%.

   In terms of the spontaneous rate 1 rem per generation gives $\frac{0.0005}{10.7}$ = 0.000047 = 0.0047% increase and $\frac{0.0075}{10.7}$ = 0.0007 = 0.07% increase.

IV. CALCULATIONS OF RISK

Table 1 gives the radiation dose values provided by Dr. Robison for use in developing estimates of increased health risks in the Bikini population.

A. Risks for 14 Different Living Conditions

1. Cancer Risks

Table 3 shows the calculations for estimates of increased cancer risk for 14 different living conditions.

2. Birth Defects Risks

Table 3 gives the calculations for the estimates of birth defects.

B. Risk Estimates Based on BEIR-III

Table 4 gives risk estimates based on BEIR-III risk coefficients. These were calculated for comparison purposes only and were not used in the Bikini book. The highest estimates for cancer risk result from using the linear relative risk model and are about the same as those given in Table 2 for the relative risk model. The lowest estimates result from the linear-quadratic absolute risk model and are slightly less than those for the absolute model in Table 2. Thus, as far as estimates of cancer risk are concerned, those obtained using risk coefficients from BEIR-I are in the same general range as those obtained using risk coefficients from BEIR-III.

Risk estimates for birth defects obtained using the risk factor from BEIR-I gives values about three times those obtained using the upper value of the range of risk factors given in BEIR-III. If BEIR-III risk factors for birth defects represent a more enlightened assessment of this potential consequence of radiation exposure than the factor taken from BEIR-I for overall health defects, then the estimates in the Bikini book may be conservative by a factor of three.

Females

Identification Number	Age	Total Whole Body Dose (mrem)	
6111	32	250	
6097	19	950	
6115	43	1600	
6109	15	760	
6091	13	1300	
6046	43	600	
6061	32	1400	
6122	70	1600	
6030	10	1600	
6129	13	850	
6027	6	1200	
6010	8	2000	
6105	5	1500	
6059	19	400	
6124	54	390	
6058	18	1200	
6036	27	340	
6110	32	1400	
6051	19	1200	
6092	8	2400	(highest value)
6080	7	310	
6038	6	1400	
6103	9	1600	
6028	7	1800	
6044	6	2200	
6062	21	1100	
6034	46	1800	
865	45	1300	
6050	22	710	
6094	10	2100	
6112	35	420	
6035	20	1400	
6045	28	270	
6108	24	730	
6063	24	1100	
525	37	470	
934	43	2100	
6106	6	1100	
6025	5	1300	
6113	25	880	
6060	22	790	
6032	32	1400	
6123	50	1000	
6098	16	720	
6065	19	910	
6114	32	290	
6064	30	1300	
6081	9	610	
6048	13	660	
		44,320	(Total for 41 under age 40) Average = 1080.98 mrem

Total for all 49 females = 54,710

Average = 1116.55 mrem

APPENDIX

Estimates of Radiation Doses Received By Person Who Visited at Bikini for About 10 Years Until August 1978

A. Bone Marrow Doses - Calculation of Average Dose (Values in mrem)

Male		Female	
1600	2600	260	430
1600	1600	1000	1500
300	710	1700	280
1300	510	810	770
1200	2100	1400	1100
1300	1800	700	430
1600	680	1500	2200
890	500	1700	1200
2400	1100	1600	1300
1300	350	900	900
1500	2700	1200	820
1900	1600	2100	1400
900	210	1500	1100
2100	2100	410	760
310	1400	400	1000
1500	1900	1300	300
370	1600	340	1400
1300	1900	1500	620
2300	1600	1200	670
1900	3000 (highest value)	2400	56,200 mrem
1600	72,360 mrem	320	
480	n = 50	1400	n = 49
1800		1600	
2000		1900	
2500		2300	
2300		1100	
1900		1900	
590		1400	
1500		740	
2600		2200	

