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A RADIOLOGICAL STUDY OF RONGELAP ATOLL, MARSHALL ISLANDS, DURING 1954-1955

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ABSTRACT

The detonation of shot one at Bikini Atoll on March 1, 1954, produced a fallout of radioactive ash upon Rongelap Atoll, Marshall Islands. The distribution of the radioactive ash on the islands and in the plants and animals of the area has been studied and evaluated by the Applied Fisheries Laboratory, University of Washington.

During the first expedition to Rongelap Atoll on March 26, 1954, biological samples were collected and measurements made of the radiation contamination. On three additional expeditions extensive collections of material were made for this study, the last on January 25-30, 1955.

The decline in radioactivity was measured in 1499 samples of fish, invertebrates, land plants, algae, birds, plankton, soil and water from the Rongelap area.

During this study particular emphasis was placed upon evaluation of the radioactivity in food used by the natives. Coconut milk collected on March 26, 1954, contained 1.03 microcuries per kilogram of wet tissue while the coconut meat had 1.16 uc/k. By January 25-30, 1955, the level in coconut milk had declined to 0.041 uc/k and the meat to 0.036 uc/k. Fish muscle on March 26, 1954, averaged 2.74 uc/k and fish liver 204. uc/k. The decline to January 25-30 was 0.10 uc/k for the muscle and 3.52 uc/k for the liver of fish. Somewhat similar declines were found for clam muscle, crab muscle, bird muscle and liver, and for squash,

papaya, arrowroot and pandanus.

The level of radioactivity was highest in the northern portion of the atoll, except for samples of algae and fish-eating birds, collected during January 1955 from the southern part of the atoll, which had higher levels of radioactivity than samples collected from the northern islands on the same date. This may indicate a translocation of radioactive materials within the lagoon.

A RADIOLOGICAL STUDY OF RONGELAP ATOLL, MARSHALL ISLANDS DURING 1954 - 1955

Introduction

The program of study of the Applied Fisheries Laboratory, University of Washington, (Program 19.1 of Operation Castle) was outlined in the Laboratory's report UWFL-36. This program involved detailed studies of radiological contamination of the fauna and flora of Eniwetok Atoll, with exploratory trips to Bikini Atoll on a quarterly basis to ascertain the levels of radiation remaining during the year following the test program.

The unexpected pattern and magnitude of the fallout of radioactive materials from the March 1, 1954 experiment introduced the need for new areas of study over and above the planned program. One such area was Rongelap Atoll where the fallout caused the evacuation of the native people.

On March 21, 1954, the Laboratory received a request from Dr. Paul B. Pearson, AEC Division of Biology and Medicine, to make a survey of the islands in Rongelap Atoll to determine the extent of radiological contamination of the native foods.

The expedition to Rongelap, in response to this request, was organized by Task Group 7.1, with transportation and support provided by the USS Nicholas (D.D.E.449). Members of Program 19.1 were Lauren R. Donaldson, Major Charles Barnes, Edward Held, Ralph Palumbo and Paul Olson. Dr. Thomas Shipman, Dr. Thomas N. White, P. R. Schivone and W. W. Robbins accompanied the expedition to aid the natives in capturing some of their animals on Rongelap Island and to make radiation readings on some of the

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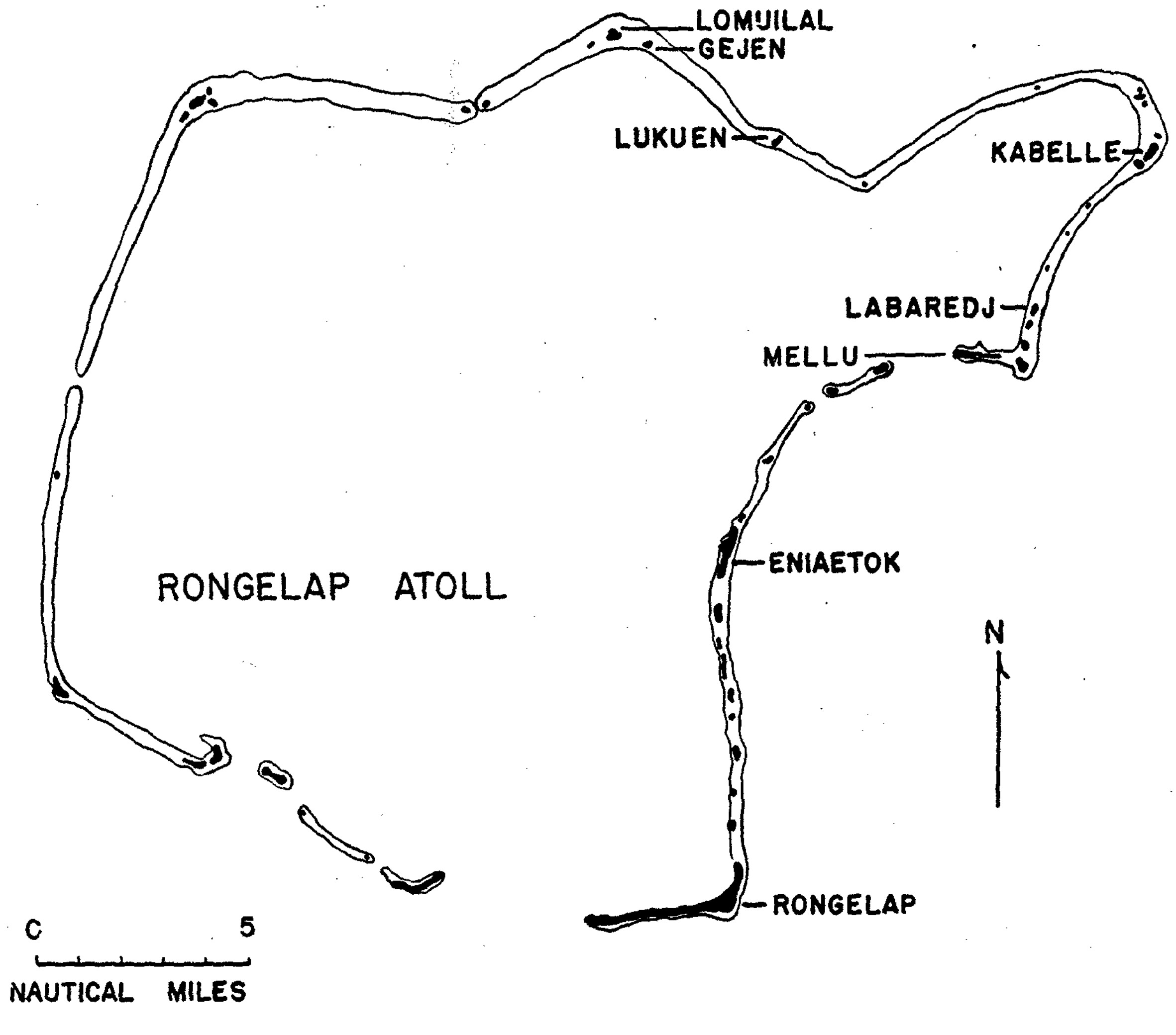

FIG. I COLLECTING AREAS AT RONGELAP ATOLL

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islands in the southern part of the atoll.

Collections of plants and animals, soil samples and radiation readings were made at Labaredj Island on March 26, 1954. Radiation readings were obtained with a Juno (AEC model SIC-17C, serial No. 89) under a variety of conditions. The shield of the instrument was closed for the first reading and open for the second for each of the locations listed below.

Radiation Levels Labaredj Island

March 26, 1954 - mr/hr

Location	Height 3'	Height 1"
Intertidal zone	26 31	
High tide line	215 395	300 1000
Open grass area on island	250 330	370 900
Open grass area on island	240 500	280 (6") 700 (6")
In Pisonia woods	270 700	600 1500
Beach rock slabs	37 100	29 400
Beach above high tide line north side of island	180 300	220 600
East side of island above high tide line	200 350	220 700

A second series of collections were made on the same day at Kabelle Island in the extreme northeastern part of the lagoon. Radiation readings were also taken at this island as follows:

Radiation Levels Kabelle Island

March 26, 1954 - mr/hr

Location	Height 3'	Height 1"
Beach rock inter-tidal zone	48 90	30 300
Beach sand at high tideline	190 260	150 350
Edge of brush line on island lagoon side	280 500	370 1400
Open area in vegetation-covered portion of island	300 600	410 1700
Coconut grove on lagoon side of island	250 370	480 1500
Edge of trees	(shield open)	2000
Lee side of trees	"	1500
Windward side of trees	"	2800

The second expedition to Rongelap Atoll was made on July 16, 1954. A U.S. Navy Grumman Albatross plane (U.S.N. ASR-16, No. 902) from the U.S. Naval Station, Kwajalein, was used to transport the group to the atoll. Program 19.1 members making the trip were Lauren R. Donaldson, Frank Lowman, Arthur Welander and Lt. Cmdr. Clarence F. Pautzke.

