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RADIOBIOLOGICAL RESURVEY OF RONGELAP AND AILINGINAE ATOLLS MARSHALL ISLANDS OCTOBER - NOVEMBER 1955

By the Staff of the

Applied Fisheries Laboratory
University of Washington
Seattle, Washington

December 30, 1955

by the University of Washington under Contract No. AT(45-1)540
United States Atomic Energy Commission.

ABSTRACT

The radiological contamination of Rongelap and Ailinginae Atolls in the eastern Marshall Islands has been evaluated from samples of material collected and from surface readings. The results of expeditions sponsored by the United States Atomic Energy Commission, Division of Biology and Medicine, and carried out by the Applied Fisheries Laboratory, University of Washington, between March 26, 1954 and June 30, 1955 are summarized in UWFL-42. Additional observations and collections made during October-November, 1955, are evaluated in this report.

The decline of the radioactivity was found to be -1.75, i.e., $r = t^{-1.75}$ and steeper than the rate of decay for mixed fission products at a year and one-half (-1.55).

The radioactive content of most samples collected from the northern part of Rongelap Atoll continues to be higher than similar samples from the southern part of the atoll. The birds continue to be an exception to this generalization.

Soil and lagoon bottom samples were collected extensively during October-November, 1955. These samples show great variability. Activity levels in the top 3 inches of soil at Kabelle and Labaredj Islands varied from 4.4 to 11.5 $\mu c/kg$. The highest value (20.3 $\mu c/kg$) of any soil sample of the October-November collections, oddly, was found in the top 3 inches of soil from Rongelap Island. Other Rongelap Island values averaged

1.7 μc/kg for the top 3 inches of soil. Similar samples from Enibuk Island, Ailinginae Atoll, averaged 0.61 μc/kg.

The decline curves and the chemical separations show a great variability in the materials contributing to the radioactivity of the various samples. In the samples separated chemically, Sr^{90} is virtually absent in the coconuts and in the marine animals sampled, but constitutes 2 - 5 percent of the total activity in other land plants and 50 percent of the skeletal salts of the land crabs. Radiocesium was found in only small amounts in marine animals, but accounted for up to 100 percent of the activity in some of the land plants. The marine animals contained more Ce^{144} than the land plants. Fission products do not account for all of the activity in most samples.

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RADIOBIOLOGICAL RESURVEY OF RONGELAP AND AILINGINAE ATOLLS MARSHALL ISLANDS OCTOBER-NOVEMBER 1955

Introduction

During the weapons testing program in the spring of 1954 (Operation Castle), radioactive fallout on some of the atolls was of sufficient intensity to make necessary the evacuation of the native peoples as a health protective measure [1, 2, 3]. The contamination from radioactive material falling upon the islands was especially heavy in the northern portion of Rongelap Atoll and much less at Ailinginae Atoll. The summary statement from the Eighteenth Semiannual Report of the U.S. Atomic Energy Commission outlines the contamination due to fallout as follows.

> The highest radiation measurement outside of Bikini Atoll indicated a dosage of 2300 roentgens for the same period (the first 36 hours). This was in the northwestern part of the Rongelap Atoll, about 100 miles from the point of detonation. Additional measurements in Rongelap Atoll indicated dosages, for the first 36-hour period, of 2000 roentgens at 110 miles, 1000 roentgens at 125 miles, and farther south, only 150 roentgens at 115 miles from Bikini. [4]

In addition to the external radiation problem, there is also interest in the fate of radioactive materials adsorbed or absorbed by the biota and their possible inclusion into the food of the native people, should they be returned to the area.

Numerous expeditions have been made to the atolls to study the problem;

radiation readings have been taken, samples collected, and changes recorded. The results of the expeditions sponsored by the U.S. Atomic Energy Commission Division of Biology and Medicine and carried out by the Applied Fisheries Laboratory, University of Washington, between March 26, 1954 and June 30, 1955 are summarized in UWFL-42 [5]. The results of the jointly-sponsored expedition of the AEC and the U.S. Naval Radiological Defense Laboratory during January 1955 are summarized in USNRDL-454 [6].

The need for further studies to bring the evaluations up to date was expressed by the AEC Division of Biology and Medicine in a communication from Dr. Charles L. Dunham, Director, on September 19, 1955. Acting on this request from Dr. Dunham, a field party from the Applied Fisheries Laboratory composed of Allyn H. Seymour, Edward E. Held, Kelshaw Bonham, and Frank G. Lowman left Seattle on October 12, 1955 and returned November 13, 1955. Collections of material for radiological contamination evaluation and survey meter readings of residual contamination were obtained by the field party on their visits of October 21-23 and November 7, 1955 to Rongelap and Ailinginae Atolls.

The fine support and cooperation from all the organizations concerned made it possible to conduct this program with the maximum of efficiency. We are especially grateful for the support received from the Division of Biology and Medicine, the Eniwetok Field Office, Holmes and Narver, the U.S. Naval Station, Kwajalein, and the units of the Department of Defense stationed at Eniwetok.

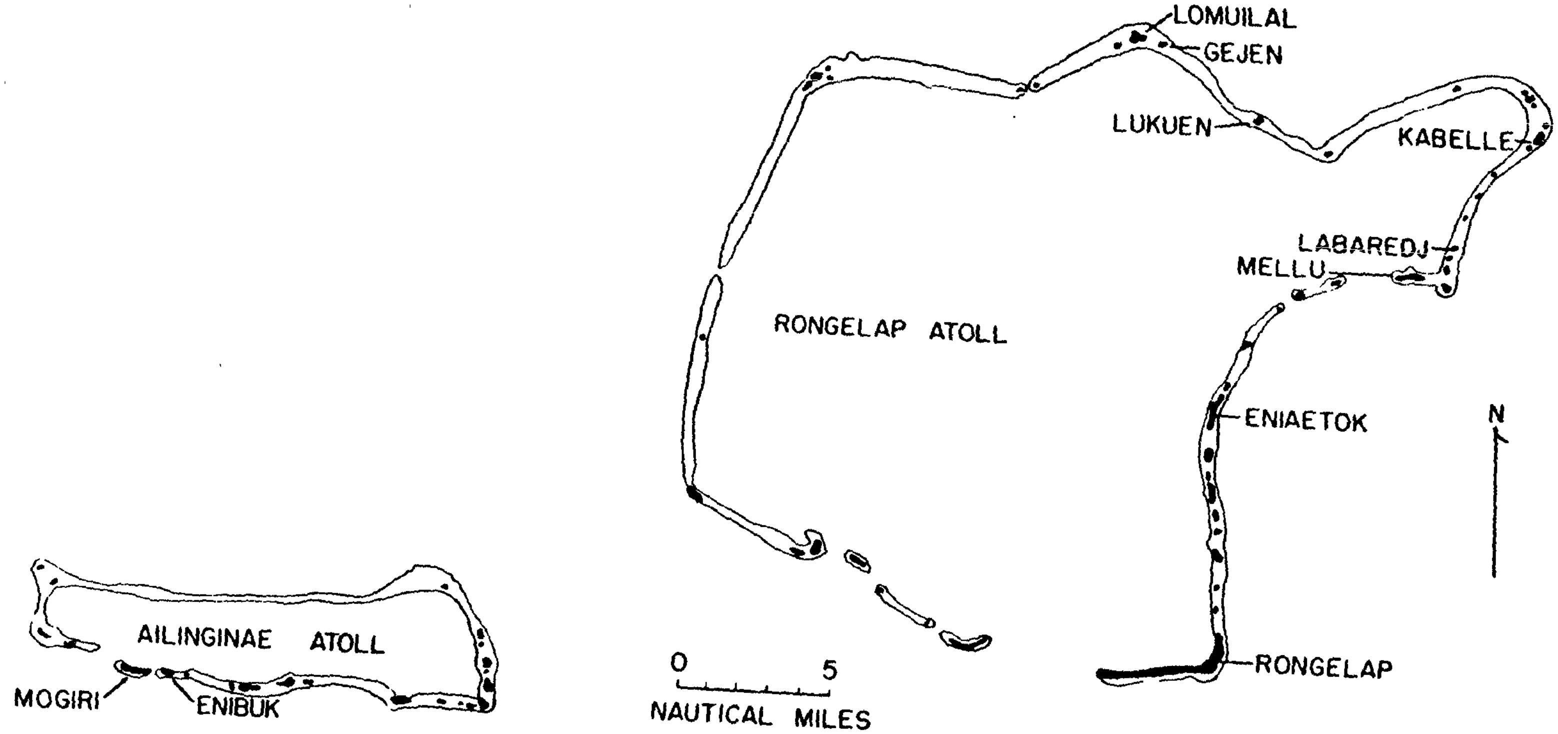


Figure 1. Map of Rongelap and Ailinginae Atolls

Radiation Readings on the Islands of Rongelap and Ailinginae Atolls

A summary of the radiation readings obtained on the five study-collecting trips in which the Applied Fisheries Laboratory participated from March 26, 1954 to November 7, 1955 is given in Table 1.

On the October 21-23 survey, Mr. Robert Taft, Radiological Safety Officer of the AEC Resident Engineer's staff, accompanied the field party and made the survey readings with a Beckman MX-5 meter. All readings were obtained one inch above ground and were recorded in millireps per hour.

The highest readings were again obtained on the more northern islands of Kabelle and Labaredj where maximum readings were 4 mrep/hr with the shield closed and 14 mrep/hr with the shield open. Readings at Rongelap Island and Enibuk Island (Ailinginae Atoll) were much lower than the northern islands, in some cases approaching the background range of the instrument (0.03 mrep/hr).

The individual readings for the October 21-23, 1955 visit, with the locations and terrain conditions, are recorded in Appendix A.

It was learned after the survey group of October 1955 had returned to the Eniwetok Marine Biological Laboratory that the Division of Biology and Medicine was in need of a complete survey of the islands with readings at the three-foot level in addition to those previously taken at the one-inch level. On November 7, 1955, Seymour and Held were flown to Rongelap

Table 1. Summary of Survey Meter Readings, March 1954-November 1955

Values expressed in millireps per hour

Date and Island	Shield Closed: Intertidal at 3'	Shield Closed: Intertidal at 1"	Shield Closed: High Tide at 3'	Shield Closed: High Tide at 1"	Shield Closed: Island at 3'	Shield Closed: Island at 1"	Shield Open: Intertidal at 3'	Shield Open: Intertidal at 1"	Shield Open: High Tide at 3'	Shield Open: High Tide at 1"	Shield Open: Island at 3'	Shield Open: Island at 1"
Rongelap Atoll												
3/26/54*												
Labaredj	32.	29.	200.	250.	250.	420.	65.	400.	340.	770.	510.	1000.
Kabelle	48.	30.	190.	150.	280.	420.	90.	300.	260.	350.	490.	1800.
7/16/54*												
Kabelle	9.	15.	20.	70.	32.	110.						
1/25-30/55**												
Rongelap					0.5							
Eniaetok					2.0							
Busch					1.5							
Labaredj					2.5							
Kabelle					3.0	5.0						
Lomuilal					8.0							
Gejen					7.0							
Lukuen					4.0							
10/21-11/7/55**												
Kabelle		0.1		2.		2.5		0.4		6.		9.2
Labaredj	0.05	0.08	0.7	1.9	1.1	2.2	0.17	0.31	4.8	10.	7.5	12.
Rongelap	0.04	0.04	0.09	0.16	0.2	0.38	0.04	0.04	0.6	1.1	1.4	2.2
Ailinginae Atoll												
10/23/55**												
Enibuk						0.08						0.6

* With a Juno AEC Model SIC-17C
** With a Beckman MX-5

and Labaredj Islands by the U.S. Navy plane, PBM 612. Their extensive survey readings are recorded in detail in Appendix A.

Procedures Used in Collecting and Processing Samples and Recording Radioactivity

The procedures used in collecting samples of biological material in the Marshall Islands have evolved over a period of years. An effort was made during each expedition to obtain as complete a sample as necessary for an adequate evaluation of the problems studied, without completely swamping the Laboratory with samples.

To carry out the program of sampling, specific animals and plants with wide distribution have been selected for study. From these selected samples certain tissues are evaluated to determine the distribution of radioactivity.

Collections made in the field were retained on ice or frozen until they could be returned to the Division of Biology and Medicine field laboratory at Parry Island. There the organisms were identified, selected tissues were dissected, weighed and then dried. The packaged dried samples, together with the data cards, were sent by airmail to the Applied Fisheries Laboratory, University of Washington, for further processing.

At the Applied Fisheries Laboratory, the dried samples were ashed at temperatures up to 540°C, cooled, slurried, dried, and then counted in an internal gas-flow counting chamber. The counts per plate were converted to disintegrations per minute per gram (d/m/g) of wet tissue, as of the date of collection, by correcting for sample weight, geometry, backscatter, self-absorption, coincidence, and decay. For a more complete discussion of these procedures see WT-616 [7].

In preparing the summary tables as used in this report the radioactivity expressed in disintegrations per minute per gram (d/m/g) was converted to microcuries per kilogram in the following manner:

$$\mu c/kg = \frac{d/m/g}{(2.2)(10)^3}$$

Rate of Decline of Radioactivity in Food Items

The rate of decline is the rate of change of activity in a group of organisms and is the consequence of the interaction of physical decay, of biological uptake, and of biological decay.

The activity of the principal food items for the five dates of collection is presented in Table 2 and Figure 2. The values were obtained by averaging sample counts from all areas. The individual counts from which the values for the October 1955 collection were determined can be found in Appendix B. For the earlier dates the values are taken from UWFL-42, Table I. Table 2 and Figure 2 give the general picture of radioactivity of the food items and are useful to those who wish to calculate the health hazard. The coefficient of variation (standard deviation ÷ mean) for these values averages about 60 percent, which indicates considerable variability. Area and species differences and sampling error account for this variability. In the sections on fish, invertebrates, plants, etc., the samples are grouped in smaller divisions, with area and species differences eliminated.

From Table 2 the absolute values of the food items can be obtained, and from Figure 2 the rate of decline can be directly calculated. These data are closest to being points on a straight line when plotted on a log-log scale with March 1, 1954 as the date of origin. For the purpose of making an approximation of the general rate of decline, the slope of a least-squares line determined from the average values for all items on each collecting date was calculated and found to be -1.75, i.e., $r = t^{-1.75}$ (the decay rate

Table 2. Radioactivity of Food Items

Values expressed in uc/kg of wet tissue

Date and Island	Coconuts			Fish		Clams	Crabs	Birds	
	Milk	Meat	Misc.*	Muscle	Liver	Muscle Mantle	Muscle	Muscle	Liver
Rongelap Atoll									
3/26/54 Kabelle, Labaredj	1.00	1.2	11.	2.7	200.	44.	70.	5.4	25.
7/16/54 Kabelle	0.049	0.12		0.42	24.	2.1	2.4	0.58	3.2
12/8 or 12/18/54 Kabelle, Rongelap	0.019	0.048	0.021	0.066	2.0			0.040	0.22
1/26-30/55#	0.041	0.036	0.049	0.10	3.5	1.0	0.50	0.13	0.42
10/21-22/55	0.046	0.031	0.038	0.021	1.0	0.061	0.15	0.031	0.16
Ailinginae Atoll									
10/23/55 Enibuk	0.011	0.008	0.009	0.014	0.25	0.027	0.029	0.038	0.099

* May include edible portions of squash, papaya, arrowroot, pandanus, spinach.
# Rongelap, Eniaetok, Labaredj, Kabelle, Gejen, Lomuilal, Lukuen.
** Rongelap, Labaredj, Kabelle.

