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May 11, 1979

Northern Marshall Islands Advisory Group

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Enclosed is a report purported to describe the method used by Lawrence Livermore Lab to calculate dose.

Sincerely,

W. J. Bair

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

WJB:ms

Enclosure

REPORT BY

THE AEC TASK GROUP ON RECOMMENDATIONS FOR

CLEANUP AND REHABILITATION OF ENEWETAK ATOLL

June 19, 1974

APPENDIX V

Annual Bone and Whole-Body Doses

William L. Robison, William A. Phillips,

Yook C. Ng, Don E. Jones, and Ora A. Lowe

1. Introduction

The purpose of this appendix is to evaluate the potential annual bone doses for adults and children for the six living patterns considered in the Enewetak Radiological Survey Report (NVO-140). The bone doses presented in NVO-140 were calculated for mineral bone for adults as integrated doses for 5-, 10-, 30-, and 70-yr periods. Bone and whole-body doses to children were not considered separately because in most cases the doses predicted for adults are usually a good estimate of the dose to children. For example, the external gamma contributes similarly to both adults and children. Strontium-90 and ^{137}Cs contribute over 95% of the food-chain dose and there is evidence to show that doses to children from ingestion of ^{137}Cs are usually less than those to adults. Strontium-90 differs from ^{137}Cs. Doses to children can exceed adult doses; however, the additional dose increment to children over the first 1 to 5 yr is not large and increases the integral 30- and 70-yr doses by only a few percent. With the uncertainties involved in other parts of the dose assessment, for example the actual diet at time of return, the differentiation between child and adult integrated doses was not included in the tables.

Because of the magnitude of some of the 30-yr integral bone doses, it was decided that annual bone doses should be evaluated to indicate the living patterns and agricultural situations which are within FRC guides for annual bone doses. The more detailed assessment of bone doses is directed at estimating the dose to the critical cell population at risk

[redacted]

Sr/Ca ratio of the fetus or newborn is very similar to that of the mothers' milk.

There is considerable evidence to show that the OR milk/diet for human breast milk is in the range of 0.1 to 0.16.[3,5] The same observed ratio exists for the fetus and newborn relative to the adult diet.[1,2] This ratio has been observed directly and can also be calculated from data which indicate that the average OR body/diet for adults is 0.25;[1,6] when this is combined with a further discrimination of approximately a factor of 2 across the placental or mammary membrane, the range of values of 0.1 to 0.16 for milk or fetus is obtained.

than that calculated for adults. The OR body/diet for young infants is 0.9;[1,4] that is, the young infant nearly equilibrates with his diet. However, the mothers' milk, as discussed previously, has a Sr/Ca ratio ~ 0.1 that of the adult diet. The OR body/diet then decreases to 0.5 for a 1-year-old and by approximately 3 or 4 years of age has reached the adult value of 0.25.[2,4,6]

Similar data are available for ^{137}Cs. Cesium-137 is metabolized and turned over more rapidly in pregnant women than in nonpregnant women.[7,8] As a result, ^{137}Cs incorporation in the fetus and the resulting exposure are less than would be expected from normal retention times observed for adults. Experimental data further indicate that for the fetus and for breast-fed infants the concentration of ^{137}Cs and the resulting dose never exceeds that of the mother or of other adults.[9,10] Therefore, as indicated in reports by Rundo,[9] Iinuma _et al_.,[10] and Cook and Snyder,[11] the dose calculated for an adult for ^{137}Cs is a conservative estimate for the fetus and the newborn.

3. Dose to Children Relative to Adults

^{137}Cs — A considerable body of evidence is available which indicates that the half-time for ^{137}Cs in the body is a function of age, with a more rapid turnover for younger ages.[11-14] The biological half-time appears to be the order of 10-15 days for 1- to 2-year-old children and increases to ~100 days by age 20. It then remains reasonably constant throughout adult life. The body mass is less for the younger age groups, and these two factors tend to offset each other in dose calculations. Doses to children are generally less than for adults as a result of the combination of these two offsetting factors. When the relative dietary intake is included, children receive a lesser dose than adults. Therefore, dose estimates for adults are usually a conservative estimate for children.