Collections were again made at Kabelle Island and radiation readings taken in the same general areas as those recorded on March 26, 1954.

Radiation Levels Kabelle Island

July 16, 1954 - mr/hr

Location	Height 3'	Height 1"
Low water line	9	15
High tide mark on beach	20	70
50' inshore from high tide line	29	100
100' inshore from high tide line	28	100
On *Scaevola* brush	28	100
Under *Messerschmidia*	30	100
Lee edge of coconut grove	20	80
Middle of island in dead brush	25	90
Open clearing in middle of island	27	45
Middle of coconut grove	20	60

During the month of December 1954 three collections of samples were made at Rongelap Atoll. For the first trip on December 8, the U.S. Naval Station, Kwajalein, provided a PBM (No. 2471) with a fine crew. Landings were made at both Kabelle and Rongelap Islands. Dr. Walter D. Claus, AEC Division of Biology and Medicine, accompanied Edward Held, Paul Olson, John Taylor and William Blakeman on this expedition. Film strips were placed at a number of locations by Claus, Taylor and Blakeman to record radiation over an interval of time.

On December 18, the Navy again furnished a PBM for the trip to Rongelap to pick up the film strips and to collect additional biological samples. A successful landing was made at Rongelap Island where the objective was accomplished. An accident to the anchoring mechanism of the plane, however, prevented completion of the sampling at Kabelle Island. Robert Rinehart and Paul Zigman of U.S.N.R.D.L. accompanied Lauren R. Donaldson, Jared Davis, Edward Held and Paul Olson on this trip.

The most extensive survey and biological collecting trip was conducted at Rongelap Atoll from January 25 to January 30, 1955. This survey was made in conjunction with U.S.N.R.D.L., with the U.S. Navy furnishing the OG vessel "Rio Grande" for transportation and support facilities. Allyn H. Seymour and Frank Lowman, Program 19.1, shared the responsibility for the biological sampling. Readings were again made with the survey meter on most of the islands visited. The readings were taken at a height of three feet unless otherwise noted.

Radiation Levels Rongelap Atoll

January 25-30, 1955 - mr/hr

Rongelap Island	0.5
Eniaetok Island	2.0
Busch Island	1.5
Labaredj Island	2.5
Kabelle Island	3.0
" "	5.0 at ground level
Lomuilal Island	8.0
Gejen Island	7.0
Lukuen Island	4.0

The collections at Rongelap Atoll during this period of study provided material for 1499 samples which have been processed, the radioactive content determined and the results tabulated and evaluated.

Sample Processing Procedures and Techniques

The techniques and procedures used in collecting, storing, preparing, and counting the Rongelap samples were similar to those used in former years. For complete details see WT-616 (UWFL-33).* The specimens were put on ice while in the field. Tissues were dissected, weighed and dried at the Eniwetok laboratory. At the University of Washington, the dried samples were ashed at temperatures up to 540°C, cooled, slurried, dried, and then counted in an internal gas-flow counting chamber. Counts per plate were converted to disintegrations per minute per gram of wet tissue as of the date of collection by correcting for sample weight, geometry, backscatter, self-absorption, coincidence, and decay.

For 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 by

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

Radioactivity and Its Rate of Decline in Food Items

A general survey of the radioactivity of foods is given in Table I, with the rate of decline** of these items shown in Figure 2. It should be noted that the differences due to species and

* Radiobiological Studies at Eniwetok Before and After Mike Shot - Lauren R. Donaldson, Applied Fisheries Laboratory, University of Washington, Seattle, Washington, November 1952.

** The rate of decline is a phrase coined to express the combined physical decay and the biological uptake and decay rates.

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Rongelap Atoll, 1954-55

Values expressed in microcuries per kilogram of wet tissue

Date and Island	Coconuts Milk	Coconuts Meat	Misc. 1/	Fish Muscle	Fish Liver	Clams Muscle-Mantle	Crabs Muscle	Birds Muscle	Birds Liver
3/26/54 Kabelle, Labaredj	1.03	1.16	11.3	2.74	204.	43.5	70.0	5.38	25.4
7/16/54 Kabelle	.049	.123		.423	24.0	2.14	2.39	.576	3.23
12/8 or 18/54 Kabelle, Rongelap	.019	.048	.021	.066	2.05			.040	.213
1/26-30/55 2/	.041	.036	.049	.100	3.52	1.03	.498	.129	.418

1/ edible portions of squash, papaya, arrowroot, pandanus, spinach.

2/ Rongelap, Eniaetok, Labaredj, Kabelle, Gejen, Lomuilal, Lukuen

Table II. Coefficient of Variation in Per Cent 1/ for Values in Table I

Date	Coconuts Milk	Coconuts Meat	Misc.	Fish Muscle	Fish Liver	Clams Muscle-Mantle	Crabs Muscle	Birds Muscle	Birds Liver
3/26/54	42(4) 2/	--(1)	--(1)	65(12)	119(12)	36(4)	79(3)	41(5)	38(5)
7/16/54	10(2)	13(3)		73(20)	65(20)	54(2)	35(5)	75(7)	48(7)
12/8 or 18/54	37(5)	57(5)	23(8)	48(3)	30(3)			27(4)	37(4)
1/26-30/55	61(18)	76(16)	88(16)	68(81)	97(81)	115(4)	178(11)	99(13)	95(13)

1/ C in % = (standard deviation ÷ mean) (100)

2/ number of samples

area, which are considerable and which are evident in the tables of the appendix where all the individual sample counts are tabulated, are not apparent in this generalization. The significance of these differences, however, is discussed on pages 9 to 21. From Table I and Figure 2 the past, present, and future gross radioactivity in the principal food items of Rongelap Atoll can be approximated.

The method selected to indicate the error in estimating the values in Table I is the "coefficient of variation" which is the ratio of the standard deviation to the mean. These values, C, expressed in percent, are given in Table II (page 6a). The range in values from 10 percent to 178 percent indicates a high degree of variability.

These data are closest to being points on a straight line when plotted on a log-log scale using the time of the blast, March 1, 1954, as time of origin.

From these data it appears that mixed fission products are the principal source of radioactivity in the food stuffs. Exceptions are bird thyroids, in which the radioactivity was practically all I^{131}, and the gastric mill in a coconut crab, for which the decay curve was nearly a straight line on a semi-log plot. For the purpose of making an approximation of the average rate of decline, the slope of a least-squares line through the averages of the points in Figure 2 was determined and found to be -1.75.

The variation in radioactivity associated with area, in most instances, is related to fallout. Rongelap Atoll was on the southern edge of the fallout from the March 1, 1954 Bikini experiment and as a consequence there was considerably more radioactivity in the northern part of that area. The biological samples show the same pattern except for the bird collections and the algae and sand samples from deep waters of the lagoon, taken during January 1955.

Evaluation of Radioactivity in the Biological Samples

Fish

Most of the fish specimens, as in former years, were collected by poisoning with derris root in shallow waters on or near the reefs. Some specimens were caught in the deeper waters of the lagoon with hook and line. Two flying fish were obtained outside the atoll when they landed aboard ship during the night.

The species selected for analysis are those commonly found on the atolls and used for food. They include damsel fish, groupers, parrot fish, squirrel fish, surgeon fish, goatfish, wrasse, snappers, mullet and tuna. The scientific names of the species are given in the appendix.

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 the alimentary canal, in most cases.

In an attempt to compare similar species from the same locality analysis was limited to the samples from Kabelle Island. Collections of fish were made in waters adjacent to this island on March 26, 1954, July 16, 1954, and January 29, 1955. The collecting area lies near the north end of the island and consists of a coral-filled channel open to the sea at high tide. The radioactivity of the tissues from the fish collected at Kabelle is summarized in Figure 3. The data are listed in Table III.