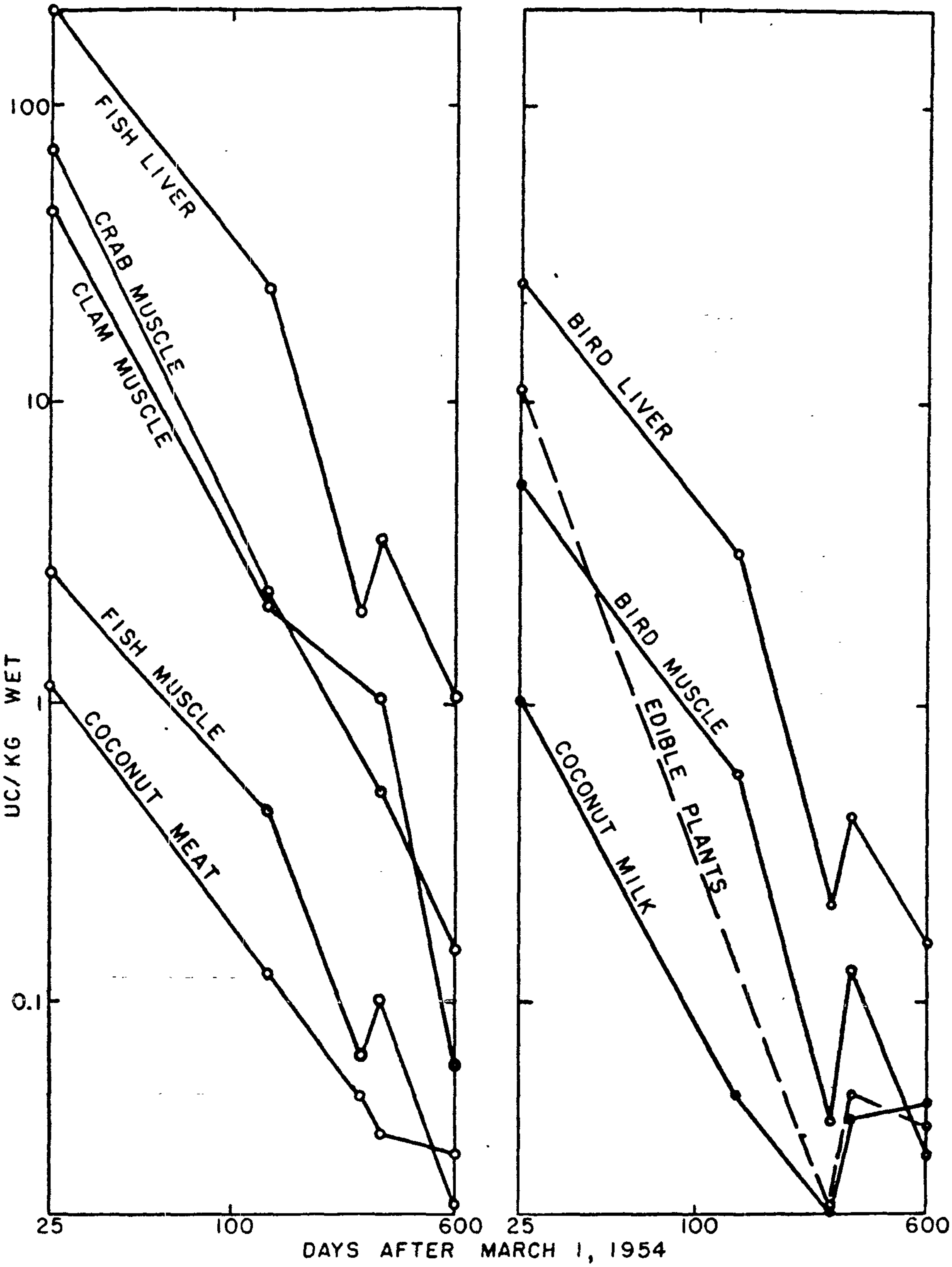


Figure 2. Rate of decline of radioactivity in food items from collections at Rongelap Atoll between March 26, 1954 and October 22-23, 1955.

for mixed fission products at a year and a half is less, being about -1.55).

One use of the decline curve is to predict the level of activity of food items at some future date. For example, if the value for a food item was 100 on November 1, 1955 it would be 85 on January 1, 1956 and 56 on July 1, 1956.

Evaluation of Radioactivity in the Biological Samples

Fish

As part of the program to evaluate the residual radioactivity in the food items of the Marshall Islands, reef fish and some lagoon fish were collected from several areas in Rongelap and Ailinginae Atolls (Tables 3 and 4). The fish were collected by underwater detonations using Primacord or by poisoning with derris root. Some specimens were caught in the deeper waters of the lagoon with hook and line.

The species selected for analysis were those commonly found in the Marshall Islands and included damselfish, groupers, parrot fish, squirrelfish, surgeonfish, goatfish, wrasse, snappers, mullet and tuna. The scientific names of the species are given in the appendix of UWFL-42.

The tissues used for analysis of radioactivity were skin, muscle, bone, liver and other viscera. The latter included part of the stomach contents as well as part of the alimentary canal, in most cases. From the October 1955 collections only the muscle, bone and liver were used, as these three tissues represent, in the above order, the minimum, intermediate and maximum amounts of radioactivity found in the tissues and serve as the best examples of the trends. The itemized data for the October 1955 collections of tissues and specimens of fish are listed in Appendix B.

The collections from Kabelle Island, which were taken over a longer period than those from the other islands, offer the best data for determination of the decline of radioactivity in the fish. The collections from this

Table 3. Radioactivity of Fish from Kabelle Island Reef, March 1954-October 1955

Values expressed in uc/kg of wet tissue

	Date	Number Specimens	Skin	Muscle	Liver	Bone	Viscera
Rongelap Atoll							
All Fish	3/26/54	12	21.	2.7	200.	13.	510.
	7/16/54	32	2.5	.50	22.	2.9	36.
	1/29/55	27	.36	.083	3.2	.49	3.6
	10/21/55	34		.026	1.6	.12*	
Omnivores	3/26/54	4	34.	4.5	440.	25.	1,300.
	7/16/54	15	3.0	.65	22.	3.0	60.
	1/29/55	18	.33	.082	2.6	.49	4.1
	10/21/55	19		.028	1.2	.088*	
Carnivores	3/26/54	8	15.0	2.0	100.	8.0	110.
	7/16/54	17	2.0	.37	23.	2.9	14.
	1/29/55	9	.41	.085	4.4	.50	2.6
	10/21/55	15		.023	2.1	.14*	
Damselfish	3/26/54	2	21.	3.4	610.	9.4	1,700.
	7/16/54	2	2.7	.26	44.	2.3	38.
	1/29/55	4	.54	.085	4.2	.43	3.2
	10/21/55	2		.033	.80		
Grouper	3/26/54	3	7.5	1.4	38.	3.4	100.
	7/16/54	6	1.5	.31	16.	1.5	12.
	1/29/55	5	.30	.051	5.2	.29	1.4
	10/21/55	5		.023	2.8	.077*	

* Represent averages obtained from 3, 1, 2 and 1 specimens respectively.

Table 4. Radioactivity of Fish from Areas Other Than Kabelle Island Reef, December 1954-October 1955

Values expressed in uc/kg of wet tissue

Date and Island		Number* specimens	Muscle	Liver	Bone
Rongelap Atoll					
1/25/55	omnivores	10	.022	1.0	.18
Rongelap	carnivores	12	.045	2.7	.39
	all fish	22	.034	2.0	.30
1/28/55	omnivores	23	.16	5.4	.68
Labaredj	carnivores	11	.15	3.3	.78
	all fish	34	.16	4.7	.72
1/30/55	omnivores	1	.16	12.	1.1
Gejen	carnivores	8	.12	6.2	.80
	all fish	9	.13	6.9	.84
12/54 and 1/55 Lagoon Fish Combined	carnivores	10	.081	2.1	.28
10/21/55	omnivores	10	.039	.67	
Labaredj	carnivores	10	.028	1.1	
	all fish	20	.033	.90	
10/22/55	omnivores	11	.009	.91	.053
Rongelap	carnivores	22	.009	.44	.086
	all fish	33	.009	.60	.070
10/21/55 Lagoon	tuna	2	.032	.74	
Ailinginae Atoll					
10/23/55	omnivores	23	.014	.29	.034
Enibuk	carnivores	5	.021	.16	.060
	all fish	28	.015	.27	.039
10/23-24/55 Lagoon	carnivores	8	.009	.20	

*Number of specimens for bone - 1, 1, 2, 4, 1, 5 (reading down).

island were made in approximately the same area, a coral-filled channel open to the sea at high tide, lying near the north end of the island. The data are summarized in Table 3 and Figures 3 and 4.

The radioactivity in Kabelle Island fish muscle tissue showed levels of about 2.7 μc/kg on March 26, 1954. By October 1955 levels had dropped to less than .030 μc/kg, which is less than $(1/2)^6$ that of the March 1954 samples and the liver samples $(1/2)^7$ for the same period.

Decline and decay of radioactivity show differences in rate, the former declining at a slower rate than decay the first 100 days after March 1, 1954, and then at a greater rate thereafter; thus the curves appear to be approximating each other at the present time. Differences in rate of decline and decay might be explained by the postulate that in the first 100 days after March 1, 1954, the radioactive materials existed in greater abundance than could be utilized by the fish so that during this period the fish tissues were more or less "saturated" with the materials. As the radioactivity decayed and was dispersed with time, the tissues declined in radioactivity at an increasing rate commensurate with the amounts available in the food chain and in the surrounding water.

Decline in amounts of radioactivity in omnivorous and carnivorous fish indicates some differences in rate, at least for the first 100 days (Fig. 4). These differences decreased with passage of time.

The grouper and damselfish in Table 3 represent rather common species of carnivorous and omnivorous fish, respectively, and are the best represented, of all the species, in the collections. For the most part the averages

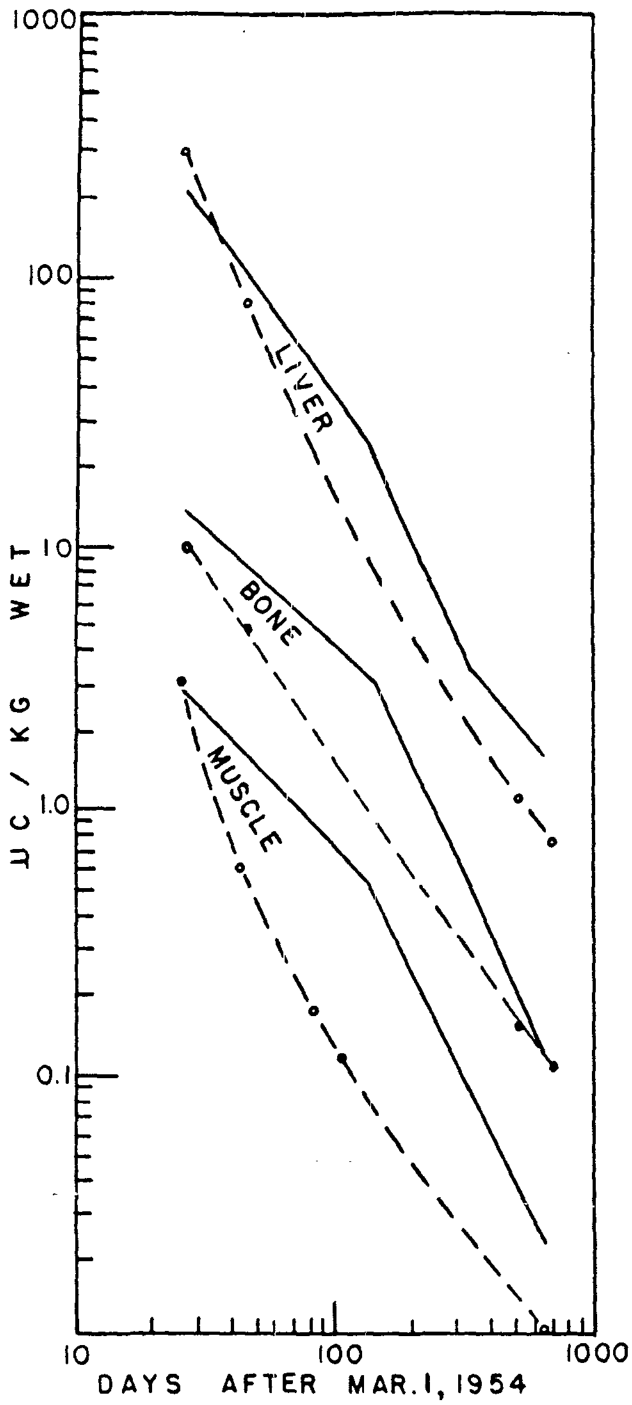


Figure 3. Decline (solid line) of average amounts of radioactivity in fish tissues compared with decay (broken line) of three specimens collected March 26, 1954. All specimens from Kabelle Island, Rongelap Atoll.

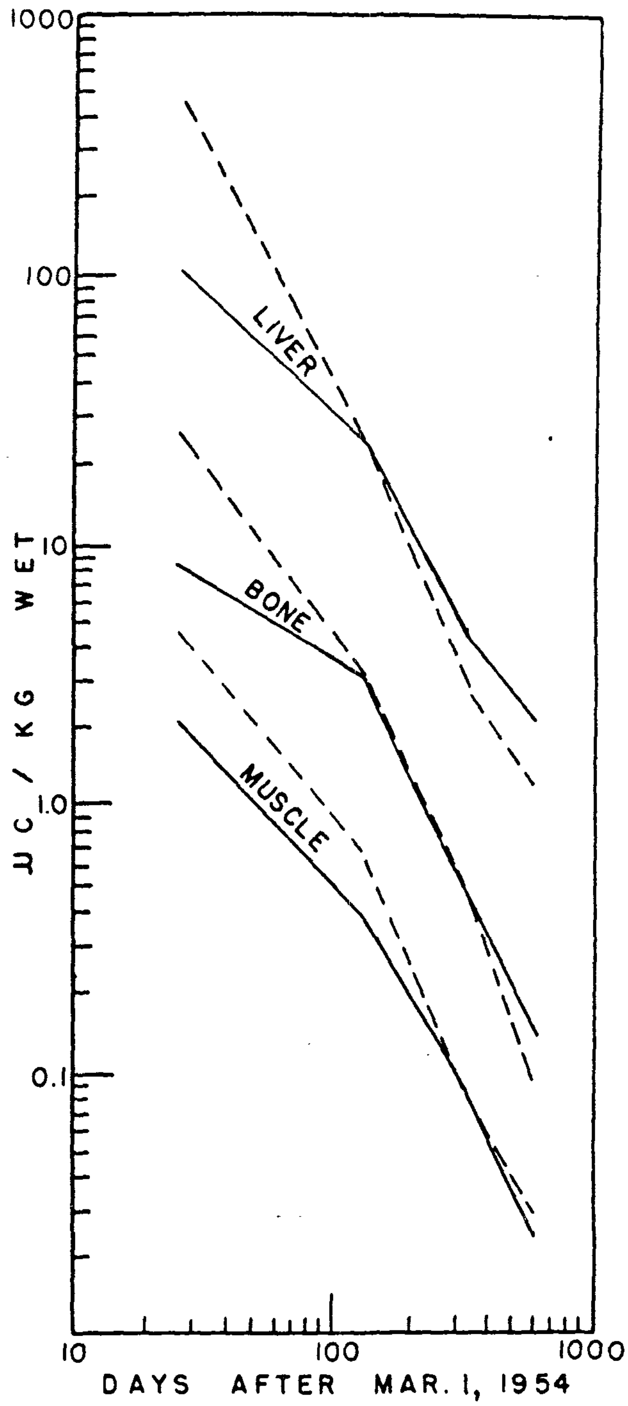


Figure 4. Decline of average amounts of radioactivity in fish tissues of carnivores (solid line) and omnivores (broken line) from Kabelle Island, Rongelap Atoll 1954-1955.

compare with those of omnivores and carnivores generally.

In the data there appears to be a distinct pattern of relative amounts of radioactivity in different organs which is maintained more or less constantly, indicating that the activity in the various tissues declines at approximately the same rate.

Most of the decline curves and, at least the decay curve for muscle, deviate from a straight line, and although the curves indicate some mixture of isotopes, they do not apparently contain similar ratios of isotopes to those found in the mixed product curve of Coryell and Sugarman (1951)[8].

The distribution of radioactivity in the fish from various parts of Rongelap and Ailinginae Atolls is summarized in Table 4. By October 1955 radioactivity averages of fish muscle tissue ranged from 0.009 μc/kg at Rongelap Island to 0.033 μc/kg at Labaredj Island. Liver tissues ranged from 0.20 μc/kg in Ailinginae lagoon to 1.6 μc/kg at Kabelle Island (Table 3). Extreme range of the samples were, for muscle, 0.003 to 0.10 μc/kg and for liver, 0.026 to 4.7 μc/kg. In general, the activity was highest in the northern islands of Rongelap Atoll. Enibuk Island (Ailinginae Atoll) and Rongelap Island (Rongelap Atoll) appeared to be similar in activity.

The coefficient of variation for muscle tissue radioactivity in Kabelle Island fish, where 12 or more specimens were involved, varied from 46 to 143 percent. In liver tissue the coefficient of variation ranged from 64 to 119 percent. There appeared to be no decrease in variation with time.

Invertebrates

The invertebrates were assayed because of their potentiality as food for humans and for animals that might serve as food. The giant clam, longusta or spiny lobster, and coconut crab undoubtedly are eaten by the natives. Corals and sea cucumbers are considered chiefly because of their abundance and role in the ecology of the atolls.

Radioactivity in Rongelap invertebrates declined from about 10^2 - 10^4 $\mu c/kg$ on March 26, 1954 to approximately 10^{-1} - 10^1 $\mu c/kg$ on October 21-22, 1955, as shown in Tables 5 and 6 and Figures 5 - 10. Levels of radioactivity in October 1955 at Kabelle, Labaredj, and Rongelap Islands and at Enibuk Island (Ailinginae Atoll) were, respectively, 3+, 6+, 2, and 1 $\mu c/kg$ of wet tissue. Individual values for the October 1955 collections appear in Appendix C.

Liver of the spider snail (Fig. 8) averaged highest in radioactivity throughout the 1.6-year period of study, being most closely approached early by the hermit crab liver, which declined rapidly (Fig. 6) and at the end of the period, by the slowly-declining coconut crab carapace (Fig. 5). The low level of activity of the basic coral organisms (Fig. 10) is of special interest. Of the tissues analyzed muscle had least activity, that of the giant clam in October 1955 being less than 0.1 $\mu c/kg$ (Fig. 7).

