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RESIDUAL CONTAMINATION OF PLANTS, ANIMALS, SOIL, AND WATER OF THE MARSHALL ISLANDS TWO YEARS FOLLOWING OPERATION CASTLE FALLOUT

Research and Development Report USNRDL-455
NS 081-001

15 August 1956

by

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ABSTRACT

The amount and distribution of radioactive material remaining on several atolls and incorporated into plants and animals of the Marshall Islands was determined two years after their contamination by fallout from the March 1, 1954 nuclear detonation of Operation CASTLE.

Readily detectable amounts of radioactive contamination were found in animals, plants and soil. Most of the activity in the edible portion of plant specimens was contributed by cesium-137

The major radionuclides found in the tissues of fish was zinc-65, and that in clams, cobalt-60.

Residual soil contamination remained confined to the surface.

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SUMMARY

The Problem

To determine the amount and distribution of radioactive material remaining on several atolls and incorporated into plants and animals two years after their contamination by fallout from the 1 March 1954 nuclear detonation of Operation CASTLE.

Findings

Readily detectable amounts of radioactive contamination were found in Marshall Island animals, plants, water and soil samples.

An increase was observed in the activity of coconuts, compared with the results of a survey made one year ago (about one year post-detonation).

Some samples of portulaca, coconut husks, pandanus keys, pandanus air roots, a clam, and certain potable water contained levels of strontium-90 which exceeded the maximum permissible concentration.

The gamma radiations over the atolls decreased by 80 per cent over the past year. This loss of activity was attributed to radioactive decay rather than the migration of nuclides to deeper layers or their erosion into the surrounding water.

The activity in fish was almost 25 per cent of that determined at the one-year post-detonation survey.

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ADMINISTRATIVE INFORMATION

This is the second report of the atoll Resurvey Project. The resurvey was made under the joint sponsorship of the Bureau of Ships and the Atomic Energy Commission, Bureau of Ships Project Number NS 081-001, Technical Objective AW-7, as described in U.S. Naval Radiological Defense Laboratory Annual Progress Report to the Bureau of Ships, DD form 613, of 6 October 1955.

The work was done jointly by the Chemical Technology Division and the Biological and Medical Sciences Division of this laboratory.

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Mr. Jarvis Todd assisted in the preparation of this report.

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CHAPTER 1

INTRODUCTION

The object of this study was to determine the persistence and fate of radioactive material in the biological systems and in the physical environment of those Marshall Islands contaminated by fallout from the 1 March 1954 nuclear detonation. For this purpose a resurvey of the islands was conducted in February 1956 by a group of scientists from the U.S. Naval Radiological Defense Laboratory. Specimens of animals (land and marine) and birds, and samples of plants, soil and water were collected for analysis. Radio assays for gross beta and gamma activity were conducted and in addition radiochemical determination of individual fission products and induced activities were made.

A few weeks after the 1954 incident a survey was made of the contaminated atolls,[1] and soil, water, and biological specimens were collected from Rongelap and Utirik. These samples were analyzed and the results were given in the Operation CASTLE, Project 4.1 report.[2] Soil and water samples contained microcurie amounts of activity; barely detectable quantities were found in plants. Approximately one year following the nuclear detonation, a survey of the islands indicated that the activity was present in metabolic systems and was still in the environment at lower but significant levels.[3] The present study, conducted two years post-detonation, provides further data on the persistence and distribution of the fallout activity. From these data an evaluation can be made of the potential hazard from the ingestion of contaminated materials.

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CHAPTER 2

GROSS ACTIVITY IN PLANTS, WATER AND SOIL

PROCEDURES

Plant specimens were packaged and shipped in individual plastic bags, soils in stainless steel core tubes, and water samples in 1-liter polyethylene bottles.

With the exception of water samples, the samples were prepared for analysis by the procedures described in the previous report[3] which consisted of ashing biological samples and counting soil samples as received. Water specimens were reduced to the smallest possible volume consistent with maintaining the salts in solution. An aliquot of the concentrate was placed on a planchet and heated to dryness under an infrared lamp prior to counting.

After the mounting, the samples were beta-counted in a gas flow proportional counter at 1[illegible].8 per cent geometry as determined with a Sr^{90}-Y^{90} standard mounted on aluminum. Gross gamma measurements were made in a well scintillation counter with a counting efficiency of 43 per cent for a Co^{60} standard.

Gamma dose rates of the islands at 3 ft above ground were determined with AN/PDR 27C survey meter between February 7 and 14, 1956.

RESULTS AND DISCUSSION

Plants

The gross beta activity of the plant specimens analyzed is recorded in Table 2.1 according to the island from which the sample was recovered. The data were corrected for the counting efficiency of Sr^{90} and presented

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TABLE 2.1

Gross Beta Activity in [illegible] and Soil Samples(a)

Plant	Part	Gejen	Eniwetak	Eniaetok	Rongelap	Sifo	Utirik	Likiep
		PLANTS(b) (c/m/kg x 10^{-5})						
Portulaca	Whole Plant	87.4	19.2	3.05	1.26	-	1.71	1.33
Arrowroot	Stems, Leaves	11.0	4.5	0.32	0.25	0.21	-	0.03
	Tubers	2.32	0.57	0.69	0.55	0.08	0.14	0.03
Pandanus	Air Root	2.87	0.17	1.05	0.32	0.96	0.08	0.02
	Leaves	2.64	1.02	5.26	0.38	0.15	0.21	0.03
	Green Keys	1.27	0.37	0.70	0.22	0.10	0.09	0.03
	Ripe Keys	-	-	0.53	0.17	-	0.07	0.02
Papaya	Ripe	-	-	-	0.12	-	0.11	-
	Green	-	-	-	0.25	-	0.09	0.04
	Leaves, Trunk	-	-	-	0.09	-	0.16	0.06
Ripe Coconut	Milk	/ 2.87	-	-	0.54	0.63	0.12	0.57
	Meat	1.90	0.36	1.97	0.24	0.17	0.08	0.06
	Shell	4.98	0.38	0.72	0.44	0.28	0.06	0.02
	Husk	1.83	0.65	1.57	1.31	0.77	0.21	0.09
Green Coconut	Whole	3.1	-	-	-	-	-	-
	Milk	-	0.29	0.11	0.05	0.13	-	0.05
	Meat	-	0.33	0.25	-	0.08	0.07	0.02
	Shell	-	-	0.80	-	0.37	0.08	0.09
	Husk	-	-	0.48	0.12	0.11	0.11	0.02
	Shell, Husk	-	0.11	-	-	-	-	-
Sprouting Coconut	Milk	-	1.61	0.76	0.79	0.71	0.11	0.09
	Meat	-	0.38	0.40	0.12	0.30	0.07	0.06
	Shell	-	0.29	0.41	0.35	0.18	0.04	0.02
	Husk	-	0.73	1.57	0.88	0.68	0.26	0.07
Coconut	Leaves	-	15.4	0.86	-	0.84	4.7	1.66
	Frond	-	0.94	0.51	-	0.23	0.09	0.11
	Leaves, Frond	1.48	-	-	-	-	-	-
Banana	Fruit	-	-	-	-	-	-	0.06
	Bark	-	-	-	-	-	-	0.07
	Leaves	-	-	-	-	-	-	0.18
Taro	Leaves, Stalks	-	-	-	-	-	-	0.06
	Tuber, Roots with Soil	-	-	-	-	-	-	0.19

(a) All counts were corrected for the counting efficiency of Sr^{90}-Y^{90}.

(b) Gross beta activity of plant samples was determined in April 1956 and that of soil and water in May 1956.

[redacted]

TABLE 2.1 (continued)

Gross Beta Activity in Plant, Water and Soil Samples[a]

Source	Gejen	Eniwetak	Eniaetok	Rongelap	Sifo	Utirik	Likiep
	WATER[b] (c/m/liter x 10^{-5})						
Cistern	-	-	-	0.008	-	NDA[c]	-
Well	-	-	NDA	-	-	0.1, 0.03, NDA	NDA
Ocean	NDA	NDA	0.08	0.06	0.09	NDA	0.08
Lagoon	NDA	NDA	NDA	NDA	0.08	0.09	NDA
Depth (in.)	SOIL[b] (c/m/kg x 10^{-5})						
0-1	3470	34.8	6.43	7.00	4.97	4.43	NDA
12	-	-	-	0.70	-	-	-
18	0.80	-	NDA	-	-	-	NDA
24	-	NDA	-	-	0.04	0.51	-
33	1.33	-	-	NDA	-	-	-
36	-	-	-	-	-	-	NDA
44-45	-	-	0.07	-	-	-	-
48	-	NDA	-	-	NDA	-	-
55-56	-	-	-	-	-	0.70	-

(a) All counts were corrected for the counting efficiency of Sr^{90}-Y^{90}.

(b) Gross beta activity of plant samples was determined in April 1956 and that of soil and water in May 1956.

(c) NDA indicates no detectable activity.

as corrected counts per minute per kilogram of wet sample. Empirical corrections for self-absorption were not applied because the activity of most samples was so low as to prevent such evaluation with expediency. Furthermore since the nuclide composition varied among plants and even within different sections of the same plant, a blanket correction was impossible.

The gross gamma activity of these samples is shown in Table A.1, Appendix. The activities corrected for the counting efficiency of Co^{60}, are essentially the same as those calculated for the beta activity. The exceptions are portulaca, the leaves of arrowroot, and the coconut palm where the beta activity was consistently slightly greater than the gamma activity. Data presented in Chapter 3 show these exceptions are expressions of the nuclide composition.

Portulaca was many times more active than other plant specimens recovered from the same island. Leaves of plants were generally more active than their fruit counterpart. The fact that surfaces of leaves were not decontaminated prior to analysis may account at least in part for this difference.

Three stages of coconuts - green, ripe, and sprouting nut - were analyzed. Both green and ripe pandanus keys were examined. No distinct differences between the stage of growth and activity were discernible.

Where possible the meat, milk, shell, and husk of coconuts were analyzed separately. Within the limits of the analysis, the activity appears equally distributed among these fractions.

The order of plant activities relative to the island from which they were recovered was: Gejen > Eniwetak , Eniaetok > Rongelap > Sifo, Utirik > Likiep. These results agree well with the activities of the respective soils as shown in Table 2.1.

An accurate comparison of the gross beta activity of samples analyzed in the current survey with the data secured one year ago was not possible since self-absorption corrections were applied in the previous survey. It was, however, interesting to note that, although such corrections were not made, coconuts exhibited greater beta activity in the present study. This finding, as will be discussed later, suggests that coconuts possess an unusual capacity to concentrate a component of the residual activity.

<u>Water</u>

The gross beta activity of well, cistern, ocean, and lagoon water is shown in Table 2.1. Gamma measurements of these samples are recorded

TABLE 2.2

Average Gamma Dose Rates from Previous and Current Surveys

Island	11 Months (mr/hr)	23 Months (mr/hr)		Remaining Activity (per cent)
Likiep	0.04	<0.05		-
Utirik	0.14	0.05		35
Eniwetak	0.7	0.16		23
Rongelap	0.7	0.09		13
Eniaetok	2.4	0.28		12
Kabelle	4.2	0.96		23
Gejen	5.4	1.5		28
			Average:	26

[redacted]

in Table A.1, Appendix. The activities were either imperceptible or of a low order of magnitude.

Soil

To describe the downward movement of the activity, profile soil samples were obtained in increments to a depth of 56 in. As shown in Table 2.1, the greater part of the beta activity appeared fixed to the upper surface of the soil; the remaining part diminished sharply and progressively at deeper levels. The bulk of the activity appeared to be firmly absorbed to the soil since it resisted the downward migration of the heavy rains to which these islands are subject.

Table 2.2 lists the gamma dose rates found on the island survey; levels observed 1 year before are included. The gamma activity was reduced over the 12-month period by 74 $\pm$ 8 per cent. Calculations based on the Hunter-Ballou curves for beta decay of mixed fission products[4] predict that 80 per cent of the gamma activity is lost by radioactive decay over this interval. This decay was obviously the significant factor in reduction of the gamma field rather than the leaching of nuclides to deeper layers and their eroding into the adjacent waters.

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CHAPTER 3

NUCLIDE COMPOSITION IN PLANTS, WATER AND SOIL

The long-lived isotopes of mixed fission products, which present the greatest internal radiation hazard to human inhabitants of a contaminated area, were analyzed in plant, soil and water samples. These isotopes were the total rare earths, Sr^{90}, Cs^{137}, and Ru^{106} and comprised the total detectable fission product activity remaining 2 years after the nuclear detonation.

Prior to nuclide analysis, samples of sufficient activity were submitted to gamma spectrum analysis in a single channel analyzer to establish whether some unexpected isotope was contributing to the activity.

The nuclides were isolated[5] from samples which exhibited the greatest beta activity and were mounted on brass planchets. Corrections for geometry, forescatter, backscatter, self-absorption, and for window, air and pliofilm absorption were evaluated for Sr^{90} by reference to data procured from a National Bureau of Standards solution. The beta counting efficiency correction for Ru^{106}, Cs^{137}, and the total rare earths was made by comparison with a U_3O_8 standard. An estimated error of the order of ± 20 per cent may result from such comparison. Self-absorption, air, window and pliofilm absorption were calculated from aluminum absorption curves of the respective nuclides. Absorption corrections for the total rare earths were calculated from the aluminum absorption curve derived from Ce^{144}-Pr^{144}. Beta measurements were made on the first shelf of an end-window, gas flow, proportional counter with a geometry of 46 per cent for the U_3O_8 standard mounted on aluminum. In the case of Sr^{90}, measurements were also made with Geiger counters with a geometry of 25 and 30 per cent. Samples were analyzed for calcium by a flame photometric method to report Sr^{90} in sunshine units (defined as 2.2 disintegrations of strontium-90 per minute per gram of calcium).* The preparatory procedure involved wet-ashing the samples with fuming nitric and perchloric acids and removing phosphates by percolation of the digest through an anion exchange column. The standard error in calcium determinations was in the order of 10 per cent.

* Or 0.001 microcuries of strontium-90 per kilogram of calcium.

[redacted]

TABLE 3.1

Average [illegible]
Plants, Soil, and Water

Source		No. of Samples Averaged	Relative Composition (per cent) Cs137	Total Rare Earths	Sr90	Ru106
Plant	**Part**	**PLANTS**				
Portulaca	Whole	1	48.9	39.2	11.8	-
Papaya	Fruit	1	79.8	17.8	2.5	-
Coconut	Husk	3	98.2	1.1	0.7	-
	Meat	2	98.9	0.05	1.0	-
	Shell	2	99.5	0.4	0.1	-
	Milk	1	99.6	0.2	0.2	-
	Leaves	2	8.3	86.5	0.4	5.1
Pandanus	Keys	2	92.6	2.2	5.5	-
	Leaves	2	72.7	13.3	5.1	8.9
	Air Root	2	88.9	10.3	0.8	-
Arrow Root	Tuber	1	75.4	16.8	1.0	6.8
	Leaves	1	11.7	83.9	3.0	1.4
		SOIL				
Depth, 0-1 in.		2	0.34	83.8	5.6	10.0
Source		**WATER**				
Cistern		2	-	64.4	35.6	-
Well		2	-	100	0	-
Lagoon		2	-	94.5	5.5	-
Ocean		2	-	100	0	-

Note: column headers are Cs^{137}, Sr^{90}, Ru^{106}.

RESULTS AND DISCUSSION

In Table 3.1 the relative contribution of the nuclides recovered from plant, soil and water are recorded. The data from which these values were computed are shown in Table A.2, Appendix. In most cases the sum of the separate nuclides exceeded the gross beta activity, a result expected from the self-absorption of radiations which were uncorrected in the gross beta determinations. The notable exceptions were the leaves of arrowroot, pandanus and coconut, where only 57 to 85 per cent of the gross beta activity was represented by the nuclides sought. Gamma-emitters other than those anticipated were not in evidence. Unfortunately, insufficient active samples precluded clarification of this discrepancy.

The primary contaminating isotope in coconuts, papaya fruit, pandanus keys and arrowroot tubers was Cs^{137}. Significant quantities of the rare earth components (16 to 18 per cent) were recovered from papaya and arrowroot tubers and only a small fraction from coconuts and pandanus keys. The Sr^{90} concentration in these specimens was uniformly low.

The nuclide composition of the leafy structures in the coconut palm and the arrowroot plant differed markedly from the respective nut and tuber. These structures accumulated the rare earth isotopes in exceedingly greater concentration than Cs^{137}. These relationships account for the observed gross beta-to-gamma ratio previously mentioned. Samples containing a preponderance of the rare earth radioelements would be expected to give a higher beta-to-gamma ratio than those composed almost entirely of Cs^{137}.

Table 3.1 shows further that plant leaves contained varying percentages of Ru^{106} and that the concentration of this isotope represented only a small fraction of the total activity.

In portulaca, a widely distributed plant, the nuclide composition was 49, 39 and 12 per cent Cs^{137}, rare earths, and Sr^{90}, respectively.

Despite the inactivity of the water samples, rare earth and Sr^{90} determinations were performed since self-absorption as well as the size of aliquot used may have obscured the activity. Cs^{137} and Ru^{106} were not determined because self-absorption does not play an important role in the detection of these gamma-emitters. The results of these analyses are shown in Tables 3.1 and A.2. With the exception of a sample of cistern water which had a significant quantity of Sr^{90}, the observed activity was attributable to the rare earths.

With regard to soil, the average of two complete assays gave 84 per cent rare earths, 10 per cent Ru^{106}, 5 per cent Sr^{90} and less than 1 per cent Cs^{137}.

[redacted]

TABLE 3.2

Sunshine Units of Plant, Water and Soil Samples

Sample	Island	PLANTS Sample Weight (g)	Calcium Content (mg)	Sr^{90} (d/m/sample)	Sunshine Units (2.2 d/m Sr^{90}/g Ca)
Portulaca	Enlaetok	223	178	10000 ± 100	2.53 x 10^4 ± 250
	Gejen	23	398	5380 ± 106	6140 ± 120
Papaya	Rongelap	240	338	240 ± 33	322 ± 44
Coconut Husk	Rongelap	200	162	340 ± 28	950 ± 78
	Enlaetok	23	58	150 ± 24	1200 ± 190
	Gejen	360	47	420 ± 24	4060 ± 240
Coconut Meat	Rongelap	450	28	110 ± 60	1801 ± 960
	Enlaetok	160	40	18 ± 29	200 ± 320
	Gejen	190	20	28 ± 23	635 ± 520
Coconut Shell	Enlaetok	90	16	25 ± 18	708 ± 500
	Enlaetok	120	8	NDA[a]	0
	Gejen	85	23	NDA	0
Coconut Milk	Gejen	140	20	41 ± 21	955 ± 500
Coconut Leaves	Eniwetak	35	89	197 ± 37	1300 ± 250
	Utirik	38	163	NDA	0
Coconut, Whole	Gejen	170	19.5	157 ± 22	3600 ± 520
Arrowroot Tuber	Enlaetok	305	1140	250 ± 26	103 ± 10
	Sifo	280	383	73 ± 16	86 ± 19
	Gejen	103	114	196 ± 35	780 ± 140
Arrowroot Leaves and Stalks	Gejen	15	385	290 ± 44	340 ± 50
Pandanus Keys	Enlaetok	130	86	1020 ± 50	5600 ± 230
	Enlaetok	215	[illegible]	[illegible] ± [illegible]	1400 ± [illegible]
Pandanus Leaves	Enlaetok	10	65	480 ± 41	3200 ± 300
	Gejen	32	43	NDA	0
Pandanus Air Root	Enlaetok	43	23	20 ± 33	390 ± 650
	Gejen	30	14	105 ± 27	3360 ± 840

[redacted]

[redacted]

TABLE 3.2 (Continued)

Sunshine Units of Plant, Water and Soil Samples

Sample	Island	Calcium in kg of Soil (g)	Sr^{90} (d/m/liter)	Sunshine Units (2.2 d/m Sr^{90}/g Ca)
		SOILS		
Depth, (0-1 in.)	Rongelap	316	$3.3 \times 10^4 \pm 1.3 \times 10^3$	47 ± 2
	Gejen	341	$5.26 \times 10^6 \pm 5.2 \times 10^3$	$7 \times 10^3 \pm 70$
	Eniaetok	352	$2.1 \times 10^4 \pm 2.2 \times 10^3$	28 ± 3
	Sifo	350	$1.3 \times 10^4 \pm 1.0 \times 10^3$	17 ± 1
	Eniwetak	360	$5.8 \times 10^4 \pm 2.3 \times 10^3$	73 ± 3
	Utirik	268	$4.8 \times 10^4 \pm 3.0 \times 10^3$	92 ± 6
		WATER		
		Calcium in Liter (mg)	Sr^{90}(d/m/liter)	
Cistern	Rongelap	48	1180 ± 10	$1.1 \times 10^4 \pm 230$
	Utirik	61	20 ± 14	147 ± 104
Well	Utirik	88	39 ± 10	201 ± 54
	Utirik	80	NDA	0
	Eniaetok	2300	NDA	0
Ocean	Rongelap	352	NDA	0
	Utirik	408	NDA	0
	Eniwetak	402	NDA	0
Lagoon	Rongelap	456	190 ± 68	188 ± 68
	Eniwetak	137	NDA	0
	Utirik	441	204 ± 150	208 ± 150

(a) NDA indicates no detectable activity

[redacted]

Where comparisons were available, the relationships among nuclides in the current survey in general agreed with those previously reported.[2] The only sharp difference was the higher percentage of Cs^{137} in the one papaya analyzed in the present study.

In the previous chapter it was mentioned that coconuts exhibited greater beta activity in the present survey than in the previous one. Interpretation of the nuclide data in coconuts and soils indicates that this phenomenon is concerned with the apparent capacity of coconuts to concentrate cesium. Analyses reveal that the activity in coconuts was contributed almost entirely by Cs^{137}. The argument that this nuclide was made available to the root system in greater concentration by preferential translocation during this one year interval is untenable since the concentration of Cs^{137} in relation to other nuclides in the upper surface of the soil is essentially unchanged.

Further substantiation of the concentrating capacity of coconuts is found when the quantity of Cs^{137} in the coconut is compared with that of the soil. The soil concentration in the area of the root system which is situated well below the surface is lower than that of the top inch of soil. Yet, as shown in Table A.2, the Cs^{137} concentration of coconuts often exceeded even that which was present in the surface soil.

The sunshine units are recorded in Table 3.2 for the plant, water and soil samples analyzed. The table includes the d/m Sr^{90} for the samples and the standard error of measurement. The standard error was large in samples with less than 100 d/m Sr^{90}. Two instruments were used in counting the activity: a gas flow proportional counter with a background of about 40 c/m and Geiger counters with backgrounds of 20 and 25 c/m. Although the counting time was routinely 20 min, a sizable statistical error was involved in measurements of samples whose rate was only one to several counts above background.

To improve the counting statistics, a number of samples with low activity was permitted to stand until Sr^{90} and Y^{90} were in equilibrium. Both radiations were counted, an appropriate correction was applied for self-absorption of Sr^{90}, and the Y^{90} contribution was mathematically subtracted.

Of the plant samples examined, portulaca had the highest sunshine units; values were 6140 and 25,000 for the two specimens analyzed. In coconuts the activity of meat, shell and milk was not statistically significant, whereas the value for husks ranged from 1200 to 4000. Pandanus keys and pandanus air root values also fell within this range. Arrowroot leaves, stalks and tubers were significantly lower, ranging from 86 to 780 sunshine units.

The sunshine units in the 0 to 1 in. layer of soil on five islands were 17 to 92; the exception [illegible] value of 1000.

Strontium-90 was not detectable in most water samples; however four samples showed some activity with sunshine units between 150 to 200. A sample of cistern water from Rongelap, the notable exception, had a value of 10,000.

Noteworthy is the fact that the activity in portulaca, coconut husks, pandanus keys and air roots, as well as a sample of potable water, exceeded the maximum tolerance level of Sr^{90} (Ref. 6).

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CHAPTER 4

RESIDUAL RADIOACTIVE CONTAMINATION IN FISH, MARINE INVERTEBRATES, RATS AND BIRDS

PROCEDURE

Fish and birds were collected from the following islands of the Rongelap Atoll: Rongelap, Eniaetok, Gejen and Kabelle. In addition, four rats and one rooster were collected on Rongelap Island. Fish and marine invertebrates were also collected from Sifo Island in the Ailingnae Atoll; Eniwetak Island in the Rongerik Atoll; Utirik Island, Utirik Atoll; and Likiep Island, Likiep Atoll. Marine specimens were collected in the lagoons off the shores of the islands.

The fish were collected following the detonation of depth charges of dynamite. The birds (terns) were shot. The rats were collected in traps. All the specimens collected were placed in individual plastic bags and immediately frozen with dry ice. The frozen samples were transported to the USNRDL where they were analyzed for gross radioactivity and for the presence of their specific radionuclide content.

The small fish were analyzed whole and the marine invertebrates were analyzed either whole or after removal from the shell. A number of the large fish were separated into skeleton, muscle, head, gills, liver, skin and viscera for a study of the distribution of the internally deposited radionuclides.

The samples were dried, ashed and the gross beta and gamma activity determined in the manner previously described.[3] The gamma activity is reported in d/m (Co^{60} equivalent); the beta activity in d/m (Sr^{90} equivalent). These "equivalent units" were derived from a comparison with the activity of standards of Sr^{90} and Co^{60} counted in an identical manner with the samples as described in Chapter 2.

Radiochemical analyses were performed to determine the concentration of several pre-selected radionuclides and of others whose presence was indicated by a single-channel gamma analyzer. Calcium was determined with a flame spectrophotometer. The radiochemical techniques employed are described in an earlier report.[5] Cobalt-60 was determined by a method previously described[7] and Zn^{65} by the mercuric thiocyanate procedure.

[redacted]

TABLE 4.1

Summary of Beta and Gamma Activity in Fish and Marine Invertebrates

Island	Fish			Crabs			Clams			Snails		
	No. of Samples	Activity (d/m/kg x 10^{-4}) β	γ	No. of Samples	Activity (d/m/kg x 10^{-4}) β	γ	No. of Samples	Activity (d/m/kg x 10^{-4}) β	γ	No. of Samples	Activity (d/m/kg x 10^{-4}) β	γ
Rongelap Atoll												
North: Gejen	8	24.5	78.8	2	28	87				4	648	573
Kabelle	10	14.9	55.4							1	17.7	43.9
Central: Eniaetok	5	19.3	45.1	1	4.5	14.1	1	4.5	8.8			
South: Rongelap	5	17.7	32	6	25.4	24.5	2	23	56	2	31	51
Rongerik Atoll												
Eniwetak	8	2.2	7.8	1	2.8	18.3						
Ailingnae Atoll												
Sifo	6	4.5	22.7	3	21.9	14.5	1	6.4	15.0			
Utirik Atoll												
Utirik	8	1.6	2.1							3	.006	2.8
Likiep Atoll												
Likiep	8	2.6	1.3									

RESULTS AND DISCUSSION

Readily detectable levels of radioactivity in land and marine animals of the Marshall Islands contaminated by the 1954 nuclear detonation were detected in February 1956. The residual radioactive contamination expressed in terms of gross beta and gamma activity of the tissues of 85 fish and marine invertebrates is presented in Table 4.1. The complete data appear in Table A.3, Appendix.

Considerable variation was observed in the concentration of activity per unit weight of individual fish and marine invertebrates from the same area as well as from different geographic locations. Part of this variation may be attributed to differences in feeding habits. However, no correlation between the level of radioactivity and the eating habits of the fish (carnivorous, herbivorous, omnivorous) could be ascertained. Of course, currents and localized concentrations of radionuclides may also play a role in determining concentrations of residual activity in the lagoon fish. In Table 4.1 an average value for the analysis of the fish in each locality is reported.

Fish and invertebrates caught in the northern section of the Rongelap Lagoon had the same level of beta activity but twice the gamma activity of fish from the southern section of the lagoon (Table 4.1). The ratio of activity in marine invertebrates between the north and south ends of the lagoon was considerably lower than that observed one year following the detonation. This finding suggests a redistribution of activity from the higher concentration originally existing in the northern end of the lagoon. The pattern of the 1954 fallout was such that the activity on the northernmost islands was tenfold higher than on Rongelap Island, at the southern end of the atoll.

The internally deposited activity in the fish was only very roughly proportional to the external radiation dose over that island.

Crabs and clams were found to have a residual concentration of beta-emitting radionuclides of about the same level as fish from the corresponding locality (Table 4.1). This is in contrast to the larger differences noted between crabs and clams as compared to fish at one year post-detonation.

Snails from Gejen had considerably higher concentrations of activity than fish from the same locality, as was noted in the one-year resurvey. The higher level of activity of the snails may be related to their habit of feeding on the bottom of the lagoon where higher concentrations of radionuclides were found. The relatively lower values of activity in clams is

TABLE 4.2

Distribution of Gross Beta and Gamma Activity in Tissues of Fish

Island	Fish	Wet wt (g)	Total β	Total γ	Skin β	Skin γ	Head β	Head γ	Muscle β	Muscle γ	Bone β	Bone γ	Gill β	Gill γ	Viscera β	Viscera γ
			Radioactivity (d/m/tissue x 10^{-4})													
Rongelap Atoll, South																
Rongelap	Goat	218	8.8	15.5	0.2	2.4	0.45	3.3	1.1	2.1	1.5	2.7	0.6	2.2	4.[illegible]	2.8
Rongelap	Grouper	452	5.2	5.7	0.4	0.3	0.8	0.7	0.4	0.5	1.4	2.6	0.3	0.3	1.9	1.4
	Average		7.0	10.6	0.3	1.3	.63	2.0	0.8	1.3	1.6	2.7	0.5	1.3	3.4	2.1
	Per cent of total activity		100	100	4.2	12.1	8.8	18.7	11.2	12.1	21.0	25.2	7.0	12.1	47.7	[illegible]
Rongelap Atoll, North																
Gejen	Snapper	1154	26.3	87.0	1.0	11.8	6.6	24.7	5.4	16.8	5.5	15.7	1.7	2.1	6.[illegible]	15.9
Kabelle	Snapper	735	12.3	18.5	1.0	11.2	4.5	1.9	1.0	0.7	2.4	4.4	0.5	1.1	2.[illegible]	6.3
Kabelle	Parrot	1957	24.8	71.3	1.1	8.9	8.5	20.9	2.4	6.6	7.0	23.4	0.8	2.7	5.[illegible]	8.8
	Average		21.1	58.9	1.0	10.6	6.5	15.8	2.9	8.0	5.0	14.5	1.0	2.0	4.7	10.3
	Per cent of total activity		100	100	4.8	17.3	30.8	25.9	13.7	13.1	23.7	23.7	4.8	3.3	22.3	16.9
Ailingnae Atoll																
Sifo	Snapper	640	3.2	38.9	0.3	5.9	0.7	9.9	0.6	6.2	0.5	10.6	0.1	2.7	0.9	3.6
	Per cent of total activity		100	100	9.7	15.2	22.5	25.4	19.3	15.9	16.1	27.2	3.2	7.0	29.0	9.4
Rongerik Atoll																
Eniwetak	Squirrel	387	0.41	2.0	.02	.35	.23	.55	.04	.27	.06	.39	.02	.08	.04	0.4
	Per cent of total activity		100	100	4.9	17.3	55	27.2	9.8	13.4	14.6	19.3	4.9	4.0	9.8	18.8
Utirik Atoll																
Utirik	Parrot	425	0.66	0.87	0	.24	0	.09	.15	.22	.13	.13	0	.04	.38	0.2
	Per cent of total activity		100	100	0	27.6	0	10.3	22.7	25.3	19.7	15.0	0	4.6	57.5	17.2
Likiep Atoll																
Likiep	Snapper	453	1.1	2.2	0	0	0	.02	0.1	0.2	0	0	0	0	[illegible]	2
	Per cent of total activity		100	100	0	0	0	0.9	9	9	0	0	0	0	9[illegible]	90

[redacted]

probably related to the fact that clams feed primarily on plankton which have low levels of activity.

The beta-to-gamma ratio (as determined by the method used here) in whole fish varied considerably but was approximately 1:2 in most of the specimens analyzed. This is in contrast to the 1:4 ratio observed at one year post-detonation. This ratio 1:2 is approximately the ratio of the beta-to-gamma activity of Zn^{65}, the principal radionuclide found in fish. Physical and radiochemical analysis of a number of fish indicated, as previously noted,[3] that the high gamma-to-beta ratio was accounted for by the gamma from the induced activity, Zn^{65}.

The internal distribution of radioactivity in the tissues of fish (primarily carnivores) collected in the various lagoons indicated that an average of 20 per cent of the total beta and gamma activity was found in the skeleton (Table 4.2). The head contained an average of 30 per cent of the total beta and 21 per cent of the gamma activity. Muscle contained approximately 14 per cent of the total beta and gamma activity. The activity of the viscera and contents varied considerably but contained on the average about 33 per cent of the total beta activity and 16 per cent of the total gamma activity. The remainder of the activity was found on the skin and gills. The internal distribution of activity, particularly the muscle activity concentration, was very similar to that found in the fish collected and analyzed at one year post-detonation.

The results of the radiochemical analyses for specific radionuclides are presented in Table 4.3. The most important finding is the very high percentage of the total activity in fish which is contributed by Zn^{65}. The manner in which this induced activity is concentrated has not been determined. The Zn^{65} in fish is distributed fairly evenly among the various tissues. This contrasts with the localization of Zn^{65} in the liver of mammals following ingestion. The Zn^{65} was not found in clams, crabs or snails, with the exception of one helmet snail from Mabelle Island.

The rare earth group of fission products constituted a small percentage of the total beta activity in clams and fish. The rare earth elements as a group do not appear to be selectively localized. The rare earth activity of the crabs was high, an average of 20 per cent of the total beta activity. Snails concentrated the largest amounts of rare earth elements.

The Sr^{90} concentration was very low, contributing generally a fraction of 1 per cent of the total beta activity. The Sr^{90} content is of particular importance, since it is the radionuclide of greatest potential hazard. The Sr^{90} hazard derives principally from its long radioactive half-life (26 yr) and also from its high fission yield and its availability to biological organisms. Sr^{90} activity and sunshine units are reported for a number of samples in Table 4.3.

[redacted]

TABLE 4.3

Radiochemical Analysis of Biological Specimens from Rongelap Atoll

Sample No.	Sample	Tissue	Wet Wt. (g)	Ca (mg)	Beta Activity (d/m sample) x 10^{-4}	Gamma Activity (d/m/sample x 10^{-4})	Nuclide	Nuclide Activity (d/m/sample x 10^{-4})	Per Cent of Total Activity	Sunshine Units(a)
Rongelap Island										
1502C	Goat Fish	Bone	29	860	1.5	217	R.E.(b)	NDA(c)	0	
							Sr^{90}	11 ± 1.7	7.3	[illegible] ± 90
							Zn^{65}	240	89 -	
		Viscera	10	37.5	4.9	2.8	R.E.	0.68	0.14	
							Sr^{90}	NDA	0	
							Zn^{65}	250	89.3	
		Skin	28	337	0.2	2.4	R.E.	2.5	12.5	
							Sr^{90}	0.34 ± 0.26	1.7	[illegible] 34
							Zn^{65}	230	95.8	
		Muscle	87	111	1.1	2.1	R.E.	NDA	0	
							Sr^{90}	0.46 ± 0.76	0.4	[illegible] ± 313
							Zn^{65}	190	90.6	

(Continued)

(a) Sunshine Unit = 0.001 μc Sr^{90}/kg Ca.
(b) R.E. = Rare Earth Group
(c) NDA = No Detectable Activity

TABLE 4.3 (Continued)

Radiochemical Analysis of Biological Specimens from Rongelap Atoll

Sample No.	Sample	Tissue	Wet Wt. (g)	Ca (mg)	Beta Activity (d/m/sample x 10^{-4})	Gamma Activity d/m/sample x 10^{-4})	Nuclide	Nuclide Activity d/m/sample x 10^{-4})	Per Cent of Total Activity	Su[illegible]e Units(a)
1509	Killer Clam	Soft Tissue	1800	743	20	33	R.E.	NDA	0	
							Sr^{90}	2.4 ± 0.69	0.12	1[illegible] ± 42
							Co^{60}	2090	63.4	
1513	Killer Clam	Soft Tissue	882	1565	31	83	R.E.	77	2.5	
							Sr^{90}	83.8 ± 0.90	2.7	24[illegible] ± 31
							Co^{60}	7370	89	
1520A	Langousta Crab	Soft Tissue	79	330	1.3	2.1	R.E.	26	20	
							Sr^{90}	NDA	0	0
1520C	Red Eye Crab	Soft Tissue	57	2343	0.75	3.8	R.E.	37	49	
							Sr^{90}	0.13 ± 0.07	0.2	[illegible] 1
1520D	Red Spotted Crab	Soft Tissue	73	2900	0.75	0.43	R.E.	15	20	
							Sr^{90}	1.28 ± 0.18	1.7	[illegible] 3
1520B	Coconut Crab	Soft Tissue	114		3.5	3.1	Cs^{137}	26	7.4	
							R.E.	0.58	16.5	
Kabelle Island										
1538	Snapper Fish	Muscle	281	85	0.95	0.69	R.E.	4.1	4.2	
							Sr^{90}	NDA	0	0
							Zn^{65}	58	84.2	
		Skin	89	987	1	4.1	R.E.	2.4	2.4	
							Sr^{90}	0.53 ± 0.76	0.5	24 ± [illegible]4
							Zn^{65}	380	92.7	

(Continued)

TABLE 4.3 (Continued)

Radiochemical Analysis of Biological Specimens from Rongelap Atoll

Sample No.	Sample	Tissue	Wet Wt. (g)	Ca (mg)	Beta Activity (d/m/sample x 10^{-4})	Gamma Activity (d/m/sample x 10^{-4})	Nuclide	Nuclide Activity (d/m/sample x 10^{-4})	Per Cent of Total Activity	Sunshine Units[a]
		Bone	141	1842	2.4	4.4	R.E.	19	7.9	
							Sr^{90}	3.0 ± 0.36	1.2	73 ± 3
							Zn^{65}	440	100	
		Viscera		2413	2.7	6.3	R.E.	120	44	
							Sr^{90}	7.85 ± 0.94	2.0	147 ± 18
							Zn^{65}	530	84.2	
1540	Grouper Fish	Whole	176	1630	0.75	6	R.E.	NDA	0	
							Sr^{90}	0.79 ± 0.17	1.0	22 ± 4
							Zn^{65}	580	97	
1544	Parrot Fish	Bone	449	1905	7.0	23.4	R.E.	5	0.7	
							Sr^{90}	13.7 ± 1.0	2	326 ± 22
							Zn^{65}	1870	79.8	
		Gill	56	428	0.83	2.7	R.E.	3.9	4.7	
							Sr^{90}	0.55 ± 0.44	0.7	59 ± 46
							Zn^{65}	180	66.8	
		Head	280	7920	8.5	20.9	R.E.	3.7	0.4	
							Sr^{90}	0.97 ± 0.52	0.1	6 ± 3
							Zn^{65}	1670	80	

(Continued)

TABLE 4.3 (Continued)

Radiochemical Analysis of Biological Specimens from Rongelap Atoll

Sample No.	Sample	Tissue	Wet Wt. (g)	Ca (mg)	Beta Activity (d/m/sample x 10^{-4})	Gamma Activity (d/m/sample x 10^{-4})	Nuclide	Nuclide Activity (d/m/sample x 10^{-4})	Per Cent of Total Activity	[illegible]ine [illegible]s(a)
		Viscera	258	11450	5	8.3	R.E.	NDA	0	
							Sr^{90}	2.5 ± 1.38	0.3	1[illegible] ± 5
							Zn^{65}	820	93	
737	Helmet Snail	Soft Tissue	271	224	4.8	11.9	R.E.	59	12.3	
							Sr^{90}	1.36 ± 0.34	0.3	2[illegible]9
							Zn^{65}	1090	91.6	
Gejen Island										
1621	Snapper Fish	Head	219	3250	6.6	24.7	R.E.	NDA	0	
							Sr^{90}	1.65 ± 2.4	0.2	2[illegible]3
		Skin	73	1315	1.0	11.8	R.E.	NDA	0	
							Sr^{90}	0.68 ± 0.48	0.7	2[illegible]6
		Bone	173	3270	5.5	15.7	R.E.	NDA	0	
							Sr^{90}	1.5 ± 0.44	0.3	2[illegible]
							Zn^{65}	1540	93	
		Muscle	511	190	5.4	16.8	R.E.	3.5	0.7	
							Sr^{90}	0.22 ± 0.35	0.04	6[illegible]8
							Zn^{65}	1600	95	
		Viscera	87		6.1	15.9	R.E.	11	1.8	
							Sr^{90}	1.2 ± 0.29	0.2	
							Zn^{65}	1480	93	

(Co[illegible]ued)

TABLE 4.3 (Continued)

Radiochemical Analysis of Biological Specimens from Rongelap Atoll

Sample No.	Sample	Tissue	Wet Wt. (g)	Ca (mg)	Beta Activity (d/m/sample x 10^{-4})	Gamma Activity (d/m/sample x 10^{-4})	Nuclide	Nuclide Activity (d/m/sample x 10^{-4})	Per Cent of Total Activity	Sunshine Units(a)
		Gill	28	403	1.7	2.1	R.E.	NDA	0	
							Zn^{65}	210	100	
1636	Grouper Fish	Whole	169	2190	1.8	77.9	R.E.	13.3	7.4	
							Sr^{90}	1.7 ± 0.92	0.1	[illegible] ± 18
							Zn^{65}	6230	80	
1629	Sand Crab	Soft Tissue	46	1090	1.3	2.3	R.E.	0.8	0.3	
							Sr^{90}	4.72 ± 0.59	2.0	[illegible] ± 25
1637	Spider Snail	Soft Tissue	90	713	18.7	18	Ru^{106}	360	19.2	
							R.E.	1210	65	[illegible] ± 30
							Sr^{90}	5.28 ± 0.47	0.3	
1638	Spider Snail	Soft Tissue	56	175	102	68	R.E.	11900	116	
							Sr^{90}	1.95 ± 0.60	0.02	[illegible] ± 331

(a) Sunshine Unit = 0.001 μc Sr^{90}/kg Ca.

(b) R.E. = Rare Earth Group.

(c) NDA = No Detectable Activity.

[redacted]

The skeletons of fish concentrated and retained the largest amounts of Sr^{90}, as would be expected from the similarity of strontium metabolism to calcium metabolism. The skeleton of a fish from Rongelap had 587 sunshine units, the highest observed in any fish. The highest number of sunshine units in any of the samples analyzed appeared in a clam from Rongelap (2.43×10^3 units).

In general, snails had a high number of sunshine units (276 to 502). A relatively high level of Ru^{106} (19.2 per cent of beta activity) was also found in a snail from Gejen.

A high level of Cs^{137} (with a 37-yr half-life) was found in a coconut crab. A similar finding was noted at one year post-detonation. In the analyses from previous island resurveys, Cs^{137} was the major radionuclide found in land food plants and also in the tissues of land animals. The coconuts, which had high levels of Cs^{137}, were undoubtedly the source of the Cs^{137} activity found in the coconut crab.

The presence of Co^{60} in two samples of clams was noted for the first time in the two-year period since the detonation. The Co^{60} accounted for the major fraction of the total activity in these samples. The Co^{60} was detected by gamma spectral analysis, and confirmed by chemical separation and absorption measurements.[7] The ability of clams to concentrate Co^{60} selectively was verified in laboratory experiments using clams obtained locally.*

Comparison of the fish and marine specimens collected immediately after detonation and one year later with those studied in the present report (two years after detonation) indicate a drop in activity. The fish from the Rongelap lagoon had approximately one fourth the activity of those analyzed one year post-detonation. Based on radioactive decay of Zn^{65}, the change in level is about what would be expected.

The total activity found in the terns, whose diet is primarily fish, was low. The level of activity in the terns collected from the various atolls varied considerably, but was generally less than half per unit weight of the activity in fish from the same locality (Table 4.4). The activity of the terns collected from the northern islands of the Rongelap Atoll was higher than that of terns collected on the southern island. The terns collected on Rongerik, however, had a higher average concentration of activity than those from Rongelap, in spite of the lower levels of radioactive contamination of Rongerik and the fish in its lagoon.

The tibia of the terns, except for that of one tern from Kabelle, contained no detectable activity at this time. Although the activity in the tibia of the Kabelle tern had a high value when measured per kilogram

* Unpublished observations, J.K. Gong, W. Shipman, S.H. Cohn, and H.V. Weiss.

[redacted]

TABLE 4.4

Summary of Gross Beta and Gamma Activity in Birds and Eggs

Island	Sample	No. of Samples	Average Weight (g)	Radioactivity: Beta (d/m/sample x 10^{-4})	Radioactivity: Beta (d/m/kg x 10^{-4})	Radioactivity: Gamma (d/m/sample x 10^{-4})	Radioactivity: Gamma (d/m/kg x 10^{-4})
Rongelap Atoll							
Rongelap	Tern						
	Egg shell	1	6	NDA	0	0.62	10.3
	Egg, soft tissue	1	33	0.26	7.9	0.11	3.3
Gejen	Tern	1	92	0.93	10.1	0.32	3.5
	Viscera	1	101	0.38	3.8	0.025	0.25
	Muscle	1	141	NDA	0	0.019	0.14
	Tibia	1		NDA	0	NDA	0
Kabelle	Tern	1	145	1.1	7.8	1.7	12
	Muscle	1	16.9	0.1	5.9	0.13	7.7
	Tibia	1	0.9	0.07	79	.027	30
	Egg shell	2	5.3	NDA	0	0.13	26
	Egg, soft tissue	2	22.8	0.15	6.7	.03	1.3
Ailingnae Atoll							
Sifo	Tern	7	116	0.38	3.3	1.7	14.7
	Muscle	7	11.7	0.057	4.9	0.43	36.7
	Viscera	7		0.08		0.14	
	Tibia	7	0.31	NDA	0	NDA	0
	Egg shell	1	6	NDA	0	0.06	10
	Egg, soft tissue	1	33	0.26	7.9	0.11	3.3
Rongerik Atoll							
Eniwetak	Tern	2	92	1.9	21.0	0.9	9.8
	Muscle	2	19.7	0.04	2.3	0.03	1.9
	Tibia	2	.23	NDA	0	NDA	0
	Viscera	2		0.05		0.09	

[redacted]

the absolute activity was extremely low and therefore of doubtful statistical significance. The muscle in the terns contained levels of activity varying from 2.3×10^4 to 5.9×10^4 d/m/kg, depending on the island on which the birds were collected. The soft tissue of tern eggs had 7×10^4 to 8×10^4 d/m/kg, while the shells showed no detectable activity.

Radioanalysis of a rooster caught on Rongelap Island indicated a beta activity of 6.05×10^5 d/m and a gamma activity of 1.19×10^6 d/m (Table 4.5). The level of beta activity of this rooster was 40 per cent of that of a rooster from the same locality analyzed at one year post-detonation.[1] The ratio of beta-to-gamma activity in the rooster was 1:2 at two years, as compared to 1:1 at one year post-detonation. About 86 per cent of the total activity in the body was concentrated in the skeleton. The distribution of residual activity within the skeleton is shown in the autoradiograph of the rooster tibia (Fig. 1). The activity is diffusely spread throughout the diaphysis. The concentration of activity in the diaphysis and its absence in the ends of the bone indicates that the primary deposition occurred soon after the detonation while the chickens were young and growing. The radiation dose to the skeleton from the internal emitter is obviously considerably higher than that to any other tissue. The muscle contained 8 per cent of the beta activity, and the liver, 4 per cent. The gastrointestinal tract had 1.3 per cent of the beta activity, and about one fourth of this was found in the respiratory tract. The relatively higher levels of activity in the gastrointestinal tract as compared with the respiratory tract suggest that ingestion was the primary route of current entry of the fallout material into the body.

The average activity for individual tissues of four rats collected on Rongelap are presented in Table 4.5. The rats had a beta activity of 0.095 μc/kg body weight. This is very close to the activity of the rooster, 0.12 μc/kg body weight. The distribution of activity in the tissues of the rat differed from that in the rooster in that the skeleton and head together contained 65 per cent of the total beta activity, while the gastrointestinal tract had 24 per cent. The distribution of residual activity in the rat skeleton is illustrated in the autoradiograph of the femurs of the four rats, Fig. 2. The activity is diffusely spread throughout the bone.

[redacted]

[redacted]

TABLE 4.5

Summary of Gross Beta and Gamma Activity in Rongelap Island Animals

Sample	No. of Samples	Average Weight (g)	Radioactivity: Beta (d/m/sample x 10^{-4})	Beta (d/m/kg x 10^{-4})	Gamma (d/m/sample x 10^{-4})	Gamma (d/m/kg x 10^{-4})
Rooster	1	2250				
Skeleton		560	52	93	101	181
Muscle		1050	5.1	4.9	6.9	6.6
Gastrointestinal Tract		185	0.8	4.3	1.6	8.7
Liver		192	2.4	12.5	9.4	49.0
Respiratory Tract		32	0.2	8.7	0.4	17.4
Total Activity			60.5		119.3	
Rats	4	62.9				
Skeleton		4.1	0.73	179	0.15	35.5
Head		5.4	0.15	36	0.1	18
Muscle		39	0.03	7.5	0.04	10.2
Gastrointestinal Tract		10	0.32	32.0	0.27	27
Liver		3.8	0.08	21.7	0.06	15.8
Respiratory Tract		0.5	0.03	62.0	0.02	36.0
Total Activity			1.34		0.64	

[redacted]

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Fig. 1 Autoradiograph of Tibia of Rongelap Rooster

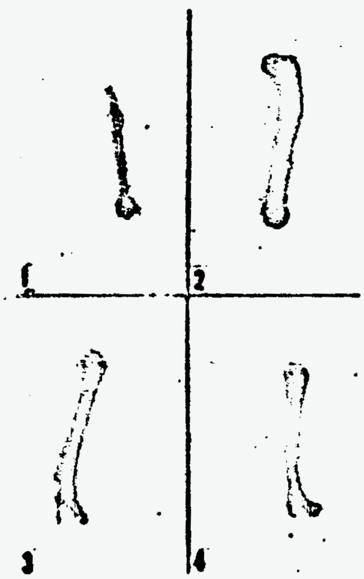

Fig. 2 Autoradiograph of Femurs of Rongelap Rats(1- Rat No. 1514; 2- No. 1515; 3- No. 1516; 4- No. 1517)

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CHAPTER 5

SUMMARY

The residual radioactive contamination on the Marshall Islands and in the surrounding water was evaluated two years after the nuclear detonation of Operation CASTLE by an examination of plants, soil, water, fish, marine invertebrates, birds and land animals and by gamma survey of the islands.

In plants, readily detectable levels of gross activity were found. The activity of portulaca exceeded that of other plants. In general, leafy structures were more active than their fruit counterpart in the coconut palm, pandanus and arrowroot. The primary contaminating isotope in coconuts, pandanus keys and arrowroot tubers was cesium-137. On the other hand, structural parts accumulated the rare earth radioelements. The relative nuclide composition in these plants was similar to that of a year ago. Coconuts were more radioactive in the current survey than in the previous one. Interpretation of the data indicated that this fruit possessed an unusual capacity to concentrate cesium-137.

The activity in lagoon, ocean, cistern and well water was either of a low order of magnitude or imperceptible. In soil, the activity remained firmly affixed to the surface. Gamma dose measurements indicated that the reduction in the gamma field over the past year was attributable to radioactive decay rather than to leaching or eroding of the nuclides from the soil.

Expression of Sr^{90} assays in terms of sunshine units showed that portulaca, coconut husks, pandanus keys and air roots, and certain potable water exceed the maximum permissible concentration.

Significant levels of activity remained in land animals although marine life contained the highest concentrations of internally deposited radionuclides of the animals analyzed. The levels of activity in fish were approximately one fourth of those determined at one year post-detonation. However, the tissue distribution of activity had not altered significantly. The rare earth group constituted a small fraction of the total activity in fish and a larger proportion in marine invertebrates. Strontium-90

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contributed less than one per cent of the total beta activity in all marine specimens except one clam.

The most striking fact was that about 90 per cent of the total activity in fish was contributed by the induced activity, Zn^{65}. Another induced activity, Co^{60}, was found in high concentration in the soft tissues of clams.

Approved by:

P.C. TOMPKINS
Scientific Director

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APPENDIX

GROSS BETA, GROSS GAMMA, AND NUCLIDE ANALYSES OF SPECIMENS RECOVERED FROM THE MARSHALL ISLANDS TWO YEARS AFTER OPERATION CASTLE FALLOUT

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TABLE A.1

Gross Gamma Activity in Plant, Water and Soil Samples(a)

Source: Plant	Source: Part	Gejen	Eniwetak	Enlaetok	Rongelap	Sifo	Udrik	Likiep
		PLANTS(b) (c/m/kg x 10^{-5})						
Portulaca	Whole Plant	54.3	6.33	3.97	1.25	-	1.28	.89
Arrowroot	Stems, Leaves	5.31	2.68	.28	.23	.14	-	.02
	Tubers	2.67	.88	.41	.73	.49	.12	.03
Pandanus	Air Root	2.82	.20	.99	.32	.59	.03	.01
	Leaves	2.58	.72	.48	.28	.15	.19	.02
	Green Keys	1.78	.48	.92	.22	.12	.04	.02
	Ripe Keys	-	-	.83	.20	-	.04	.02
Papaya	Ripe	-	-	-	.12	-	.12	-
	Green	-	-	-	.48	-	.01	.03
	Leaves, Trunk	-	-	-	.05	-	.17	.08
Ripe Coconut	Milk	3.17	-	-	.73	.59	.08	.53
	Meat	2.29	.89	1.36	.34	.29	.04	.04
	Shell	5.30	.38	1.03	.43	.30	.04	.02
	Husk	5.66	1.25	3.16	1.39	.89	.10	.07
Green Coconut	Whole	4.17	-	-	-	-	-	-
	Milk	-	.23	.14	.06	.10	-	.04
	Meat	-	.27	.21	-	.13	.08	.006
	Shell	-	-	1.04	-	.32	.03	.04
	Husk	-	-	.79	.12	.18	.06	.02
	Shell, Husk	-	.32	-	-	-	-	-
Sprouting Coconut	Milk	-	1.43	.80	.80	.77	.11	.03
	Meat	-	[illegible]	[illegible]	[illegible]	.21	.05	.04
	Shell	-	.28	.41	.51	.19	.02	.02
	Husk	-	1.22	2.40	1.47	.82	.11	.08
Coconut	Leaves	-	10.6	[illegible]	-	.50	2.80	1.09
	Frond	-	.71	.52	-	.33	.05	.10
	Leaves, Frond	1.57	-	-	-	-	-	-
Banana	Fruit	-	-	-	-	-	-	.10
	Bark	-	-	-	-	-	-	.02
	Leaves	-	-	-	-	-	-	.05
Taro	Leaves, Stalk	-	-	-	-	-	-	.06
	Tuber, [illegible] with Soil	-	-	-	-	-	-	.08

(a) All counts were corrected for the counting efficiency of Co^{60}.

(b) Gross gamma activity of plant samples was determined in April 1956 and that of soil and water in May 1956.

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TABLE A.1 (continued)

Gross Gamma [illegible] [a]

Source	Gejen	Eniwetak	Enlaetok	Rongelap	Sifo	Utirik	Likiep
			WATER[b] (c/m/liter x 10^{-5})				
Cistern	-	-	-	.005	-	.08	-
Well	-	-	.05	-	-	.008, .03, .06	.05
Ocean	.02	NDA[c]	NDA	.24	.22	NDA	.09
Lagoon	.03	NDA	NDA	.008	.13	.23	.10
Depth (in.)			SOIL[b] (c/m/kg x 10^{-5})				
0-1	719	.41	4.23	3.46	2.02	.13	NDA
12	-	-	-	.41	-	-	-
18	NDA	-	.28	-	-	-	.19
24	-	.40	-	-	.23	NDA	-
33	NDA	-	-	.38	-	-	-
36	-	-	-	-	-	-	.23
44-45	-	-	.66	-	-	-	-
48	-	.19	-	-	.30	-	-
55-56	-	-	-	-	-	NDA	-

(a) All counts were corrected for the counting efficiency of Co^{60}.

(b) Gross gamma activity of plant samples was determined in April 1956 and that of soil and water in May 1956.

(c) NDA indicates no detectable activity.

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TABLE A-[illegible]

Nuclide Analyses of Plant, Soil and Water Samples(a)

Island	Sample	Disintegrations (d/m/kg or d/m/liter) Total Rare Earths(b)	Sr^{90}	Cs^{137} (b)	Ru^{106} (b)
Gejen	Soil (0-1 in.)	1.75×10^{8}	5.3×10^{6}	3.49×10^{5}	3.23×10^{7}
	Portulaca	4.2×10^{6}	2.3×10^{5}	1.09×10^{5}	
	Coconut, Whole	5.9×10^{2}	9.2×10^{2}	1.3×10^{5}	
	Coconut Milk	6.1×10^{2}	6.0×10^{2}	2.7×10^{5}	
	Coconut Shell	1.6×10^{3}	NDA(c)	6.4×10^{5}	
	Coconut Meat	2.2×10^{2}	1.5×10^{2}	2.1×10^{5}	
	Coconut Husk	1.3×10^{3}	1.2×10^{3}	5.1×10^{5}	
	Arrowroot Leaves	[illegible] $\times 10^{5}$	1.9×10^{4}	7.4×10^{4}	8.66×10^{3}
	Arrowroot Tubers	3.2×10^{4}	1.9×10^{3}	1.4×10^{5}	1.3×10^{4}
	Pandanus Leaves	4.4×10^{4}	3.5×10^{3}	1.9×10^{5}	9.9×10^{3}
	Pandanus Air Root	4.8×10^{4}	NDA	2.6×10^{5}	
Eniaetok	Soil (0-1 in.)	3.7×10^{5}	2.1×10^{4}	6.1×10^{3}	
	Portulaca	1.5×10^{5}	4.5×10^{4}	1.9×10^{5}	
	Coconut Husk	8.8×10^{3}	6.7×10^{3}	5.9×10^{5}	
	Coconut Shell	8.9×10^{2}	2.8×10^{2}	1.0×10^{5}	
	Coconut Meat	NDA	1.1×10^{2}	8.8×10^{4}	
	Coconut Shell	NDA	NDA	3.2×10^{4}	
	Arrowroot Tubers	6.8×10^{3}	8.2×10^{2}	5.1×10^{4}	
	Pandanus Keys	1.7×10^{3}	5.8×10^{3}	6.3×10^{4}	
	Pandanus Keys	1.5×10^{3}	2.0×10^{3}	[illegible] $\times 10^{4}$	
	Pandanus Leaves	3.6×10^{4}	4.6×10^{4}	2.3×10^{5}	5.72×10^{4}
	Pandanus Air Root	5.6×10^{3}	4.3×10^{2}	9.9×10^{4}	
	Water, Well	1.3×10^{2}	NDA		
Rongelap	Soil (0-1 in.)	7.2×10^{5}	3.3×10^{4}	1.7×10^{4}	
	Papaya	7.1×10^{3}	9.9×10^{2}	3.2×10^{5}	
	Coconut Husk	3.1×10^{3}	1.7×10^{3}	2.1×10^{5}	
	Coconut Meat	NDA	2.5×10^{2}	1.9×10^{4}	
	Water, Cistern	7.8×10^{2}	1.2×10^{3}		
	Water, Ocean	1.3×10^{3}	NDA		
	Water, Lagoon	1.8×10^{3}	[illegible]		
Eniwetak	Soil (0-1 in.)	2.9×10^{6}	[illegible] $\times 10^{4}$	2.0×10^{3}	2.1×10^{5}
	Coconut Leaves	6.7×10^{5}	5.6×10^{3}	7.9×10^{4}	6.07×10^{4}
	Water, Lagoon	6.7×10^{2}	NDA		
	Water, Ocean	4.5×10^{2}	NDA		

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TABLE A.2 (Continued)

Nuclide Analyses of Plant, Soil and Water Samples(a)

Island	Sample	Disintegrations (d/m/kg or d/m/liter) Total Rare Earths(b)	Sr^{90}	Cs^{137} (b)	Ru^{106} (b)
Sifo	Soil (0-1 in.)	2.1×10^5	1.3×10^4	3.6×10^3	7.2×10^3
	Arrowroot Tubers	1.3×10^3	2.6×10^2	2.8×10^4	
Utirik	Soil (0-1 in.)	4.1×10^5	4.8×10^4	3.3×10^3	6.7×10^4
	Coconut Leaves	3.2×10^5	NDA	2.4×10^4	9.9×10^3
	Water, Well	2.5×10^2	39		
	Water, Well	70	NDA		
	Water, Cistern	1.8×10^2	20		
	Water, Ocean	5.9×10^2	NDA		
	Water, Lagoon	1.5×10^2	204		

(a) Rare earth, Cs^{137}, and Ru^{106} analyses of plants were performed in May 1956 and those of water and soil in June 1956. Samples were analyzed for Sr^{90} in July 1956.

(b) Beta counting efficiency for Ru^{106}, Cs^{137}, and total rare earths was compared with U_3O_8 standard. Absorption corrections were computed from Al curves for Ru^{106} and Cs^{137}; corrections for total rare earths, from Al absorption of Ce^{144}.

(c) NDA indicates no detectable activity.

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TABLE [illegible]

Gross Beta and Gamma Activity of Animal Specimens

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10⁻⁴)	Gross Beta (d/m/kg x 10⁻⁴)	Gross Gamma (d/m/sample x 10⁻⁴)	Gross Gamma (d/m/kg x 10⁻⁴)
RONGELAP ATOLL							
Rongelap Island							
	Fish						
1502A	Mullet	Whole	182	1.6	8.9	4.7	26
1505	Grouper	Whole	10	0.2	20	0.07	7.0
1512	Surgeon	Whole	40	0.3	7.5	1.7	43
1502C	Goat	Whole	218	8.8	40	15.5	71
		Muscle	87	1.1	12	2.1	24
		Bone	29	1.5	52	2.7	95
		Viscera	10	4.9	490	2.8	280
		Gills	12	0.6	52	2.2	190
		Head	26	0.45	17	3.3	130
		Skin	28	0.2	5.1	2.4	200
1507C	Grouper	Whole	452	5.2	12	5.7	13.0
		Muscle	172	0.4	2.3	0.5	2.9
		Bone	73	1.4	19	2.6	36
		Viscera	90	1.9	21	1.4	15
		Gills	9	0.3	33	0.25	28
		Head	36	0.8	22	0.7	20
		Skin	39	0.4	11	0.26	6.6
	Clams						
1509	Killer	Soft tissue	1800	20	11	33	18
1513	Killer	Soft tissue	882	31	35	83	94
	Snails						
1522	Snail	Soft tissue	67	0.08	1.3	0.07	1.1
1530	Snail	Soft tissue	115	6.9	60	12	100

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TABLE A.3 Cont'd

Gross Beta and Gamma Activity of Animal Specimens

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10^{-4})	Gross Beta (d/m/kg x 10^{-4})	Gross Gamma (d/m/sample x 10^{-4})	Gross Gamma (d/m/kg x 10^{-4})
RONGELAP ATOLL							
Rongelap Island							
	Crabs						
1502B	Coconut	Soft tissue	114	3.5	31	3.1	27
1520A	Langousta	Soft tissue	79	1.3	16	2.1	2.7
1520C	Red eye	Whole	57	0.75	13	3.8	67
1520C [1]	Reef	Whole	61	0.25	4.1	0.99	16
1520D	Red Spotted	Whole	73	0.75	10	0.43	5.6
1529	Grapsus (2)	Whole	94	0.88	9.3	3.8	41
1533	Hermit	Whole	88	8.9	100	1.3	15
	Eel						
1502B	Moray	Whole	136	1.3	9.2	8.4	62
	Birds						
1020	Noddy tern	Egg shell	6.0	NDA [(a)]	NDA	0.62	103
		Egg, soft tissue	33	0.26	8	0.11	3.2
1510	Rooster	Whole	2250				
		G.I. tract	185	0.80	4.3	1.6	8.7
		Muscle	1050	51	4.9	6.9	6.6
		Liver	192	2.4	12.5	9.4	49.0
		Respiratory system	23	0.20	8.7	0.4	17.4
		Skeleton	560	52	93	101	181

(a) NDA = No detectable activity

(Continued)

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TABLE A.[illegible] (Cont.)

Gross Beta and Gamma Activity of Animal Specimens

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10^{-4})	Gross Beta (d/m/kg x 10^{-4})	Gross Gamma (d/m/sample x 10^{-4})	Gross Gamma (d/m/kg x 10^{-4})
RONGELAP ATOLL							
Rongelap Island							
Mammals							
1514	Rat	Whole	48.5				
		G.I. tract	7.65	0.38	49.8	0.25	32.7
		Skeleton	3.1	0.58	187.0	0.15	48.3
		Skin, muscle	30.0	0.39	13.0	.045	15.0
		Head	4.2	0.14	33.3	.086	20.5
		Liver	2.86	.063	22.1	.052	18.2
		Respiratory tract	.39	.029	74.3	.015	38.5
1515	Rat	Whole	65				
		G.I. tract	10.5	.34	32.3	.26	24.7
		Skeleton	4.2	0.74	176.0	0.51	121.0
		Skin, muscle	40.2	0.31	21.5	.073	1.8
		Head	5.6	.19	34.0	.085	15.2
		Liver	3.7	.071	19.2	.061	16.5
		Respiratory tract	0.52	.041	79.0	.023	42.3
1516	Rat	Whole	91				
		G.I. tract	14.4	0.20	14.3	.025	1.7
		Skeleton	5.8	.74	127.4	.43	74.0
		Head	7.8	.15	19.3	.08	10.2
		Skin, muscle	57.0	.36	6.4	.13	2.3
		Liver	5.2	.09	17.3	.061	11.9
		Respiratory tract	0.73	.02	27.4	.022	30.1
1517	Rat	Whole	47				
		G.I. tract	7.4	.33	48.8	.34	46.0
		Skeleton	2.7	.97	360.0	.30	111.0
		Skin, muscle	29.4	.83	282.0	0.14	48.8
		Head	4.1	0.13	31.8	0.14	34.1
		Liver	2.7	.068	32.6	.049	18.1
		Respiratory tract	0.38	.036	95	.011	29

(Continued)

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TABLE A.3 Cont'd

Gross Beta and Gamma Activity of Animal Specimens

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10^{-4})	Gross Beta (d/m/kg x 10^{-4})	Gross Gamma (d/m/sample x 10^{-4})	Gross Gamma (d/m/kg x 10^{-4})
RONGELAP ATOLL							
Enlaetok Island							
	Fish						
1523	Angel	Whole	48	0.98	20.5	2.76	57.4
60	Mullet	Whole	80	2.38	29.7	1.05	13.2
1525C	Parrot	Whole	55	1.38	25.1	2.0	36.7
1525A	Parrot	Whole	1140	18.8	16.5	36.9	32.4
		Head	135	0.45	3.33	7.0	52
		Gill	56	0.55	9.9	4.1	73.2
		Viscera	164	15.9	97.2	11.5	70
		Bone	210	0.76	3.6	7.1	33.8
		Muscle	338	0.67	1.99	4.1	12.1
		Skin	131	0.46	3.47	3.07	23.4
1525E	Goat	Whole	87	0.39	4.5	7.5	86
	Clam						
1527	Killer	Soft tissue	736	3.3	4.5	6.5	8.8
	Crab						
1524	Grapsus	Soft tissue	82	.37	4.5	1.2	14.1
	Bird						
1004	Plover	Whole	281	1.25	4.4	5.3	18.3
Gejen Island							
	Fish						
1620	Snapper	Whole		1.7		5.3	
1630	Grouper	Whole	169	1.8	10.4	9.6	57
1623	Squirrel	Whole	216	1.3	5.8	7.1	32.8
1623A	Squirrel	Whole	189	3.6	19.2	12.3	64.9
1623B	Squirrel	Whole	113	2.5	21.2	10.3	87.7
1624	Butterfly	Whole	115	7.1	62	21.2	185

(Continued)

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TABLE A.3 Cont'd

Gross Beta and Gamma Activity of Animal Specimens

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10^{-4})	Gross Beta (d/m/kg x 10^{4})	Gross Gamma (d/m/sample x 10^{-4})	Gross Gamma (d/m/kg x 10^{-4})
RONGELAP ATOLL							
Gejen Island							
	Fish (cont'd)						
1625	Surgeon	Whole	136	3.9	28.5	7.2	53
1621	Snapper	Whole	1154	26.3	23.0	87	75
		Head	219	6.6	30.1	24.7	113
		Gill	28	1.7	58.9	2.1	74.2
		Viscera	87	6.1	70.1	15.9	184
		Muscle	511	5.4	10.5	16.8	32.9
		Bone	173	5.5	31.8	15.7	907
		Skin	73	1	13.7	11.8	161
	Crabs						
1629	Sand	Whole	46	1.3	28.3	2.3	39.1
1632	Red eye	Whole	32	0.88	27.3	4.3	134
	Snail						
1636	Spider	Soft tissue	91.5	11.3	124	6.5	71.4
1637	Spider	Soft tissue	90	18.7	207	18	201
1638	Spider	Soft tissue	56	102	1820	68	1210
1639	Scorpion	Soft tissue	39.5	17.7	440	23	580
	Birds						
1035	Fairy tern	Whole	92	0.93	10.1	0.32	3.5
W1035	Fairy tern	Viscera	101	.38	0.38	.025	0.25
		Muscle	141	NDA		.019	0.13
		Tibia		NDA		NDA	
Kabelle Island							
	Fish						
1540	Grouper	Whole	176	0.75	13.4	6	107

(Continued)

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TABLE A.3 Cont'd

Gross Beta and Gamma Activity of [illegible]