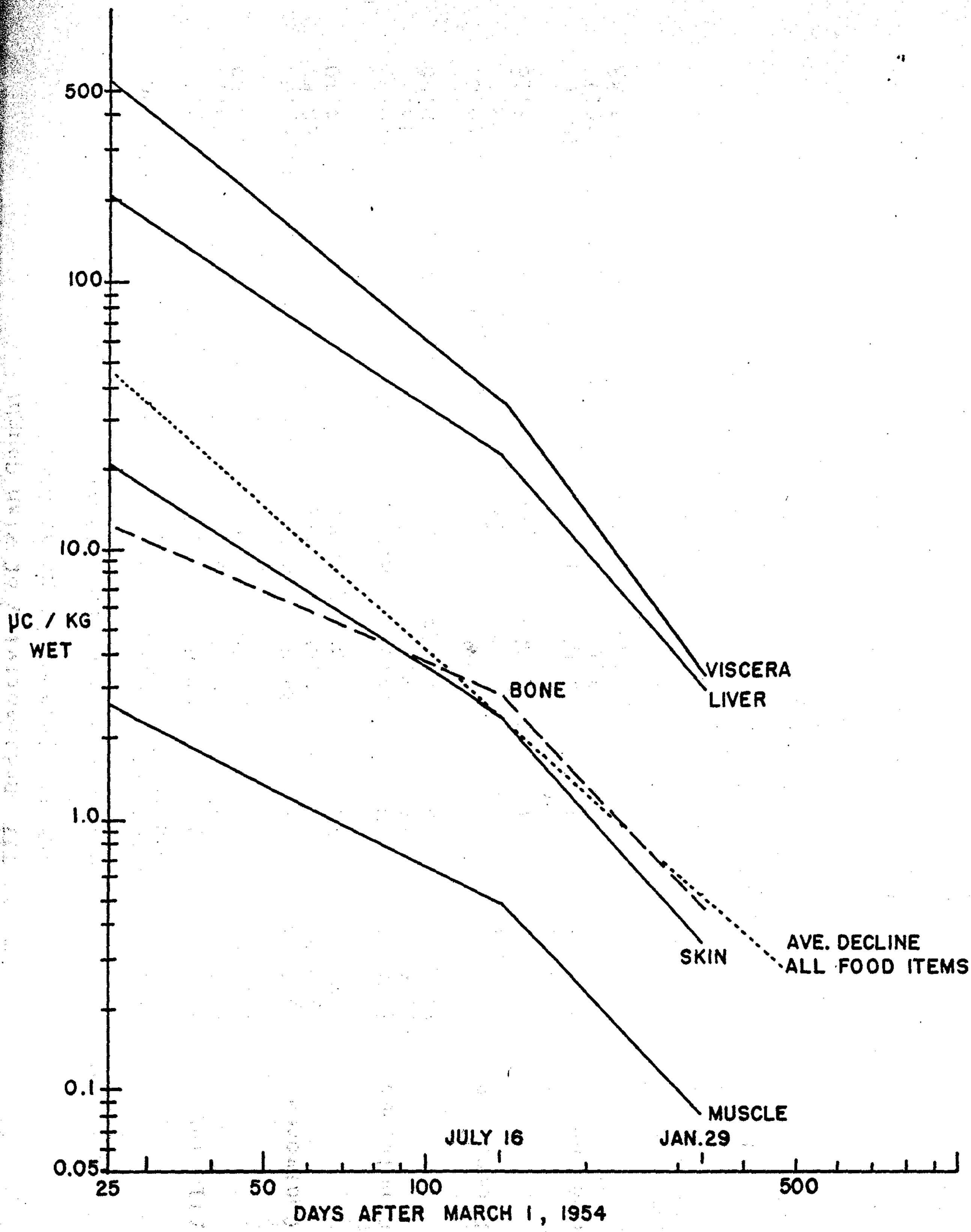

FIG. 3 AVERAGE AMOUNTS OF RADIOACTIVITY IN MICROCURIES PER KILOGRAM IN FISH TISSUES FROM KABELLE ISLAND 1954 — 1955

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Table III. Radioactivity of Fish Caught at Kabelle Island, Rongelap Atoll

Values expressed in microcuries per kilogram of wet tissue

	Date	Number of Specimens	Skin	Muscle	Bone	Liver	Viscera
All fish	3/26/54	12	20.8	2.74	12.8	204.0	514.0
	7/16/54	32	2.46	0.50	2.92	22.4	35.7
	1/29/55	27	.359	.083	.491	3.18	3.59
Omnivores	3/26/54	4	34.5	4.54	24.7	439.0	1,345.0
	7/16/54	15	2.95	.650	2.95	22.2	60.4
	1/29/55	18	.330	.082	.486	2.55	4.10
Carnivores	3/26/54	8	14.8	2.01	7.95	103.0	110.0
	7/16/54	17	2.03	.370	2.90	22.7	13.9
	1/29/55	9	.414	.085	.500	4.42	2.56
Damsel fish	3/26/54	2	21.4	3.45	9.45	614.0	1,700.0
	7/16/54	2	2.74	.256	2.30	44.4	38.4
	1/29/55	4	.545	.085	.426	4.24	3.18
Grouper	3/26/54	3	7.54	1.42	3.37	38.5	101.0
	7/16/54	6	1.47	.309	1.50	16.4	11.7
	1/29/55	5	.303	.051	.288	5.23	1.43

These data substantiate the general hypothesis, mentioned earlier in this report, that the radioactivity in the tissues appears to be due principally to mixed fission products. Deviations from a straight line in the curves might be due to selective uptake, either by the tissues themselves or because there was selective uptake in the animals used as food by the fishes. In general the slope of the curves compares favorably with the average decline curve used for all food items discussed at the beginning of this report.

Differences between the omnivorous and carnivorous fishes as to amounts of radioactivity in comparable tissues were greatest on March 26, 1954. These differences decreased with passage of time and by January 29, 1955, were negligible in some tissues (Figure 4, Table III). These same data when analyzed by definite species of omnivorous fish (damsel fish) and carnivorous fish (grouper) show the same trends (Table III).

Variation in radioactivity, associated with area and related to fallout and current movements within and around the atoll, indicates an increase in the contamination of the atoll from south to north (Figure 5, Table IV). The lagoon fish taken in the northern part of the lagoon, off Kabelle or Mellu Island, are comparable in levels of radioactivity to reef fishes taken in this region. The two flying fish taken outside the atoll are remarkably alike in tissue radioactivity.