Average dose to all people

72.36 rem
56.20 rem
128.56

$$\frac{128.56}{99} = 1.2986 = 1.3 \text{ rem per person}$$

B. Whole Body Dose

Males

Identification Number	Age	Total Whole Body Dose (mrem)
6001	66	1400
6127	13	1500
6130	29	300
6076	39	1300
813	23	1200
6019	48	1100
6132	12	1500
6066	32	830
6070	28	2200
6118	22	1200
6117	22	1400
6128	31	1800
6015	11	870
6033	27	2000
6007	35	300
6008	32	1400
6071	32	350
863	27	1200
6086	46	2100
6067	32	1700
6073	24	1400
6072	20	460
6119	17	1700
864	51	1900
966	56	3200 (highest value)
6009	6	2200
6049	8	1900
6042	7	580
6014	5	1500
6012	7	2400
6016	10	2400
6013	5	1600
6005	38	700
6135	35	500
6125	35	2100
6067	56	1700
6002	65	670
6006	37	490
6096	48	1100
80	69	330
6017	49	2300
6058	56	1500
6004	28	200
6018	34	1900
6126	35	1400
6003	22	1700
6023	8	1500
6131	14	1800
6011	11	1400
6133	11	2800
		53,230 (Total for 39 under age 40)

Total for all 50 males = 70,530

Average = 1410.6 mrem

Average = 1364.87 mrem

Table 1

ESTIMATED RADIATION DOSES TO RESIDENTS OF
ENEU AND/OR BIKINI ISLANDS ASSUMING VARIOUS LIVING PATTERNS*

Residence Island	Years on/ Years off	Time on Eneu (%)	Time on Bikini (%)	Imported Food (50% of Diet)	Maximum Annual Dose (Millirem)** to Bone Marrow	30 Year Dose (Millirem)	
						Whole Body	Bone Marrow
Eneu	Permanent	100	0	Yes	390	2,800	3,000
Eneu	Permanent	100	0	No	780	5,400	6,000
Bikini	Permanent	0	100	Yes	3300	24,000	25,000
Bikini	Permanent	0	100	No	6200	44,000	47,000
Eneu	Permanent	90	10	Yes	440	3,200	3,400
Eneu	Permanent	90	10	No	830	5,900	6,500
Eneu	1/1	100	0	Yes	280	1,400	1,500
Eneu	1/1	100	0	No	540	2,800	3,100
Eneu	1/1	90	10	Yes	330	1,600	1,700
Eneu	1/1	90	10	No	590	3,000	3,300
Eneu	1/2	100	0	Yes	280	960	1,030
Eneu	1/2	100	0	No	540	1,900	2,100
Eneu	1/2	90	10	Yes	330	1,100	1,200
Eneu	1/2	90	10	No	590	2,000	2,200
Eneu	1/3	100	0	Yes	280	760	810
Eneu	1/3	100	0	No	540	1,500	1,700
Eneu	1/3	90	10	Yes	330	860	920
Eneu	1/3	90	10	No	590	1,600	1,800

* Doses are rounded off.

** Numerical value given is three times the average.

Table 2
CANCER RISKS

1 Living Conditions	2 Initial Population	3 30-Yr Bone Marrow Dose (rem)	4 30-Yr Person (rem)	5 # of Births Expected in 30 Yr	6 30-Yr Dose (0.36 x Col. 3) (rem)	7 30-Y Additi Person
NEU-100%						
1. Imported food	550	3.0	1650	1300	1.08	140
2. No imported food	550	6.0	3300	1300	2.16	280
IKINI-100%						
3. Imported food	550	25.	13750	1300	9.0	1170
4. No imported food	550	47.	25850	1300	16.92	2199
NEU-330 days BIKINI-35 days						
5. Imported food	550	3.4	1870	1300	1.224	159
6. No imported food	550	6.5	3575	1300	2.340	304
ENEU-1 year on and 1 year off						
7. Imported food	350	1.5	525	800	.54	4
8. No imported food	350	3.1	1085	800	1.116	8
ENEU-330 days BIKINI-35 days 1 year on and 1 year off						
9. Imported food	350	1.7	595	800	.612	4
10. No imported food	350	3.3	1155	800	1.188	9
ENEU-1 year on and 2 years off						
11. Imported food	235	1.03	242	550	.371	2
12. No imported food	235	2.1	494	550	.756	4
ENEU-330 days BIKINI-35 days 1 year on and 2 years off						
13. Imported food	235	1.2	282	550	.432	[illegible]
14. No imported food	235	2.2	517	550	.792	[illegible]

