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

Atoll Resurvey Project
Final Report

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47

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CONTENTS

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418

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LIST OF TABLES

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CHAPTER 1

INTRODUCTION

As a result of a nuclear detonation in Operation CASTLE, several atolls in the Marshall Islands were contaminated by radioactive fall-out to such an extent that evacuation of the inhabitants was necessary. Plants, animals, water and soil were collected from the islands one month after the fall-out occurred. The live animals were sent to the USNRDL and radiochemical analysis was made of their tissues to provide information on the internal radiation hazard. A report[1] of this study has been published.

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

1.1 Objectives

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

(1) To provide data upon which a decision can be based as to whether and when the evacuated islands may be safely re-occupied by their former

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1. Study of the Internal Radioactive Contamination of Human Beings and Animals and Contamination of the Environment Resulting from Fall-out in Operation CASTLE Addendum report, Project 4.1 Operation CASTLE WT-936.

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inhabitants.

(2) To provide information about distribution of the 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 plant, soil, coral and algae samples were placed in individual plastic bags for shipment to USNRDL. 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 the entire sample evaporated to dryness. The residue was taken up in water and the slurry transferred to a planchet for drying, weighing and counting. The activity 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 flock 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 Nuclear Instruments 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 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.

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 coconuts. Wide variation in levels among samples from the same island can probably be accounted for in terms of the age of the nut, age of the tree, humus content and pH of the soil in which the tree grows and a number of lesser important factors such

6058

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Table 2.1 Summary of Gross Beta Activity in Major Plant Foods

Source		Average Activity in $\mu c/g$ or cc x 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

as depth of island profile, density and type of plant growth around the coconut tree.

Since arrowroot is in intimate contact with 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 between specimens. Also, the growing season of arrowroot had apparently ended and only mature corms could be obtained thereby stratifying the development stage of this food material.

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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 activity available to plant uptake. The age of the grass and 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(1). 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

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Table 2.2 Summary of Gross Beta Activity in Miscellaneous Plant Samples

Average Activity in $\mu c/g \times 10^6$

Material	Likiep	Utirik	Rongelap	Busch	Eniaetok	Labaredj	Kabelle	Lukuen	Gajen	Lomuilal	Bikar	Eniwetak
Grass	20	400	3000	420	2800	5300	1900	2100	68,000	5,600	180	400
Coconut leaf		1100				750	1800	670				
Coconut frond stem												
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

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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.

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 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	β^-/min/g 0 to 1 in.	β^-/min/g 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
Eniwetok	1	12,000	240

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57

Table 2.4 Beta Activity in Soil Samples Taken from Exposed Profiles

Depth (in.)	β^-/min/g				
	Rongelap	Labaredj	Kabelle	Kabelle	Kabelle
0-1	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	160	40	580	140
18	70	120	70	70	90
24		40	100	70	NDA
30				NDA	
36				60	
40				40	

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 inescapable the results for the most part agreed rather well with those obtained by the other sampling procedures.

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Table 2.5 Beta Activity in Core Samples of Soil

Island	No. of Cores	β^-/min/g 1 in.	2 in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.
Likiep	1	140	40	40	NDA	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	18,000	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		
Eniwetok	2	16,000	7,500	3,000	2,000	1,800	1,100	160	100	

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 a function of the soil particle size and not a mechanical cross-contamination.

The above data 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 a later section deal with the nature of the contamination in the environment and from these it can be deduced that fractionation takes place with Ce^{144}-Pr^{144} and Ru^{106}-Rh^{106}

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tending to make up the bulk of the fixed contamination. The plant 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 appear 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 available to the plant systems.

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, 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.

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 algae are much more effieient at concentrating activity than is the highly calcareous Halimeda.

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

Table 2.6 Gross Beta Activity in Coral and Algae

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

(a) G = green H = Halimeda SC = Sea Cucumber

The above data 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 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 celected to describe

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61

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 on 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

β^-/min/liter

Island	Ocean Water Lagoon Side	Ocean Water Ocean Side	Cistern Top	Cistern Bottom	Well	Barrel	Tree Bole	Exposed Profile
Likiep	NDA	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					
Lobaredj	7,700	56					8,100	
Kabelle	2,300	60						15,000
Lomuilal	380	170						
Eikar	37	28						
Eniwetok	100	170						

The ocean water data indicate that activity is being washed off of 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 lagoon and ocean side 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

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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 the above data show 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 lesser importance show varying degrees of contamination depending on such things as the cleanliness of the reservoir, 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.

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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 beings inhabiting the contaminated area.

Radiochemical analysis for $Sr^{89,90}$, total rare earths (RE), Zr^{95}, Ru^{106}, and Cs^{137} were performed as these fission products comprise the bulk of the activity remaining at T_o + 16 months.

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 and 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 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 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.

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Table 3.1 Radiochemical Composition of Residual Contamination on Marshall Islands Atolls

Material	Sr^{89}	Sr^{90}	RE Group	Zr^{95}(b)	Ru^{106}(b)	Cs^{137}
	Percentage of Total Activity Observed(a)					
Arrowroot	1.3	5.9	3.0	0.5	7.8	80
Breadfruit	NDA	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	95
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

(b) Nb^{95} and Rh^{106} may be calculated from the reported parent values.

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Lagoon bottom silt gives very nearly the same nuclide distribution as soil and it would appear that solubility may be a better criteria of nuclide transfer 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.

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 Lelerdj. 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 terns were shot with a rifle. Each specimen was placed in a plastic bag and frozen. The frozen samples were transported to the UWAFL.

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 "μc (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

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techniques employed will be described in a forthcoming publication.

4.2 Results and Discussion

Significant amounts of beta and gamma activity were found in the tissues of 65 Marshall Island fish and marine invertebrates collected one year after exposure to the fall-out from Operation CASTLE (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 and the viscera contained approximately 20 per cent of the total internal activity. 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 the 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 4.1) 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)

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Table 4.1

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

Island	LARGE FISH (> 150 g)			SMALL FISH (< 150 g)			CRABS and CLAMS			SNAILS		
	No. of Fish	μc/kg[a] β	μc/kg[a] γ	No. of Fish	μc/kg[a] β	μc/kg[a] γ	No. of Specimens	μc/kg[a] β	μc/kg[a] γ	No. of Snails	μc/kg[a] β	μc/kg[a] 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	-	-	-
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.

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69

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Table 4.2

Distribution of Gross Beta and Gamma Activity in Tissues of Marshall Island Fish

	Island	Fish	Net Weight (g)	Total Activity		Skin		Muscle		Bone		Gills		Viscera	
				μc 10³/Tissue[a]											
	Rongelap Atoll, North			β	γ	β	γ	β	γ	β	γ	β	γ	β	γ
	Gajen	Flat Fish with Orange Spots[b]	597	196	714	25	24	18	96	120	310	7	16	26	26
	North Rong. Lagoon	Pelargic Snapper	503	84	500	6	69	9	78	29	271	3	16	37	66
3.	"	"	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
	Per Cent 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														
4.	Southeast Lagoon	Grouper	1490	112	590	19	16	14	93	41	308	4	33	34	140
5.	"	Lutinius	2170	69	513	25	69	19	119	18	111	6	51	1	163
6.	"	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	11[illegible]
	Per Cent Total Activity					19.8	8.3	16.7	21.9	40.7	37.5	6.3	7.7	16.7	24.
	Rongerik Atoll														
1.	Eniwetak	Parrot	1450	272	339	1	39	48	44	8	105	8	10	207	140
2.	"	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	[illegible]
	Per Cent Total Activity					3.0	12.7	15.5	14.7	5.2	30.4	3.2	3.4	82.0	39.2

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

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Table 4.3

Summary of the Gross Beta and Gamma Activity in Small Fish (< 150 g) and Marine Invertebrates of the Marshall Islands

Island and Specimen	No. of Specimens	Ave. Weight (g)	$\mu c \times 10^3$ [(a)] Beta	$\mu c \times 10^3$ [(a)] Gamma
Rongelap Atoll				
1. Rongelap				
Fish	7	72	10	64
Crab	2	50	12	30
Clam[(b)]	1	200	210	150
2. Gejen				
Fish	8	59	27	105
Crab	1	30	13	42
Crab, Coconut[(b)]	1	1008	223	321
Snail[(b)]	2	19	373	108
3. Lorbardj				
Fish	8	62	75	70
Crab	1	68	33	105
Clam[(b)]	1	9	21	13
4. Kebelle				
Fish	7	33	19	68
Crab, Coconut[(b)]	1	490	164	156
Rongerik Atoll				
Eniwetak				
Fish	2	24	24	55
Bikar Atoll				
Bikar				
Crab	1	50	20	7
Clam[(b)]	1	31	11	8
Rat tail	1	-	0.4	0
Likiep Atoll				
Likiep				
Fish	4	155	5	1
Clam[(b)]	1	230	27	80
Utirik Atoll				
Utirik				
Fish	4	82	2.1	3.5

(a) μc are in terms of Co^{60} equivalent.
(b) Without shell.