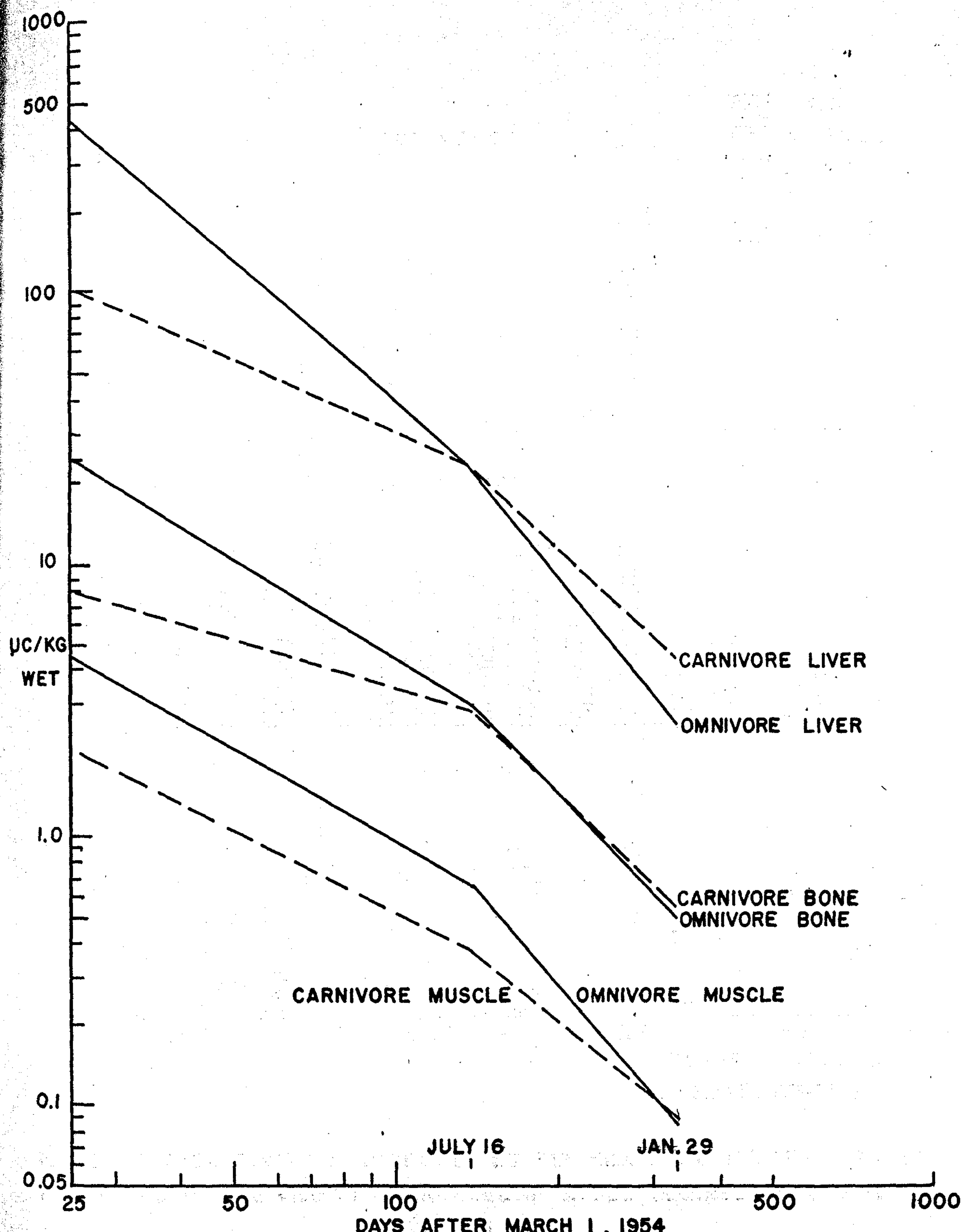

FIG. 4 AVERAGE AMOUNTS OF RADIOACTIVITY IN MICROCURIES PER KILOGRAM IN LIVER, BONE AND MUSCLE TISSUE OF CARNIVOROUS AND OMNIVOROUS FISHES FROM KABELLE ISLAND 1954– 1955

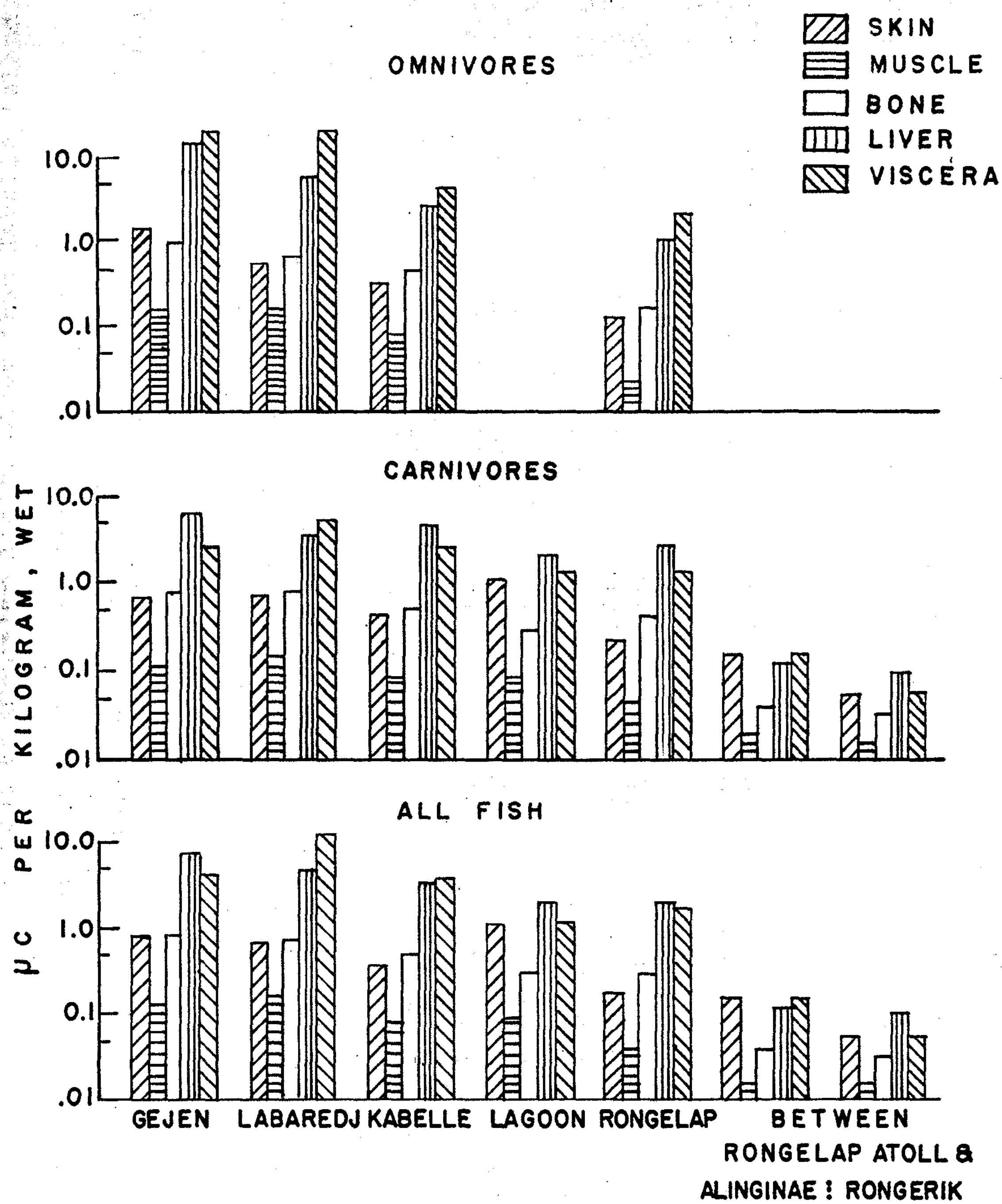

FIG. 5 RADIOACTIVITY IN MICROCURIES PER KILOGRAM IN FISH TISSUES COLLECTED IN THE VICINTY OF RONGELAP ATOLL, DECEMBER 1954 AND JANUARY 1955

Table IV. Radioactivity in Fish
Caught at Rongelap Atoll, other than Kabelle Island

Values expressed in microcuries per kilogram of wet tissue

Date and Area		Number of Specimens	Skin	Muscle	Bone	Liver	Viscera
1/30/55 Between Rongelap and Rongerik Atolls	Flying fish	1	.050	.017	.031	.094	.052
2/1/55 Between Rongelap and Ailinginae Atolls	Flying fish	1	.152	.014	.035	.110	.145
1/25/55 Rongelap Island	Omnivores	10	.124	.022	.184	1.02	2.07
	Carnivores	12	.235	.045	.390	2.74	1.20
	All fish	22	.185	.034	.296	1.95	1.60
1/28/55 Labaredj Island	Omnivores	23	.577	.159	.682	5.36	17.00
	Carnivores	11	.741	.153	.782	3.31	5.36
	All fish	34	.632	.157	.718	4.64	12.90
1/30/55 Gejen Island	Omnivores	1	1.56	.159	1.09	12.4	17.1
	Carnivores	8	.709	.125	.804	6.18	2.75
	All fish	9	.804	.129	.836	6.86	4.34
December, 1954 and January, 1955 Lagoon Fish Combined	Carnivores	10	1.11	.081	.278	2.06	1.20

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Invertebrates

Rongelap invertebrates showed levels of activity of from 10^2 to 10^4 uc/kg on March 26, 1954. By late January 1955 the levels had dropped about two orders of magnitude. The almost ubiquitous black sea cucumber, Holothuria atra, serves best to exemplify the trend (Figure 6). Next best as indicators were giant clams, Hippopus and Tridacna; land hermit crab, Coenobita; coconut crab, Birgus; corals; and spider snail, Pterocera. Radioactivity was highest in the digestive and excretory organs, intermediate in the integumentary organs, and lowest in the muscle. Actual values for the samples are tabulated in the appendix. The kidney of the giant clam (Figure 7) is of special interest because of its high level of activity and slow rate of decline. A graph of activity of the tissues of land hermit crabs collected at the more radioactive northern islands in March and July 1954 and from a less radioactive southern island in January 1955, shows the effect of geographical differences in radioactivity upon the trend of decline, accentuating the slope in the later period (Figure 8). The spider snail was similar to the hermit crab in the level of activity of its tissues, while the corals were about an order of magnitude lower.