The low level of activity in the giant clams, Tridacna and Hippopus, presumably results from feeding upon plankton, which is also low. In contrast, the spider snail, Pterocera, with activity about 10 times that of the plankton-

Table 5. Radioactivity of Invertebrates Other Than Coral, March 1954-October 1955

Values expressed in uc/kg of wet tissue

Date and Area	Organism	*	Muscle	Gut and Content	Integument or Carapace	Gill	Mantle	Gonad	Liver or Visc. Mass	Kidney	Misc.
Rongelap Atoll											
3/26/54	sea cucumber	1	230.	1660.	260.			540.			
Kabelle	giant clam	5	24.	270.		240.	51.			260.	590.a/
	spider snail	11	64.	1640.			200.		5900.		3400.a/
	rock crab	6	83.	1270.	730.	1360.			2500.		
Labaredj	hermit crab	9	118.	1170.	680.	640.			4300.		
	coconut crab	10	9.1	2400.	450.	590.			360.		
7/16/54	sea cucumber	1	5.0	41.	11.			3.8			
Kabelle	giant clam	4	1.3	28.		11.	3.0			55.	9.1a/
	hermit crab	9	3.0	71.	61.	23.			39.		
	coconut crab	10	1.5	124.	29.	13.			19		
12/8/54	sea cucumber	1	1.8	10.	2.2			3.5			
Kabelle	spider snail	11	7.2	37.			28.		129.		5.8a/
1/26-30/55	nerite snail	12									10. b/
Rongelap	nerite snail	12									0.31a/
	ghost crab	7	.037	0.91	0.73	0.73			0.23		
	red-eyed crab	8	0.29	0.58	0.077	0.73			0.59		0.20c/
	rock crab	6	0.11	0.22	0.085	0.37			0.27		
	hermit crab	9	0.35	0.64	2.6	0.42			0.43		
	coconut crab	10	0.27								
Labaredj	giant clam	4	0.22	2.5		0.82	0.73			12.	1.1a/
Kabelle	sea cucumber	1	2.2	3.4	0.55			3.5			
	coconut crab	10	0.32	14.	4.8	2.0			2.1		
	orange sponge										30. d/
	sea urchin	3									0.43e/
Gejen	giant clam	4	0.39	8.6		2.8	2.8			17.	5.5 a/
	octopus	13	0.64	5.5			1.0		12.		1.8a/

p. 2 Table 5 (continued)

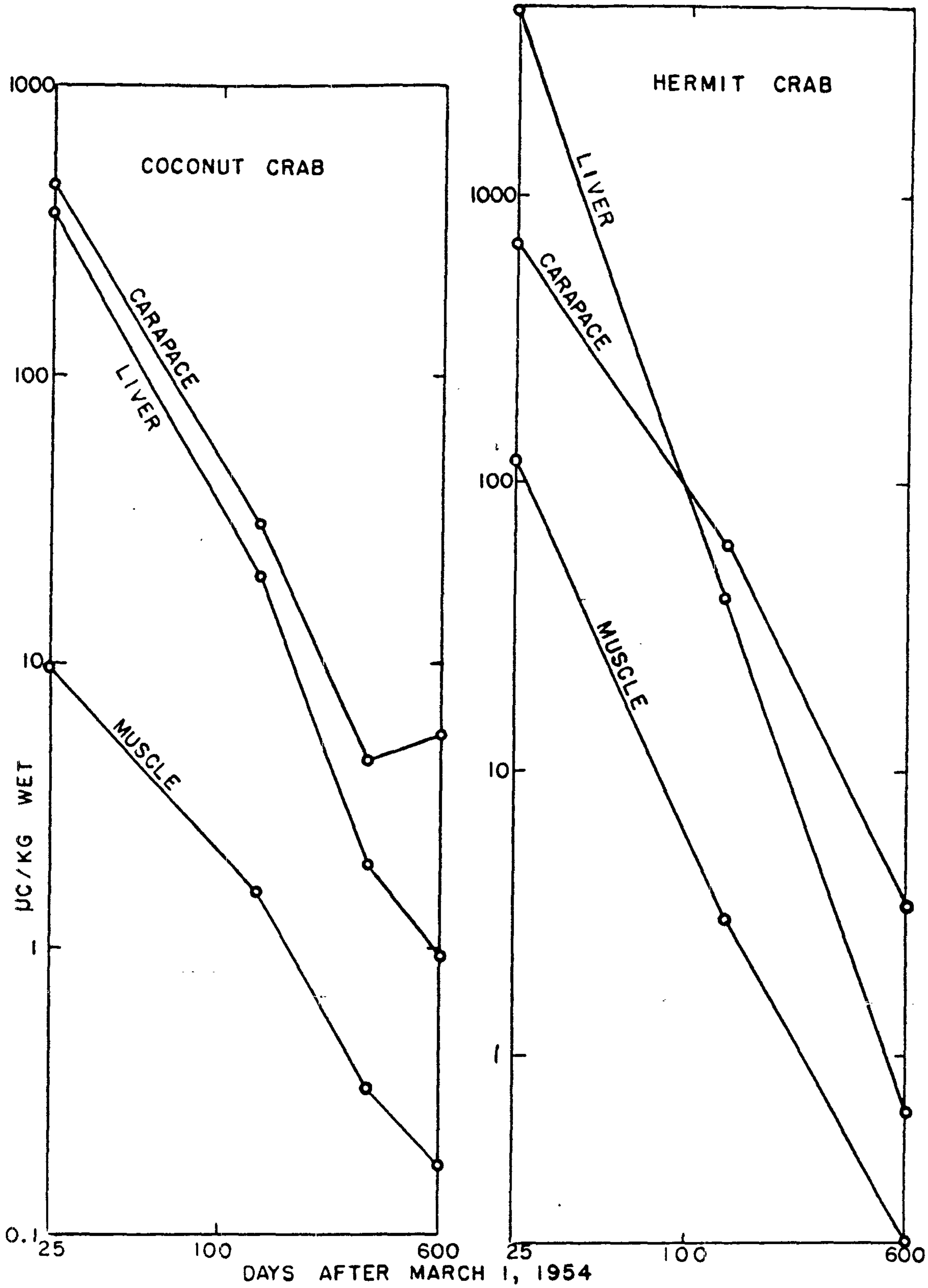
Date and Area	Organism	*	Muscle	Gut and Content	Integument or Carapace	Gill	Liver or Visc. Mass	Kidney	Misc.
Rongelap Atoll (continued)									
1/26-30/55	coconut crab	10	3.1	2.3	0.41	1.5	1.5		
Gejen	spiny lobster	14	0.55	0.91	0.24	1.1	2.0		
Eniaetok	yellow sponge								0.77[d/]
10/21/55	coconut crab	10	.072		3.2		.61		
Kabelle	hermit crab	9	.14		2.3		.32		
	giant clam	4	.053				.90	2.7	
	spider snail	11	3.8				18.		
	sea cucumber	1		2.6	.34				
Labaredj	coconut crab	10	.23		5.7		1.3		
	hermit crab	9	.30		4.2		.92		
	giant clam	4	.11				1.7	6.3	
	spider snail	11	4.1				34.		
10/22/55	hermit crab	9	.093		1.4		.54		
Rongelap	giant clam	4	.014				1.4	.71	
	sea cucumber	1		.40	.12				
	hydroid	15							.24[d/]
Ailinginae Atoll									
10/23/55	coconut crab	10	.027		.72		.14		
Enibuk	hermit crab	9	.030		.71		.10		
	giant clam	4	.027				.59	3.2	
	spider snail	11	.12				.58		
	sea cucumber	2		.12	.19				

* Scientific name: 1. Holothuria; 2. tan Stichopus ?; 3. Echinothrix; 4. Tridacna; 5. Hippopus; 6. Grapsus; 7. Ocypode; 8. Eriphia; 9. Coenobita; 10. Birgus; 11. Pterocera; 12. Nerita; 13. Polypus; 14. Panulirus; 15. Pennaria.
a. shell; b. soft parts; c. egg; d. entire; e. spines.

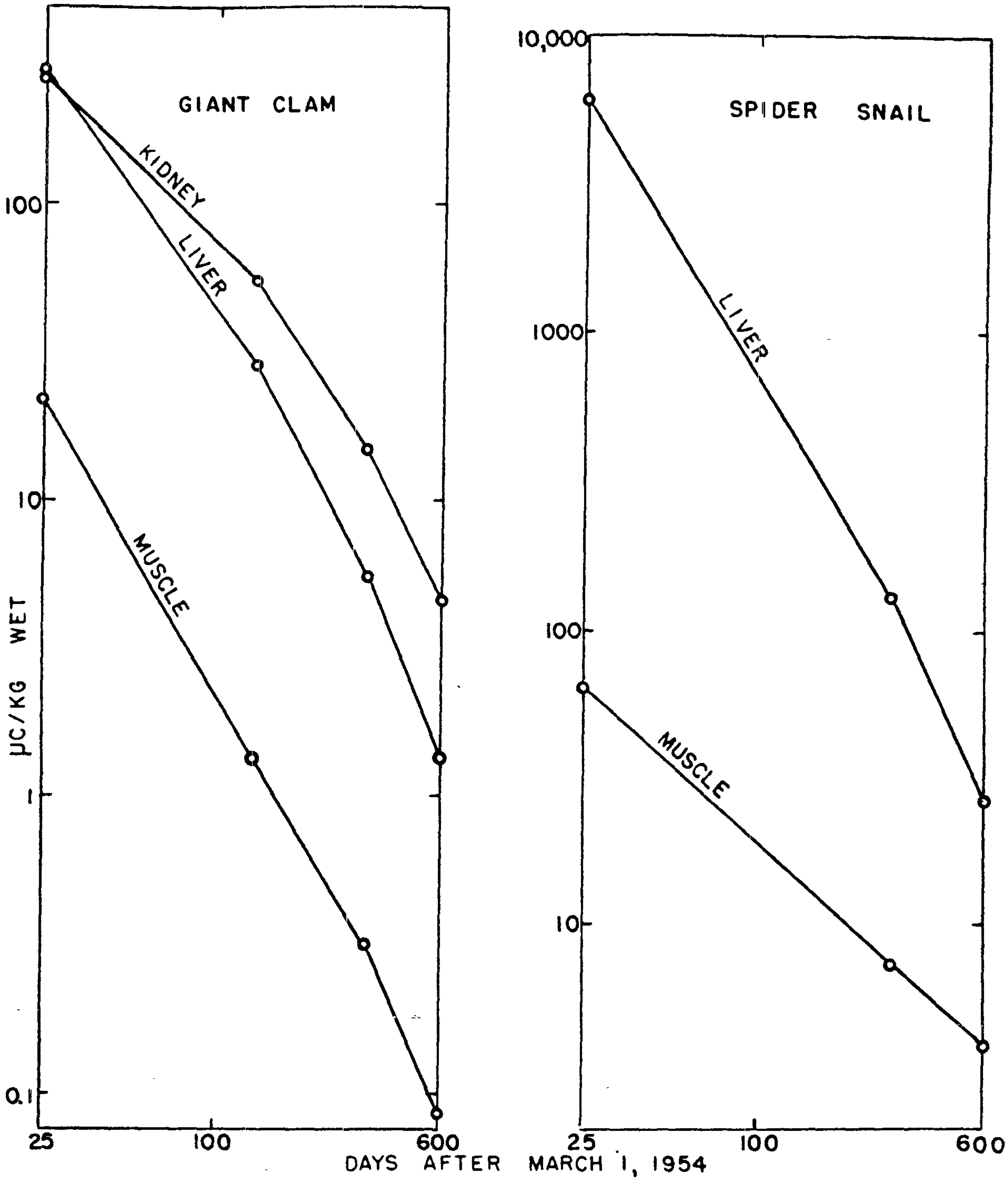
Table 6. Radioactivity of Coral, March 1954-October 1955

Values expressed in uc/kg of wet tissue

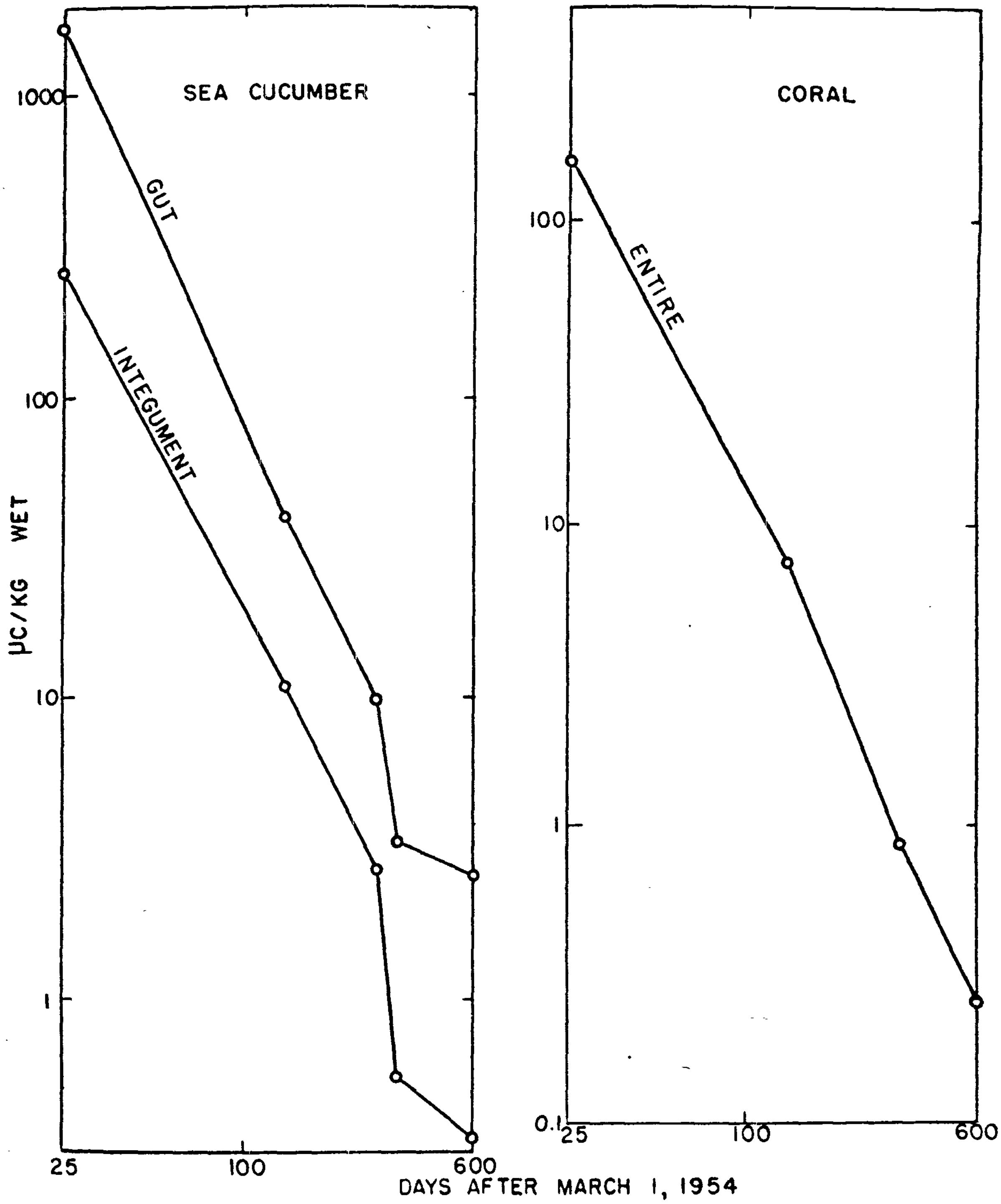
Date and Island	Acropora	Fungia	Heliopora	Leptastrea	Millipora	Pocillopora	Porites
Rongelap Atoll							
3/26/54							
Kabelle	440.	64.				110.	18.
7/16/54							
Kabelle	5.1	1.5	19.		4.0		
1/28-29/55							
Kabelle	.84						0.78
Labaredj	1.2			0.40	0.59	0.86	1.2
10/21-22/55							
Kabelle	0.25						
Rongelap						0.033	
Ailinginae Atoll							
10/23/55							
Enibuk	0.039					0.020	0.020



Figures 5 (left) and 6 (right). Decline in radioactivity of tissues of coconut crab and hermit crab from the northern islands of Rongelap Atoll.



Figures 7 (left) and 8 (right). Decline in radioactivity of tissues of giant clam and spider snails from northern islands of Rongelap Atoll.



Figures 9 (left) and 10 (right). Decline in radioactivity of tissues of sea cucumber and of coral from northern islands of Rongelap Atoll.

feeding clam, feeds on bottom material, which is about 10 times that of plankton.

The land-inhabiting hermit crab, Coenobita, and the coconut crab, Birgus, were intermediate in their general level of radioactivity between spider snail and giant clam.

As shown in Table 5 and Figures 8 and 6, rates of decline as expressed on logarithmic paper varied from -0.9 for spider snail muscle to -2.8 for hermit crab liver, and averaged -1.75.

Negative Slopes of Decline Rate of Invertebrates Logarithmically Graphed in Figures 5-10, Based on First and Last Observations

Tissue	Coconut Crab	Hermit Crab	Giant Clam	Spider Snail	Sea Cucumber	Coral
Muscle	1.3	2.0	1.7	0.9		
Gut and content					2.0	
Integument	1.4	1.7			2.1	
Liver	1.9	2.8	1.7	1.7		
Kidney			1.3			
Entire						2.0

Land Plants

Collections of both edible and non-edible plants were made at Rongelap Atoll during the period from March 26, 1954 to October 21-23, 1955. In the last survey, the emphasis was placed upon those plant parts important in the native diet. These food items included coconut meat and milk and the edible portions of the papaya, arrowroot, Morinda and Pandanus plants. Soil samples also were taken in the vicinity of the plants in order to compare the levels of residual contamination in these items and to determine whether there had been any selective uptake of radionuclides from the soil.

Counts of all the land plant samples for the first five surveys are given in UWFL-42, Appendix Tables IV, V, and VI, and are summarized in Tables 7, 8, and 9 of this report to include the values for the October 1955 collections. Values for these collections are given in detail in Appendix D.

Summary of Radioactivity in the Edible Portion of Land Plants and in the Island Soils Collected October 1955. Values Expressed in $\mu c/kg$ of Wet Tissue.