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Table 4.4

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

Island and Specimen	No. of Specimens	Wet Weight (g)	μc x 10^4/Tissue[a] Beta	Gamma
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	0
Muscle			22	6
Carcass			242	133
			300	148
Larbardj				
Terns	2	146		
Gut			114	37
Tibia			29	4
Rongelap Island				
Rooster	1	1140		
Skeleton		268	6800	8270
Muscle		434	250	120
Viscera		64	166	51
Liver		144	29	6
Heart		15	8	2
Skin		157	16	18
Lung			2	2
			7231	8479
Rongerik Atoll				
Eniwetak				
Terns	2			
Gut			10	9
Tibia			6	0
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

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indicated relatively high beta and gamma activity (0.7 μc/whole animal). The ratio of beta to gamma activity was approximately one. The rooster roaming freely on the Island 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 an 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. 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 (.04 mr/hr external gamma on 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

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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(2) 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 clam collected at one year post detonation with those collected at one month post detonation and analyzed 4 months

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2. Hunter, H.F. and N.E. Ballou, Fission Product Decay Rates, Nucleonics, Vol. 9, No. 5, pp c-1 to c-7, Nov. 1951

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Table 4.5

Radiochemical Analysis of Marshall Island Fish and Chicken

Island	Fish	Weight g	Sample	Total Beta Activity d/m x 10^{-3}	Per Cent of Total Beta Activity Sr^{89}	Sr^{90}	Rare Earths	Cs^{137}	Ru^{106} Rh^{106}	Zr^{95} Nb^{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	-			
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	1,204	0.1	0.1	7.8			
	"	11	"	432	0.1	0.0	1.9		5.3	65
"	Red eye Crab	30	"	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	"	7	-	-	-			
RONGERIK ATOLL										
Eniwetak	Mullet	230	Muscle	7	0.8		8.2			
			Viscera	100	0.2	0.2	39.[illegible]	0.04		

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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.

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CHAPTER 5

GAMMA DOSE RATES

Gamma dose rates at 3 ft above ground were determined with AN/PDR 27 C's.

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 which was made available to us by the AEC Radiological Safety Section in the PPG. 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	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
"	Busch	0.8
"	Eniaetok	2.4
"	Labaredj	3.0
"	Kabelle	4.2
"	Lukuen	4.8
"	Gejen	5.4
"	Lamuilal	5.8

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Photodosimetry data (courtesy of Mr. R. L. Taylor, AEC Radiological Safety Representative) 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 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.

Table 5.2 Gamma Dose Rates at Specific Locations on Islands

Island	Location	mr/hr at 3 ft
Utirik	Stake 100 ft in westward direction from SW corner of church (in coconut grove)	0.2
Rongelap	Wood enclosure 30 yd inland from cemetery	0.6
	West side of flagpole, center of N 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
	Sotthernmost cistern of N village	0.5
	Cistern 100 yd S of burned church, Road Marker XV	0.4
Busch	Stake 50 yd from beach, center of path in coconut grove	0.8
Enieetok	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, SW corner of island	4.8

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78

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Table 5.2 Gamma Dose Rates at Specific Locations on Islands (Con't)

Island	Location	mr/hr at 3 ft
Gejen	Stake painted yellow, at high tide line, near west coconut trees	3.6
Lomuilal	Stake painted yellow, at high tide line S end of island	5.8
Eniwetok	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

In general, most of the specific locations had been set up in living areas by earlier survey teams and the levels are lower than those encountered over the major portion of the island.

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79

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.

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.

Residual soil contamination was primarily contained in the top several inches of soil with movement down to the lens water indicated. 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}.

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.

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.