Land Plants and Algae

Land plant and algae collections were made at Labaredj, Kabelle, Lomuilal, Gejen, and Rongelap Islands. Most of the edible plants were collected in December 1954 and January 1955 at Rongelap Island. These were coconut, squash, papaya, arrow-

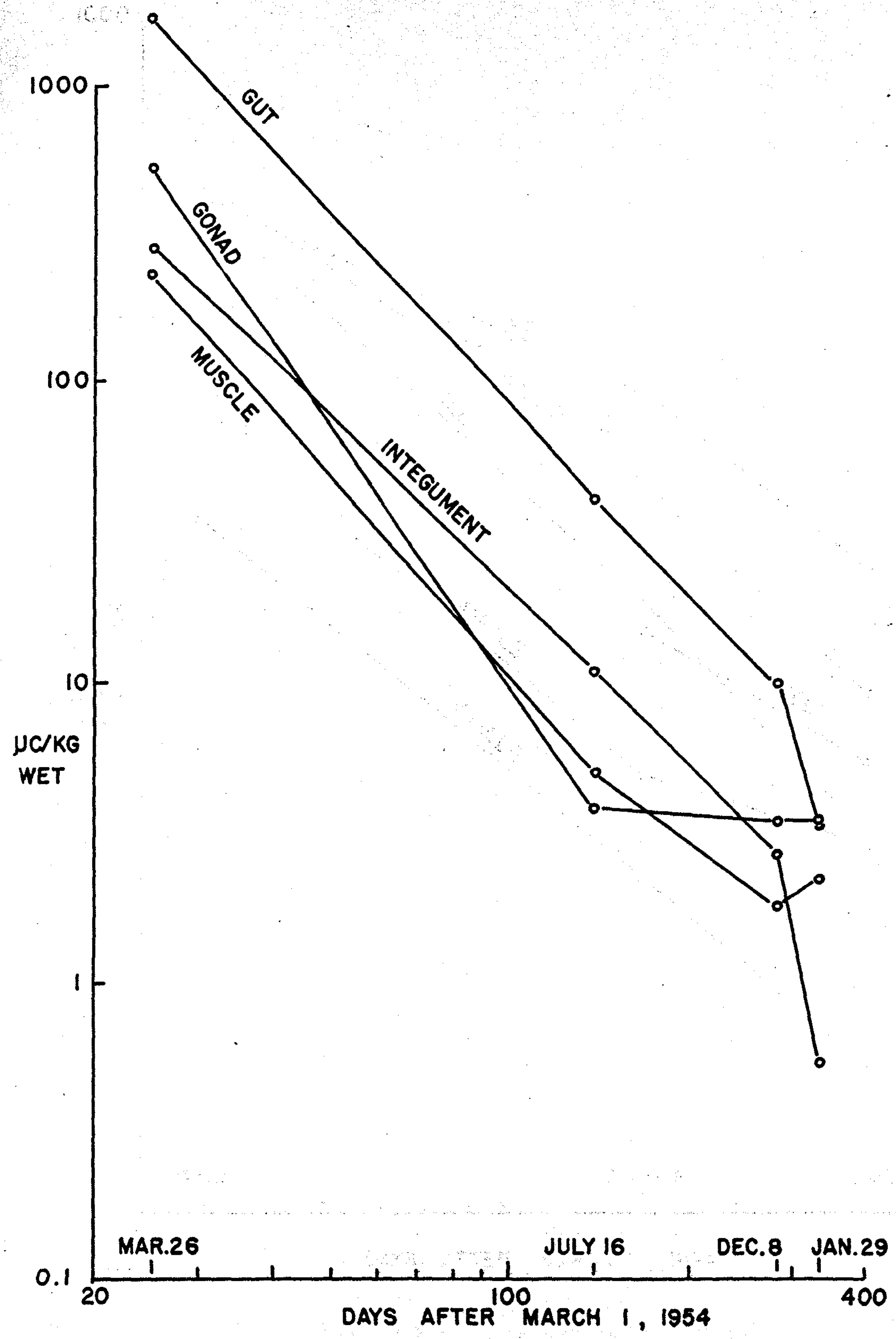

FIG. 6 RADIOACTIVITY IN SEA CUCUMBER (HOLOTHURIA ATRA) TISSUES FROM KABELLE ISLAND 1954 — 1955

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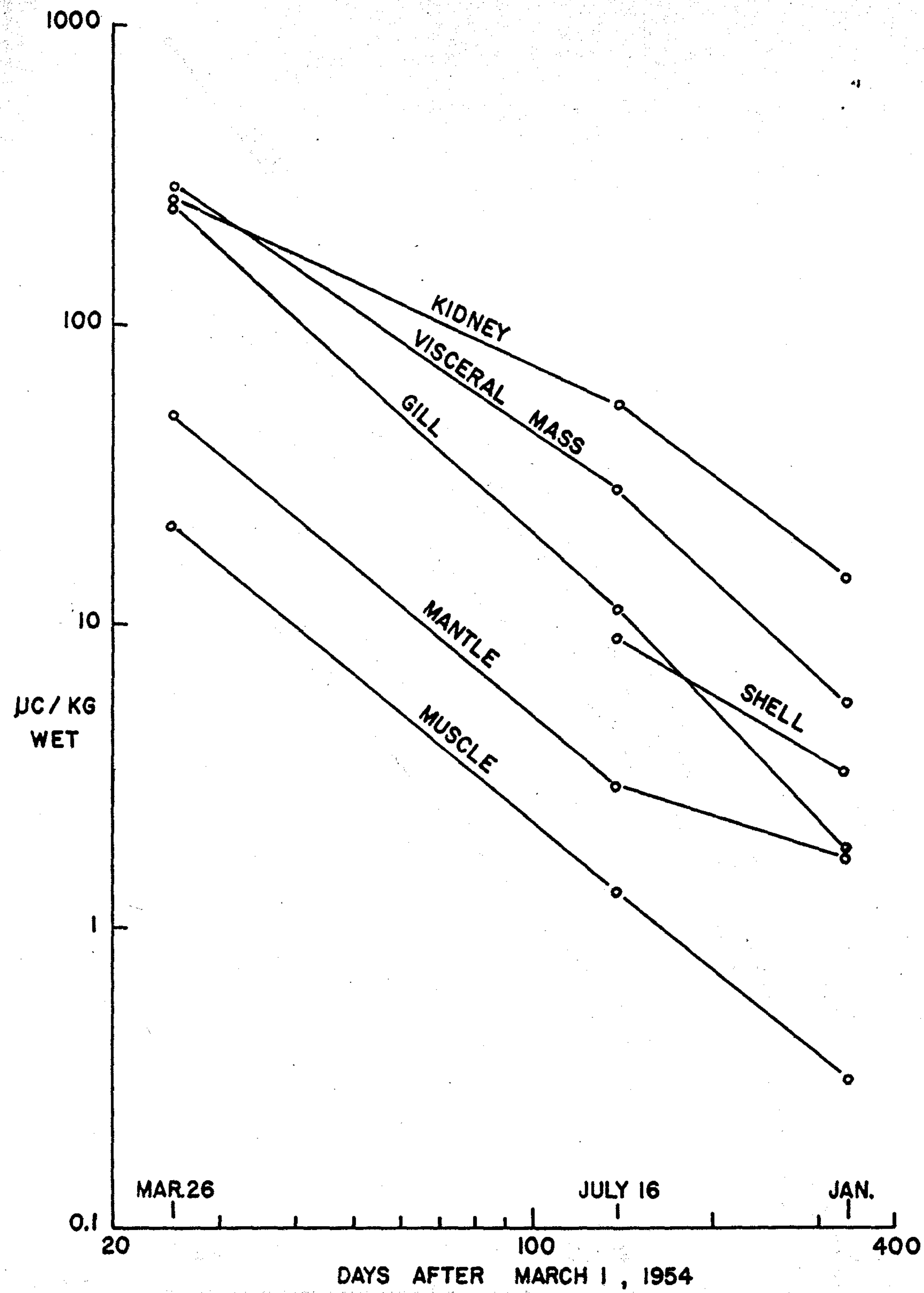

FIG. 7 RADIOACTIVITY IN GIANT CLAM TISSUES : HIPPOPUS ON MARCH 26, 1954 AT KABELLE ; TRIDACNA ON JULY 16, 1954 AT KABELLE, ON JANUARY 28, 1955 AT LABAREDJ AND ON JANUARY 30, 1955 AT GEJEN

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root, pandanus, spinach, and Morinda. The algae were collected both in the shallow water near shore and in the deeper water of the lagoon, usually in the vicinity of the fish-collecting stations.