	Rongelap Atoll	Ailinginae Atoll
Coconut		
Meat	0.038	0.008
Milk	0.045	0.011
Papaya		
Meat	0.023	
Seeds	0.079	
Pandanus	0.074	0.017
Arrowroot	0.034	0.005
Morinda	0.013	0.007
Island Soil	9.2	1.2

Soil: Plant Ratio - 190

In October 1955, the levels of radioactivity in all species of plants were higher at Rongelap Atoll than at Ailinginae Atoll by a factor of two to seven. In general, the levels in the plants were highest at the northern islands of Kabelle and Labaredj. The only exception was the corm of the arrowroot

Table 7. Radioactivity of Coconuts, March 1954-October 1955

Values expressed in uc/kg of wet tissue

Date and Island	Milk	Meat	Skin	Husk	Shell	Misc.	
Rongelap Atoll							
3/26/54 Kabelle	1.0	1.2	21.	15.	1.1	98.	primary leaf
						64.	old leaf, external
						16.	old leaf, internal
						180.	secondary root
						50.	primary root
7/16/54 Kabelle	.049	.12	3.0	.13		0.11	entire fruit
						0.31	flower
						0.21	pedicel
12/8/54 Kabelle	.022	.062	0.66	.096	.053	0.074	flower
						0.071	pedicel
12/18/54 Rongelap	.015	.026		.024			
1/26/55 Rongelap	.022	.020					
1/29/55							
Kabelle	.051	.045				0.20	primary leaf
Labaredj	.021	.020					
1/30/55							
Gejen	.077	.12					
Lukuen	.049	.054					
10/21/55							
Kabelle	.039	.050					
Labaredj	.029	.050					
10/22/55 Rongelap	.026	.036					
Ailinginae Atoll							
10/23/55 Enibuk	.008	.011					

Table 8. Radioactivity of Edible Plants Other Than Coconuts, March 1954-October 1955

Values expressed in uc/kg of wet tissue

Date and Island	Name	Edible Portion	Seeds	Skin	Leaves	Misc.
Rongelap Atoll						
3/26/54						
Labaredj	Morinda	11.			490.	
12/18/54						
Rongelap	squash	.016	.076	.032		.030 pulp
	papaya	.018	.068	.044		
	arrowroot	.022		.024	.083	
	Morinda	.028	.042	.032		
	Pandanus	.027	.022	.047		
1/29/55						
Kabelle	arrowroot	.030				
	Pandanus	.056		.060		
Labaredj	arrowroot	.007				
Lomuilal	arrowroot	.16				
	Pandanus	.080	.080	.086		
Gejen	arrowroot	.050		.096		
Rongelap	papaya	.050	.061			
	arrowroot	.032				
	Pandanus	.034				
	squash	.053	.013			
	spinach				.017	
10/21/55						
Kabelle	arrowroot	.024				
Labaredj	Pandanus	.079				
	arrowroot	.020				
10/22/55						
Rongelap	arrowroot	.058				
	papaya	.023	.079			
	Pandanus	.071				
	Morinda	.013				
	Squash				.055	.010 flower
Ailinginae Atoll						
10/23/55						
Enibuk	Morinda	.007				
	Pandanus	.017				
	arrowroot	.005				

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Table 9. Radioactivity of Rongelap Plants Other Than Those Commonly Eaten, March 1954-October 1955

Values expressed in uc/kg of wet tissue

Date and Island	Name*	Fruit Flower	Leaves Apical bud	Leaves Old Green	Leaves Mixed	Stems Entire	Stems Debarked	Stems Bark	Roots
Rongelap Atoll									
3/26/54									
Kabelle	herb 1				400.	360.			
	herb 2	210.			2,800.	64.			
	grass 1				1,800.				150.
Labaredj	tree 1							740.	
	tree 2	28.			940.	740.	19.	140.	
	shrub 1	360.			490.		6.4	200.	
	herb 1				970.	560.			
7/16/54									
Kabelle	tree 1		0.65	0.78		15.		33.	
	tree 2		0.71	0.57		3.5	0.44	5.6	
	shrub 1		0.71	0.67		1.4	0.25	2.9	
	shrub 2				10.	30.	0.17	8.1	
	herb 1				1.6	1.2			
	herb 2				2.0	2.0			
	grass 1				7.4				
12/8/54									
Kabelle	tree 1	0.23	0.43	0.49		0.29	0.18	0.38	
	tree 2			1.5		0.84	0.35	1.1	
	shrub 1	0.11	0.19	0.23		0.078	0.075	0.12	
	herb 1			1.2		0.57			
	herb 2			0.40		0.43	0.42	2.1	
	herb 3	1.2	0.78	1.3		0.45	0.22	0.73	
	grass 1				2.2				6.4

Table 9 (continued)

Date and Island	Name*	Fruit Flower	Leaves: Apical bud	Leaves: Old Green	Leaves: Mixed	Stems: Entire	Stems: Debarked	Stems: Bark	Roots
Rongelap Atoll 1/29/55									
Kabelle	tree 1		2.1	0.60			0.94		
	tree 2		0.15	0.14					
	shrub 1	0.069	0.15	0.24			0.067		
	herb 1			0.67					
	herb 2				0.23	0.65			
	herb 3		0.79	1.9		1.2			
	grass 1				4.7				5.5

* tree 1, *Messerschmidia argentea*; tree 2, *Guettarda speciosa*; shrub 1, *Scaevola frutescens*; shrub 2, *Suriana maritima*; herb 1, *Boerhaavia tetrandra*; herb 2, *Portulaca oleracea*; herb 3, *Triumfetta procumbens*; grass 1, *Lepturus repens*.

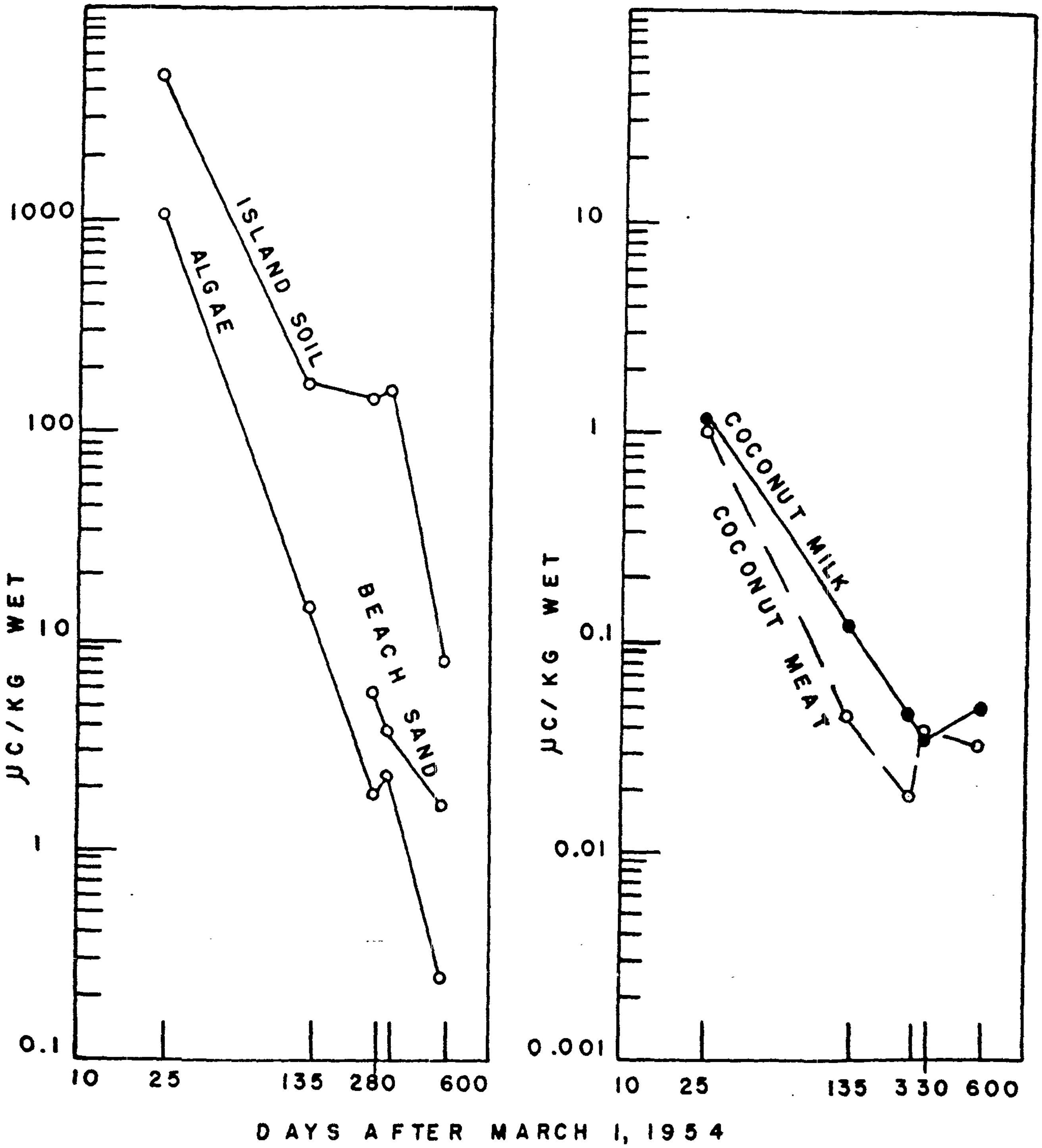
plant in which the Rongelap Island value was almost three times greater than for the other collecting areas. The corms had been washed and peeled to avoid contamination from the adhering soil. Since there is no evidence to indicate that the rate of uptake of radioactive materials should be higher at one island than another, and since the levels of activity in the soils at Rongelap Island varied considerably in two neighboring locations (from 1.7 μc/kg to 20 μc/kg), it is probable that the arrowroot at Rongelap Island was collected in relatively "hot" spots. In the early surveys it was found that the meter readings were highest in soil depressions and in pits such as those used by the natives for growing crops, and this may account for the values.

During October 1955 the radioactivity in the soil was much higher than that in the plants, indicating a low rate of uptake. This seems to be correlated with the loss from the soil of those isotopes which are readily taken up by the plants. The ratio of soil/plant activity has increased from 8 to 190 in the period from March 1954 to October 1955. This would be true if there was a selective uptake of short half-life fission products by the plants. It was also borne out by the radiochemical determinations, which showed that in addition to the rare earth isotopes, Zr^{95} was the principal source of radioactivity in the soil in March 1954[5], whereas it was Ru^{106} in July 1955[6]. Although Ru^{106} comprised a relatively large fraction (23.3%) of the activity in the soil, in most plants it was minor (7.8%). Much of the activity in the plants - up to 96 percent - was due to Cs^{137}, which comprised a very small part of the total activity in the soil (1.1%)[6].

In the period from March 1954 to October 1955 the levels of radioactivity in the land plants were generally higher in the northern islands of the atoll, which was in accord with the survey meter readings and the radioactivity in the soils. The activity in the land plants, however, declined at a faster rate than that in the soils for the period March 1954 to January 1955, after which the rate of decline appeared to be slower in the land plants. The rate of decline at Kabelle and Labaredj Islands is presented in Figure 11 for island soil and in Figure 12 for coconut meat and milk. The activity in the coconuts does not appear to be declining appreciably with time, but since it is due mostly to Cs^{137}, it does not present a health problem at this time. (The average level for coconuts in October 1955 was approximately 4.5 x 10^{-5} $\mu c/g$ of wet tissue, which is less than 1 percent of the tolerance level[9]).

Edible plants other than coconuts have been found to contain levels of Sr^{90} which are above the tolerance level as defined in the Radiological Health Handbook[9]. Among these plants are Pandanus, papaya, Morinda, squash, and possibly arrowroot. The level of Sr^{90} in coconut meat and milk is very low[5,6]. Thus it can be stated that certain plants are selectively absorbing this isotope, while others are not.

Another indication of selective uptake of radioactive materials from the soil is shown by the difference in the decay slopes of coconut meat and milk. They are not only different from one another, but also are different from the decay slopes of other plants and soils, the average slope of which logarithmically is about -1.25. The decay slopes for different samples of coconut meat and milk taken from Kabelle and Rongelap Islands are presented



Figures 11 (left) and 12 (right). Rate of decline of radioactivity in algae and soils and coconut meat and milk at Rongelap Atoll from March 26, 1954 to October 23, 1955.

in the following table.

Log-log Slopes of Coconut Meat and Milk Taken from Rongelap and Kabelle Islands in 1954.

Kabelle 3/26/54		Kabelle 7/16/54		Kabelle 12/8/54		Rongelap 12/18/54	
Meat	Milk	Meat	Milk	Meat	Milk	Meat	Milk
1.0	0.9	0.5	0.1	0.7	0.19	1.1	0.2
	0.8	0.8	0.15	0.8	0.3	1.4	0.1
	0.8	1.0		0.8	0.2		
	0.7						

These slopes indicate that coconut meat and milk select different radioactive isotopes during their metabolic activities and that the milk is definitely absorbing an isotope mixture containing, for the most part, long-lived isotopes. From the chemical data, fission products yield and decay analyses, it is believed that Cs^{137} is the major contributor.

It has been shown that the level of radioactivity in the plants at the northern islands of Rongelap Atoll is higher than that at the southern islands, that this activity is declining at the present time at a slow rate (Fig. 12), and that there is a selective uptake of certain isotopes among which Cs^{137}, Ce^{144}, Ru^{106}, Zr^{95}, and Sr^{90} are the most important.

Algae

In the October 1955 survey, samples of marine algae were taken from the shallow water of the lagoon near shore and by diving to the bottom in the deeper waters of the lagoon. Fresh and brackish water algae were collected from a well and from a concrete cistern found near the village on Rongelap Island. Samples of two species of algae, Halimeda and Caulerpa, were taken from all islands visited and other species were taken whenever found. Samples of marine sand were taken near the algae collecting locations.

The radioactivity found in the algae for the first five collections is presented in detail in Appendix Table VII of UWFL-42. A summary of all the collections is given in Table 10 of this report. The radioactivity found in the algae collected in October 1955 is presented in Appendix E and is summarized with the marine sand in the following table.

Summary of the Radioactivity in the Algae and in the Lagoon Sand Collected in October 1955. Values Expressed in $\mu c/kg$ of Wet Tissue.

Rongelap Atoll

	Kabelle	Labaredj	Rongelap Shore	Rongelap 22'*	Rongelap 49'	Rongelap Well	Rongelap Cistern
Algae	0.18	0.31	0.089	0.066	0.048	0.50	6.8
Sand	2.6	--	0.084	0.34	0.23	3.3**	--
Ratio $\frac{\text{Soil}}{\text{Algae}}$	15	--	1.	5.1	4.8	6.6	--

Ailinginae Atoll

	Enibuk Shore	Enibuk 35'
Algae	0.033	0.064
Sand	0.039	0.13
Ratio	1.2	2.0

* At bottom of lagoon in 22 feet of water; ** island soil.

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Table 10. Radioactivity of Lagoon Algae March 1954-October 1955

Values expressed in uc/kg of wet tissue

Island	3/26/54	7/16/54	12/8/54	1/27-30/55	10/21-23/55
Rongelap Atoll					
Kabelle reef	830.	15.	1.9		0.20
" deep water				1.8	
Rongelap reef					.058
" deep water				3.4	.067
Labaredj reef					.31
Eniaetok "				1.4	
Gejen "				1.8	
Ailinginae Atoll					
Enibuk reef					.033
" deep water					0.052

In October 1955, the highest values in the marine algae were at Kabelle and Labaredj Islands and the lowest in the shallow water of the lagoon at Enibuk Island, Ailinginae Atoll. The highest of all were the fresh-water and brackish water algae from Rongelap Island which were collected in locations where fission product material would tend to accumulate. These algae were collected from the bottom of a concrete cistern which was used to collect rainwater and from the sides of a well which contained water originating from the fresh water lens. In both of these locations the water contained much more activity than the water in the lagoon (see Table 13). Considering all the samples collected on this date, the ratio of the activity in the soil to that in the algae varied from 1 to 15, an indication that the level in the soil is not the primary factor in determining the level of activity in the algae.

A comparision of the radioactivity in the algae collected in the shallow water near the lagoon shore with that of those collected at the bottom of the lagoon in deeper water shows that the latter were slightly more radioactive at Enibuk Island and less radioactive at Rongelap Island.

The radioactivity in the algae at Rongelap Atoll is declining at a rapid rate. This is illustrated in Figure 11, a log-log plot of radioactivity in the algae at Kabelle Island from March 26, 1954 to October 21, 1955. The slope of this line is -2.5, which is steeper than that for beach sand (-1.5). It is also steeper than that for the land plants (-1.25), which indicates that different fission products were being absorbed by the two types of plants. This difference in composition of the radioactive material is also borne out by the faster

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decay of individual samples of algae and by the radiochemical determinations which showed that in January 1955 a large fraction of the total radioactivity in the algae Caulerpa and Halimeda was due to Ce^{144} and that none of it was due to Cs^{137}, which contributed most of the activity in land plants.

Birds

Birds were collected at four islands of Rongelap and Ailinginae Atolls during the latter part of October 1955. Terns were taken at Kabelle and Labaredj Islands in Rongelap Atoll and at Enibuk Island in Ailinginae Atoll and included three species: the fairy tern (Gygis alba), the noddy tern (Anous stolidus), and the black-naped tern (Sterna sumatrana). Terns were not available at Rongelap Island but two species of shore birds were collected at this site, including two ruddy turnstones (Arenaria interprés) and a reef heron (Demigretta sacra sacra).