<u>^{90}Sr</u> – Reports by Loutit,[15] Bennett,[16] and Rivera[17] indicate that the pCi ^{90}Sr/g Ca in human bone is greater for ages 1-5 than for ages greater than 6 yr, including adults. However, the turnover rate is much more rapid and the retention time much shorter for ^{90}Sr in ages 1-5. The combination of these two factors determines the bone burden, the annual dose, and the dose commitment resulting from a specified ingestion of ^{90}Sr. For children, these two factors tend to offset each other; the resulting dose to children, therefore, is not straightforward and is dependent upon the relative interaction of these two factors.[1] Any comparison with adults must therefore take into account the age dependence of these factors, as well as the difference in dietary intake. The model reported by Bennett[16] is therefore used for estimating the doses to children.

4. <u>Dose Models and Diet</u>

<u>^{90}Sr</u> – Models developed by ICRP for estimating the bone dose from ingested ^{90}Sr are considered to be age invariant.[18-20] A recent model from Bennett[16] does model the child separately from the adult, and this model is applied for estimating the bone doses to children.

The bone-marrow dose-rates to children are calculated by combining Bennett's model for children with the approach developed by Spiers[21] and used in the UNSCEAR report[22] for estimating bone-marrow dose from the mineral or matrix bone dose. The values used for converting D_o doses, to bone-marrow and endosteal cell doses, are 0.314 and 0.434 respectively. Bennett's model also extrapolates to the adult case and is combined with the Spiers approach for predicting the bone-marrow doses to adults.

The bone mass is assumed to correlate directly with body mass, and these data as a function of age are taken from Spiers.[21] These body masses are based upon average data from the U.S. population and a factor of 0.85 was incorporated to account for the smaller size of the Enewetakese. The calcium concentration in bone (gCa/g bone) as a function of age is taken from Bennett.[16]

In calculating the mineral bone dose (D_o dose) in NVO-140, the approach of ICRP[18] was followed, using a QF = 1 and n = 5. The doses calculated from this model are compared to the 3-rem/yr guide (ICRP 9)[23] for bone for general public. However, in assessing the annual dose to both children and adults, the bone marrow is taken as the critical organ, and the recommendations in ICRP 11[24] are used.

In this model the quality factor is still one (QF = 1), and the "n" factor is no longer applicable. The bone marrow is considered in the category of sensitive blood-forming organs, and the corresponding dose guide for such organs is 0.5 rem/yr rather than the 3 rem/yr for mineral bone.

[redacted]

Initial dietary intakes are calculated and doses are predicted, based upon the initial intake and the exponential loss of ^{137}Cs in the diet at a rate equal to the physical half-time of ^{137}Cs.

<u>Diet</u> — The diet for adults is that listed in the original report NVO-140. For children from ages 1 through 10, the intake of coconut milk and coconut meat is doubled to 600 and 200 g/day, respectively. These two products are the most likely to be consumed in greater quantity by children than by adults. The rest of the diet for children is assumed to be one-half of the adult diet.

[redacted]

At age 10, it is assumed that the child is on the full adult diet. From information available, this is a conservative assumption in that children are not usually considered to reach the average adult intake until age 14 or 15. However, because of the diet changes which occur at 10 yr (i.e., pandanus, breadfruit, coconut, etc., which become available) it is convenient to use this point for adjusting the child to the adult diet, and if anything, this adjustment produces a slightly conservative dose estimate for the children due to the high ^{90}Sr content in the adult diet.

[redacted]

and decreases exponentially thereafter. The annual dose is then selected for the years at which the sum of these three components was maximum.

The maximum annual bone-marrow doses are listed in Table 1 for the case where no restrictions are placed upon the location of agriculture and source of the diet and no modifications are made for external gamma on the village island. Table 2 lists the results for the case where no restrictions

[redacted]

living patterns is the result of the [redacted] each of the situations (Table 5). For all the cases where there is a restriction on the agriculture and diet, it is assumed the village island will be plowed and graveled.

Similar results for whole-body exposure for the four different agricultural situations are presented in Tables 6-10. With no restrictions on the diet, Living Patterns 1, 2, and 5 are under FRC guides. Therefore, the bone-marrow is the more limiting feature. When the other agricultural conditions are used, the living patterns which fall below the FRC guide are the same as those for the bone-marrow dose.

[redacted]

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[redacted]

6	JANET	ALICE-IRENE	Northern Is.

a Diet change at 10 yr., i.e., 1984.

b Diet change at 10 yr., i.e., 1994.

Include
Ext.
Int.

No restrictions on diet

Village island graveled and plowed

Living Pattern	Start January 1974 Child [a]	Start January 1974 Adult [a]	Start January 1984 Child [b]	Start January 1984 Adult
1	0.047	0.045	0.047	0.043
2	0.314	0.294	0.282	0.290
3	0.718	0.677	0.680	0.672
4	2.08	1.92	1.93	1.90
5	0.317	0.300	0.285	0.296
6	1.06	0.989	0.988	0.977

Table 3. Maximum annual bonemarrow dose (rem).

Pandanus and breadfruit from southern islands

Village island graveled and plowed

Living Pattern	Start January 1974 Child [a]	Start January 1974 Adult [a]	Start January 1984 Child [b]	Start January 1984 Adult
1	0.047	0.045	0.047	0.043
2	0.148	0.149	0.200	0.142
3	0.293	0.294	0.418	0.284
4	0.786	0.774	1.16	0.749
5	0.151	0.178	0.201	0.148
6	0.428	0.437	0.574	0.419

[a] Diet change at 10 yr., i.e., 1984.

[b] Diet change at 10 yr., i.e., 1994.

Table 4. Maximum annual bonemarrow dose (rem).

Pandanus, breadfruit, coconut, tacca from southern islands

Village island graveled and plowed

	Start January 1974		Start January 1984	
Living Pattern	Child [a]	Adult [a]	Child [b]	Adult
1	0.047	0.045	0.047	0.043
2	0.122	0.130	0.092	0.101
3	0.168	0.204	0.138	0.166
4	0.415	0.516	0.325	0.392
5	0.121	0.135	0.094	0.106
6	0.253	0.354	0.202	0.254

Table 5. Maximum annual bonemarrow dose (rem).

Total diet from southern islands

Village island graveled and plowed

	Start January 1974		Start January 1984	
Living Pattern	Child [a]	Adult [a]	Child [b]	Adult
1	0.047	0.045	0.047	0.043
2	0.097	0.091	0.071	0.069
3	0.094	0.094	0.077	0.079
4	0.199	0.193	0.133	0.129
5	0.096	0.096	0.074	0.074
6	0.189	0.213	0.123	0.134

[a] Diet change at 10 yr., i.e., 1984.

[b] Diet change at 10 yr., i.e., 1994.

Table 6. Maximum annual whole-body dose (rem).

No restrictions on diet

Village island unmodified for external gamma

Living Pattern	Start January 1974 Child[a]	Start January 1974 Adult[a]	Start January 1984 Child[b]	Start January 1984 Adult
1	0.039	0.039	0.038	0.039
2	0.234	0.236	0.200	0.233
3	0.619	0.630	0.531	0.628
4	1.81	1.80	1.54	1.79
5	0.285	0.291	0.252	0.291
6	0.798	0.812	0.674	0.802

Living Pattern	Village island	Agriculture	Visitation
1	Enewetak-Parry	ALVIN-KEITH	Southern Is.
2	Enewetak-Parry	KATE-WILMA + LEROY	Northern Is.
3	JANET	JANET	Northern Is.
4	BELLE	BELLE	Northern Is.
5	JANET	KATE-WILMA + LEROY	Northern Is.
6	JANET	ALICE-IRENE	Northern Is.

[a]Diet change at 10 yr., i.e., 1984.

[b]Diet change at 10 yr., i.e., 1994.

Table 7. Maximum annual whole-body dose (rem).

No restrictions on diet

Village island graveled and plowed

Living Pattern	Start January 1974 Child[a]	Start January 1974 Adult[a]	Start January 1984 Child[b]	Start January 1984 Adult
1	0.039	0.039	0.039	0.038
2	0.234	0.236	0.200	0.233
3	0.540	0.542	0.452	0.540
4	1.56	1.55	1.30	1.55
5	0.237	0.241	0.204	0.240
6	0.749	0.761	0.631	0.757

Table 8. Maximum annual whole-body dose (rem).

Pandanus and breadfruit from southern islands

Village island graveled and plowed

Living Pattern	Start January 1974 Child[a]	Start January 1974 Adult[a]	Start January 1984 Child[b]	Start January 1984 Adult
1	0.039	0.039	0.039	0.038
2	0.125	0.128	0.146	0.127
3	0.245	0.252	0.304	0.249
4	0.662	0.663	0.846	0.656
5	0.128	0.133	0.149	0.132
6	0.350	0.367	0.430	0.363

[a]Diet change at 10 yr., i.e., 1984.

[b]Diet change at 10 yr., i.e., 1994.

Table 9. Maximum annual whole-body dose (rem).

Pandanus, breadfruit, coconut, and tacca from southern islands

Village island graveled and plowed

Living Pattern	Start January 1974 Child[a]	Start January 1974 Adult[a]	Start January 1984 Child[b]	Start January 1984 Adult
1	0.040	0.039	0.039	0.039
2	0.091	0.122	0.078	0.093
3	0.146	0.187	0.119	0.151
4	0.357	0.475	0.280	0.355
5	0.093	0.127	0.080	0.098
6	0.246	0.328	0.160	0.241

Table 10. Maximum annual whole-body dose (rem).

Total diet from southern islands

Village island graveled and plowed

Living Pattern	Start January 1974 Child[a]	Start January 1974 Adult[a]	Start January 1984 Child[b]	Start January 1984 Adult
1	0.040	0.039	0.039	0.039
2	0.090	0.083	0.065	0.066
3	0.087	0.097	0.070	0.076
4	0.192	0.191	0.126	0.126
5	0.089	0.094	0.066	0.071
6	0.182	0.211	0.116	0.131

[a] Diet change at 10 yr., i.e., 1984.

[b] Diet change at 10 yr., i.e., 1994.

[redacted]

FOLDER Enewetak April–May 1977

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Reviewed by R. Schuette Date 4/30/97

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RO Gilbert
DL Hessel
JJ Praino
WL Templeton
RC Thompson
EC Watson

Battelle
Pacific Northwest Laboratories

Date May 7, 1979

To Joe Soldat

From W. J. Bair Bill

Subject Verification of Enewetak Dose Calculations

I learned last Friday that we won't get the Lawrence Livermore Laboratory dose calculations for review until the week of May 21. If I am away when the material arrives, Roy Thompson will get it to you. Roy, Dick and Bill ar members of the Advisory Group and will be able to answer your questions.

The schedule has slipped somewhat. We will need the dose confirmation by about June 7 or 8 since the Advisory Group may meet on June 11, 12 or 13.

Costs for your work are to be charged to A56302. Martha is sending you a copy of a LLL report which they say describes their methods. Roy is reviewing this to determine whether it really does.

WJB:ms

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Pacific Northwest Laboratories

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RO Gilbert
WL Templeton
RC Thompson
EC Watson
lb/file

Date April 18, 1979

To Joe Soldat

From W. J. Bair W. J. Bair /gm

Subject

Thanks very much for your response on the question of validating the Enewetak dosimetry calculation.

I discussed your approach in Washington last week so you can probably count on having a go at it. We might gain a little more time than the ∿10 days initially indicated; we might have all of two weeks. The reason for the short time frame is a commitment made to provide some answers to the Enewetak people in late May or the 1st week of June. Data needed for the calculations are not yet available. Roy, Dick, Bill and I will be available to provide guidance.

WJB:gm

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Pacific Northwest Laboratories

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File/LB

Date April 5, 1979

To J. Soldat and E. C. Watson

From W. J. Bair W. J. Bair/ms

Subject

Can you give me a quick idea about how much effort would be required to calculate the radiation dose (whole body, bone and lung to people who might return to live on an island in the Enewetak Atoll?

The following are known:

1. Constituents of diet

2. Levels of ^{90}Sr, ^{137}Cs, ^{241}Am and ^{239}Pu in soil

3. Radionuclide contents of foodstuffs grown in soil of known radionuclide levels at Bikini. Since there are no data available on food grown at Enewetak, levels in food will have to be calculat as follows:

$$\frac{\text{Radionuclides in Bikini Food}}{\text{Radionuclides in Bikini Soil}} = \frac{\text{Radionuclides in Enewetak Food}}{\text{Radionuclides in Enewetak Soil}}$$

4. Assumptions about Resuspension, etc.

We would probably want to calculate annual and 30-year doses if the people moved back in 1980 and possibly in 1990 or some other given time in the future.

Livermore is actually doing this dose calculation. However, since so much is riding on these dose estimates, we on the Enewetak Advisory Group have recommended that the Livermore calculations be verified. It is possible that two or three labs would be asked to do the verification. I don't think it is necessary to make a major production of this. For one thing there won't be time. We would probably have about two weeks--2nd or 3rd week in May. The Livermore calculation won't be available until then. It might be possible to get the input data before then.

If you could give me a quick idea about this by Friday pm, I would appreciate it since I need it for a trip to Wash. on Sunday.

I'd also like to know whether you would be interested in doing this if DOE decides to go ahead. I don't know how much money, if any, would be available, but I would assure that you don't bear the cost.

WJB:ms

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Project Number

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BA Napier
DL Strenge
File/LB

RECEIVED APR 6 1979 W. J. BAIR

Date April 5, 1979

To W. J. Bair JKS

From J. K. Soldat/E. C. Watson

Subject Dose Calculations for Enewetak Atoll

Reference: Your memo same subject to J. K. Soldat/E. C. Watson, dated 4/5/79

Your offer to ask DOE to have PNL (and perhaps another laboratory or two) perform an independent assessment of the potential doses to future residents of Enewetak Atoll is in accordance with our discussions last week. We would be interested in performing the calculations as outlined in your memo. A quick estimate of time and cost has been made subject to the conditions given below and to refinement when the work is better defined by DOE.

• 2 man-weeks of technical manpower	$3500
• computer time	<500
TOTAL COST	$4000

The time required to conduct the analysis would be two weeks after receipt of all necessary input data from LLL.

The conditions are as follows:

1) Timing depends on potential interference of high-priority work on RHO High- and Low-Level Waste EIS's.

2) We would use the following dose codes:

   - DACRIN - inhalation (based on the new ICRP lung model)
   - PABLM - ingestion of terrestrial and aquatic foods and drinking water, if required (based on the internal dosimetry model in ICRP Publication 2).

3) We have not yet developed any dose codes which incorporate the newer formulation in ICRP-26, nor do we plan to in the near future. However, the small number of dose results requested lend themselves to hand calculations of "effective" doses and/or SI Units, if required.

4) We assume that external dose rates have been measured and calculations would not be required. A detailed calculation of the dose rates at various heights above ground contaminated with a known nuclide composition could be performed with a "shielding" type code. Such a calculation has not been included in the time and cost estimate provided above.

5) Doses would be calculated to the population group and to either an average or maximum member of the group depending upon availability

of diet data. Dose calculations for ages other than adults are not included in the estimate. Such calculations might possibly be made by hand, if data were available, for a limited number of cases.

6) Doses would be calculated for the first year of chronic intake of air, water, and food and as an accumulated 30 (or 70) year dose from 30 (70) years exposure to a decaying source. Organs of interest would be whole body, lung and bone. Others could be added at minimal cost.

7) In addition to the four nuclides you requested (Sr-90, Cs-137, Pu-239 and Am-241) several others could be added, if data were available, at minimal cost.

8) Under the time and cost constraints, we could not verify the accuracy or reasonableness of the input data received from LLL, nor could we verify that all important pathways of exposure had been identified.

If you have any questions on the calculations before you leave, call Joe Soldat on 942-4116 (work) or 943-4123 (home), or from Washington, DC (FTS: 444-4116). Ed Watson may not be in town next week.

JKS:cs

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COLLECTION Marshall Islands

BOX No. 5686

FOLDER Enewetak April-May 1979

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Reviewed by R K Schuette Date 4/30/97