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Reviewed by [signature] Date 5/1/97

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409943

October 8, 1987

REPOSITORY P.N.N.L.
COLLECTION Marshall Islands
BOX No. 5689
FOLDER Marshall Islands

Dr. Henry I. Kohn
Chairman
1203 Shattuck Avenue
Berkeley, CA 94709

Dear Dr. Kohn:

Enclosed are copies of the calculations used to project health effects for the Northern Marshall Islands used in the book, "The Meaning of Radiation for Those Atolls in the Northern Part of the Marshall Islands That Were Surveyed in 1987." I believe this will fully explain the values in the book, but if you have questions please call.

I apologize for having to cancel our meeting last week. I returned from Europe to an unexpectedly full schedule.

I hope your work for the Marshallese goes well.

With best regards,

Bill

W. J. Bair, Ph.D.
Manager
Life Sciences Center

WJB:kb

Enclosures

September 10, 1982

MT

CALCULATION OF POTENTIAL RADIATION CAUSED HEALTH EFFECTS FOR PERSONS LIVING IN THE NORTHERN MARSHALL ISLANDS

Potential health effects for persons living in the northern Marshall Islands are calculated using the same assumptions and same methods used for the Bikini population (copy attached). Risk coefficients from both BEIR I and BEIR III were used providing not only a range of estimates but also a comparison of the most conservative (linear, relative risk model) with what would be described by many radiation biologists as the most probable (linear-quadratic, absolute model).

POPULATION ESTIMATES

The following population estimates are derived by simple ratios from the Bikini calculation (copy attached) for a population of 550. These calculations predicted 1277 births, 164 deaths over a period of 30 years and a final population of 1684 after 30 years for an initial population of 550.

Deaths in 30 years: $\frac{164}{550} = \frac{\text{deaths in population of interest}}{\text{initial population of interest}}$

Births in 30 years: $\frac{1277}{550} = \frac{\text{births in population of interest}}{\text{initial population of interest}}$

Population after 30 years: $\frac{1684}{550} = \frac{\text{population after 30 years}}{\text{initial population of interest}}$

Also from the Bikini population, the estimate of the full 30 year dose received by children born during the 30 year period is 0.36 of the dose persons living the entire 30 year period would receive.

September 10, 1982

RISK COEFFICIENTS

Both BEIR I and BEIR III risk coefficients are used. These are as follows:

BEIR I

Cancer--Minimum: Absolute risk of leukemia (26×10^{-6} rem^{-1}) + 30 year elevated risk for other cancers (61×10^{-6} rem^{-1}) = 87×10^{-6} rem^{-1}.

Maximum: Relative risk of leukemia (37×10^{-6} rem^{-1}) + lifetime elevated risk (421×10^{-6} rem^{-1}) = 458×10^{-6} rem^{-1}.

Genetic Effects: 0.2% per rem in first generation.

BEIR III

Cancer--Minimum: Absolute lifetime risk of cancer for continuous exposure, 67×10^{-6} rad^{-1} (low LET) based on linear quadratic model.

Maximum: Relative lifetime risk of cancer for continuous exposure, 430×10^{-6} rad^{-1}, based on linear model.

Genetic Effects--Minimum: ~~75~~ 5 $\times 10^{-6}$ increase per rem in first generation.

Maximum: ~~5.0~~ 75 $\times 10^{-6}$ increase per rem in first generation.

CANCER RISK

OCTOBER 31, 1982

Atoll	1 Initial Population	2 30-Year Bone Marrow Dose* (rem)	3 30-Year Person Rems (Col. 1 x Col. 2)	4 Number of Births Expected in 30 Years	5 30-Year Dose (0.36 x Col. 2) (rem)	6 30-Year Additional Person Rems (Col. 4 x Col. 5)	7 Total Person Rems (Col. 3 + Col. 6)
Rongelap (Rongelap) [135]	233	3.300	768.9	541	1.19	643.8	1412.7
Likiep (Likiep) [25]	487	0.580	282.5	1130	.21	237.3	519.8
Mejit [32]	329	0.730	240.2	764	.26	198.6	438.8
Utrik (Utrik) [24 (25)]	328	0.590	193.5	762	.21	160.02	353.5
Ujelang [6.2 (6)]	100	0.150	15	232	.054	12.5	27.5
Ailuk (Ailuk) [30]	420	0.680	285.6	975	.245	238.9	524.5
Wotho (Wotho) [10]	76	0.230	17.5	177	.083	14.7	32.2
Taka (Taka) [7]	100	0.170	17	232	.061	14.5	31.2
Jemo [16]	100	0.390	39	232	.14	32.5	71.5
Bikar [69 (70)]	100	1.800	180	232	.65	150.8	330.8
Rongerik (Rongerik) [90]	100	2.100	210	232	.756	175.4	385.4
Ailinginae (Knox) [87 (90)]	100	2.100	210	232	.756	175.4	385.4

* Highest dose values were used. These were based on BNL Community A or B Survey.
( ) Numbers used in book.
[ ] Maximum annual dose in millirem.