Specimens taken at Kabelle and Labaredj were treated as northern atoll birds and as one group. Those birds from the southern island of Rongelap as well as those from Enibuk Island (Ailinginae Atoll) were considered to constitute a southern group[5].

The birds of the southern group were further subdivided according to their feeding habits into (1) the terns, which forage in the area of a few islands within the atoll and feed principally on fish and (2) the shore birds, which are migratory, any one bird remaining in the area of an atoll for only a limited time, and which feed for the most part on crustacea along the beaches. The northern group of birds consisted entirely of terns.

Because of their limited migrational tendencies, the terns provide a more representative sample for the determination of continued uptake and metabolism of radioactive materials at Rongelap Atoll than do the shore birds[5], although in some respects the two groups are similar.

In the collections prior to October 1955 the following organs were processed: skin, muscle, bone, lung, liver, kidney, ileum, and thyroid. In the October collections only muscle, bone and liver were taken in an effort to reduce the total number of samples.

The average specific activities of muscle, bone and liver of Rongelap and Ailinginae birds are given in Table 11. At the time of the October collections the radioactivity levels in the three tissues of the north Rongelap terns were approaching a common value, with the most radioactive tissue (liver) having an activity only 2.45 times that of the least active tissue (bone). In the Enibuk terns the ratio of highest radioactivity to lowest was 1:3.67. The differences between the highest and lowest levels of activity in the three tissues of the north Rongelap terns for any one collection date have consistently declined since the first collections in March 1954. The dates and ratios are as follows:

March 26, 1954 - 1:8.5
July 16, 1954 - 1:5.6
December 8, 1954 - 1:5.4
January 28-30, 1955 - 1:3.1
October 21, 1955 - 1:2.5

Table 11. Radioactivity of Birds and Tern Eggs, March 1954-October 1955

Values expressed in uc/kg of wet tissue

Date and Island	Name	Number Specimens	Muscle	Liver	Bone
Rongelap Atoll					
3/26/54					
Labaredj and Kabelle	noddy and fairy terns	4	4.8	23.	41.
Kabelle	curlew	1	7.7	36.	160.
7/16/54 Kabelle	noddy, fairy and crested terns	6	0.64	3.6	0.75
	curlew	1	0.18	1.0	1.7
12/8/54 Kabelle	noddy and fairy terns	4	0.40	0.21	0.097
1/26-30/55 Rongelap	fairy terns	5	0.26	0.81	0.65
	turnstone and plover	2	0.044	0.23	0.18
Gejen, Kabelle and Labaredj	noddy and fairy terns	6	0.050	0.15	0.10
10/21-22/55					
Labaredj and Kabelle	noddy and fairy terns	7	0.020	0.049	0.014
Rongelap	reef heron and turnstones	3	0.059	0.41	0.12
Ailinginae Atoll					
10/23/55 Enibuk	black-naped, fairy and noddy terns	8	0.038	0.099	0.027

Tern Eggs

	Number Specimens	Egg Shell	Yolk	White	Embryo
Rongelap Atoll					
7/16/54 Kabelle	5	.65	.93	.026	.34
12/8/54 Kabelle	3	.30	.13	.0091	
1/29/55 Kabelle	4	.14	.020		
10/21/55 Labaredj and Kabelle	2	.013	.015		

A similar decline occurs in ratios of radioactivity in the tissues of the shore birds. However, the ratio of the most active tissue to the least active on any given date is usually about twice that found for the terns. In addition, the points in the decline of ratio with increasing time are more variable in the shore birds than those found in the terns.

The rate of decline of radioactivity in muscle, liver, and bone of north Rongelap terns is of two general types, logarithmic and semilogarithmic. A logarithmic decline as used here refers to a decline best described by a straight line on log-log paper. A semilogarithmic decline is best described by a straight line on semi-log paper (Fig. 13). Bone exhibits the former type of curve ($r = t^{-2.49}$). Also the decay curve for samples of bone taken on March 26 and July 16 is logarithmic ($r = t^{-1.65}$). In liver and muscle the decline is semilogarithmic with a half life of approximately 40 days. In the October collections the average radioactivity from 7 samples each of muscle and liver suggested that the decline in activity was beginning to assume a longer half life than 40 days (Fig. 13). However, a straight line (half life of 40 days) extended through the averages of the previous collections falls within the 95 percent confidence limits of the October values. The deviations of the latter points from the decline curve derived from the previous collections are therefore probably not significant.

The radioactive decay of three liver samples from north Rongelap terns taken on March 26, 1954 is logarithmic ($r = t^{-1.33}$).

Shore birds taken at Rongelap Island in October 1955 continued to contain higher levels of activity than terns. Ratios of shore bird radioactivity to those of northern Rongelap terns were as follows: muscle, 2.9:1 ;

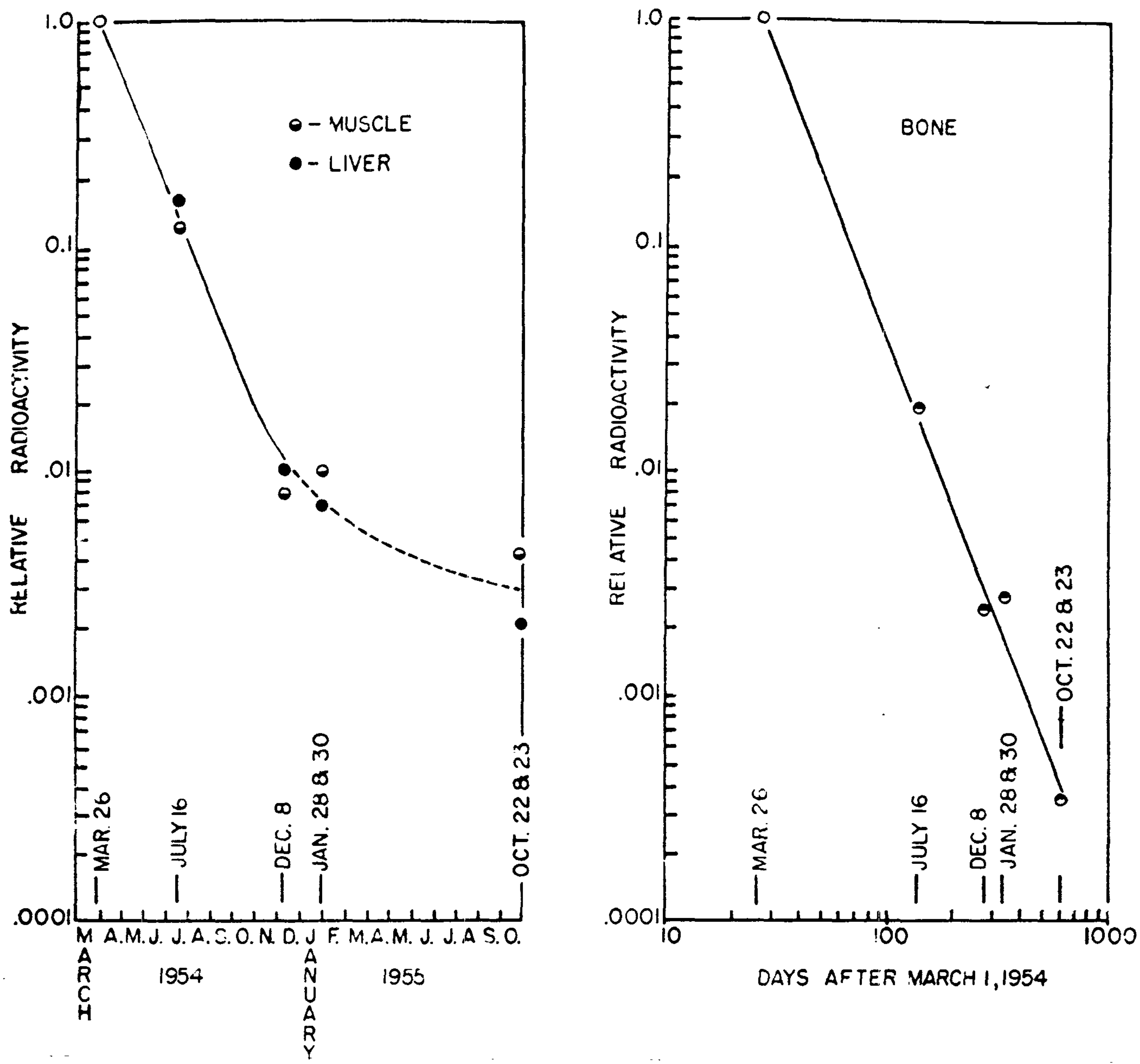

Figure 13. Decline in the radioactivity of bird liver, muscle, and bone tissues collected at Rongelap Atoll between March 26, 1954 and October 22-23, 1955, expressed as a ratio of the activity of the March 26, 1954 collection.

bone, 8.7: 1; and liver, 8. 4: 1.

The decline curve for shore bird bone is logarithmic and similar to that of the tern bone ($r = t^{-2.5}$). The variability in the muscle and liver samples from the shore birds precludes the drawing of decline curves for these tissues.

In the January 26-30, 1955 collections[5], the northern Rongelap terns from Gejen, Kabelle and Labaredj Islands were found to contain less radioactive material per unit weight than did the terns from the southern island of Rongelap. This finding was unexpected because of the fact that the average levels of radioactive contamination were higher in the northern than in the southern islands.

Because the Rongelap natives usually collect birds at Ailinginae Atoll, seven and one-half nautical miles to the southwest of Rongelap Atoll, and in view of the observation that the southern Rongelap terns were more radioactive than the northern Rongelap birds, collections of terns were made at Ailinginae Atoll on October 23, 1955. The ratios of Ailinginae Atoll tern tissues to north Rongelap Atoll tern tissues are as follows: muscle, 1.9:1.0; bone, 1.9: 1.0; liver, 2.0: 1.0. Thus the Ailinginae terns contain, on the average, about twice as much radioactivity as the terns from the northern islands of Rongelap Atoll, although the general level of contamination at Ailinginae is much lower than in the north end of Rongelap. Inasmuch as these birds are predominantly fish eaters, the higher levels of radioactivity in the tissues of the southern birds suggest the availability of a supply of food fish with a higher average radioactive content in the southern area compared with that of northern Rongelap. The fish utilized for food by the terns are small (one to two inches in length) and travel in schools in the open waters of the lagoon. A satisfactory method of obtaining samples of these animals has not been found, other than that of taking them from the gastrointestinal tract of the birds.

Tern eggs were collected in October 1955 at Labaredj and Kabelle Islands. Previous collections had been made at Kabelle on July 16, December 8, 1954, and January 29, 1955[5]. The levels of radioactivity in both the shells and yolks of eggs of the last collection were low, approximating those found in the bones of terns from the same area. In contrast to the logarithmic decline and decay curves observed for tern bones, radioactivity in the egg shells declined semilogarithmically with an 80-day half-life; the decay curves also exhibit semilogarithmic decrease with time but contain two components, one with a 50-day half life and the other with a 300-day half life.

The rate and type of decline for the egg yolks cannot be determined because of the great variability in the average values for the various collecting dates.

Plankton

The equipment and methods for obtaining the October 1955 plankton samples were the same as for the previous Rongelap collections, except that the nets were of nylon rather than silk and the mesh was slightly more open in the "fine"net. (For the "fine" net, mesh size was 157 per inch as compared to 174 per inch when silk was used.)

The radioactivity of the plankton samples from the six collections since March 1954 is summarized in Table 12. It will be noted that the present level of activity in Rongelap lagoon is less than 0.5 of a microcurie per kilogram of wet sample, that the radioactivity of the plankton off Rongelap Island continues to be less than that of the sample off Kabelle Island, and that the radioactivity of the plankton in Ailinginae lagoon was somewhat greater than the radioactivity of the plankton in Rongelap lagoon. The significantly greater activity of the Ailinginae plankton was unexpected.

This greater value may be within the error that is typical of plankton samples; another explanation is the possibility that the exchange of ocean water and lagoon water is slower at Ailinginae than at Rongelap. The shape of the atolls would suggest this although the relative rates of exchange are not known. Rongelap is roughly circular in shape with wide, deep passes in both the northeast and south while Ailinginae is rectangular in shape with its largest pass, in the southern part of the atoll, shallower than the Rongelap passes (Fig. 1). The wind-driven ocean currents are from the north-northeast. Water samples from off Rongelap Island and from Ailinginae lagoon do not indicate differences in activity, possibly because the counting techniques of the Laboratory are insensitive to very low counts.

The rate of decline of radioactivity of Rongelap lagoon plankton was determined from the data in Table 12 by averaging all the values for any one

Table 12. Radioactivity of Plankton Samples
March 1954-October 1955

Values expressed in uc/kg of wet sample

Date	Off Lukuen	Off Kabelle	Off Labaredj	Off Rongelap
Rongelap Atoll				
3/26/54			140.	
7/16/54		2.4		
12/8/54		8.4		
12/18/54			4.4	
1/26-30/55	3.0	3.9	0.66	0.75
10/21-22/55		0.19		0.045

	Off Mogiri
Ailinginae Atoll	
10/23-24/55	0.70

date regardless of area collected and by plotting the logarithm of these values against the logarithm of the collecting date, expressed as the number of days after March 1, 1954. The slope of the least squares regression line computed from these data is -1.80, i.e., $r = t^{-1.80}$.

Counting of the Rongelap lagoon plankton samples, the decay rates of which were reported in UWFL-42, was continued and the decay rates were found to be practically the same as determined earlier. For the March 1954 Labaredj sample, the July 1954 Kabelle sample, and the December 1954 Kabelle sample, the decay rates were -1.27, -1.38 and -1.35 respectively.

Water

Both lagoon and island water samples were taken and processed in the same manner as previously but in addition new refinements to the technique were also tried. Results of the water analyses are presented in Table 13. (It is to be noted that the values in this table are in d/m and not μ/c.)

With salt water samples that are prepared for counting by drying only, the amount used is limited by the quantity of salt remaining on the counting plate. For the October 1955 samples, 10 cc per plate were used. The values for the dried samples are listed in the column headed "untreated" in Table 13. F or the samples in the column headed "treated", about 5 cc of

Table 13. Radioactivity of Water Samples, July 1954-October 1955

Values expressed in d/m/liter ±0.95 counting error

Date and Island	Lagoon Water: Untreated	Lagoon Water: Treated	Island Water: Unfiltered	Island Water: Filtered: Filtrate	Island Water: Filtered: Residue
Rongelap Atoll					
7/16/54					
Kabelle	3800±3200				
12/18/54					
Rongelap			3000± 190*	1800±180#	
1/26-30/55					
Eniaetok			17000±2200##		
Kabelle	3300±2700		48000±3200**		
Labaredj	6800±3000		25000±2200##		
Lomuilal	5600±3000				
Rongelap	5600±3000		4200±1800*		
10/21-22/55					
Kabelle	3500±1600	410±150			
Labaredj	600±1500	450±160			
Rongelap	1900±1600	60±120	540±120	310±190	75±17#
			5300±140	4300±200	1200±34*
			1300± 86	850±140	75±19***
Ailinginae Atoll					
10/23/55					
Enibuk	1600±1400	80±130	1400± 91	820±140	820±56##

* from cistern near schoolhouse; # from well back of schoolhouse; ** ground water; ## standing water from can, drum, etc.; *** from cistern with collapsed roof.
Date of analysis: November 18-20, 1955.

saturated sodium carbonate were added to 100 cc of sample, the sample then filtered through millipore filter paper, and the precipitate ashed and counted. The purpose of the sodium carbonate was to remove naturally occurring K^{40} (approximately 540 d/m/liter) from the precipitate. Tests performed by the Health and Safety Laboratory, New York Operations Office, on this technique indicate that potassium does not co-precipitate and that from spikes using 18-month-old mixed fission products, only 23 percent of the activity escaped precipitation[10]. The counting error per unit weight is considerably less in the "treated" column because of larger sample size and a smaller correction for self-absorption.

Values in the "untreated" column for the October collection indicate some radioactivity in the Kabelle sample, but a questionable amount of activity in the three other samples. However, the values in the "treated" column definitely indicate activity in both the Kabelle and Labaredj samples. The best estimate of the maximum value of mixed fission product activity in Rongelap lagoon water is 0.0006 μc per liter.

The island water samples were prepared for counting by drying both an unfiltered and filtered sample. The filtered sample was passed through a millipore filter and both the filtrate and the residue were counted. One hundred-cc samples were used without difficulty as there was very little residue remaining on the plates after drying. However, the well sample from Rongelap Island had some salts and from the weight of the salts it was estimated that 8 percent of the sample was sea water.

The well water on Rongelap Island was less radioactive than cistern water.

This was also true of the December collection. The maximum value for cistern water was 5300 d/m/liter (0.0024 μc/liter).

The Ailinginae water sample was taken from a half-full 55-gallon metal drum standing open beneath a palm. The value for this sample was 1300 d/m/liter (0.0006 μc/liter) which is the same order of magnitude as Rongelap Island cistern water.

Evaluation of Radioactivity in the Soils

Soil samples for the October 21-23, 1955 collections were taken from the islands proper. Sand specimens were collected at the low tide line and from the lagoon bottom. One sample was taken from the bottom of the well at Rongelap village.

The sampling method for soils differed from that of the previous Rongelap collections. In the earlier collections single samples of the top inch of soil were taken. In the October collections two samples were taken at each soil station, one to a depth of 3 inches and another directly below to a depth of 6 inches. Since, on the average, 65 percent of the activity of the top 3 inches of soil is located in the top inch*, direct comparisons between samples from the previous collections and the October collections may be made if the latter values for the top 3 inches are multiplied by two.

Profile samples from the lagoon bottom were taken by a diver driving a 12-inch long, 1 1/2-inch diameter aluminum tube into the sand and corking the top and bottom of the tube. The core was removed from the tube at the Eniwetok laboratory and divided into 1-inch increments.

Levels of radioactivity in the sand and soil of Rongelap and Ailinginae Atolls on October 21-24, 1955 are shown in Appendix G. Activity levels in the top 3 inches of soil at Kabelle and Labaredj varied from 4.4 to 11.5 μc/kg. The highest value for any soil sample collected during the above-mentioned time was found in a sample from Rongelap Island which contained 20.3 μc/kg of top 3 inches of soil. This sample is not representative of the

* Unpublished observation.

general level of radioactivity at Rongelap Island, but does illustrate the problem introduced by sample variation when too few samples are taken. The other soil sample from Rongelap Island contained 1.7 μc/kg of top 3 inches of soil and agrees favorably with that expected from a consideration of the values obtained in previous collections when radioactivity decline is taken into consideration.

The rate of decline of radioactive contamination in the combined soil samples from Kabelle and Labaredj Islands between the dates, March 26, 1954 and October 23, 1955 is best represented by a straight line on log-log coordinates with a slope of approximately -1.6. The decay curve for a Labaredj Island soil sample extending through the same period of time[5] is expressed by the formula $r = t^{-1.31}$. In both curves March 1, 1954 is the date of origin.

Enibuk Island (Ailinginae Atoll) soil contained 1.2 μc/kg of top inch of soil or an average of 0.61 μc/kg of top 3 inches of soil on October 23, 1955. Thus the soil at Enibuk was about 1/3 as radioactive as was soil from Rongelap Island, a relationship which was reflected in the radioactivity levels of land plants from the same islands. The sand at low tide line at Enibuk also contained about 1/3 as much radioactive contamination as did a like sample from Rongelap. At both Enibuk and Rongelap the radioactivity level in the low tide line sand was about 1/18 that found in the island soil (top 3 inches).

The levels of radioactivity in the top 6 inches of sand profiles taken on the lagoon bottom off Kabelle Island varied from 1/3 to 1/1 that for the top 6 inches of soil on the island proper. A similar comparison for Rongelap Island gives values for lagoon sand of 2/11 to 2/5 that of the land soil. At Enibuk the soil and lagoon sand were essentially equal in levels of radioactivity.

In sand profiles taken at Kabelle and Rongelap Islands the radioactivity levels of samples taken in water depths of less than 25 feet were approximately 1 1/2 times those found in samples from 50 to 60 feet of water. Bottom samples obtained from the anchor chain in 150 feet of water off Rongelap Island and Mogiri Island (Ailinginae Atoll) contained from 0.7 to 1.2 times as much radioactive contamination as was found on the islands proper.

Comparisons of the distribution of radioactivity in the top 6 inches of soil and lagoon sand were made and are as follows.

Island	Percent of radioactivity in top 3 inches	Percent of radioactivity in 3 to 6 inches depth
Kabelle soil	97	3
Lagoon bottom off Kabelle	57	43
Labaredj soil	97	3
Rongelap soil	89	11
Lagoon bottom off Rongelap	55	45
Lagoon bottom off Enibuk	42	58

Thus on land most of the activity is concentrated in the top 3 inches whereas under water it is distributed throughout the top 6 inches (Fig. 14 A).

Sand profiles from the lagoon off Kabelle Island under 6 and 60 feet of water, from off Rongelap Island under 22 feet of water, and from the Enibuk low tide line were fractionated according to particle size as follows: greater

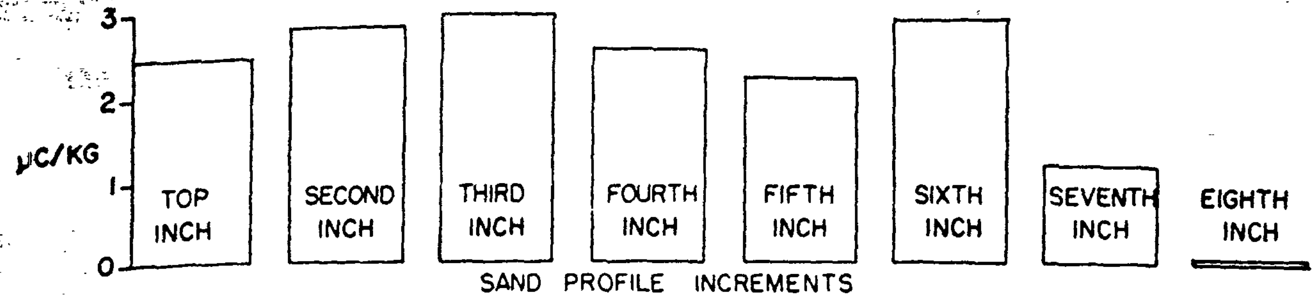

Figure 14 A. Radioactivity in eight increments of a sand profile taken in Rongelap lagoon off Kabelle island under six feet of water.

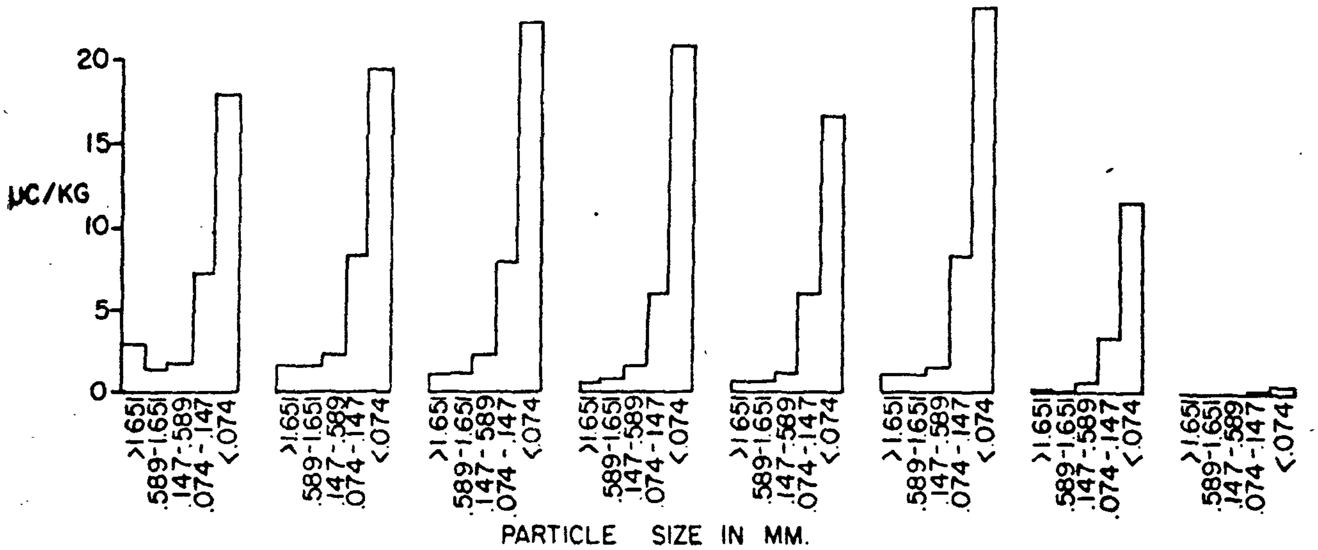

Figure 14 B. Specific radioactivity in five different particle size fractions for each of the soil profile increments shown in Figure 14 A. The highest radioactivity levels are in the smallest particle size fraction in each increment.

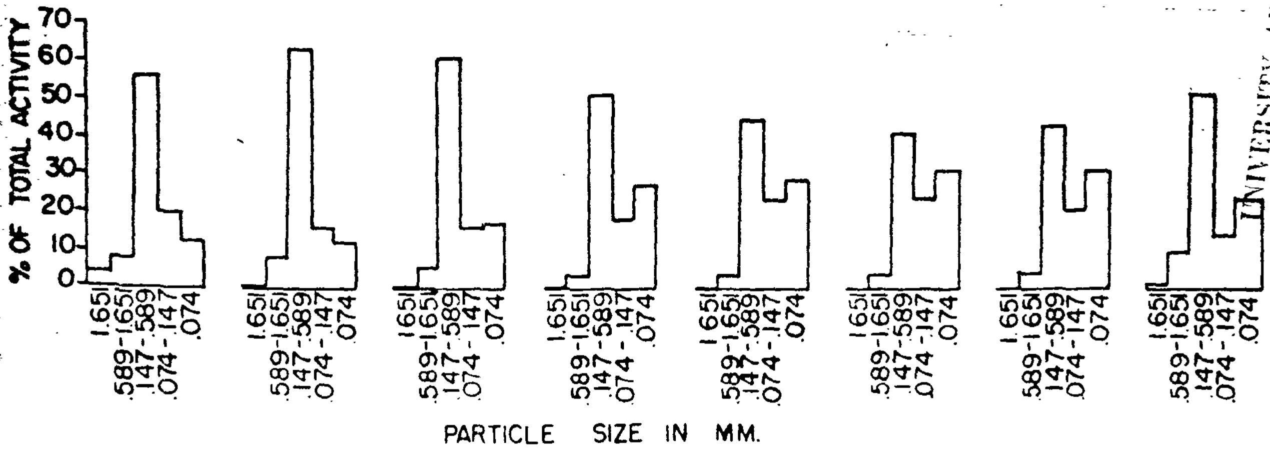

Figure 14 C. The percent of the total radioactivity in each increment contributed by the different particle size fractions of that increment. The percent contributed by the two finer fractions increases with depth down to the eighth inch.

than 1.651 mm, 0.589 - 1.651 mm, 0.147 - 0.589 mm, 0.074 - 0.147 mm, and less than 0.074 mm. In the Enibuk low tide-line samples the two smaller particle size fractions did not account for more than 0.3 percent of any of the increments.

Although there was a tendency for a smaller average particle size with increased depth of water in the lagoon there was no detectable change of pattern regarding particle size in the increments of individual profiles.

The smaller particles tend to have higher specific radioactivities than do the larger particles (Fig. 14 B), and the percent of total activity contributed by the smaller particle size groups tends to increase with increase in depth within the soil profile (Fig. 14 C) down to 6 or 8 inches.

Radiostrontium analyses were made on the top inch and the seventh inch of the lagoon bottom profile taken under 6 feet of water off Kabelle. In both samples Sr^{90} accounted for 0.7 percent of the activity (maximum and minimum in 4 samples: 0.64 % and 0.78 %).

The sand profile in 49 feet of water off Rongelap Island had the lowest level of radioactivity of the lagoon bottom profiles taken in October 1955. The average radioactivity level for the top 8 inches of sand in this sample was 0.19 μc/kg. Using this value as the average of the radioactive contamination on the bottom of Rongelap lagoon and a Sr^{90} content of 0.7 percent, a total of 380 curies of Sr^{90} for the top 8 inches of lagoon bottom is obtained. This is probably a minimum value.

6

Radiochemical Analyses

Radiochemical analyses of some of the samples collected at Rongelap Atoll have been completed and the data are partially reported to show the trends of distribution. Detailed chemical studies on the samples collected should be forthcoming from the samples sent to the New York Operations Office* and from other samples being studied in detail at the Applied Fisheries Laboratory.

The procedures used for the strontium and cerium determinations were the same as those described in UWFL-42. Analysis for cesium followed the method outlined in the Los Alamos report LA-1566[11].

Data for the analyses are given in Appendix H and are summarized in text Tables 14 and 15.

Radiostrontium (Tables 14 and 15). The Sr^{90}** values for food plants, except coconuts, collected in October 1955 approximate the theoretical proportion of mixed fission products activity[12] at 1.7 years, 4 percent. Coconuts contained 0.1 percent Sr^{90} with appropriate correction for time of collection. This is roughly in agreement with values reported in UWFL-42 and USNRDL-454, assuming that Table 3.1, page 14, in the latter report includes radioactivity from Y^{90} with Sr^{90}.

No Sr^{90} was found in the soft tissues of pelagic or reef fish or clams. Analysis of a single sample of bonito bone yielded a maximum Sr^{90} level of

* Letters of October 26 and November 9, 1955 from Allyn H. Seymour, Applied Fisheries Laboratory, to Merrill Eisenbud, New York Operations.

** Sr^{90} values given in text and tables do not include radioactivity due to the Y^{90} daughter.

Table 14. Radiostrontium, Radiocesium and Radiocerium-Praseodymium in Biological Samples, December 1954-January 1955

Island	Organism	Percentage of Total Activity Sr^{89}	Sr^{90}	Cs^{137}	$Ce^{144}Pr^{144}$
Rongelap Atoll					
Gejen	#31 coconut milk	<0.1	<0.1	81.	0.0
Kabelle	#37 *Caulerpa*	-	-	0.0	71.
	#30 coconut milk	-	-	72.	0.0
	#38 *Halimeda*	-	-	0.0	28.
	#39 coconut crab muscle	0.86	4.8	67.	1.0
	#41 mullet muscle	0.0	0.0	0.0	1.5
Labaredj	#29 coconut milk	<0.5	<0.5	76.	0.0
	#42 tern bone	0.0	0.0	0.0	28.
	#43 tern bone	0.0	0.0	0.0	26.
Mellu	#40 dogtooth tuna muscle	0.0	0.0	4.8	0.6
Rongelap	#27 coconut meat	0.0	0.0	26.	<0.4
	#28 coconut milk	0.0	0.0	78.	<0.2
	#32 pandanus fruit	<0.1	1.3	110.	0.7
	#34 papaya meat	<0.1	2.5	68.	3.7
	#33 squash meat	<0.1	1.5	51.	1.0
	Dates of analysis	June-July 1955		Sept. Oct. 1955	July Aug. 1955

Table 15. Sr^{90} in Biological and Lagoon Bottom Samples from Rongelap Atoll, October 1955

Island	Sample	Total Activity d/m/g*	Sr^{90}, Percent of Total Activity
Rongelap	coconut meat	110	0
	pandanus fruit	180	2.1
	morinda "	47	4.6
Labaredj	arrowroot corm	40	3.2
Kabelle	coconut crab muscle	440	2.9
	" " "liver"	1,200	12.
	" " salts of carapace		50.
	" " cuticle " "		29.
Labaredj	giant clam mantle and muscle	1,700	0
	" " kidney	5,200	0
Labaredj	bonito muscle	150	0
	" liver	1,700	0
	" bone	390	<0.6
Kabelle	grouper muscle	31	0
	" liver	5,500	0
	goatfish muscle	42	0
Labaredj	tern muscle	61	0
Kabelle	lagoon bottom, depth of water 6', fraction containing particles <0.074 mm diameter. — top inch	40,000	0.73
	lagoon bottom, depth of water 6', fraction containing particles <0.074 mm diameter. — 7th inch	25,000	0.71

* Wet weight basis except lagoon bottom which is on a dry weight basis.

0.6 percent of the total activity. Two fish muscle samples collected in January 1955 were reported in USNRDL-454 (Table 4.5) to have Sr^{90} levels of 0.2 percent of the total beta activity. The muscle and bone of terns, which feed on fish, contained no Sr^{90}

In contrast to the strictly marine forms, the coconut crab, which feeds principally on land plants, had Sr^{90} levels of 3 percent in the muscle and 12 percent in the hepato-pancreas or liver, where calcium salts are stored. The radioisotopes in salts leached from the carapace were found to consist entirely of $Sr^{90} + Y^{90}$. The levels relative to total activity would be expected to remain constant in the salts of the carapace, to increase in muscle, as Sr^{90} makes up a greater proportion of the total activity with the passage of time, and to be variable in the liver depending on the physiological state of each crab with respect to molting. Sr^{90} levels in the liver would be expected to be at a peak immediately pre- and post molt.

In the lagoon bottom samples collected in October 1955, 0.7 percent of the activity was Sr^{90}. Estimates of total radiostrontium content of Rongelap lagoon are discussed in the soils section.

Radiocesium (Table 14). The highest Cs^{137} levels were found in the land plants and the coconut crab, 26 percent-100 percent. Cs^{137} in marine algae, fish muscle and fish-feeding birds was absent or present in only small amounts (maximum 4.8 percent).

Radiocerium (Table 14). The levels for Ce^{144} were highest in marine birds and algae, 26 percent - 71 percent. In tuna muscle, however, Ce^{144} accounted for only 0.6 percent of the total activity. There was none in coconuts and less than 4 percent in pandanus, squash and papaya fruit. Values for rare earths given in USNRDL-454 agree closely, with the exception of papaya for which their value is higher by a factor of ten.

Non-fission-product radionuclides. Radionuclides of Sr, Cs, Ce and their daughters did not account for the total activity in most samples analyzed. Complete fission product analyses of samples collected at Eniwetok and Bikini Atolls indicate that non-fission-product radionuclides may account for more than half of the total activity in some fish; Zn^{65} contributes one-fourth or more of the total activity in shark muscle as determined by radiochemical analysis and confirmed by following the decay.

Physical Decay of Samples

Extensions into December 1955 of the nine decay curves of Figures 11, 12 and 13, UWFL-42, show little change in direction. Gastric mill of a crab began to decay with semi-log linearity and changed between 200 and 300 days post shot to the log-log linearity now apparent in Figure 15. Muscle of a sea cucumber changed similarly. The other decay curves tabulated in Appendix Table XII of UWFL-42 have not yet been extended, but approximately straight-line log-log curves may be expected.

The more rapid rate of decline (-1.75) than of decay (-1.43) noted earlier (UWFL-42:28) has persisted and is encouraging.

It is understandable that decline should exceed decay in an area of high activity because of dilution by rain and sea. In an area of relatively low activity decay would exceed decline because of additions from the surroundings.

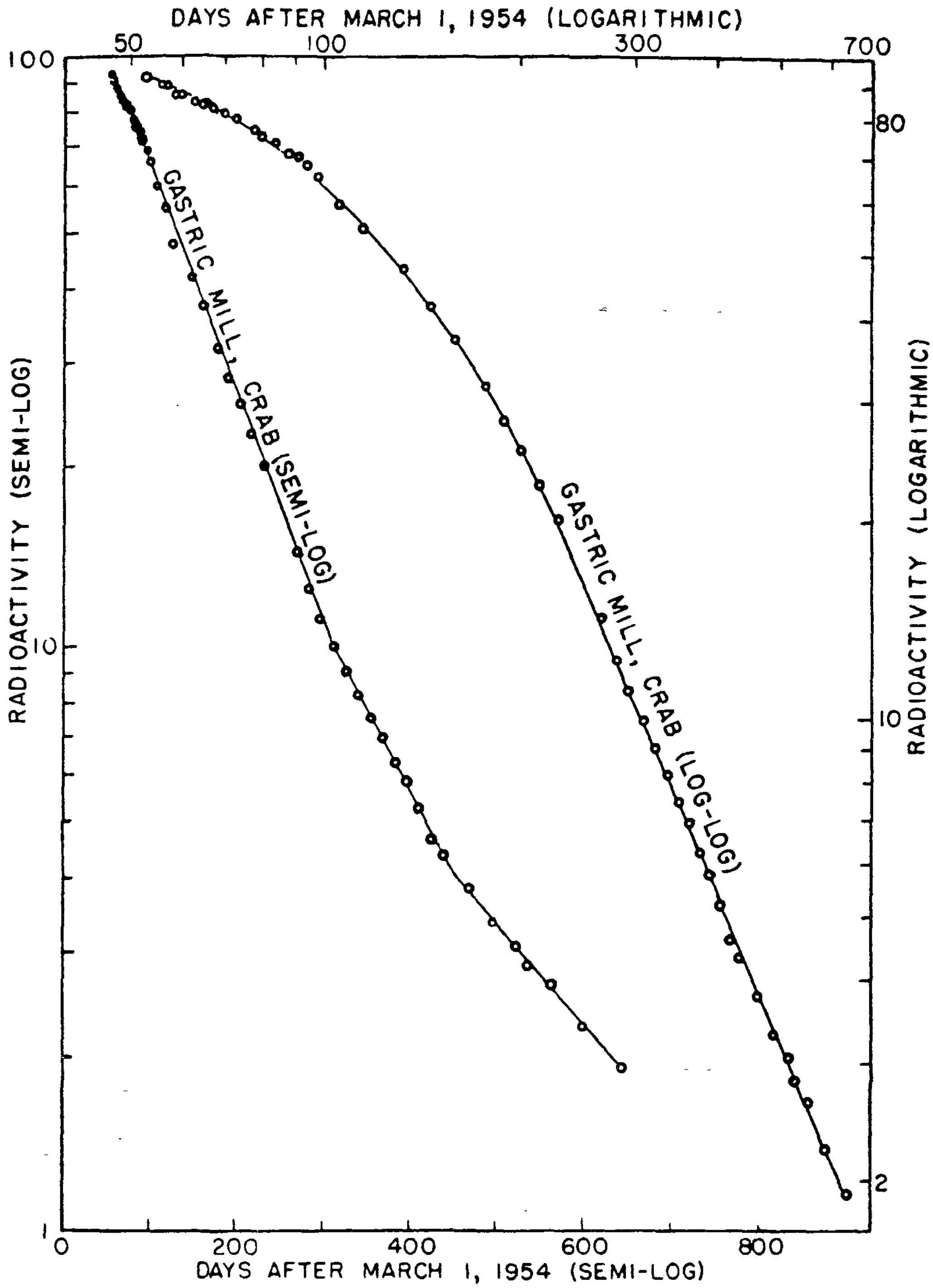

Figure 15. Radioactive decay of tissue of gastric mill of crab, *Grapsus grapsus*, collected March 26, 1954 at Kabelle, plotted both as semi-log and log-log curves.

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A P P E N D I X

APPENDIX A

Table 1. Survey Meter Readings, October 21-23, 1955

Values expressed in millireps per hour*

Location	Description	Closed	Open
Rongelap Atoll 10/21/55 Kabelle	W to E transect across middle of island at 1 inch	Closed	Open
	above high tide	2.	6.
	open area soil sample #1	3.5	12.
	grassy area soil sample #3	2.	8.
		2.5	8.
		2.	8.5
		2.5	9.
		2.	8.
		3.5	12.
		4.	14.
		2.5	10.
	in *Scaevola* litter	1.5	7.
	in *Scaevola* litter	1.5	5.
	oceanside, intertidal	0.1	0.4
Labaredj	SW part of island, 100-200 yards from lagoon at 1 inch	Closed	Open
	open, soil sample #5	2.	8.
	under trees, soil sample #7	0.6	7.
		1.2	10.
		3.	11.
		0.7	7.
10/22/55 Rongelap	At northern village at 1 inch	Closed	Open
	above high tide line	0.1	0.2
	grass near well	0.5	2.
	soil sample #9	0.3	0.9
	soil sample #11	0.3	1.
Ailinginae Atoll 10/23/55 Enibuk	At 1 inch	Closed	Open
	west end in brush	0.05	0.5
	soil under trees	0.1	0.6

* With a Beckman MX-5

APPENDIX A

Table 2. Survey Meter Readings at Rongelap Atoll
November 7, 1955

Rongelap Island

Area	3' above ground closed	3' above ground open	1" above ground closed	1" above ground open
Landing in front of village intertidal area	.04	.04	.04	.04
Landing in front of village above high tide line	.06	.10	.08	.13
60 paces from lagoon to cistern	.08	0.3	.08	0.4
Schoolhouse - hospital area	.07	0.3	.10	.25
Schoolhouse - papaya cluster (soil sample A-11 & 12)	.09	0.5	0.4	1.2
Well behind schoolhouse, grassy area (soil sample A-9 & 10)	.14	0.8	0.10	0.6
(Heading south along path near lagoon side of island. General direction N - S.)				
Village center - concrete posts grass	.07	0.3		
Village center - concrete posts gravel	.07	0.15	0.09	0.4
Village plus 100 paces grass			0.15	0.9
Village plus 100 paces gravel	.11	0.6	0.10*	0.4*
And plus 75 paces, at church				
grass	.06	.25	.06	0.35
gravel			.07	0.4
Plus 70 paces, inside hut	0.4	3.0		
inside hut, pandanus mat			1.0	7.0
inside hut, roof			0.5	4.0
outside of hut, roof			1.2	8.0
Plus another 200 paces, pandanus grove	0.4	3.5	0.5*	2.0*
Plus another 350 paces, mostly grass	0.4	3.0	0.6	5.0
Schoolhouse, inside	0.09	0.7	0.05*	0.4*
Schoolhouse, table			0.2	1.2
Hospital, inside	0.11	0.9	0.12	0.9
Hospital mattress			0.06	0.5

* Values rechecked because they were less at 1" than at 3'.

APPENDIX A

Table 2. (continued)

Rongelap Island

Area	3' above ground closed	open	1" above ground closed	open
(Path from lagoon to ocean side starting from lagoon side. General direction E - W.)				
Fifty paces from junction with N - S path - well - grass	0.09	0.4	0.06	0.3
Plus 100 paces, open grass	0.3	2.0	0.5	3.5
And plus 110 paces, *Sida* bushes	0.3	3.0	0.9	5.0
Plus another 110 paces, open grass	0.4	3.0	1.2	7.0
Plus 100 paces, grass and sand under coconut	0.4	3.0	0.7	6.0
Plus 100 paces, under *Guettarda*, dead leaves	0.15	1.5	0.4	1.0
Plus 55 paces ocean side, above high tide line, leaves and sand	0.12	1.0	0.3	3.0
Ocean side - intertidal area, sand and beach pavement	0.03	0.03	0.03	0.03

Labaredj Island

Area	3' above ground closed	open	1" above ground closed	open
Boat landing, south end, intertidal - sand	0.04	0.06	0.06	0.10
Boat landing, south end, above high tide, pavement	0.7	5.0	1.3	8.0
One hundred paces N of boat landing, lagoon side, dead leaves			4.0	off scale
One hundred paces N of boat landing, lagoon side, gravel	1.1	8.0	3.0	15.0
Plus 175 paces, lagoon side gravel	0.6	4.0	1.4	7.0

APPENDIX A

Table 2. (continued)

Labaredj Island

Area	3' above ground closed	3' above ground open	1" above ground closed	1" above ground open
From lagoon high tide line, 40 paces east, under pandanus trees	2.5	16.0	5.0	off scale
Plus 35 paces east, gravel open area	0.9	6.0	3.0	17.0
Plus 45 paces east, under Messerschmidia	1.0	5.0	1.5	11.0
Plus another 50 paces east, open sand	0.9	8.0	3.0	off scale
Plus 50 paces east, high tide line, ocean side, sand and gravel	0.6	3.0	0.8	4.0
And plus 40 paces east, intertidal, ocean side, sand	0.09	0.4	0.14	0.6
Plus another 10 paces east, ocean side, beach pavement	0.03	0.07	0.04	0.15
Northern tip of Island - intertidal area	0.05	0.15	0.07	0.4
Northern tip of Island - above high tide	0.6	4.0	0.8	6.0
Coconut grove near north end under coconut tree - dead fronds	1.0	5.0	0.8	4.0
And beneath the dead fronds			2.0	11.0
Coconut grove near north end among arrowroot plants	1.1	8.0	3.0	12.0
Coconut grove near north end bottom of Rhinehart "hole" about 12 inches			0.5	3.5
Southwest part of Island, under tree, dead leaves, at site of soil sample A-7 & 8	0.9	6.0	1.5	12.0
And 10 paces west, open, site of soil sample A-5 & 6	0.8	6.0	3.5	18. +
Unnamed island just south of Labaredj (100 yards) at yellow stake, open beach, above high tideline, sand & gravel	0.9	6.0	1.1	6.0

APPENDIX B

Table 1. Radioactivity in Fish from Rongelap Atoll, Kabelle Island

Values expressed in thousands of d/m/g of wet tissue

Date and Island	Common Name	Muscle	Liver	Bone
10/21/55 Kabelle	blenny	0.046	0.875	
	"	.048	1.03	
	"	.048	2.00	
	"	.034	1.09	
	"	.034	1.41	
	butterfly	.063	4.95	
	"	.084	3.91	
	"	.057	3.38	
	damselfish	.084	0.730	
	"	.062	2.78	
	goatfish	.042	6.32	0.431
	"	.031	1.16	
	"	.035	5.12	
	"	.030	1.26	
	"	.035	1.38	
	grouper	.031	10.3	
	"	.031	5.16	.170
	"	.073	2.28	
	"	.056	8.11	
	"	.065	5.25	
	halfbeak	.168	4.81	
	"	.083	3.13	
	"	.068	2.46	
	"	.073	4.43	
	"	.052	0.713	
	jackfish	.066	3.810	
	parrot	.037	1.80	0.194
	"	.050	2.08	
	surgeonfish	.052	6.94	
	"	.028	0.308	
	wrasse	.078	5.88	
	"	.046	5.82	
	"	.073	5.59	
	"	0.058	1.04	

Date of analysis: November 14 - 15, 1955

APPENDIX B

Table 1. Radioactivity in Fish from Rongelap Atoll, Labaredj Island

Values expressed in thousands of d/m/g of wet tissue

Date and Island	Common Name	Muscle	Liver	
10/21/55 Labaredj	blenny	0.049	1.66	
	"	.030	.573	
	"	.089		
	"	.050	1.02	3 liver samples pooled
	"	.074		
	bonito	.102	2.17	
	damselfish	.225	3.12	2 " " "
	"	.097		
	grouper	.069	5.99	
	"	.046		
	"	.055	2.19	4 " " "
	"	.016		
	"	.050		
	halfbeak	.091	1.58	
	"	.119	.792	
	"	.027	.901	
	triggerfish	.087	1.29	
	"	.118	1.100	
	tuna	.040	1.07	
	wrasse	.028	4.30	
	"	.073	1.74	2 " " "
	"	0.065		

Date of analysis: November 15 - 22, 1955

APPENDIX B

Table 1. Radioactivity in Fish from Rongelap Atoll, Rongelap Island

Values expressed in thousands of d/m/g of wet tissue

Date and Island	Common Name	Muscle	Liver	Bone
10/22/55 Rongelap	damselfish	0.009	0.810	
	"	.012	.522	
	"	.014	.664	
	"	.016	1.25	
	"	.015	.962	
	"	.013	.057	
	flatfish	.014	.165	
	goatfish	.037	2.94	
	"	.023	.257	
	"	.018	.470	
	"	.021	.309	
	"	.023	.235	0.188
	"	.033	10.20	
	grouper	.020	4.37	
	"	.032	4.21	
	"	.020	.684	
	"	.017	3.03	
	"	.024	1.99	
	jackfish	.026	.489	
	squirrelfish	.017	.285	
	"	.007	.116	
	"	.028	.302	
	"	.023	.770	
	"	.026	.470	
	surgeonfish	.037	3.24	
	"	.015	.459	
	"	.022	.293	
	"	.019	2.25	
	"	.025	1.51	0.116
	wrasse	.020	0.066 (wrasse, pooled)	
	"	.011		
	"	.028		
	"	0.012		

Date of analysis: November 16 - 22, 1955

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APPENDIX B

Table 1. Radioactivity in Fish from Ailinginae Atoll

Values expressed in thousands of d/m/g of wet tissue

Date and Island	Common Name	Muscle	Liver	Bone
10/23/55 Enibuk	butterfly	0.020	0.939	
	"	.023	.646	
	mullet	.017	.336	
	"	.034	.332	
	"	.022	.360	
	"	.027	.288	
	"	.030	.521	
	"	.025	.297	0.051
	needlefish	.039	.149	
	"	.018	.100	
	"	.068	.269	
	"	.044	.133	
	"	.056	1.080	.132
	surgeonfish	.041	.898	
	"	.022	.321	
	"	.028	1.000	
	"	.033	1.280	
	"	.019	.803	.053
	"	.021	.313	
	"	.019	.940	
	"	.012	.318	.024
	"	.021	2.380	
	"	.071	1.640	
	"	.043	.421	
	triggerfish	.056	.163	
	"	.025	.156	
	"	.058	.263	
	"	.017	.216	0.169
10/23/55 Mogiri	gray shark	.032	.284	
	" "	.017	.055	
	" "	.022	.210	
	" "	.019	.269	
	" "	.014	.472	
10/24/55 Mogiri Pass	grouper	.015	.667	
	mackerel	.020	.516	
	snapper	0.021	0.482	

Date of analysis: November 21 - 23, 1955

APPENDIX C

Table 1. Radioactivity of Invertebrates

Values expressed in thousands of d/m/g of wet weight

Date and Island	Organism	Scientific Name*	Muscle	Gut Content	Integument or carapace	Liver or visc. mass	Kidney	Entire
Rongelap Atoll								
10/21/55 Kabelle	coconut crab	1	0.093		5.8	0.82		
	" "		0.15		7.5	1.62		
	" "		0.23		8.2	1.62		
	hermit crab	2	0.28		4.5	0.63		
	" "		0.33		6.0	0.77		
	giant clam	3	0.089			2.1	1.96	
	" "		0.057			1.7	4.1	
	" "		0.202			2.2	12.1	
	spider snail	4	4.7			31.0		
	" "		7.6			50.0		
	" "		12.7			38.0		
	sea cucumber	5		2.7	0.53			
	" "			4.4	1.18			
	" "			11.0	0.30			
	" "			4.8	0.99			
	coral	6						0.61
	"							0.51
10/21/55 Labaredj	coconut crab	1	0.44		12.8	3.2		
	" "		0.59		11.2	2.4		
	hermit crab	2	0.78		9.1	1.4		
	" "		0.54		9.3	2.7		
	giant clam	3	0.52			3.3	15.7	
	" "		0.31			6.5	15.5	
	" "		0.21			6.2	14.1	
	" "		0.13			2.3	15.8	
	" "		0.09			0.79	8.2	
	spider snail	4	5.2			25.0		
	" "		6.0			45.0		
	" "		10.3			125.0		
	" "		11.1			92.0		
	" "		12.3			90.0		

Date of analysis: November 22-23, 1955

APPENDIX C

p.2 Table 1. (continued)

Date and Island	Organism	Scientific Name*	Muscle	Gut Content	Integument or carapace	Liver or visc. mass	Kidney	Entire
Rongelap Atoll (continued)								
10/22/55 Rongelap	hermit crab	2	0.13		6.3	3.1		
	" "		.20		1.3	0.57		
	" "		.26		1.5	0.59		
	" "		.23		3.5	0.48		
	giant clam	3	.035			3.4	1.7	
	" "		.030			5.2	1.5	
	" "		.022			0.96	1.8	
	" "		.033			3.1	1.1	
	" "		.030			--	1.5	
	sea cucumber	5		1.16	0.39			
	" "			0.65	0.24			
	" "			0.83	0.16			
	coral	7						0.014
	"							0.129
	hydroid	8						0.52
Ailinginae Atoll								
10/23/55 Enibuk	coconut crab	1	.062		1.4	0.33		
	" "		.058		1.8	0.27		
	hermit crab	2	.076		1.7	0.23		
	" "		.064		1.7	0.23		
	" "		.060		1.4	0.22		
	giant clam	3	.050			2.2	7.7	
	" "		.096			0.76	6.7	
	" "		.044			1.02	6.2	
	" "		.050			1.31	7.8	
	sea cucumber	9		0.23	0.28			
	" "			0.29	0.61			
	" "			0.18	0.29			
	" "			0.30	0.24			
	" "			0.35	0.64			
	spider snail	4	0.26			1.3		

APPENDIX C

D. 3 Table 1 (continued)

Date and Island	Organism	Scientific Name*	Muscle	Gut Content	Integument or carapace	Liver or visc. mass	Kidney	Entire
Rongelap Atoll (continued)								
10/22/55	coral	7						0.044
Rongelap	"	10						0.085
	"	11						0.045

* (1) Birgus; (2) Coenobita; (3) Tridacna; (4) Pterocera; (5) Holothuria; (6) Acropora; (7) Pocillopora; (8) undetermined; (9) small tan, Stichopus?; (10) Acropora; (11) Porites.
Date of analysis: November 22-23, 1955.

APPENDIX D **Table 1. Radioactivity in the Edible Plants**

Values expressed in thousands of d/m/g of wet weight

Date and Island	Coconut Meat	Coconut Milk	Papaya Meat	Papaya Seeds	Pandanus*	Arrowroot Corm	Morinda*
Rongelap Atoll							
10/21/55	0.050	0.074				0.058	
Kabelle	.044	.055				.017	
	.050	.089				.076	
	.129	.160				.078	
	.154	.175				.032	
Labaredj	.066	.094			0.206	.036	
	.042	.086			.176	.057	
	.070	.097			.160	.044	
	.081	.213			.154	.046	
	.054	.064				.041	
10/22/55							
Rongelap	.023	.100	0.042	0.127	.183	.088	0.073
	.050	.020	.017	.048	.183	.193	.025
	.079	.097	.035	.093	.189	.144	.019
	.046	.115	.017	.037	.149	.078	.014
	.083	.069	.137	.503	.076	.131	.014
			.024	.063			.024
			.117	.460			
			0.021	0.058			
Ailinginae Atoll							
10/23/55	.022	.024			.072	.008	.019
Enibuk	.014	.015			.064	.019	.018
	.015	.018			.007	.005	.011
	.024	.054			0.008	.010	.014
	.014	.018				0.011	0.014
	.015	.026					
	0.017	0.016					

* edible portion
Date of analysis: November 25-26, 1955

APPENDIX E **Table 1. Radioactivity of Algae**

Values expressed in thousands of d/m/g of wet weight

Date and Island	Halimeda	Caulerpa	Lyngbya	Rosen-vingea	Padina	Jania	Entophy-salis	Dictyo-sphaeria
Rongelap Atoll								
10/21/55	0.447	0.559						0.113
Kabelle	.658	.521						.268
lagoon shore	.661	.423						
	.319	.508						
	.320	.461						
Labaredj	.544	.654						
	.330	.984						
	.807	.870						
	.505	.851						
	.596	.712						
Rongelap	.040	.618	0.218					
lagoon shore	.047	.133	.189					
	.034	.201	.181					
	.074		.181					
	.074		.294					
lagoon	.231	0.055	.071	0.100	0.202	0.122		
22 ft. depth	.506		.069	0.104	0.199			
	.216			0.120				
lagoon	.228		.051					
49 ft. depth	.075		.071					
	.177		0.059					
	.084							
	0.196							
cistern							8.86	
							23.6	
							12.8	
well			1.88					
			0.569					
			0.878					

Date of analysis: November 25-26, 1955

APPENDIX E

p. 2 Table 1 (continued)

Values expressed in thousands of d/m/g of wet weight

Date and Island	Halimeda	Caulerpa	Microdictyon
Ailinginae Atoll			
10/23/55	0.059	0.065	
Enibuk	.066	.076	
lagoon shore	.062	.080	
	.149	.068	
	.024	0.074	
lagoon			
in 35 feet of	.092		0.187
water	.106		
	0.076		

Date of analysis: November 25-26, 1955

APPENDIX F

Table 1. Radioactivity of Birds and Bird Eggs

Values expressed in thousands of d/m/g of wet tissue

Date and Island	Species*	Muscle	Liver	Bone
Rongelap Atoll				
10/21/55	fairy tern	0.046	0.14	0.053
Kabelle	" "	.025	0.092	.017
	noddy tern	.041	0.17	.019
Labaredj	fairy tern	.031	0.044	.013
	" "	.098	0.097	.039
	" "	.039	0.17	.038
	" "	.028	0.045	.036
10/22/55	ruddy turnstone	.034	0.020	.022
Rongelap	" "	.18	1.0	.34
	reef heron	.17	1.6	.44
Ailinginae Atoll				
10/23/55	black-naped tern	.10	0.30	.077
Enibuk	" " "	.18	0.47	.110
	fairy tern	.076	0.18	.063
	" "	.046	0.23	.039
	" "	.054	0.083	.009
	" "	.068	0.25	.075
	noddy tern	.10	0.19	.093
	" "	0.051	0.046	0.009

		Egg Shell	Egg contents (yolk + white)
Rongelap Atoll			
10/21/55			
Kabelle	fairy tern	0.028	0.052
Labaredj	" "	0.028	0.013

* Noddy tern, Anous stolidus; fairy tern, Gygis alba; black-naped tern, Sterna sumatrana; ruddy turnstone, Arenaria interpres morinella; reef heron, Demigretta sacra sacra.

Date of analysis: November 17-18, 1955

APPENDIX G

Table 1. Radioactivity of Fractionated Sand Profiles

Values expressed in thousands of d/m/g

Date and Island	Type of sample		Total sample activity	Particle size > 1.651 mm			Particle size .589 to 1.651 mm			Particle size .147 to .589 mm			Particle size .074 to .147 mm			Particle size < .074 mm		
				d/m/g / 10^3	% of sample weight	% of total activity	d/m/g / 10^3	% of sample weight	% of total activity	d/m/g / 10^3	% of sample weight	% of total activity	d/m/g / 10^3	% of sample weight	% of total activity	d/m/g / 10^3	% of sample weight	% of total activity
Rongelap Atoll																		
10/21/55 Kabelle	profile	top inch	5.4	6.6	3.32	4.1	3.0	13.75	7.8	4.0	74.60	56.1	16.	6.69	20.0	39.	1.64	12.1
	in 6'	2nd "	6.1	3.4	1.54	0.8	3.4	14.73	8.3	5.0	76.81	63.3	18.	5.22	15.8	42.	1.70	11.8
	water,	3rd "	6.4	2.3	1.59	0.6	2.4	14.45	5.5	5.1	75.61	61.0	17.	6.07	15.9	48.	2.28	17.0
	in	4th "	5.5	1.2	1.05	0.2	1.9	10.30	3.5	3.6	77.52	50.9	13.	7.87	18.3	45.	3.26	26.9
	lagoon	5th "	4.8	1.6	0.63	0.2	1.6	11.59	3.8	2.8	75.45	44.7	13.	8.64	23.0	36.	3.70	28.4
		6th "	6.3	2.5	0.38	0.15	2.3	10.49	3.8	3.4	76.68	41.2	18.	8.52	23.8	50.	3.93	31.1
		7th "	2.6	0.55	0.43	0.1	0.88	11.93	4.0	1.5	76.77	43.3	7.3	7.58	21.1	25.	3.29	31.5
		8th "	0.10	0.12	1.33	1.5	0.069	13.76	9.3	0.069	76.55	51.8	0.23	6.12	13.8	1.1	2.24	23.7
10/21/55 Kabelle	profile	top inch	5.1	0.0	0.0	0.0	3.5	5.28	3.6	3.4	35.05	23.3	6.2	24.88	30.1	6.3	34.77	43.0
	in 60'	2nd "	4.2	0.84	0.22	0.05	1.6	9.02	3.4	2.8	38.42	26.0	4.9	24.17	28.5	6.2	28.17	42.1
	water,	3rd "	4.9	1.2	0.21	0.05	1.9	5.14	2.0	3.1	33.65	21.7	5.1	25.55	26.8	6.8	35.45	49.4
	in	4th "	3.6	0.50	0.20	0.03	1.8	5.41	2.7	2.1	35.00	20.0	4.1	24.90	27.8	5.2	34.49	49.5
	lagoon	5th "	2.0	0.50	1.00	0.3	0.65	6.76	2.2	1.4	35.14	25.8	1.8	25.14	23.8	2.9	31.95	48.0
10/22/55 Rongelap	profile	top inch	0.74	0.21	5.24	1.5	0.58	37.34	29.0	0.67	53.86	48.4	3.3	2.49	10.1	6.5	1.27	11.1
	in 22'	2nd "	0.94	0.21	4.97	1.1	0.48	32.12	16.6	0.62	57.99	55.1	3.6	2.76	10.6	7.2	2.16	16.7
	water,	3rd "	0.72	0.37	6.66	3.4	0.44	35.16	21.4	0.55	53.11	40.9	3.0	2.59	10.8	6.8	2.49	23.5
	in	4th "	0.80	0.74	6.73	6.2	0.37	36.38	16.8	0.55	50.22	34.8	3.1	3.16	12.3	6.8	3.50	29.8
	lagoon	5th "	0.66	0.18	2.69	0.8	0.30	36.00	16.3	0.46	53.44	37.2	1.9	3.50	9.9	5.4	4.37	35.8
		6th "	0.37	0.14	2.18	0.8	0.14	35.09	13.3	0.37	54.15	54.6	0.12	4.03	1.3	2.4	4.55	30.1
		7th "	0.13	0.046	4.41	1.5	0.023	33.51	5.8	0.14	53.58	56.0	0.42	4.01	12.6	0.72	4.50	24.2
		8th "	0.13	0.16	2.81	3.5	0.046	31.78	11.0	0.12	56.23	49.0	0.28	4.34	9.0	0.76	4.84	27.7
Ailinginae Atoll																		
10/23/55 Enibuk	profile	top inch	0.085	0.092	1.8	2.0	0.092	68.5	73.9	0.069	29.7	24.1	--	--	--	--	--	--
	low	2nd "	0.059	0.023	1.0	0.3	0.46	86.5	65.4	0.16	12.5	34.2	--	--	--	--	--	--
	tide	3rd "	0.16	0.092	4.6	2.7	0.16	86.9	89.7	0.14	8.6	7.6	--	--	--	--	--	--
	line,	4th "	0.031	0.023	16.1	12.1	0.023	79.7	59.6	0.21	4.2	28.3	--	--	--	--	--	--
	lagoon	5th "	0.071	0.046	17.1	11.1	0.069	75.8	73.5	0.11	6.9	11.2	0.99	0.3	4.2	--	--	--
	side	6th "	0.039	0.069	0.9	1.5	0.0	73.3	0.0	0.16	23.4	97.7	0.37	0.07	0.8	--	--	--
		7th "	0.088	0.069	2.7	2.2	0.092	83.9	87.4	0.069	13.4	10.4	--	--	--	--	--	--
		8th "	0.018	0.0	0.0	0.0	0.023	56.2	73.7	0.0	43.8	0.0	0.92	0.05	26.3	--	--	--

APPENDIX G

Table 2. Radioactivity of Unfractionated Sand Profiles

Values expressed in thousands of d/m/g

Date and Island	Type of Sample		Total Activity
Rongelap Atoll			
10/22/55	low tide	top inch	0.18
Rongelap	line, lagoon	2nd "	0.14
	side	3rd "	0.21
		4th "	0.28
		5th "	0.25
		6th "	0.18
		7th "	0.0
	49 feet	top inch	0.51
	water,	2nd "	0.58
	lagoon	3rd "	0.53
		4th "	0.58
		5th "	0.18
		6th "	0.092
		7th "	0.14
		8th "	0.14
Ailinginae Atoll			
10/23/55	35 feet	top inch	0.28
Enibuk	water,	2nd "	0.092
	lagoon	3rd "	0.16
		4th "	1.2
		5th "	1.3
		6th "	0.30
		7th "	0.42
		8th "	0.18

APPENDIX G

Table 3. Radioactivity of Soils and Sand

Values expressed in thousands of d/m/g

Date and Island	Area	Sample Depth	Total Activity
Rongelap Atoll			
10/21/55 Kabelle	soil - 200 yards from lagoon near mid-island, open area	top 3 inches 3-6 "	15.8 0.762
	soil near above sample, level grassy area	top 3 inches 3-6 "	23.0 0.416
	lagoon sand from 6 feet of water		1.83
Labaredj	soil - SW part of island 100 yards in from lagoon, open area	top 3 inches 3-6 "	9.59 0.554
	near above sample under a tree	top 3 inches 3-6 "	25.3 0.231
10/22/55 Rongelap	10 feet west of well, near village, level grassy area	top 3 inches 3-6 "	3.67 0.808
	under papaya trees near schoolhouse, rocky soil	top 3 inches 3-6 "	44.6 1.46
	sand from anchor chain, 2 miles off Rongelap Island, in lagoon at depth of 150 feet		1.64
	sand from bottom of well, water depth 16 inches		7.346
Ailinginae Atoll			
10/23/55 Enibuk	soil		2.54
Mogiri	sand from anchor off Mogiri Island, in lagoon at depth of 150 feet		0.739

APPENDIX H **Table 1. Radiocerium-Praseodymium in Biological Samples from Rongelap Atoll December 1954-January 1955.**

Island	Organism	Total Activity: In sample d/m*	Total Activity: Per gram wet sample d/m	Ce^{144}-Pr^{144}: Per sample net c/m**	Ce^{144}-Pr^{144}: Per sample d/m***	Ce^{144}-Pr^{144}: Per gram wet sample d/m	Percent
Rongelap Atoll							
Gejen	#31 coconut milk	27,000	270	-2	0	0	
	" "			9	0	0	0
Kabelle	#37 Caulerpa	21,000	700	8,300	15,000	500	
	"			8,200	15,000	500	71
	#30 coconut milk	9,900	99	-3	0	0	
	" "			3	0	0	0
	#39 coconut crab muscle	28,000	1,100	160	280	11	
					280	11	1.0
	#41 mullet muscle	7,200	296	61	100	4.1	
				64	110	4.5	1.5
	#38 Halimeda	15,000	3,000	2,300	4,200	840	
	"			2,200	4,000	800	28
Labaredj	#29 coconut milk	4,100	41	-7	0	0	
	" "			1	0	0	0
	#42 tern bone	500	130	56	140	37	28
	#43 tern bone	500	130	54	130	34	26
Mellu	#40 dogtooth tuna muscle	3,200	22	12	21	0.14	0.6
Rongelap	#27 coconut meat	4,700	59	9	15	0.19	<0.4
	#28 coconut milk	4,900	49	6	9.8	0.98	<0.2
	#32 pandanus fruit	18,000	200	61	100	1.1	
	" "			87	150	1.7	0.7
	#34 papaya meat	7,000	160	150	270	6.1	
	" "			140	260	5.8	3.7
	#33 squash meat	37,000	320	240	410	3.6	
	" "			270	460	4.0	1.0

* One gram of ashed sample used except for #43 for which 0.3 gram was used.

** Average values for blank determinations were 16, 23, and 25. Radiochemical yield factor 73 to 76 percent.

*** Date of analysis: July-August, 1955. Values corrected to October 1955, except #42 and #43 which are corrected to July 1955.

APPENDIX H **Table 2. Radiocesium in Biological Samples from Rongelap Atoll, December 1954-January 1955.**

Island	Organism	Total activity: In sample d/m*	Total activity: Per gram wet sample d/m	Cs^{137}: Per sample net c/m**	Cs^{137}: Per sample d/m	Cs^{137}: Per gram wet sample d/m***	Percent
Rongelap Atoll							
Gejen	#31 coconut milk	27,000	270	9,000	22,000	220	81
Kabelle	#37 *Caulerpa*	21,000	700	1	0	0	
				6	0	0	0
	#30 coconut milk	9,900	99	3,100	7,400	74	
				2,800	6,800	68	72
	#38 *Halimeda*	15,000	3,000	0	0	0	
				1	0	0	0
	#39 coconut crab	6,400	1,100	1,700	4,100	690	
	muscle	6,000		1,700	4,200	740	67
	#41 mullet muscle	7,200	300	6	0	0	
		7,200		7	0	0	0
Labaredj	#29 coconut milk	4,100	41	920	2,700	27	
				1,200	3,500	35	76
	#42 tern bone	500	130	2	0	0	0
	#43 tern bone	500	130	6	0	0	0
Mellu	#40 dogtooth tuna	3,200	22	61	150	0	
	muscle			68	160	0	4.8
Rongelap	#27 coconut meat	4,700	59	480	1,400	18	
				330	1,000	12	26
	#28 coconut milk	4,900	49	1,600			
					3,800	38	78
	#32 pandanus fruit	18,000	200	6,400	19,000	210	
				6,800	20,000	220	110
	#34 papaya meat	7,000	160	2,000	4,900	110	
				1,900	4,700	100	68
	#33 squash meat	37,000	320	7,900			
					19,000	170	51

* One gram of ashed sample used except for #43 for which 0.3 gram was used, and #39 for which 0.2 gram was used.
** Radiochemical yield factor 53 to 64 percent.
*** Date of analysis: September-October 1955.