Sample values are given in Appendix Tables IV, V, VI and VII. From these tables it can be seen that the activity varies widely even within samples of the same kind. In January, for example, the pulp from one papaya had an activity of 8.6×10^{-7} uc/g (wet), the highest level found in any edible plant portion on that date, while the pulp from a second papaya specimen had an activity of 1.3×10^{-7} uc/g (wet).

In both edible and non-edible plants the specific activity was higher in the leaves than in the fruit, the difference generally being two to eightfold. Much of the activity in the March 1954 plant samples was probably due to surface contamination. High counts in the internal portions of stems, however, indicated rapid uptake of fission products by absorption through the root systems. Later collections also indicate uptake of fission product material within the leaf tissue. For example, leaf buds formed after the initial fallout contain as much activity as do older leaves, and washing removes very little of the activity.

In the earliest collections the bark of shrubs and trees and the epidermis of edible plant parts contained from 1½ to 40 times more activity than the internal parts. In the later collections, however, this ratio was always less than two. It is not definitely known, however, whether differential uptake or residual surface contamination accounts for the higher activity of the external plant parts.

Levels of activity in successive collections through and including December 1954 drop in accordance with the expectation for mixed fission products. The January 1955 land plant collections, however, show a trend toward increasing activity levels (Figure 9). This could be due to a sampling error, but might also be a reflection of greater availability of the fission products to the plants associated with more rainfall during late December to January.

The values for arrowroot collected on Rongelap Island in January 1955 fell within the range of values for arrowroot from the northern islands. The same is true of algae collected at depths of 10 to 25 fathoms in the vicinity of Kabelle and Rongelap Islands. However, the maximum activity levels found in Halimeda sp. and Caulerpa sp. from Rongelap are higher by a factor of about two than the maximum levels found in the same species collected at Kabelle. It appears likely then that although maximum fallout occurred at the north end of the atoll, the radioactive material is being redistributed throughout the atoll, at least in the deeper waters.

Decay rates of five individual samples of algae and land plants collected in July and December 1954 indicate half-lives ranging from 160 - 210 days during the period from December 1954 to April 1955. A sample of coconut milk collected at Kabelle Island in December 1954, however, shows a half-life of approximately three years. The slopes of the decay curves of land and

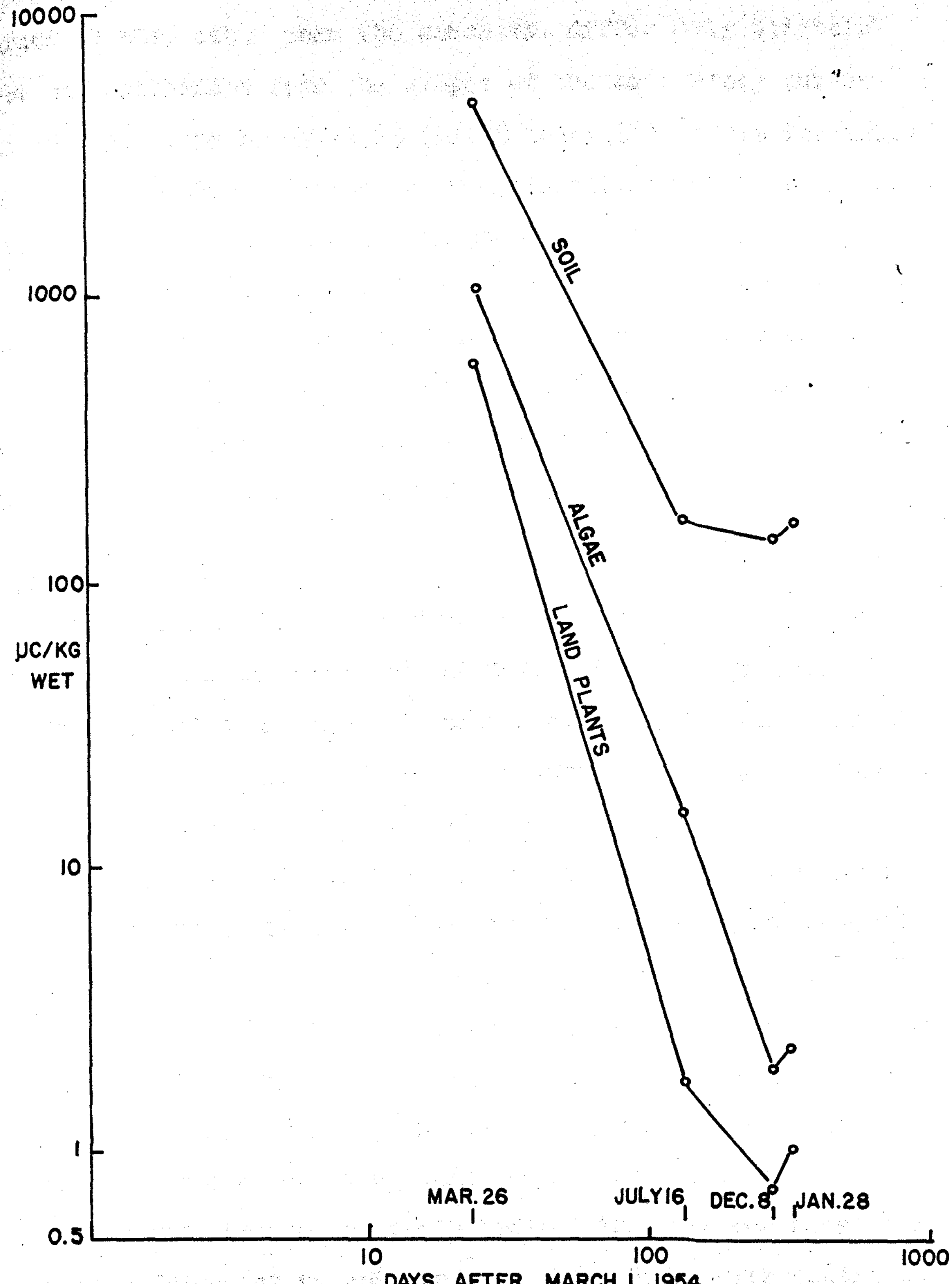

FIG. 9 RATE OF DECLINE IN LAND PLANTS, ALGAE AND SOIL SAMPLES AT KABELLE 1954 — 1955

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marine plants, other than the coconuts, differ only slightly from one another and from the slopes of the soil decay curves, the average slope being -1.25 (-1.05 to -1.36). This indicates that in these plants little or no differential uptake of fission product material has been taking place. In coconuts, however, fission products mixtures with longer half lives have been absorbed into the meat and milk fractions. Decay curve slopes of -.96 and -.54 for the coconut meat and -.24 from the coconut milk indicate a different isotope mixture from that found in soil collected in the same area.

Birds

Birds were collected at four islands of the atoll. Specimens from the northern islands of Gejen, Kabelle and Labaredj were considered to be from the same area and were collected on all four dates, while those from the southern island of Rongelap were taken only on January 26, 1955.

The birds are of two types as based on feeding habits and migratory characteristics. These are: (1) the noddy, crested and fairy terns, which tend to stay in the vicinity of a few islands within the atoll and feed principally on small fish, and (2) the migratory shore birds, which are transients and feed mainly on crustaceans along the beaches. The latter group includes the plovers, curlews, turnstones, and tattlers.

The terns, because of their limited tendency for migration, are more representative than are the shore birds with regard to chronic uptake of radioactive material.

The shore birds contained greater amounts of radioactive materials in the different organs and tissues shortly after the fallout at Rongelap than did the terns. A similar tendency was noted in 1952 at Eniwetok following Mike shot (see WT-616 (UWFL-33)).* However, the average levels of activity in the organs of the shore birds decreased more rapidly with increasing time after fallout than did those of the terns. These differences may be accounted for, in part at least, by the differences in feeding habits and migrational characteristics.

The average specific activities of the organs and tissues of Rongelap terns are given in Table V. With the exception of muscle, which is consistently low compared with the other tissues, there is no distinct pattern of relative activities between different organs.