8	9	10	11	12	13	14
	Number of Cancer Deaths			Natural Rates		
BEIR-I Absolute (Col. 7 x 87 x 10^{-6} rem^{-1})	BEIR-I Relative (Col. 7 x 458 x 10^{-6} rem^{-1})	BEIR-III Absolute (Col. 7 x 67 x 10^{-6} rem^{-1})	BEIR-III Relative (Col. 7 x 430 x 10^{-6} rem^{-1})	Deaths in 30 years	Cancer (15% of All Deaths)	Percent Increase = (Col. 11 ÷ Col. 13 x 100)
	0.647 (0.6)	0.095 (0.1)		69.5	10	
	0.238 (0.2)	0.0348 (0.03)		145	22 (20)	
	0.201 (0.2)	0.0294 (0.03)		98	15	
	0.162 (0.2)	0.0237 (0.02)		97.8	15	
	0.0123 (0.01)	0.0018 (0.002)		30	4.5 (5)	
	0.240 (0.2)	0.035 (0.04)		125	19 (20)	
	0.0147 (0.01)	0.0022 (0.002)		22.7	3	
	0.0143 (0.01)	0.0021 (0.002)		30	4.5 (5)	
	0.0327 (0.03)	0.0048 (0.005)		30	4.5 (5)	
	0.152 (0.2)	0.022 (0.02)		30	4.5 (5)	
	0.177 (0.2)	0.0258 (0.03)		30	4.5 (5)	
	0.177 (0.2)	0.0258 (0.03)		30	4.5 (5)	

2

1 [redacted]

Atoll	Initi Populat[redacted]
Rongelap (Rongelap)	233[redacted]
Likiep (Likiep)	487[redacted]
Mejit	329[redacted]
Utrik (Utrik)	32[redacted]
Ujelang	10[redacted]
Ailuk (Ailuk)	42[redacted]
Wotho (Wotho)	7[redacted]
Taka (Taka)	10[redacted]
Jemo	10[redacted]
Bikar	10[redacted]
Rongerik	10[redacted]
Ailinginae (Knox)	10[redacted]

* Highest dose values were used. [redacted]
( ) Numbers used in book.

8	9	10	11
	BEIR-III		
30-Year WB Dose x Number of Births (Column 2 x Column 4)	Minimum Number of Increased Effects (Column 8 x 5 x 10^{-6} per rem)	Maximum Number of Increased Effects (Column 8 x 75 x 10^{-6} per rem)	Percent Increased (Column 10 ÷ Column 3 x 100)
1352.5	0.0068 (0.007)	0.10	
598.9	0.003	0.045 (0.05)	
542.44	0.0027 (0.003)	0.041 (0.04)	
373.4	0.0019 (0.002)	0.028 (0.03)	
29.9	0.00015 (0.0002)	0.0022 (0.002)	
633.75	0.0032 (0.003)	0.0475 (0.05)	
35.4	0.00018 (0.0002)	0.0027 (0.003)	
32.2	0.00016 (0.0002)	0.0024 (0.002)	
75.9	0.00038 (0.0004)	0.0057 (0.006)	
119.6	0.0006	0.009	
414.	0.0021 (0.002)	0.031 (0.03)	
391.	0.00196 (0.002)	0.029 (0.03)	

data in purple – Called to me by Bill Robison Oct 30, 1982

DRAFT

Table 21. Maximum annual wholebody and bone marrow doses in mrem/y for alternate diets.

Atoll/Island	MLSC Ujelang Diet Survey: Whole body	MLSC Ujelang Diet Survey: Bone marrow	BNL Community B Diet Survey: Whole body	BNL Community B Diet Survey: Bone marrow	BNL Community A Diet Survey: Whole body	BNL Community A Diet Survey: Bone marrow
Likiep						
Rikuraru	3.4 ✓	3.6 ✓			16 14	17 15
Likiep	5.2 ✓	5.4 ✓			25 23	26 [25]
Agony	3.7 ✓	4 ✓			20 18	21 20
Kapenor	3.1 3.2	3.4 ✓			14 13	15 14
Taka						
Taka	4.8 —	5.1 5.3	6.2 6.1	7.7 [7.0]		
Eiluk	4.1 3.6	4.5 4.0	4.9 3.8	7.4 4.3		
Jemo						
Jemo	4.3 4.2	4.7 4.5			19 14	21 [16]
Bikar						
Jaboerukku	6.1 ✓	8.8 10			19 ✓	57 [69] (90Sr – high)
Bikar	6 ✓	6.4 6.6			23 ✓	28 30
Rongerik						
Rongerik	60 ✓	66 ✓	81 ✓	151 [90]		
Eniwetak	42 ✓	44 45	69 ✓	89 73		
Mejit						
Mejit	5.8 5.9	5.9 6.0			31 ✓	[32] ✓
Rongelap						
Naen	330 325	350 330	505 490	796 580		
Kabelle	130 ✓	140 ✓	~~196~~ 200	300 ✓		
Mellu	92 91	97 ✓	212 200	284 270		
Eniaetok	95 ✓	96 100	154 150	172 220		
Rongelap	56 ✓	58 ✓	112 110	138 [135]		
Arbar	34 35	37 39	57 55	89 90		

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Table 21. (Continued)

Atoll/Island	MLSC Ujelang Diet Survey: Whole body	MLSC Ujelang Diet Survey: Bone marrow	BNL Community B Diet Survey: Whole body	BNL Community B Diet Survey: Bone marrow	BNL Community A Diet Survey: Whole body	BNL Community A Diet Survey: Bone marrow
Utirik						
Utirik	11 (11)	12 ✓	23 (22)	27 (24)		
Aon	15 ✓	16 ✓	30 (29)	30 (31)		
Ujelang						
Ujelang	3.2 (3.3)	3.4 (3.5)	5.6 (5.7)	6.2 (6.2)		
Wotho						
Medyeron	2.4 ✓	2.6 (2.7)			10 ✓	13 (14)
Wotho	2.5 ✓	2.7 ✓			8.6 ✓	9.6 ✓
Kabben	2.5 ✓	2.7 ✓			7.7 ✓	8.7 ✓
Ailinginae						
Knox	25 ✓	25 (27)	77 (76)	78 (67)		
Nechuwanen	22 ✓	23 (24)	45 (44)	49 (54)		
Mogiri	24 ✓	25 (26)	45 (44)	61 (58)		
Sifo	13 ✓	14 ✓	20 ✓	29 (25)		
Ailuk						
Kapen	4.6 (4.7)	26 (4.8)			23 (22)	263 (23)
Enijabro	3.9 ✓	4.0 (4.1)			21 (20)	22 (21)
Enejelar	4.1 ✓	4.2 ✓			25 (24)	25 (24)
Bigen	5.9 ✓	9.7 (6.1)			29 (29)	93 (29)
Aliet	3.9 ✓	4.1 ✓			28 (27)	29 (28)
Berejao	4.1 ✓	4.2 (4.3)			35 (34)	36 (35)
Ailuk	4.7 ✓	4.8 (4.9)			29 ✓	30 ✓
Agulne	4.8 (4.5)	4.6 (4.7)			24 ✓	25 ✓

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Table 22. The 30-y integral wholebody and bone marrow dose in rem for alternate diets.

Atoll/Island	MLSC Ujelang Diet Survey Whole body	MLSC Ujelang Diet Survey Bone marrow	BNL Community B Diet Survey Whole body	BNL Community B Diet Survey Bone marrow	BNL Community A Diet Survey Whole body	BNL Community A Diet Survey Bone marrow
Likiep						
Rikuraru	0.077	0.084			0.36	0.4
Likiep	0.12	0.12			0.56	0.60
Agony	0.084	0.097			0.45	0.5
Kapenor	0.071	0.079			0.31	0.36
Taka						
Taka	0.11	0.12	0.14	0.19		
Eluk	0.093	0.11	0.11	0.19		
Jemo						
Jemo	0.098	0.11			0.44	0.50
Bikar						
Jaboerukku	0.14	0.22			0.44	1.5
Bikar	0.14	0.15			0.52	0.69
Rongerik						
Rongerik	1.3	1.6	1.8	3.8		
Eniwetak	0.94	1.0	1.5	2.2		
Mejit						
Mejit	0.13	0.14			0.71	0.73
Rongelap						
Naen	7.1	7.9	11	20		
Kabelle	2.9	3.3	4.4	7.6		
Mellu	2.0	2.2	4.8	7.0		
Eniaetok	2.1	2.2	3.5	4.1		
Rongelap	1.3	1.3	2.5	3.4		
Arbar	0.75	0.86	1.3	2.2		

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Table 22. (Continued).

Atoll/Island	MLSC Ujelang Diet Survey Whole body	MLSC Ujelang Diet Survey Bone marrow	BNL Community B Diet Survey Whole body	BNL Community B Diet Survey Bone marrow	BNL Community A Diet Survey Whole body	BNL Community A Diet Survey Bone marrow
Utirik						
Utirik	0.25	0.28	0.53	0.68		
Aon	0.35	0.39	0.68	0.72		
Ujelang						
Ujelang	0.073	0.081	0.13	0.15		
Wotho						
Medjeron	0.054	0.063			0.24	0.33
Wotho	0.057	0.062			0.2	0.23
Kabben	0.056	0.063			0.18	0.20
Ailinginae						
Knox	0.57	0.57	1.8	1.8		
Uechuwanen	0.5	0.53	1.0	1.2		
Mogiri	0.53	0.58	1.0	1.5		
Sifo	0.28	0.32	0.45	0.73		
Ailuk						
Kapen	0.11	0.30			0.52	2.5
Enijabro	0.088	0.094			0.48	0.5
Enejelar	0.092	0.098			0.56	0.58
Bigen	0.13	0.20			0.66	1.3
Aliet	0.088	0.094			0.63	0.66
Berejao	0.092	0.098			0.79	0.82
Ailuk	0.10	0.11			0.66	0.69
Agulne	0.10	0.11			0.55	0.57

SUMMARY DATA - BOOK FOR NORTHERN MARSHALLS, OCTOBER 31, 1982

Atoll (1980) Population)	Highest Dose to Individual in 1 Year (mrem)	30 Year Whole Body Dose (mrem)	30 Year Bone Marrow Dose (mrem)	30 Year Excess Cancers	30 Year Excess Birth Defects
Ujelang (100)	A. 6.2 x 3 ≈ 20	130	150	0.002 - 0.01	0.0002-0.002
	B. 6.2 x 3=18.6 (20)	130	150	0.002 - 0.01	0.0002-0.002
Wotho (76)	A. 9.6 x 3 ≈ 30	200	230	0.002 - 0.01	0.0002-0.003
	B. 10 x 3 = 30	200	230	0.002 - 0.01	0.0002-0.003
Ailinginae (100*)	A. 78 x 3 ≈ 230	1800	1800	0.02 - 0.2	0.002 - 0.03
	B. 87 x 3 = 261 (270)	1 00	2100	0.03 - 0.2	0.002 - 0.03
Rongelap (233)	A. 138 x 3 ≈ 400	2500	3400	0.1 - 0.7	0.007 - 0.1
	B. 135 x 3 =405	2500	3300	0.1 - 0.6	0.007 - 0.1
Rongerik (100*)	A. 151 x 3 ≈ 450	1800	3800	0.05 - 0.3	0.002 - 0.03
	B. 90 x 3 = 270	1800	2100	0.03 - 0.2	0.002 - 0.03
Likiep (487)	A. 26 x 3 ≈ 80	560	600	0.04 - 0.3	0.003 - 0.05
	B. 25 x 3 = 75	530	580	0.03 - 0.2	0.003 - 0.05
Taka (100*)	A. 7.7 x 3 ≈ 20	140	190	0.002 - 0.02	0.0002-0.003
	B. 7. x 3 = 21 (20)	140	170	0.002 - 0.01	0.0002-0.002
Jemo (100*)	A. 21 x 3 ≈ 60	440	500	0.006 - 0.04	0.0005-0.008
	B. 16 x 3 = 48 (50)	330	390	0.005 - 0.03	0.0004-0.006
Utrik (328)	A. 27 x 3 ≈ 80	530	680	0.03 - 0.2	0.002 - 0.03
	B. 24 x 3 = 72	490	590	0.02 - 0.2	0.002 - 0.03
Bikar (100*)	A. 57 x 3 ≈ 170	520	690	0.02 - 0.1	0.0006-0.009
	B. 69 x 3 = 207 (210)	520	1800	0.02 - 0.2	0.0006-0.009
Ailuk (420)	A. 30 x 3 ≈ 90	660	690	0.04 - 0.2	0.003 - 0.05
	B. 30 x 3 = 90	650	680	0.04 - 0.2	0.003 - 0.05
Mejit (329)	A. 32 x 3 ≈ 100	700	730	0.03 - 0.2	0.003 - 0.04
	B. 32 x 3 = 96 (100)	710	730	0.03 - 0.2	0.003 - 0.04

* For uninhabited islands, calculations were based on possibility of 100 people living there in the future.

^ Based on first draft dose data

[redacted]

Please call if you have any questions.

Battelle

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

BASES FOR CALCULATION OF RISK ESTIMATES USED IN "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

was already conservative based on comparisons with BEIR-III, we elected to use the 30-year whole body dose as provided us--not doubled.

5. For the 140 persons who returned to Bikini and were removed in August 1978, it was assumed that no children will be conceived by persons above age 40, that 300 children will be born after August 1978, and that all children born will be offspring of parents, both of whom returned to Bikini. The parental dose was obtained as follows:

Average dose to males < 40 years old	=	1.36 rem
Average dose to females < 40 years old	=	1.08 rem
Total parental dose	=	2.44 rem
Parental dose used in calculations	=	1.22 rem

6. The average dose values for persons who lived on Bikini were calculated from individual dose data (whole body and bone marrow) for 50 males and 49 females. These values are tabulated in the appendix.

7. The spontaneous incidence of birth defects was taken to be 10.7% of all live births from BEIR-III.

8. The normal incidence of cancer deaths was assumed to be 15%. A value less than the approximately 20% given for the U.S. population was used because the Bikini people have been and will probably be exposed to much lower limits of environmental carcinogens than people living in the U.S. and because of limited medical services and prevalence of other risks such as drowning, poisoning, etc. Other causes of death are probably higher in the Bikini population than in the U.S. population. We also suspected the average life span was less than in the U.S. population, which might tend to reduce the number of cancers that would occur in the elderly.

9. The largest dose a person might receive in a year was estimated to be three times the average dose. Data in the appendix for individuals show that the highest individual dose is more than twice the average but less than three times.

[redacted]
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.

show that the highest individual dose is more than twice the average but less than three times.

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:

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

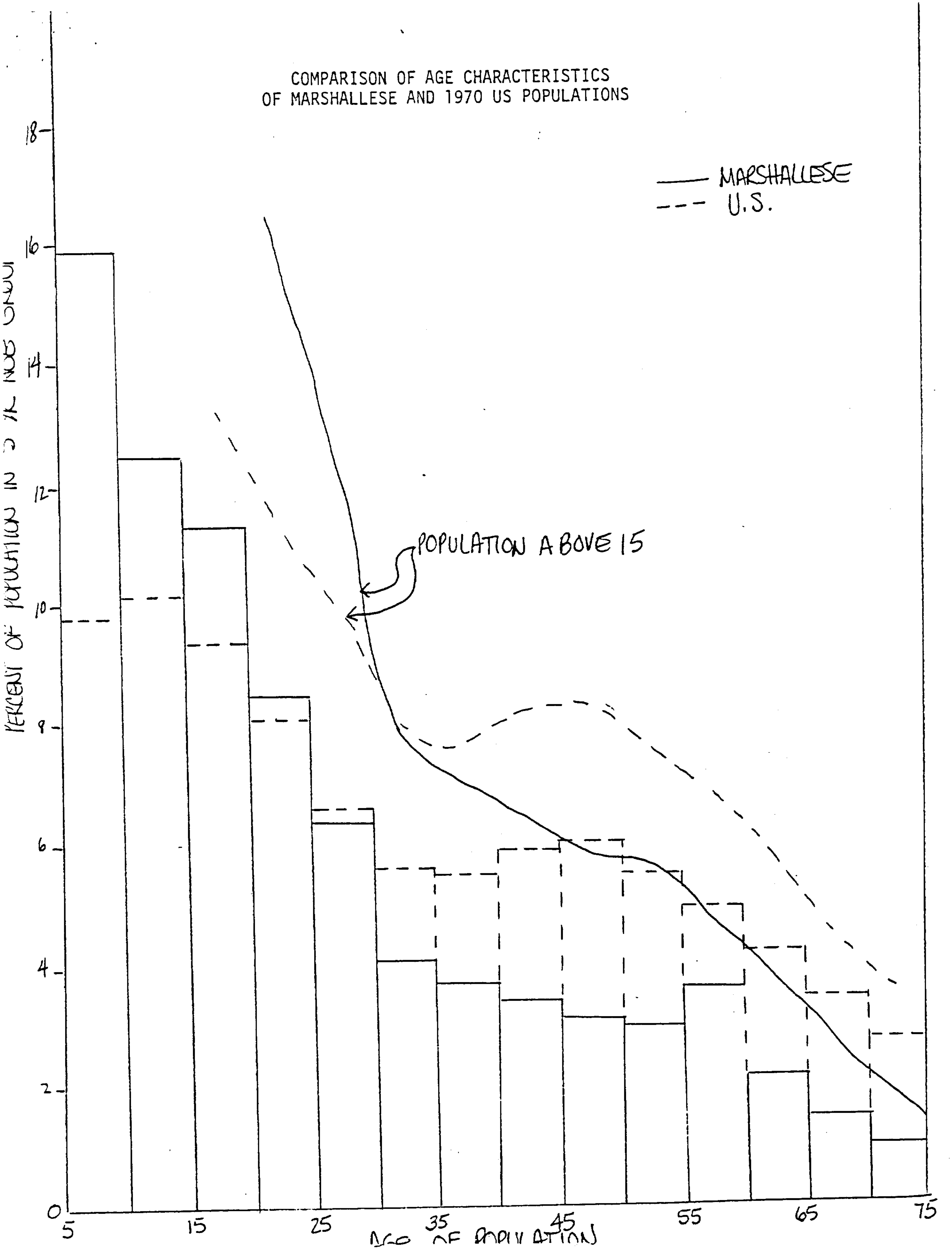
$$\text{Deaths} = \frac{0.0054 \times 550}{\ln 1.038}\ [1.038^{30} - 1] = 164$$

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
0
2
4
6
8
10
12
14
16
18
5
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

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)

	Single exposure to 10 rad		Continous xposure to 1 rad/yr	
Model	Absolute	Relative	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

[redacted]

1300	[redacted]	[redacted]	[redacted]
1200	2100	1400	1100
1300	1800	700	480
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 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	2	3	4	5	6	7	8	9	10	11	
								# Cancer Deaths		Natural Rates	
Living Conditions	Initial Population	30-Yr Bone Marrow Dose (rem)	30-Yr Person (rem)	# of Births Expected in 30 Yr	30-Yr Dose (0.36 x Col. 3) (rem)	30-Yr Additional Person (rem)	Total Person (rem)	Absolute Risk *	Relative Risk +	Deaths	Cancer 15Δ
ENEU-100%											
1. Imported food	550	3.0	1650	1300	1.08	1404	3054	.266	1.399	160	24
2. No imported food	550	6.0	3300	1300	2.16	2808	6108	.531	2.797	160	24
BIKINI-100%											
3. Imported food	550	25.	13750	1300	9.0	11700	25450	2.214	11.66	160	24
4. No imported food	550	47.	25850	1300	16.92	21996	47846	4.16	21.92	160	24
ENEU-330 days BIKINI-35 days											
5. Imported food	550	3.4	1870	1300	1.224	1591	3461	.301	1.585	160	24
6. No imported food	550	6.5	3575	1300	2.340	3042	6617	.576	3.03	160	24
ENEU-1 year on and 1 year off											
7. Imported food	350	1.5	525	800	.54	432	957	.083	.438	100	15
8. No imported food	350	3.1	1085	800	1.116	892.8	1978	.172	.906	100	15
ENEU-330 days BIKINI-35 days 1 year on and 1 year off											
9. Imported food	350	1.7	595	800	.612	489.6	1085	.094	.497	100	15
10. No imported food	350	3.3	1155	800	1.188	950.4	2105	.183	.964	100	15
ENEU-1 year on and 2 years off											
11. Imported food	235	1.03	242	550	.371	203.9	446	.0388	0.204	70	11
12. No imported food	235	2.1	494	550	.756	415.8	909.8	.0792	.417	70	11
ENEU-330 days BIKINI-35 days 1 year on and 2 years off											
13. Imported food	235	1.2	282	550	.432	237.6	520	.045	.238	70	11
14. No imported food	235	2.2	517	550	.792	435.6	952.6	.083	.436	70	11

* 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 % Increas
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

SAME AS IN Table 1

* Values were rounded for use in the Bikini book.

Table 4

Risk Estimates Based on BEIR-III

		Cancer Risk				Birth Defects				
	Total Person rem	Relative L-Q 182*	Relative L-L 430	Absolute L-Q 67	Absolute L-L 158	Number of Births in 30 Yrs	30-Yr Whole Body Dose (rem)	Birth Defects (5-75/10 /rem)	Spontaneous Number	% Increase**
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.