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RESIDUAL CONTAMINATION OF PLANTS, ANIMALS, SOIL, AND WATER OF THE MARSHALL ISLANDS ONE YEAR FOLLOWING OPERATION CASTLE FALL-OUT

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12 August 1955

by

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Weapons

Chemical Technology Division
R. R. Tompkins

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U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

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Effects of Atomic Weapons

Technical Objective
AW-7

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ABSTRACT

The amount and distribution of radioactive material remaining on several atolls and incorporated into the flora and fauna of the Marshall Islands was determined one year after their contamination by fallout from the March 1, 1954 nuclear detonation of Operation Castle.

Significant amounts of radioactive contamination were found in animals, food plants, water and soil samples. The highest concentrations of internally deposited activity were found in marine specimens taken from the northern Rongelap lagoon. Most of the activity in the marine specimens was contributed by Zr^{95}-Nb^{95} and Ru^{106}-Rh^{106}. No fractionation of Sr^{89}-Sr^{90} occurred in the tissue of the fish analyzed.

Residual soil contamination was confined to the top several inches of soil, with movement indicated down to the lens water.

The major radionuclide found in the tissues of land animals and plants was Cs^{137}. The island soil and lagoon water were contaminated principally by the rare earth elements, Ru^{106}-Rh^{106} and Zr^{95}-Nb^{95}. The amount of activity in the specimens analyzed was generally proportional to the external gamma reading in each of the areas.

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SUMMARY

Problem

The problem was to determine the amount and distribution of radioactive material remaining on several atolls and incorporated into the flora and fauna of the Marshall Islands one year after their contamination by fallout from the March 1, 1954 nuclear detonation of Operation CASTLE.

Findings

Significant amounts of radioactive contamination were found in the Marshall Island animals, food plants, water and soil samples. The highest concentrations of internally deposited activity were found in marine specimens taken from the northern Rongelap lagoon. Most of the activity in the marine specimens was contributed by Zr^{95}-Nb^{95} and Ru^{106}-Rh^{106}. No fractionation of Sr^{89}-Sr^{90} occurred in the tissue of the fish analyzed.

Residual soil contamination was confined to the top several inches of soil, with movement indicated down to the lens water.

The major radionuclide found in the tissues of land animals and plants was Cs^{137}. The island soil and lagoon water were contaminated principally by the rare earth elements, Ru^{106}-Rh^{106} and Zr^{95}-Nb^{95}. The amount of activity in the specimens analyzed was generally proportional to the external gamma reading in each of the areas.

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ADMINISTRATIVE INFORMATION

This is the final report of the Atoll Resurvey Project. The resurvey was made by this Laboratory together with Applied Fisheries Laboratory of the University of Washington, under the joint sponsorship of the Bureau of Ships and the Atomic Energy Commission, Bureau of Ships Project Number NS 081-001 and Bureau of Medicine and Surgery Project Number NM 006-015.04, Technical Objective AW-7.

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

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CHAPTER 1

INTRODUCTION

As a result of a nuclear detonation in Operation CASTLE, several atolls in the Marshall Islands were accidentally contaminated by radioactive fall-out to such an extent that evacuation of the inhabitants was necessary.[1] Plants, animals, water, and soil were collected from the islands one month after the fall-out occurred. The animals not sacrificed at the site were sent to this laboratory and radiochemical analysis was made of their tissues to provide information on the internal radiation hazard. A report[2] of this study has been published.

As a follow-up to the original study a resurvey of the contaminated Marshall Islands was undertaken one year after the fall-out. Radiochemical analysis of food plants, fish, water, soil, coral, algae, and birds was made to determine the nature and extent of the internal and external radiation hazard created by the residual contamination on the islands. A gamma dose-rate survey was conducted to determine the external radiation hazard extant. Such data were necessary to determine the possibility of re-occupying the islands. The present report presents the data obtained from the resurvey of the contaminated islands.

1.1 OBJECTIVES

This work was named the Atoll Resurvey Project, entitled "Follow-up Determination of the Extent and Distribution of Fall-out Contamination on Rongelap and Other Atolls in the Marshall Group." Its specific objectives were:

a. To provide data upon which a decision can be based as to when the evacuated islands may be safely re-occupied by their former inhabitants.

b. To provide information about distribution of the residual contamination on a land area which had been heavily contaminated by fall-out.

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CHAPTER 2

GROSS ACTIVITY IN PLANTS, SOIL, CORAL, ALGAE, AND WATER

At the time of their collection in the field, the representative plant, soil, coral, and algae samples were placed in individual plastic bags for shipment to this laboratory. Water samples were collected in 1-liter polyethylene bottles.

2.1 PROCEDURES AT THE LABORATORY

The edible portions of the food plants were separated from the inedible portions with every precaution being taken to ensure a low probability of cross-contamination. Weighed samples of the food were dried at 110°C and then ashed in a muffle furnace at 500°C. The ash was transferred to tared aluminum planchets, weighed, and prepared for counting. Samples of supporting plant systems and grass were prepared in the same fashion.

Fresh water samples were acidified and evaporated to dryness. The residue was taken up in water and the slurry transferred to a planchet for drying, weighing, and counting. The radioactivity was isolated from ocean water samples by (a) buffering with NH_4Cl to hold magnesium in solution, and (b) precipitating the natural calcium with Na_2CO_3. The resulting flocculation was allowed to settle overnight and the bulk of the supernatant was removed by suction or decantation. The remaining slurry was transferred to lustroid tubes and centrifuged. The precipitate was washed once with water, transferred to an aluminum planchet, and dried at 110°C. Analysis of the supernatants from the more active samples showed that recovery of activity by precipitation ran from 80 to 90 per cent.