The decline of radioactivity levels in the organs and tissues of terns may be divided into three types (Figures 10a and b): (1) organs in which the decline is semilogarithmic, half-life 40 days - these include the muscle, liver, and kidney; (2) organs in which the decline is logarithmic - these are the bone ($r = t^{-2.35}$) and ileum ($r = t^{-2.85}$); and (3) organs in which the variability is extremely great - the skin and lung represent this group.

The shapes of the radioactivity decline curves for the different organs are determined by a combination of (1) availability of the isotopes, (2) total uptake and degree of selective uptake of different isotopes, (3) radioactive half-life, and (4) biological half-life. Since the relative effects and

* Radiobiological Studies . . . op. cit., p. 6.

Table V. Radioactivity of Rongelap Birds and Bird Eggs

Values expressed in microcuries per kilogram of wet tissue

Date and Island	Organism	Number of Specimens	Skin	Muscle	Bone	Thyroid	Lung	Liver	Kidney	Ileum
3/26/54 Labaredj and Kabelle	noddy and fairy terns	4	167.	4.82	41.0	76.4	7.64	22.7	18.4	179.
3/26/54 Kabelle	curlew	1	2,260.	7.73	161.	6.82	16.8	35.9	132.	30.0
7/16/54 Kabelle	noddy, fairy, and crested terns	6	1.31	.641	.754	6.86	14.3	3.60	2.68	1.72
7/16/54 Kabelle	curlew	1	.714	.183	1.69	6.68	.795	1.03	1.50	9.91
12/8/54 Kabelle	noddy and fairy terns	4	.454	.0395	.0973		.169	.212	.172	.0586
1/26/55 Rongelap	fairy terns	5	.586	.256	.654		1.10	.814	.877	.486
1/26/55 Rongelap	turnstone and plover	2	.173	.0445	.182		.124	.226	.240	.425
1/28-30/55 Labaredj, Kabelle, and Gejen	noddy and fairy terns	6	.741	.0495	.105		.285	.154	.183	.0791

Bird Eggs

Date and Island	Number of Specimens	Egg Shell	Yolk	White	Embryo
7/16/54 Kabelle	5	.650	.932	.0255	.335
12/8/54 Kabelle	3	.295	.129	.00909	
1/29/55 Kabelle	4	.140	.020		

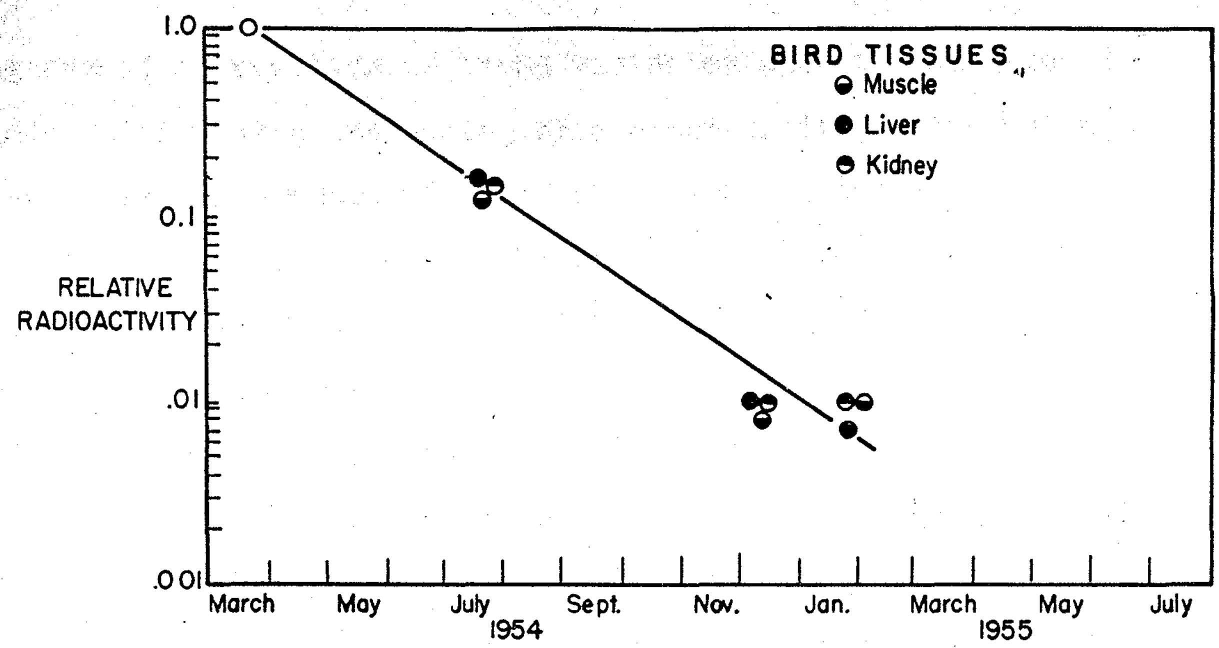

FIG. 10 A DECLINE OF RADIOACTIVITY IN MUSCLE, LIVER, AND KIDNEY SAMPLES FROM NORTH RONGELAP EXPRESSED AS A RATIO TO THE MARCH 26, 1954 COLLECTION

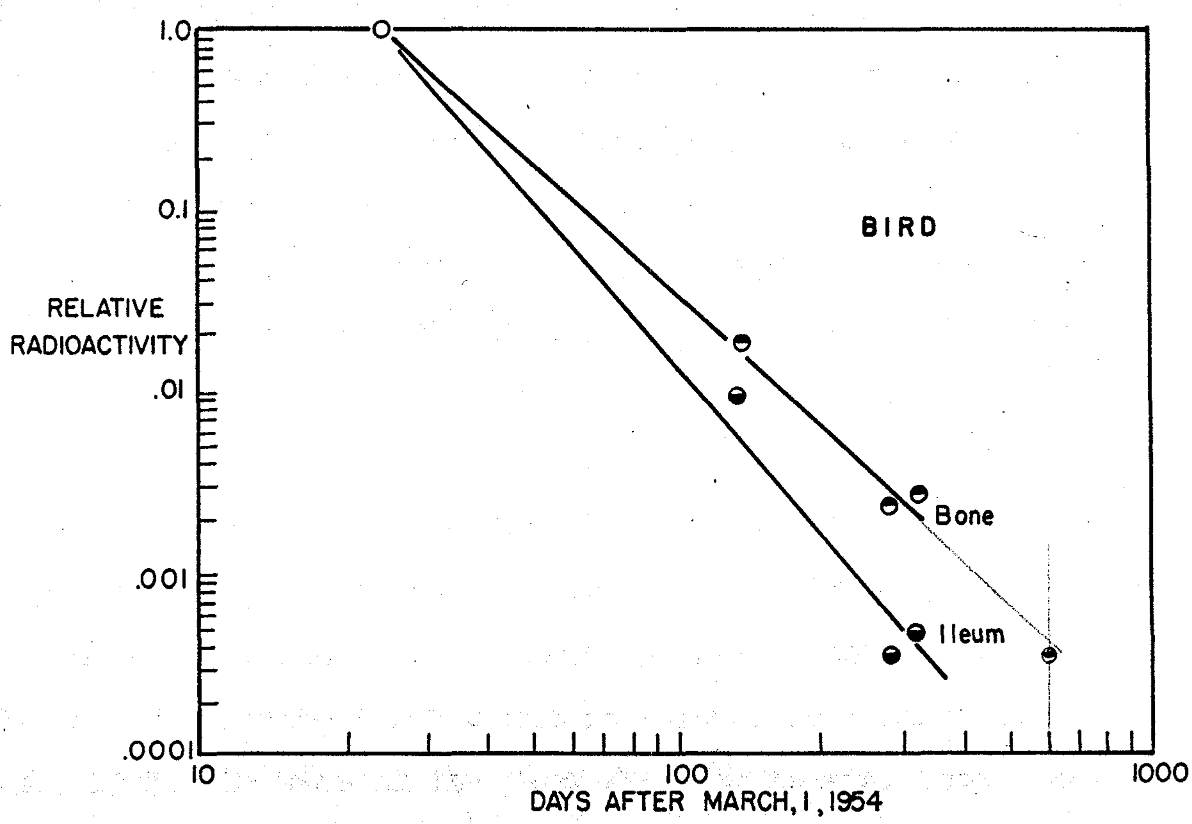

FIG. 10 B DECLINE OF RADIOACTIVITY IN BONE AND ILEUM SAMPLES FROM NORTH RONGELAP EXPRESSED AS A RATIO TO THE MARCH 26, 1954 COLLECTION

degrees of interaction of these variables upon the decline of radioactivity with increasing time after contamination are not known, rigid interpretations of the shapes of the curves should not be attempted. However, the curves are useful in estimating the levels of activity in the different organs on given dates following the contamination of the atoll.