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10^{-4})	Gross Beta (d/m/kg x 10^{-4})	Gross Gamma (d/m/sample x 10^{-4})	Gross Gamma (d/m/kg x 10^{-4})
RONGELAP ATOLL							
Kabelle Island							
	Fish (cont'd)						
1538	Red snapper	Whole	735	12.3	17.0	18.5	25.0
		Skin	89	1.0	11.2	4.1	45.7
		Muscle	281	0.95	3.4	0.69	2.4
		Bone	141	2.4	16.8	4.4	31.3
		Gill	24	0.45	18.7	1.1	44
		Head	60	4.5	75	1.9	32
		Viscera	140	2.9	29	6.3	64
1544	Parrot	Whole	1957	24.8	12.7	71.3	36.5
		Viscera	258	5	19.4	8.8	34.3
		Muscle	691	2.4	3.5	6.8	9.5
		Head	280	8.5	30.4	20.9	74.8
		Skin	223	1.1	5.0	8.9	39.9
		Gills	56	0.83	14.7	2.7	49
		Bone	449	1	25.6	23.4	86
1541	Butterfly	Whole	36	0.035	9.7	1.9	53.6
1543	Damsel (6)	Whole	69	1.5	21.7	3.8	54.9
	Snail						
737	Helmet	Soft tissue	271	4.8	17.7	11.9	43.9
	Birds						
1010	Fairy tern	Muscle	7.6	0.033	4.3	.012	1.6
		Tibia	0.3	NDA		NDA	
1011	Fairy tern	Muscle	11.2	0.028	2.5	.045	4.0
		Tibia	0.23	NDA		NDA	
1012	Noddy tern	Whole	145	1.1	7.8	1.7	12
1013	Noddy tern	Muscle	16.9	0.10	5.9	0.13	7.7
		Tibia	.895	0.07	7.5	0.027	30.2
1014	Noddy tern	Egg Shell	6	NDA	NDA	0.13	21.3
		Egg, soft tissue	21	.06	3	0.03	1.4

(Continued)

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TABLE A.3 Cont'd

Gross Beta and Gamma Activity of Animal Specimens

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10-4)	Gross Beta (d/m/kg x 10-4)	Gross Gamma (d/m/sample x 10-4)	Gross Gamma (d/m/kg x 10-4)
RONGELAP ATOLL							
Kabelle Island							
	Birds (cont'd)						
1017	Noddy tern	Egg shell	4.5	NDA	NDA	0.13	28.4
		Egg, soft tissue	24.5	0.24	9.5	0.03	1.4
RONGERIK ATOLL							
Eniwetak Island							
	Fish						
1559B	Surgeon	Whole	105	0.41	[illegible].9	0.69	6.7
1561	Half-beak	Whole	30	0.03	1.0	0.46	15.3
1563	Butterfly	Whole	28	0.03	1.2	0.16	5.9
1564	Damsel (3)	Whole	50	0.11	4.4	0.24	2.1
1565	Squirrel	Whole	102	0.15	1.4	1.2	11.8
1560	Squirrel	Whole	387	0.41	1.1	2.0	5.2
		Head	64	0.23	3.6	0.55	8.6
		Muscle	113	0.04	.36	0.27	2.3
		Gill	13	0.02	1.2	0.08	6.5
		Viscera	38	0.04	1.1	0.38	9.9
		Bone	65	0.06	0.96	0.39	6.0
		Skin	76	0.02	0.19	0.35	4.5
	Crab						
1026	Red eye	Whole	60	0.17	2.8	1.1	18.3
	Birds						
1025B	Noddy tern	Whole	98	3.1	31	1.9	20.6
1025D	Fairy tern	Whole	88	0.75	8.3	NDA	
1025A	Fairy tern	Whole	103				
		Muscle	12.4	0.033	2.7	0.026	2.22
		Tibia		NDA		NDA	
		Viscera		0.075		0.12	

(Continued)

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TABLE A.3 Cont'd

Gross Beta and Gamma Activity of Animal Specimens

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10^{-4})	Gross Beta (d/m/kg x 10^{-4})	Gross Gamma (d/m/sample x 10^{-4})	Gross Gamma (d/m/kg x 10^{-4})
RONGERIK ATOLL							
Eniwetak Island							
	Birds (cont'd)						
1025C	Noddy tern	Whole	211				
		Muscle	27	0.05	1.9	0.038	1.45
		Tibia	0.23	NDA		NDA	
		Viscera		0.03		0.05	
AILINGNAE ATOLL							
Sifo Island							
	Fish						
1551D	Surgeon	Whole	45	0.37	8.2	0.55	12.2
1551D[1]	Damsel	Whole	25	0.18	7.1	0.42	16.7
1552	Angel	Whole	203	0.68	3.4	5.0	24.7
1555	Butterfly	Whole	134	0.32	2.4	1.6	12.3
1551A	Red snapper	Whole	640	3.2	5.0	38.9	61
		Head	115	0.73	6.3	9.9	86.1
		Gills	18	0.12	6.7	2.7	153
		Viscera	24	0.92	38.2	3.6	151
		Muscle	283	0.60	2.1	6.2	21.7
		Bone	110	0.53	4.8	10.6	96.7
		Skin	75	0.31	4.1	5.9	78.7
1551C	Squirrel	Whole	373	0.28	0.75	3.5	9.4
		Head	57	0.035	0.61	0.96	16.9
		Gill	12	0.012	1.0	0.19	15.0
		Viscera	36	0.067	1.86	0.41	11.5
		Muscle	107	0.061	.57	0.41	3.8
		Bone	53	0.052	.98	0.72	13.6
		Skin	84	0.051	.61	0.83	9.9
	Crab						
670	Hermit	Whole	52	2.1	40.2	0.86	16.5
672	Coconut	Soft tissue	150	1.2	7.9	1.5	10
1021	Reef	Whole	121	0.30	2.5	1.7	14.4
1021[1]	Hermit	Whole	35	0.81	23.2	0.44	12.6

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TABLE A.3 Cont'd

Gross Beta and Gamma Activity of Animal Specimens

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10^{-4})	Gross Beta (d/m/kg x 10^{-4})	Gross Gamma (d/m/sample x 10^{-4})	Gross Gamma (d/m/kg x 10^{-4})
AILINGNAE ATOLL							
Sifo Island							
Clam							
1549	Killer	Soft tissue	1104	7.1	6.4	17.1	15.0
Birds							
1018	Fairy tern	Carcass	99	1.0	10.1	0.17	1.77
		Muscle	16	0.078	4.9	0.46	28.9
		Viscera		0.05		.04	
		Tibia	.297	NDA		NDA	
1019A	Noddy tern	Carcass	96	.038	3.9	3.3	33.9
		Viscera		0.072		0.20	
		Muscle	10.7	0.05	4.68	0.56	5.3
		Tibia	0.265	NDA		NDA	
1019B	Fairy tern	Whole	163				
		Viscera		NDA		0.14	
		Muscle	7.9	0.05	6.3	0.016	2.1
		Tibia	0.34	NDA		NDA	
1019C	Noddy tern	Whole	185	0.16	0.86	0.025	3.37
1022	Noddy tern	Whole	94				
		Viscera		0.24		0.175	
		Muscle	10	0.04	4.2	0.44	44.
		Tibia (2)	0.72	NDA		NDA	
1020	Noddy tern	Egg	39				
		Egg shell	6	NDA		0.06	10.3
		Egg, soft tissue	33	0.26	7.9	0.11	3.2

(Continued)

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TABLE A.3 Cont'd

Gross Beta and Gamma Activity [illegible]

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10⁻⁴)	Gross Beta (d/m/kg x 10⁻⁴)	Gross Gamma (d/m/sample x 10⁻⁴)	Gross Gamma (d/m/kg x 10⁻⁴)
UTIRIK ATOLL							
Utirik Island							
	Fish						
1573	Squirrel	Whole	23	NDA		0.12	5.4
1576	Angel	Whole	44	NDA		0.07	1.6
1581	Goat	Whole	46	0.3	6.5	0.14	2.9
1583	Damsel	Whole	46	NDA		NDA	
1584	Butterfly	Whole	68	NDA		NDA	
1596	Manini	Whole	129	0.88	6.8	0.58	4.5
1597	Half-beak	Whole	13	NDA		NDA	
1580	Gray parrot	Whole	425	0.66	1.5	0.87	2.1
		Head	32	NDA		0.09	2.8
		Gill	10	NDA		0.04	4.1
		Viscera	82	0.38	4.6	0.15	1.8
		Bone	65	0.13	1.9	0.13	1.9
		Muscle	172	0.15	0.87	0.22	1.3
		Skin	47	NDA		0.24	5.1
	Snail						
1590	Ghost	Soft tissue	19	NDA		0.075	3.9
1591	Reef	Soft tissue	195	NDA		1	4.6
1585	Spider	Soft tissue		0.018		NDA	
	Mammal						
1571	Rat	Tibia (2)		NDA		NDA	

(Continued)

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Gross Beta and Gamma Activity of Animal Specimens

Sample No.	Sample	Tissue	Wet Wt (g)	Gross Beta (d/m/sample x 10^{-4})	Gross Beta (d/m/kg x 10^{-4})	Gross Gamma (d/m/sample x 10^{-4})	Gross Gamma (d/m/kg x 10^{-4})
LIKIEP ATOLL							
	Likiep Island						
	Fish						
1605	Butterfly	Whole	119	0.25	2.1	0.31	2.6
1607	Parrot	Whole	349	NDA		0.38	1.1
1611	Damsel (3)	Whole	61	0.38	6.2	0.13	2.1
1612	Surgeon	Whole	51	NDA		0.02	0.39
1613	Grouper	Whole	76	0.38	4.9	.012	.16
1609	Gray snapper	Whole	453	1.1	2.4	2.2	4.9
		Head	38	NDA		0.021	5.5
		Gill	14	NDA		NDA	
		Viscera	78	1	12.8	2	25.1
		Muscle	144	0.1	0.7	0.21	1.5
		Bone	99	NDA		NDA	
		Skin	63	NDA		NDA	

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Date Issued: 28 August 1956

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USNRDL-455
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nuclear detonation of Operation CASTLE.
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The major radionuclides found in the tissues of fish was zinc-65, and that in clams, cobalt-60.

Residual soil contamination remained confined to the surface.

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