Soil and lagoon-bottom silt samples were dried and mounted in aluminum planchets for counting. Coral and algae samples were dried overnight at 110°C, ashed for 24 hr at 500°C, pulverized, and mounted in aluminum planchets.

After mounting, the samples were counted with a gas-flow proportional counter at 26 per cent geometry as determined with a U_3O_8 standard or with a 1.9 mg/sq cm, end-window, G-M tube and scaler at 14 per cent geometry as determined with a U_3O_8 standard. Absorption and scattering corrections were determined empirically by counting varying weights of individual samples and extrapolating the specific

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activities to zero sample weight. Absorption curves on all samples showed negligible amounts of K^{40} betas as compared to the gross contamination.

2.2 RESULTS AND DISCUSSION

2.2.1 Major Foods

The gross beta activities found in the major food items are summarized in Table 2.1. The data are presented on the basis of wet weight of sample. The prevalence of soft beta emission in many of the food samples necessitates rather large corrections for self-absorption but no significant errors are introduced through the correction procedure.

TABLE 2.1

Summary of Gross Beta Activity in Major Plant Foods

Source		Average Activity ($\mu c/g \times 10^{6}$[a] or $\mu c/cc \times 10^{6}$)					
						Coconut	
Atoll	Island	Arrowroot	Breadfruit	Pandanus	Papaya	Meat	Milk
Likiep	Likiep	4.0	9.1	5.7	3.6	2.5	3.0
Utirik	Utirik	16	3.4	5.0	9.0	2.3	2.6
Rongelap	Rongelap	15		28	27	9.8	9.6
Rongelap	Busch	68		13		8.0	11
Rongelap	Eniaetok	80		34		12	12
Rongelap	Labaredj	36				13	13
Rongelap	Kabelle	40		130		16	12
Rongelap	Lukuen					18	16
Rongelap	Gejen	130				72	25
Rongelap	Lomuilal	180				19	30
Bikar	Bikar					5.9	5.0
Rongerik	Eniwetak					7.8	9.4

(a) Wet weight

A number of coconut samples were collected because of their importance as a food source. Three stages of growth are represented: young green coconuts, the milk of which is drunk; copra stage nuts prized for food; and sprouting coconuts which yield highly palatable meat. In general, the activity appears to be higher in the more mature

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coconuts. Wide variation in levels among samples from the same island can probably be accounted for in terms of age of the nut, age of the tree, humus content and pH of the soil in which the tree grows, and a number of less important factors such as depth of island profile and density and type of plant growth around the coconut tree.

Since arrowroot grows in the contaminated soil, most of the factors affecting coconut uptake had little influence on the arrowroot uptake. For this reason the arrowroot samples showed relatively little variation among specimens. Also, the growing season of arrowroot had apparently ended and only mature corms could be obtained thereby specifying the development stage of this food material.

Since pandanus and breadfruit trees bore very little fruit at the time of the survey only sketchy sampling was possible. Both of these trees tend to shade out competing plants and develop fruit rather rapidly. Thus, soil variation was the main factor causing differences in uptake of activity for samples from the same area. As expected, less variation was found in the pandanus and breadfruit than in coconuts but more than in arrowroot samples. Papayas were found only near native habitations and apparently were cultivated to a greater degree than the other major food plants. This resulted in a system comparable to the pandanus and breadfruit.

2.2.2 Miscellaneous Plant Samples

A summary of the gross beta activities found in miscellaneous plant samples is contained in Table 2.2. Data in this table are on the basis of wet weight.

The grass samples are of general interest because of their similarity to the forage crops and cereal grains responsible for the major portion of the world's food supply. Likiep, Utirik, and Bikar samples indicate that grass may act as a sensitive indicator for radioactivity available to plant uptake. The age of the grass and the soil characteristics are probably responsible for the wide range of activities observed for samples from the same island.

Plant trunk and foliage samples indicate a considerable movement of activity into the plant system, as was forecast by the presence of activity in coconut tree sap run during the course of the original study.[2] The coconut tree system is especially interesting since the total activity represented by the fruit is a small fraction of that which is residual in the remainder of the plant. It is unfortunate that the survey was made when coconut tree sap ("Jugaroo") was virtually unobtainable even by native Marshallese.* Use of this material as food for infants makes it merit study from a contamination standpoint.

*Native Marshallese were included in the survey teams.

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TABLE 2.2

Summary of Gross Beta Activity in Miscellaneous Plant Samples

Plant Material	Average Activity (μc/g x 10^6) (a)											
	Island											
	Likiep	Utirik	Rongelap	Busch	Enlaetok	Labaredj	Kabelle	Lukuen	Gejen	Lomuilal	Bikar	Eniwetak
Grass	20	400	3000	420	2800	5300	1900	2100	68,000	5600	180	400
Coconut leaf		1100				750	1800	670				
Coconut frond stem								140				
Coconut shell							17		150			
Coconut husk	1.7	1.5	53				73		110		8.4	
Coconut sprout			28				110					
Sprouted coconut roots			72				740					
Scaevola leaf							120		100	290	6.7	60
Scaevola Trunk Section											23	
Arrowroot stem			19									
Arrowroot leaf			61									
Pumpkin	2.0		35									
Limes	2.0											
Taro	1.1											
Banana	4.6											
Vines									490			340

(a) Wet weight

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Arrowroot stems and leaves show a considerable amount of activity but the ratio of the activity in the supporting system to that in the edible part is much less than for coconuts. This is understandable when the relative amounts of fruit and supporting system in both instances are considered.