Decay curves were made for a limited number of samples. Of these, only that of the thyroid evidenced a preponderance of a single isotope, I^{131}, which accounted for 99.9 percent or more of the total activity. In decay curves for bone, liver, and kidney there was evidence of mixtures of isotopes. Slopes of $r = t^{-1.28}$ for liver, $r = t^{-1.65}$ for bone, and a curve for kidney, which is not a straight line either logarithmically or semilogarithmically, indicate that these organs do not contain similar ratios of radioactive isotopes. The decay curve slope for tern liver is similar to that of Rongelap soil.

Chemical separation for strontium was done on two bird samples collected March 26, 1954, at Kabelle. Skins from two different terns contained 2.9 percent and 3.5 percent of the total activity as radioactive strontium. In samples of total muscle plus total bone from the same birds, Sr^{89-90} comprised 3.9 percent and 11.3 percent of the total activity (Table VII).

The only collections at Rongelap Atoll containing birds from both the northern and southern islands were made January 26-30, 1955. In view of the fact that the general levels of contamination were higher on the northern islands, it was expected that the northern birds would contain more radioactivity than the southern birds. This was not the case except for the skin. The ratios, south to north, of activity for the different organs and tissues are as follows:

skin	muscle	bone	lung	liver	kidney	ileum
.79	5.2	6.2	3.9	5.3	4.8	6.1

The presence of more than six times as much activity in the intestinal tract of the southern island terns as that found in the same organ of the northern island terns suggests that the southern birds have access to a supply of food fish containing greater amounts of radioactive material. The higher level of activity in the southern bird intestinal tracts is reflected in the greater concentrations of radioactive material in the other internal organs of the same animals. In view of these observations it probably would be advisable to obtain samples from Alinginae Atoll, located seven and one-half nautical miles southwest of Rongelap Atoll, since the Rongelap natives collect birds at Alinginae as part of their food supply.

Tern eggs were collected at Kabelle July 16, December 8, 1954, and January 29, 1955. The levels of radioactivity in the various parts of the eggs were low, with that of the shell approximating the levels found in the bones of terns collected the same day. Radioactivity in the egg yolks varied from 1½ to 3 times that found in the muscles of birds in the same collections. The whites of the eggs contained the lowest amounts of radioactive isotopes of all bird samples examined. These levels were from 1/25 to 1/2 those found in bird muscle collected the same day. The unhatched embryos contained levels of radioactivity approximately one-half that found in bird muscle Appendix Table VIII.

Plankton

The Rongelap plankton collection consists of a single tow on March 26, paired tows on July 16, December 8 and December 18, 1954, and four paired tows January 26-30, 1955. A Michael Sars type net, ½-meter in diameter and with either #6 or #20 silk mesh was used. Tows were taken at the surface during daylight hours.

Radioactivity of the Rongelap plankton samples was more than one hundred times greater than that of plankton samples collected from the open ocean waters of the Western Pacific with the USCGC "Taney" during Operation Troll. On the cruise of the "Taney" during March and April, 1955, 85 plankton samples were taken along the route from Kwajalein to the Philippines to Japan. The average activity of these samples was .015 x 10^{-3} uc/gram of wet sample, the highest values being .050 x 10^{-3} uc/g. For the eight January 1955 Rongelap plankton samples the average value was 2.0 x 10^{-3} uc/g, the lowest value being 0.41 uc/g.

Other conclusions from the Rongelap plankton samples are (1) that the radioactivity per unit weight is greater than for most other biological samples, (2) the decay rate is similar to that for the soil sample, and (3) there is considerable variation in the radioactivity of samples from paired tows.

Soil

The soil and sand samples included those from the islands proper, from the beach, and from the lagoon bottom. The radioactivity of a sample taken from the top inch of soil on Labaredj Island March 26, 1954, was 6.8 microcuries per gram, which is equivalent to one curie per 325 pounds of top soil. The activity of this sample ten months later, January 29, 1955, was one thirtieth its original value, i.e., it had passed through nearly five half-lives. The decay rate for this period is expressed by the formula, $r = t^{-1.31}$, with March 1, 1954, as the date of origin (Figure 12). This rate approximates the mixed fission product decay rate and in general approximates the decay rate for many of the biological samples. For these reasons the decay factor for correcting counts back to the day of collection was based on the decay curve of a similar soil sample.

The decline in radioactivity of the soil samples can be observed from the figures in Appendix Table X. Considerable variation in the activity of soil samples from the same area on the same day can be expected because of the nature of the fall-out pattern and should be kept in mind when interpreting results. If consideration is given to the Kabelle samples only, the rate of decline is greater than the decay rate from March to July 1954, but less from July 1954 to January 1955. When the sample counts from all islands are averaged, the relative decline in activity of the March 1954 samples and the January 1955 samples is the same as the decline in activity of the decay sample.

Profile samples of the lagoon bottom were obtained off Kabelle Island at depths of 60 feet and 40 feet and off Lomuilal Island at 55 feet. The samples were obtained by an aqualung equipped diver driving a foot long, 1½" aluminum tube into the bottom sand. The core was removed from the tube and samples were taken at various levels. From the counts of these samples it was observed that the radioactive sand on the lagoon bottom was several inches thick with the level of activity rather constant for the first five or six inches. The radioactivity per unit weight was less than that of the soil from the island proper but off Kabelle it was greater than that of the sand in the intertidal zone.

Water

The water collection included eight salt-water samples from the lagoon and eight fresh-water samples from the islands proper. A 5-milliliter sample was used for the radioactivity determination except for the December 18th collection (cistern water, filtered well water), for which 25-milliliter samples were used. Because the radioactivity of water samples is often stated in terms of the radioactivity per liter, which would mean extrapolation considerably beyond the observed values, it is especially necessary to state the counting error. For these data the 0.95 counting error,* which is equivalent to two standard deviations, was arbitrarily selected. In Appendix

* AECU-262 (Mon P-126) Statistical methods used in the measurement of radioactivity (some useful graphs) - A. H. Jarrett, T.I.S., Oak Ridge, December 1949.

Table X the values for the water samples expressed in d/m/ml ± 0.95 counting error are given.

"Whole water" samples were used for counting, i.e., none of the natural-occurring radioisotopes were chemically removed, so the values in the above table are those for total radioactivity. For ocean waters, the atomic disintegrations per minute per kilogram for potassium-40 are 560 and for all other natural-occurring isotopes about 10.* This means that the contribution of natural-occurring isotopes to the values in Appendix Table X for lagoon water samples ranged from 0.6 to 1.2 d/m/ml.

Because of the relatively great counting error of the lagoon water samples neither the rate of decline nor the decay rate was estimated. A conservative approximation of the radioactivity of the lagoon water, based upon the average difference between the observed value and the positive 0.95 counting error for the January 26-30, 1955 samples, is 2400 d/m/l (.0011 uc/l).

For the fresh-water samples the counting data are more reliable (Appendix Table X). The samples include cistern water, filtered well water, standing water and ground water. The standing water was taken from an open can on Eniaetok Island and the ground water from a two-foot hole that was dug on Kabelle Island. The ground water was most radioactive, 48,000 d/m/l (.022 uc per liter) and may have contained radioisotopes that had leached from the soil. However, the decay rate $r = t^{-1.35}$ for the period from March 23 - July 30, 1955, was similar to that for mixed

* Schubert, J., "Radioactive Poisons," Scientific American, Vol. 193, No. 2, pp. 34-39, August 1955.

fission products. For filtered well water the decay rate for the same period was similar, $r = t^{-1.39}$. Another observation was that the radioactivity of the fresh-water samples increased from south to north with the activity of the Rongelap Island sample being 1/4, 1/6, and 1/10 of the activity of the fresh-water samples from Eniaetok, Labaredj, and Kabelle Islands, respectively.

Evaluation of the Chemical Analyses of the Biological Samples

Fission product and calcium analyses were made of three soil samples, strontium analyses of selected foods, and I^{131} analyses of plants. Additional samples collected December 8 were sent to Dr. