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BY ~~H.R. SCHMIDT,~~ D.R. GILSON DATE: 6-16-94

Frank Cluff, Safety Advisory Group, NV

BIKINI EXPOSURE CALCULATIONS

Following our discussions on the plane and in Honolulu I agreed to make a quick check of the predictions of exposures that may be associated with the diet on Bikini. Gustafson's calculations which develop the long-range exposure potential for the Bikinians, begin to produce the key results when he sums the contribution of various items of the diet for several important radionuclides and makes comparisons with standards for the individual and for the general public. See Table VI of his May 1968 report.

In Attachment 1 I have gone through a portion of this exercise for ^{137}Cs, with which I am more familiar, and then with ^{90}Sr and ^{55}Fe. As you will see, the values check with Gustafson's permissible intake numbers for ^{137}Cs and for ^{90}Sr (depending on the calcium intake) but I get a much higher allowable daily intake for ^{55}Fe. Also I obtained a somewhat lower 5 year ^{137}Cs dose for adults, 230 mrad versus 536 mrad, and about the same 5 year ^{137}Cs dose for the worst case for children, 276 mrad versus 268 mrad.

There is one additional summary report that was an appendix to the material going to the Commission that you may not have seen. See Attachment 2. You will find that Table 3 of this appendix is similar to Table VI except certain items have been omitted from the table such as Pandanus and crabs. This makes a significant reduction in the ^{90}Sr and ^{137}Cs levels in the diet but changes the ^{55}Fe intake not at all. This is why I had more concern for ^{55}Fe predictions since I could see no way of reducing that exposure short of placing restrictions on intake of fish.

The sample computations in the Attachment for ^{137}Cs and ^{55}Fe indicate that Gustafson's predicted five year total whole body dose number may be a little high. For example, the 5 year contribution to whole body dose from ^{55}Fe of 27 mrad plus 230 mrad from ^{137}Cs plus 750 mrad external is about 1 rad instead of 1.4 rad as in Table VIII. As to the spleen dose of 30 mrad/yr from ^{55}Fe, I'll say more later.

There is one additional consideration. The pandanus will be out of the diet when the natives first return since the surveys have indicated no edible variety of this food is available much less a sufficient quantity of the edible type to meet the needs of the returning natives.

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The Ad Hoc Committee has recommended certain precautions in planting pandanus, namely removal of contaminated soil from the area of the plants, which should significantly reduce the radionuclide content of the fruit. However, there must be followup studies when these locally produced foods do become available since the levels will not be zero.

As to dose to children, I have taken what may be a worst case situation for ^{137}Cs to see how the dose compares with the value for adults. I have used as a reference, "The Half-Time of Cesium-137 in Man" (Attachment 3) and have considered the improbable case where the daily ^{137}Cs intake of the 2 year old is as high as for the adult. The resultant 5 year dose of 276 mrad for the child is not significantly different from the 230 mrad 5 year dose obtained for adults. I did not correct the child's 5 year dose for changes in biological half-time or body weight that occur over that period since the curve in Figure 4 of the cesium reference indicates that for a given intake the dose rate does not change much over this range of ages. Using this worst case assumption, I get a total 5 year dose (external plus internal) of about 1 rad for the child which agrees with the value in Table VIII.

One comment on the general subject of whole body and organ dose determinations (such as spleen) and comparisons with standards for small groups such as this Bikini population. The proper standard for use as a comparison is the value for the individual in the Bikini population. The followup studies by Conard and others will establish a basis for determining the range of individual exposures so that there should not be any surprises. Thus Gustafson's "Acceptable Intake for Individuals" in Table VI is the proper column for comparison with diet levels and the dose standard for comparison purposes for whole body, blood forming organs, etc. would be 500 mrad per year.

While I don't expect we will learn anything during the cleanup operations that will change Gustafson's predictions regarding external exposures, it may be worthwhile to again review the internal exposure question at the end of cleanup operation, particularly if additional samples of items of the diet are taken and analyzed and base-line body burden data become available. I recommend that review of such data be a consideration in the AEC determination that the cleanup project is completed and that the atoll is ready for return of the population.

The conclusion to be drawn from this exercise and from working with available data is that the estimates of internal exposures I have made are not significantly different from Dr. Gustafson's. If anything, his estimates are slightly higher than my own. Additionally, it is highly desirable to obtain more information on the levels of radioactivity in foods through the radiological support activities for the cleanup project just starting at Bikini. Also, base-line determinations of internal emitters and determinations of biological half-times must be made in order to confirm the estimates of future long term exposures for the returning Bikini people.

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Enclosures:
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Attachment 1

Daily Radionuclide Intake Associated With The Maximum Permissible Body Burden*

^{137}Cs

Max. permissible burden, occupational exposure, 30 μCi (5 rad/yr)
" " " individuals in pop., 3 μCi (.5 rad/yr)
" " " suitable sample, 1 μCi (.17 rad/yr)

Effective half-life is 100 days (See FRC Report No. 7, page 25).

For conditions of continuous intake, the daily intake associated with a given equilibrium organ burden can be determined from the following:

$$B_E = R_o T_m I_f$$

where B_E = Equilibrium organ burden

R_o = Daily intake

T_m = Mean time in reference organ

= $1.44 \times T_{eff}$

I_f = Fraction of intake reaching reference organ through ingestion

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*References are, (1) Report of ICRP Committee II as published in Health Physics, June 1960, and (2) AEC 0524, June 1967.

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Therefore:

$$R_o = B_E / 1.44 \times T_{eff} \times 1$$

$$= 1{,}000 \text{ nCi}/1.44 \times 100 \text{ days}$$

$$= 6.9 \text{ nCi/day or about } 7{,}000 \text{ pCi/day}$$

This agrees with Gustafson's value in Table VI'

^{90}Sr

The value for comparison in Table VI' can be obtained from FRC Report No.2, Table 1c. The value 200 pCi/day comes from an arbitrary reduction by a factor of three (see para 4.24, page 17) of the value 600 pCi/day that is actually equivalent to the RPG. It is assumed, however, that there is one gram of calcium intake per day which, short of some dietary supplement, the Bikinians don't have. With a calcium intake of 0.42 grams per day, the guides would be about 250 and 750 pCi/day. The Ad Hoc Committee has recommended adding calcium to the Bikini diet.

^{55}Fe

Max. permissible whole body burden, occupational exposure, 3×10^3 µCi
" " " " " individual in pop., 3×10^2 µCi
" " " " " suitable sample, 1×10^2 µCi

Effective half-life is 463 days. Fraction reaching organ is 0.1

Therefore:

$$R_o = 1 \times 10^5 \text{ nCi}/1.44 \times 463 \text{ days} \times 0.1$$

$$= 1 \times 10^5/66.7$$

$$= 1.5 \times 10^3 \text{ nCi/day}$$

$$= 1.5 \times 10^6 \text{ pCi/day}$$

This differs considerably from Gustafson's 87,000 pCi/day.

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The ICRP reference lists spleen rather than whole body as the critical organ. Gustafson probably used whole body so that the doses would be additive.

For spleen, the following is obtained:

AEC Manual Chapter 0524 which treats the case for the critical organ gives an uncontrolled area MPC for ^{55}Fe for water of 8×10^{-4} μCi/ml (for individuals). The value for the general public would be $\frac{8}{3} \times 10^{-4}$ μCi/ml. Assuming an intake on a per day basis we have:

$$\frac{8}{3} \times 10^{-4} \ \mu Ci/ml \times 1{,}200 \ ml/_{day} = .3 \ \mu Ci/day$$

$$= 3 \times 10^{5} \ pCi/day$$

Thus, even for the spleen, the dietary value of 59,500 pCi/day in Table VI' is only about 1/5 of the MPC.

<u>^{137}Cs dose (adults)</u>

At equilibrium the initial body burden would be:

$$B_E = 2{,}290 \ pCi/day \times 1.44 \times 100 \ days \times 1$$

$$= 330 \ nCi$$

Initial dose rate would be:

$$\text{Dose} = \left[330 \ \mu Ci \times 0.17 \ rad\right] / 1 \ \mu Ci$$
$$= .05 \ rad/yr$$

$$\text{Dose}_{5\,yr} = \frac{\text{Initial dose rate}}{\lambda}\left[1 - e^{-\lambda t}\right]$$

$$= \frac{.05}{.693/27}\left[1 - e^{-\frac{.693}{27} \times 5}\right]$$

$$= .23 \ rad$$

This is about one half of the Table VII' five year dose for ^{137}Cs.

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^{55}Fe dose to whole body*

$$\text{Dose} = \frac{0.06\ \mu\text{Ci/day} \times 0.5\ \text{rad/yr}}{2.4\ \mu\text{Ci/day}}$$

$$= 0.01\ \text{rad/yr}$$

$$\text{Dose}_{5\ \text{yr}} = \frac{.01}{.693/3}\left[1 - e^{-\frac{.693}{3} \times 5}\right]$$

$$= .027\ \text{rad}$$

This is about one fifth of the Table VII' five year dose for ^{55}Fe.

^{55}Fe dose to spleen**

$$\text{Dose} = \frac{0.06\ \mu\text{Ci/day} \times 0.5\ \text{rad/yr}}{.96\ \mu\text{Ci/day}}$$

$$= 0.03\ \text{rad/yr}$$

^{137}Cs dose (child)

The diet of the young child, 1 to 2 years of age, will be different from that of adults, but if the intake were as high as 2,290 pCi/day, the following body burden would be obtained:

$$B = 0.018\ R\ (x^{1/2} + e^{-x})$$ (See equation 9, the Half-Time of Cesium-137 in Man)

$$= 0.018 \times 2{,}290\ (2^{1/2} + e^{-2})$$

$$= 61.4\ \text{nCi}$$

* MPC taken from ICRP Committee II
** MPC taken from AEC 0524

The whole body dose would be:

$$D_r = \frac{B/W}{85.7}$$ (See equation 5, The Half-Time of Cesium-137 in Man)

$$= \frac{61.4/12}{85.7}$$

$$= .06 \text{ rad/yr}$$

Thus the 5 year dose would be about 276 mrad which is not significantly greater than the dose to the adults from ^{137}Cs.

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APPENDIX V TO ENCLOSURE 1

Brief Summary of the Radiological Status of the Bikini Atoll

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May 1968

A number of radiological surveys of Bikini Atoll have been made since 1946. The most recent survey was conducted in April and May 1967. The main effort was devoted to the measurement of ambient radiation levels using several types of detectors. The external radiation field was mapped in considerable detail on Bikini and Eneu Islands, and less thoroughly on the remainder of the atoll. The various radionuclides and their concentrations which gave rise to the observed radiation field were determined from field gamma-ray spectrometry. Representative samples of local plants and animals which might be eaten by the returning natives were collected and have been analyzed for radioactivity.

The results of the 1967 survey provide a basis for making reasonable estimates of the total (external plus internal) radiation exposure which the Bikinians might receive over the coming years, if they return to the atoll. Background radiation on the atoll is due almost exclusively to cosmic radiation, and there are only trace amounts of the naturally occurring radioelements in the area. Except in the immediate vicinity of nuclear detonations, the composition of the residual gamma-ray radioactivity was similar throughout the atoll, consisting of about 70% ^{137}Cs, 20% ^{60}Co, and 10% ^{125}Sb. Variations in intensity were observed from place to place; Eneu was the least contaminated, followed by Bikini Island itself. A dose gradient existed across Bikini, with lowest levels on the beach areas and highest values in the heavily overgrown interior.

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The external dose received by the returned Bikinians will depend upon where various people are located, and for what periods of time, within the island complex. Location in turn depends upon whether they are men, women, or children. The returnees (see Age Distribution table) will probably consist of about equal numbers of men and women. The amount of time likely to be spent in the four radiation domains (village area, beach, interior, and lagoon) by the various groups within the population are shown in Table 1. Probably the most time will be spent in the village area, where the dose rate is intermediate between beach and interior levels. The dose rate may be reduced one half by covering the ground with an inch of clean sand or soil. This in essence will be done in the village area through the custom of covering the dirt floor and the yard with several inches of polished coral pebbles. The expected integral dose to the population over various time intervals starting in 1970 is shown in Table 2.

The actual internal dose derived from eating native foods is somewhat more difficult to assess. However, three points should be borne in mind. (1) As in the past, the natives will doubtless take much of their sustenance from the lagoon and ocean. (2) Edible land plants will be severely limited, at least at first, due to the sparcity of fruit-bearing coconut, pandanus, etc. (3) The Bikinians have become accustomed to eating new foods, and will probably continue to eat such things as rice, flour, canned meat, and powdered milk. The only radionuclides of biological importance found in foodstuffs collected at Bikini were ^{90}Sr, ^{137}Cs and ^{55}Fe. Other nuclear species were either lacking or present in very low concentration. A notion of the possible daily intake of the above three radionuclides may be obtained by taking the diet eaten by the Rongelapese as a guide, and using the observed concentrations of radioactivity in the same food items collected on Bikini. The resultant daily intakes are shown in Table 3, and are compared with the daily intakes which will lead to acceptable body burdens for individuals and a suitable sample of the population. Special procedures which will greatly reduce the ^{90}Sr content of the fruit can be undertaken at planting when edible pandanus is re-introduced to the Atoll. Edible fruit would be available about five years after planting. The fact that edible pandanus fruit will not be available for several years removes what might have been the major source of ^{90}Sr intake and materially reduces the ^{137}Cs intake as well. Removal also of land crab meat from the diet seems advisable, and such restrictions bring the ^{90}Sr intake down to 115 pCi/day or 270 pCi/g Ca. The corresponding ^{137}Cs intake is 2290 pCi/day.

Doses to the whole body from ^{137}Cs and ^{55}Fe were calculated assuming that the reduction of radioactivity in the diet occurs only from radioactive decay. Doses to bone from ^{90}Sr were also computed. Because of marked differences in metabolism, adults and children were considered separately for internal dose purposes. The total doses to whole body and to bone for children and adults from internal and external radiation over 5-, 30- and 70-year intervals starting in 1970 are indicated in Table 4. The doses acceptable for individuals and for a suitable sample of the population during the same time intervals are also indicated.

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The estimated ^{90}Sr dose to bone is maximal because additions of calcium to the diet could readily reduce ^{90}Sr uptake.

It appears unlikely that, with moderate restrictions on living and eating habits, the dose to the whole body or to bone will reach 2 rads in 5 years, 10 rads in 30 years or 16 rads in 70 years.

TABLE 1

Population and Time Breakdowns

Population	Breakdown (%)	Estimated Time Breakdown (%)			
		Village	Beach	Interior	Lagoon
Children (0-15 yrs)	50	70	20	10	--
Women	25	65	15	20	--
Men	25	60	10	20	10

TABLE 2

Integral External Doses Starting in 1970

Time Interval (years)	Integral Dose (mrads)
5	752
10	1391
20	2455
30	3332
50	4711
70	5743

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TABLE 3

Estimated Daily Intake of ^{90}Sr, ^{137}Cs, and ^{55}Fe from Bikini Foods, (pCi/day)

Food Item	Weight consumed per day (g)	^{90}Sr	^{137}Cs	^{55}Fe
Fish	554	105	178	55,400
Birds	41	5.3	1,080	4,100
Arrowroot*	41	--	--	--
Coconut	9	1.7	1,030	--
Clams	45	1.8	1.0	--
Imports	32	.5	1.0	--
Total**	782****	115	2,290	59,500
*** Acceptable intake for suitable sample		600 pCi/g Ca	7,000	87,000
*** Acceptable intake for individuals		1,800 pCi/g Ca	21,000	200,000

* ^{90}Sr and ^{137}Cs are removed in the processing of arrowroot to make flour

** This diet contains 0.42 g calcium per day

*** Calculated in the following way:

$$\text{Daily intake} = \frac{\text{MPL}}{1.44 \times T_{1/2}\ (\text{biological})}$$

where the value of the MPL for individuals is 1/10, and for suitable sample is 1/30 of the value for radiation workers

****Other foodstuffs, (free from radioisotopic contamination) necessarily will supplement this diet.

[redacted]

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TABLE 4

Summary of Radiation Exposure (rads)

Adults

Years	Bone (^{90}Sr)*	Internal Whole body (^{137}Cs & ^{55}Fe)	External Whole Body	Total: Whole Body	Total: Bone	Reference Values**: At .17 rad/year	Reference Values**: At .5 rad/year
5	.09	.68	.75	1.43	1.52	.85	2.5
30	1.37	2.68	3.33	6.01	7.38	5.1	15.0
70	3.10	4.20	5.74	9.94	13.04	11.9	35.0

Children

Years	Bone (^{90}Sr)*	Internal Whole body (^{137}Cs & ^{55}Fe)	External Whole Body	Total: Whole Body	Total: Bone	Reference Values**: At .17 rad/year	Reference Values**: At .5 rad/year
5	.98	.41	.75	1.16	2.14	.85	2.5
30	4.06	1.99	3.33	5.32	9.38	5.1	15.0
70	6.16	4.00	5.74	9.74	15.90	11.9	35.0

* Initial ^{90}Sr intake of 115 pCi/day or 270 pCi/g Ca by both children and adults.

** Acceptable exposure for individuals is .5rad/year. Acceptable exposure for suitable sample of the population is .17rad/year.

[redacted]