2.2.3 Soil

Exposed soil profile, tube coring, and gross samples were collected to describe the distribution of activity in the island profiles and especially in the areas of extensive food plant production.

A summary of the beta activity in gross samples of soil is given in Table 2.3. Table 2.4 presents data obtained from exposed soil profiles. The probability of cross-contamination in these samples was small.

TABLE 2.3

Summary of Beta Activity in Gross Samples of Soil

Island	Number of Samples	Beta Activity (β^-/min/g) Depth of Soil	
		0 to 1 in.	1 to 5 in.
Likiep	1	90	
Utirik	4	960	550
Rongelap	5	8,900	800
Eniaetok	2	48,000	640
Labaredj	3	85,000	1,300
Kabelle	6	96,000	3,100
Gejen	1	348,000	12,400
Bikar	1	8,400	90
Eniwetak	1	12,000	240

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TABLE 2.4

Beta Activity in Soil Samples Taken From Exposed Soil Profiles

Depth (in.)	Beta Activity (β^-/min/g)				
	Island				
	Rongelap	Labaredj	Kabelle	Kabelle	Kabelle
0 to 1	12,400	130,000	72,000	93,000	97,000
3	1,500	380	6,800	2,900	440
6	110	950	1,700	400	130
9	140	770	130	2,300	240
12	NDA [(a)]	160	40	580	140
18	70	120	70	70	90
24		40	100	70	NDA
30				NDA	
36				60	
40				40	

(a) No detectable activity

Table 2.5 summarizes the data derived from the tube coring samples. Cores were analyzed in 1-in. increments and while some movement of activity along the walls of the tube was probable the results for the most part agreed rather well with those obtained by the other sampling procedures.

A comparison of Tables 2.3, 2.4, and 2.5 indicates that the coring technique falls down somewhat at high levels of activity although the apparent movement of activity may be real and may be a function of the soil particle size and not a mechanical cross-contamination.

The data in Table 2.5 show very definitely that the residual activity on the islands is contained primarily in the top several inches of soil and that movement is occurring. Data presented in Chapter 3 deal with the nature of the contamination in the environment and from them it can be deduced that fractionation takes place, with Ce^{144}-Pr^{144} and Ru^{106}-Rh^{106} making up much of the fixed contamination. The plant

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TABLE 2.5

Beta Activity in Core Samples of Soil

Island	No. of Cores	Beta Activity (β^-/min/g) 1-in. Increment of Soil Coring: 1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Likiep	1	140	40	40	NDA[a]	NDA				
Utirik	3	1,250	480	240	130	100	160	60	25	
Rongelap	4	6,600	2,100	570	420	230	160	200	150	50
Busch	1	10,800	7,100	7,200	6,400	6,800				
Eniaetok	1	57,000	24,000	4,300	12,000	26,000	12,000	11,000		
Labaredj	1	42,000	33,000	29,000	23,000	19,000				
Kabelle	3	43,000	30,000	10,000	3,600	2,000	2,300	180		
Lomuilal	3	53,000	48,000	26,000	20,000	14,000	1,000			
Gejen	1	37,000	37,000	8,000	4,000	4,400	3,400			
Lukuen	2	35,000	40,000	13,000	10,500	10,000	10,000	4,700		
Bikar	3	4,000	740	250	170	120	100	27		
Eniwetak	2	16,000	7,500	3,000	2,000	1,800	1,100	160	100	

(a) No detectable activity

uptake over a long period of time may be considerable since the root systems on the islands are uniformly distributed throughout the top 14 in. of the island profiles and are extremely dense. Very few roots were found below 14 in. and those that were noted appeared to be carrying large amounts of water from the fresh water lens to the mother plant. The large amounts of activity found in the plant systems negates any possibility that direct fall-out could be solely responsible for the contamination. The nature of the contamination in the plants shows that although Ce^{144}-Pr^{144} and Ru^{106}-Rh^{106} are firmly fixed in the soil they are readily taken up by the plant systems.

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2.2.4 Coral, Lagoon-Bottom Silt, and Algae

The extent of contamination in the atoll waters adjacent to the islands was evaluated from samples of coral, lagoon-bottom silt, and algae. Numerous edible marine species exist in this area and their food chain is dependent primarily on the algae and coral. The gross beta activities in coral and algae are given in Table 2.6.

TABLE 2.6

Gross Beta Activity in Coral and Algae

Island	Beta Activity (β^-/min/g) Coral	Algae Type[(a)]	Algae Activity
Likiep	NDA[(b)]		
Utirik	NDA	G	120
Rongelap	290		
Eniaetok	790 3,400	H SC	400 34,000
Labaredj	860		
Kabelle	300 320	G	16,800
Gejen	1,300 1,140 3,260	H	4,160
Bikar	240 210	G	3,500

(a) G = green; H = Halimeda; SC = Sea Cucumber.
(b) No detectable activity.

Algae appear to concentrate activity to a much greater degree than coral. Much of the coral activity may even be due to algae which is lodged in small pores where it cannot be removed. The sea cucumber and green types of algae are much more efficient at concentrating activity than is the highly calcareous Halimeda type.

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Four samples of lagoon-bottom silt from the northeast corner of Rongelap Atoll gave beta activity values ranging from 8,000 to 12,000 β^-/min/g. Activity was uniformly distributed to a depth of 6 to 7 in. Lagoon depths were 40, 55, 60, and 120 ft.

The data in Table 2.6 indicate a considerable reservoir of activity available for contaminating marine food species. Data presented in Chapter 4 confirm that this activity contaminates the food supply.

2.2.5 Water

Water samples were collected from cisterns, wells, tree boles, barrels, exposed soil profiles, and ocean and lagoon sides of the islands. The ocean and lagoon water samples were collected within 10 ft of the water line to evaluate the movement of activity from the islands into the surrounding waters. Exposed profiles and well water samples were selected to describe any movement of activity into the fresh water lens and the remainder of the samples were collected to evaluate the hazard from drinking the water.

Gross beta activities of the above samples are presented in Table 2.7. The scarcity of potable water is demonstrated by the few islands from which cistern water was obtainable.

TABLE 2.7

Summary of Gross Beta Activity in Water

	Beta Activity (β^-/min/liter)							
	Sources of Water							
	Ocean		Cistern					
Island	Lagoon Side	Ocean Side	Top	Bottom	Well	Barrel	Tree Bole	Exposed Soil Profile
Likiep	NDA[a]	NDA	12		NDA			
Utirik	50	NDA	290	1,350	28			
Rongelap	80	330	6,300	16,000	430	44,000		
Busch	36	NDA					14,000	
Eniaetok	460	260	23,000					
Labaredj	7,700	56					8,100	
Kabelle	2,300	60						15,000
Lomuilal	380	170						
Bikar	37	28						
Eniwetak	100	170						

(a) No detectable activity

[redacted]

The ocean water data indicate that activity is being washed off the islands. It will be noted also that the levels of activity correlate with the gamma-dose rates of the islands. Such irregularities as do occur can be attributed to the ocean current movements around the islands. Lomuilal, for example, is in an exposed position and both the lagoon and ocean sides of the island are swept by strong currents. The generally higher levels of activity on the lagoon side of the islands can be explained by the same reasoning. Since the rainy season had ended at the time the sample was collected, the actual mechanism by which the active material was being moved was probably associated with the changing level of water line due to tides. The lower gamma-dose rates observed below the high tide mark would support this hypothesis.

The water from wells and exposed profiles represents the fresh water lens underlying the islands and Table 2.7 shows that they are contaminated. These data are of special interest since these lenses may be intermediate systems for transferring various nuclides from the soil to plants.

The cistern water and other potable water supplies of less importance show varying degrees of contamination depending on such factors as the cleanliness of the reservoir, the nature of the watershed areas, and the presence or absence of shielding trees. The higher levels of activity found in the bottoms of cisterns are to be expected and these data are included only for comparative purposes.

CHAPTER 3

NATURE OF THE RESIDUAL CONTAMINATION IN PLANTS, SOIL, CORAL, LAGOON-BOTTOM SILT, AND WATER

Evaluation of the residual contamination from the fall-out on the atoll islands was determined by study of the long-lived fission products. These long-lived nuclides present the greatest internal radiation hazard to human inhabitants of a contaminated area.

Radiochemical analyses for $Sr^{89,90}$, total rare earths, Zr^{95}, Ru^{106}, and Cs^{137} were performed as these fission products comprise the bulk of the activity remaining 16 months after the nuclear detonation.

3.1 RESULTS AND DISCUSSION

In Table 3.1 the relative contributions of the various nuclides are shown as percentages of the total activity.

The difference in composition of contamination in the edible coconut fractions and in the frond is to be noted, as are the similarity of coconut and pandanus contamination as well as the high Cs^{137} concentrations encountered in most food plants. An additional point of interest is the agreement of the soil composition with that predicted[2] from an analysis of Rongelap soil during Project 4.1. Rare earths and ruthenium are somewhat higher than predicted, indicating a washout of the other nuclides.

Arrowroot samples showed rather wide variation in composition which had not been expected[2] from consideration of the variables involved.

Rare earth nuclides and Ru^{106} make up the bulk of the activity which remains fixed to coral island soil under the influence of tropical rains. Ground water and lagoon water values were similar to those of the soil. Lagoon-bottom silt gives very nearly the same nuclide distribution as soil and it appears that solubility may be a better criteria for predicting nuclide mobility through soil than complex formation with matrix components.

The high uptake of Cs^{137} by the edible portions of plant foods is probably the result of potassium deficiency in the soil and the utilization of cesium to replace needed potassium. A comparison of the coconut frond and edible coconut fractions illustrates their selectivity for individual nuclides.

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TABLE 3.1

Radiochemical Composition of Residual Contamination

Material	Percentage of Total Activity Observed[a]					
	Radionuclides					
	Sr^{89}	Sr^{90}	Rare Earths	Zr^{95} [b]	Ru^{106} [b]	Cs^{137}
Arrowroot	1.3	5.9	3.0	0.5	7.8	80
Breadfruit	NDA[c]	6.3	50	19	NDA	24
Coconut Frond	1.2	5.0	80	4.2	6.7	1.6
Coconut Meat	NDA	NDA	1.2	NDA	NDA	95
Coconut Milk	NDA	NDA	0.9	NDA	NDA	96
Grass	1.3	4.6	74	6.4	4.8	8.4
Pandanus	0.5	2.4	1.2	0.2	0.6	95
Papaya	1.6	7.3	37	31	12	11
Coral	3.2	14	67	10	4.5	1.1
Soil	0.8	2.2	73	0.1	23.3	1.1
Lagoon Bottom	1.1	5.0	82	0.2	13	NDA
Cistern Water	2.9	8.6	41	24	20	13
Ground Water	0.8	2.5	49	20	16	9.2
Lagoon Water	0.9	4.0	76	9.7	7.0	0.8

(a) Values as of 15 July 1955 (16 mos after the nuclear detonation).
(b) Nb^{95} and Rh^{106} may be calculated from the reported parent values.
(c) No detectable activity.

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CHAPTER 4

INTERNAL CONTAMINATION OF FISH, MARINE SPECIMENS, AND BIRDS

Fish and birds were collected from the following islands of the Rongelap Atoll: Rongelap, Gejen, Kabelle, and Labaredj. In addition, other animals were collected from Bikar, Likiep and Utirik Atolls and Eniwetak Island of the Rongerik Atoll. The majority of the marine specimens were collected in the lagoons off the shores of the islands. The larger fish were caught in the middle of the lagoon.

Most of the fish were collected after they were poisoned by a Rotenone solution dispersed in the shallow water. The birds (terns) were shot with a rifle. Each specimen was placed in a plastic bag and frozen. The frozen samples were transported to this laboratory.

4.1 LABORATORY PROCEDURES

A number of the large fish were completely separated into skeleton, muscle, gills, liver, and viscera. The remaining fish and marine invertebrates were analyzed whole.

All samples were dried at 100°C for 48 hr and ashed for 48 hr at 550°C. The ash was dissolved in 2N HCl and made up to volume. The gamma activity was counted in a deep-well, sodium iodide crystal, gamma scintillation counter; the beta activity was counted under a thin end-window, beta counter. The beta activity in each case was corrected for counter efficiency and mass absorption. The gamma and beta activity is recorded in "$\mu c (Co^{60}$ equivalent)". This unit was derived from comparison with a Co^{60} standard counted under identical conditions as the samples.

Radiochemical analysis were performed to determine the concentration of several radionuclides in a number of the specimens. The radiochemical techniques employed will be described in a forthcoming report.

[redacted]

TABLE 4.1

Summary of Beta and Gamma Activity Concentration in Fish and Marine Invertebrates

Location	Radioactivity Concentration (μc/kg)(a): Large Fish(b) No. of Specimens	Large Fish Activity β	Large Fish Activity γ	Small Fish(c) No. of Specimens	Small Fish Activity β	Small Fish Activity γ	Crabs and Clams No. of Specimens	Crabs and Clams Activity β	Crabs and Clams Activity γ	Snails No. of Specimens	Snails Activity β	Snails Activity γ
Rongelap Atoll												
North Lagoon	3	0.22	1.2	22	.49	1.58	4	1.54	1.25	2	19.5	5.6
South Lagoon	3	.054	0.33	7	.14	0.94	3	0.49	1.76	-(d)	-	-
Rongerik Atoll												
Eniwetak	2	0.23	0.26	2	.23	.21						
Utirik Atoll												
Utirik				6	.14	.04						
Likiep Atoll												
Likiep	1	0.02	0.01	3	.05	.01	1	0.12	0.35			
Bikar Atoll												
Bikar							2	0.39	0.19			

(a) μc are in terms of Co^{60} equivalent.
(b) >150 g.
(c) <150 g.
(d) No data taken.

DOE ARCHIVES

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4.2 RESULTS AND DISCUSSION

Significant amounts of beta and gamma activity were found in the tissues of the 65 fish and marine invertebrates collected (Tables 4.1, 4.2, and 4.3). The distribution of radioactivity in the tissues of the large fish (>150 g) collected in the Rongelap and Rongerik lagoons (Table 4.2) indicated that approximately 40 per cent of the activity was found in the skeleton. Muscle contained approximately 15 per cent of the total internal activity and the viscera contained approximately 20 per cent. One exception was a parrot fish from Eniwetak which had an unusually high activity in the viscera, probably associated with recent ingestion of a highly contaminated food source. The remainder of the activity was found on the skin and gills. The beta-to-gamma ratio was approximately 1:4 in most of the tissues analyzed. Physical and chemical analysis of one fish indicated that this high gamma-to-beta ratio was largely accounted for by the induced activity of Zn^{65} and Fe^{55} K-capture emitters. *Further work on fish is in progress to see if this situation is a unique or generalized finding.*

The total activity found in the terns collected on the various atolls (Table 4.4) was less by a factor of ten or more, than that of the corresponding fish populations. The activity of the terns collected from the Rongelap Atoll was higher than that of the terns from Rongerik Atoll and considerably higher than the terns from the Bikar Atoll.

The radioanalysis of a rooster from Rongelap Island (Table 4.4) indicated relatively high beta and gamma activity (0.7 μc/whole animal). The ratio of beta activity to gamma activity was approximately one. The rooster roamed freely on the island and derived his activity from continuous ingestion of contaminated water and foodstuffs which had incorporated fission products. In comparison, chickens collected at one month post-detonation and removed from the contaminated area continued to show internally deposited activity in detectable amounts for a period of only about 6 months. In the rooster over 90 per cent of the total activity was found in the skeleton, 3.5 per cent in the muscle, and 2.3 per cent in the viscera. Only very small amounts of activity were found on the skin and feathers and even less in the lungs.

Considerable variation exists in the concentration of activity per weight of individual tissues as a function of the geographic location of the animals. In the Rongelap Atoll, for example, fish and invertebrates caught in the northern part of the lagoon contained, on the average, 3 to 4 times the amount of internally deposited fission products as that found in fish from the southern lagoon. This is consistent with the fact that the northern lagoon was exposed to higher concentrations of fall-out material.

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TABLE 4.2

Distribution of Gross Beta and Gamma Activity in Tissues of Large Fish [(a)]

Island	Fish	Wet Weight (g)	Total β	Total γ	Skin β	Skin γ	Muscle β	Muscle γ	Bone β	Bone γ	Gills β	Gills γ	Viscera β	Viscera γ
			Radioactivity (μc x 10^3/Tissue) [(b)]											
Rongelap Atoll, North														
Gejen	Flat Fish with Orange Spots [(c)]	597	196	714	25	24	18	96	120	310	7	16	26	268
North	2 Pelargic	503	84	500	6	69	9	78	29	271	3	16	37	66
Lagoon	Snappers	391	53	550	4	68	9	94	35	313	3	17	8	60
	Average	497	113	588	12	54	12	89	61	298	4	16	24	131
Percentage of Total Activity					10.6	9.2	10.6	15.1	54.0	50.7	3.5	2.7	21.0	22.3
Rongelap Atoll, South														
Southeast Lagoon	Grouper	1490	112	590	19	16	14	93	41	308	4	33	34	140
	Lutinius	2170	69	513	25	69	19	119	18	111	6	51	1	163
	Red Snapper	1980	106	339	12	36	14	104	59	122	8	27	13	50
	Average	1880	96	481	19	40	16	105	39	180	6	37	16	118
Percentage of Total Activity					19.8	8.3	16.7	21.9	40.7	37.5	6.3	7.7	16.7	24.6
Rongerik Atoll														
Eniwetak	Parrot	1450	272	339	1	39	48	44	8	106	8	10	207	140
	Mullet	230	64	68	8	13	3	15	7	18	1	3	45	19
	Average	840	168	204	5	26	26	30	8	62	5	7	126	80
Percentage of Total Activity					3.0	12.7	15.5	14.7	5.2	30.4	3.2	3.4	82.0	39.2

(a) > 150 g.
(b) μc are in terms of Co^{60} equivalent.
(c) Name unknown.

[redacted]

[redacted]

TABLE 4.3

Summary of the Gross Beta and Gamma Activity in Small Fish[a] and Marine Invertebrates

Island and Specimen	No. of Specimens	Average Weight (g)	Activity (μc x 10^3)[b] β	γ
Rongelap Atoll				
Rongelap - Fish	7	72	10	64
Crab	2	50	12	30
Clam [c]	1	200	210	150
Gejen - Fish	8	59	27	105
Crab	1	30	13	42
Coconut Crab[c]	1	1008	223	321
Snail[c]	2	19	373	108
Labaredj - Fish	8	62	75	70
Crab	1	68	33	105
Clam[c]	1	9	21	13
Kabelle - Fish	7	33	19	68
Coconut Crab[c]	1	490	164	156
Rongerik Atoll				
Eniwetak - Fish	2	24	24	55
Bikar Atoll				
Bikar - Crab	1	50	20	7
Clam[c]	1	31	11	8
Rat tail	1	-[d]	0.4	NDA[e]
Likiep Atoll				
Likiep - Fish	4	155	5	1
Clam [c]	1	230	27	80
Utirik Atoll				
Utirik - Fish	4	82	2.1	3.5

(a) <150 g.
(b) μc are in terms of Co^{60} equivalent.
(c) Without shell.
(d) No data taken.
(e) No detectable activity.

[redacted]

[redacted]

TABLE 4.4

Summary of the Gross Beta and Gamma Activity in Birds and Fowl

Island and Specimen		No. of Specimens	Wet Weight (g)	Activity($\mu c \times 10^4$/Tissue)[a] β	γ
Rongelap Atoll					
Gejen -	Terns	2	163		
	Gut			46	115
	Tibia			10	10
	Carcass			197	290
				253	415
Kabelle -	Terns	2	184		
	Gut			13	9
	Tibia			23	NDA[b]
	Muscle			22	6
	Carcass			242	133
				300	148
Larbaredj -	Terns	2	146		
	Gut			114	37
	Tibia			29	4
				143	41
Rongelap -	Rooster	1	1140		
	Skeleton		268	6800	8270
	Muscle		434	260	120
	Viscera		64	166	51
	Liver		144	29	6
	Heart		15	8	2
	Skin		157	16	18
	Lung			2	2
				7281	8479
Rongerik Atoll					
Eniwetak -	Terns	2	-[c]		
	Gut			10	9
	Tibia			6	NDA
	Muscle			33	14
	Carcass			126	294
				175	317
Bikar Atoll					
Bikar -	Terns	2	126		
	Gut			9	3
	Tibia			6	1
	Muscle			40	14
	Carcass			14	14
				69	32

(a) μc are in terms of Co^{60} equivalent.
(b) No detectable activity.
(c) No data taken.

[redacted]

[redacted]

Average external gamma readings of the northern and southern Rongelap islands were 5.8 and 0.7 mr/hr respectively. The fish caught off Eniwetak Island (0.7 mr/hr external gamma) and Utirik Island (0.14 mr/hr external gamma) contained the same average concentration of internal activity as the fish of the southern Rongelap lagoon. Likiep fish (0.04 mr/hr external gamma on the island) contained lower but still detectable amounts of internal radioactive contamination. The total activity in the smaller fish (<150 g) was in general somewhat higher per unit body weight than that of the large fish. Crabs, clams, and especially snails were found to incorporate radionuclides to a much greater extent per unit body weight than did the fish in the corresponding localities (Table 4.3).

A number of tissue samples of marine specimens and of the rooster were analyzed for the concentrations of individual radionuclides (Table 4.5). In muscle and viscera samples of the animals from Rongelap, Utirik, and Rongerik, Sr^{89} contributes approximately 0.5 per cent of the total beta activity. Sr^{90} is present in an approximately 1:1 ratio with Sr^{89}. Since the Hunter and Ballou calculations[3] indicate that Sr^{89} and Sr^{90} each contribute about 2 per cent of the total beta activity at one year after fission, there does not appear to be any fractionation of radiostrontium into the soft tissues. As expected, most of the internally deposited radioactivity was found in the skeleton.

Tissues of a few marine specimens were analyzed for Cs^{137} (37-year half-life) since this nuclide was present in high concentrations in water and coconut milk from this area. The tissues of the rooster and of the coconut crab contain significant amounts of Cs^{137}. A very high fraction of Cs^{137} activity was noted in the muscle of the rooster (40 per cent of the total beta). Further radioanalysis of marine specimens indicated that the rare earth group constituted a few per cent of the total beta activity. Ru^{106}-Rh^{106} and Zr^{95}-Nb^{95} contributed the largest percentage of the total beta activity.

Comparison of the fish and clams collected at one year post-detonation with those collected at one month post-detonation and analyzed 4 months post-detonation reveal the following differences. In the group collected at one month the concentration of internally deposited fission products was 5 to 10 times that of the fish collected at one year. The residual activity in the fish analyzed at 4 months post-detonation averaged 2.5 μc beta activity (Co^{60} equivalent) and the beta-to-gamma ratio was 1:2. In the current analyses, fish of comparable size had a beta activity of approximately 0.1 μc and a beta-to-gamma ratio of 1:4. The largest fraction of the gross beta activity in fish collected at one month was contributed by material in the viscera and liver. Smaller but equal amounts of activity were found in the muscle and skeleton in these fish. In the fish collected at one year post-detonation, in contrast to the group collected earlier, about 50 per cent of the activity was incorporated into the skeleton with only about 10 per cent found in muscle.

[redacted]

TABLE 4.5

Radiochemical Analysis of Fish and Chicken

Island	Fish	Weight (g)	Tissue	Total Beta Activity (d/m x 10^{-3})	Percentage of Total Beta Activity: Sr^{89}	Sr^{90}	Rare Earths	Cs^{137}	Ru^{106}-Rh^{106}	Zr^{95}
Rongelap Atoll										
Rongelap Lagoon	Pelargic Snapper	503	Viscera	82	1.2	1.0	3.2	0.07		
			Gill	3	0.4	0.3	3.2			
			Muscle	20	0.2	0.2	-(a)			
Gejen	Flat Fish	597	Muscle	40	0.6	0.5	5.6			
			Viscera	585	0.1	0.1	18		14.2	61
	Coconut Crab	1008	Muscle	175	0.2	0.2	1.3			
			Viscera	225	0.7	0.6	1.9	2.1		
	Spider Snail	26	Total Body	1204	0.1	0.1	7.8			
	Spider Snail	11	Total Body	432	0.1	NDA(b)	1.9		5.3	65
	Red Eye Crab	30	Total Body	29	1.1	0.8	1.6	1.0		
Labaredj	Killer Clam	230	Total Body	60	0.2	0.2	2.5			
Rongelap	ROOSTER	1140	Muscle	11	-	-	2	40		
			Viscera	23	0.6	0.5	14			
			Liver	7	2.0	1.6	4			
			Skin	12	1.3	1.0	51			
			Tibia	101	0.2	0.2	1.4	1.0		
Utirik Atoll										
Utirik	Eel	24	Total Body	1	1.1	0.9	11			
	Butterfly Fish	185	Total Body	7	-	-	-			
Rongerik Atoll										
Eniwetak	Mullet	230	Muscle	7	0.8		8.2			
			Viscera	100	0.2	0.2	39	0.04		

(a) No data taken.
(b) No detectable activity.

[redacted]

CHAPTER 5

GAMMA-DOSE RATES

Gamma-dose rates at 3 ft above ground were determined with AN/PDR 27 C survey meters.

Specific locations which had been monitored on earlier surveys were resurveyed whenever they could be located. General surveys were run on all islands. A linearity calibration was carried out on the instruments with a 93.53-mg Ra source.* Low intensity Cs^{137} standards were carried in the field in order to maintain a continual check on the behavior of the instruments.

5.1 RESULTS AND DISCUSSION

5.1.1. General Surveys

Table 5.1 contains the gamma-dose rates found on the islands surveyed. These data are reported as of 11 months post-detonation.

TABLE 5.1

Average Gamma-dose Rates on Islands

Atoll	Island	Gamma-dose Rate (mr/hr at 3 ft)
Likiep	Likiep	0.04
Utirik	Utirik	0.14
Bikar	Bikar	0.27
Rongerik	Eniwetak	0.7
Rongelap	Rongelap	0.7
Rongelap	Busch	0.8
Rongelap	Eniaetok	2.4
Rongelap	Labaredj	3.0
Rongelap	Kabelle	4.2
Rongelap	Lukuen	4.8
Rongelap	Gejen	5.4
Rongelap	Lomuilal	5.8

* Made available by the Radiological Safety Section, Atomic Energy Commission, at the Pacific Proving Grounds.

[redacted]

Photodosimetry data* on Rongelap and Kabelle islands are in good agreement with the values reported herein. In general, it was found that gamma-dose rates were uniform over any individual island. Such variations as occurred appeared to be associated with distinct features of the islands such as Marshallese living areas with little organic covering, wide roads, shifting sand dunes, and tidal washes.

5.1.2 Surveys at Specific Locations

Table 5.2 presents readings taken at various specific locations on the islands. In general, most of the specific locations had been set up in the living areas by earlier survey teams and the levels are lower than those encountered over the major portion of the islands.

* Furnished by Mr. R. L. Taylor, Atomic Energy Commission Radiological Safety Representative.

[redacted]

TABLE 5.2

Gamma-dose Rates at Specific Locations on Islands

Island	Specific Location	Gamma-dose Rate (mr/hr at 3 ft)
Utirik	Stake 100 ft westward from southwest corner of church (in grove)	0.2
Rongelap	Wood enclosure 30 yd inland from cemetery	0.6
	West side of flagpole, center of northern village	0.5
	Central cistern, 200 yd W of flagpole	0.5
	Roof, southern cistern, 350 yd W of flagpole	0.5
	Northern cistern, opposite flagpole	0.4
	Cistern 150 yd E of flagpole	0.7
	Southernmost cistern of northern village	0.5
	Road Marker XV at Cistern 100 yd S of burned church	0.4
Busch	Stake 50 yd from beach, center of path in coconut grove	0.8
Eniaetok	Two stakes at 100 yd from beach just north of west peninsula	1.8
Kabelle	Stake painted yellow, at high-tide line, west shore	3.1
Lukuen	Stake painted yellow, at high-tide line, southwest corner of island	4.8
Gejen	Stake painted yellow, at high-tide line, near west coconut trees	3.6
Lomuilal	Stake painted yellow, at high-tide line, south end of island	5.8
Eniwetak	Living area, mess hall interior	0.25
	Living area, hospital interior	0.3
	Living area, walk from hospital to mess	0.5
	Living area, store room (behind mess)	0.3
	Living area, exterior store room tent	0.3
	Living area, general area exterior	0.4
	Weather station, exterior areas, local	0.5
	Weather station, interior all tents	0.4
	Weather station, interior all buildings	0.4
	Army site, general area	0.4
	Army site, interior tents	0.4
	Army site, adjacent to trailer position	0.4

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CHAPTER 6

SUMMARY

6.1 CONCLUSIONS

Significant amounts of beta and gamma activity were found in the tissues of Marshall Island fish and marine invertebrates collected one year following exposure to the fall-out from Operation CASTLE. The highest concentrations of internally deposited activity was found in marine specimens taken from the northern Rongelap lagoon; lower concentrations of internal activity were found in specimens from the southern lagoon. The crabs, clams, and snails contained considerably higher concentrations of radionuclides than were found in the fish from the same area. Most of the activity in the marine specimens was contributed by Zr^{95}-Nb^{95} and Ru^{106}-Rh^{106}. There was no fractionation of Sr^{89}-Sr^{90} in the tissue of the fish analyzed.

Residual soil contamination was primarily contained in the top several inches of soil with movement indicated down to the lens water. The activity is being slowly leached off the islands by ocean tides. The major radionuclide found in the land food plants and in the tissues of land animals was Cs^{137}. The lagoon environment contained principally rare earth group elements, Ru^{106}-Rh^{106}, and Zr^{95}-Nb^{95}.

Radioactivity was found in all food plants on the contaminated islands. Supporting plant systems also contained a large reservoir of activity available for future incorporation into the plants.

The amount of activity in the specimens analyzed was generally proportional to the external gamma reading in each of the areas.

6.2 COMMENTS ON FUTURE WORK

In the event that future work is carried out along the lines initiated during this project the following suggestion may be helpful.

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Sampling of coconut tree sap, pandanus, and breadfruit would be greatly expedited by scheduling the major survey during the end of the rainy season, preferably in November. This would also allow a better study of the effect of rainfall on the leaching of activity from the soil into the lens water and from there into the lagoon or ocean.

Studies on the movement of activity into the supporting plant systems might be broadened to forecast the transfer of more hazardous nuclides into reproductive fractions of the plants.

Approved by:

Paul C Tompkins

P. C. TOMPKINS
Scientific Director

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3. Hunter, H. F., and Ballou, N. E. Fission Product Decay Rates, *Nucleonics, Vol. 9, No. 5*, pp c-2 to c-7, November 1951.

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