* 87×10^{-6} per person rem

+ 458×10^{-6} per person rem

Table 3

BIRTH DEFECTS

Sept. 10, 1980

1 Living Conditions	2 Initial Population	3 # of Births in 30 Yr	4 Spontaneous Birth Defects (10.7%)	5 30-Yr Whole Body Dose (rem)	6 Total % Increase (0.2%/rem)	7 No. of Increased Birth Defects*	8 % Increase
1 (SAME AS IN Table 1)	550	1300	139.1→140	2.8	.56	.78	.56
2	550	1300	139.1→140	5.4	1.08	1.51	1.09
3	550	1300	140	24	4.8	6.72	4.83
4	550	1300	140	44	8.8	12.32	8.86
5	550	1300	140	3.2	.64	.896	0.645
6	550	1300	140	5.9	1.18	1.65	1.19
7	350	800	85.6→90	1.4	.28	.252	.294
8	350	800	85.6→90	2.8	.56	.50	.58
9	350	800	90	1.6	.32	.288	.336
10	350	800	90	3.0	.6	.54	.63
11	235	550	58.85→60	.96	.192	.1152	.196
12	235	550	58.85→60	1.9	.38	.228	.387
13	235	550	58.85→60	1.1	.22	.132	.22
14	235	550	58.85→60	2.0	.4	.24	.41

* Values were rounded for use in the Bikini book.

Table 4

Risk Estimates Based on BEIR-III

	Cancer				Birth Defects					
	Total Person rem	Relative Risk		Absolute		Number of Births in 30 Yrs	30-Yr Whole Body Dose (rem)	Birth Defects (5-75/10 /rem)	Spontaneous Number	% Increase***
		L-Q 182*	L-L 430	L-Q 67	L-L 158					
1	3054	.556	1.31	.205	..483	1300	2.8	.0182-.27**	139	0.19
2	6108	1.11	2.63	.409	.965	1300	5.4	.035-.527	139	0.38
3	25450	4.63	10.94	1.71	4.02	1300	24.0	.156-2.34	139	1.68
4	47846	8.71	20.57	3.21	7.56	1300	44.0	.286-4.29	139	3.1
5	3461	.63	1.49	.23	.547	1300	3.2	.021-.312	139	0.22
6	6617	1.20	2.85	.44	1.05	1300	5.9	.038-.575	139	0.414
7	957	.174	.41	.064	.15	800	1.4	.0056-.084	85.6	0.098
8	1978	.36	.851	.133	.313	800	2.8	.011-.168	85.6	0.196
9	1085	.197	.467	.073	.17	800	1.6	.0064-.096	85.6	0.112
10	2105	.383	.905	.141	.33	800	3.0	.012-.18	85.6	0.21
11	446	.081	.192	.0298	.0705	550	.96	.0026-.04	58.85	0.068
12	910	.166	.39	.061	.144	550	1.9	.0052-.078	58.85	0.13
13	520	.095	.224	.035	.082	550	1.1	.0030-.045	58.85	0.076
14	953	.173	.41	.064	.151	550	2.0	.0055-.0825	58.85	0.14
	1	2	3	4	5	6	7	8	9	10

* Risk Coefficient
182×10^{-6} man rem

** eg. $\frac{2.8 \text{ rem} \times 5 \times 1300 \text{ births}}{10^6}$

*** Based on highest value in Column 8.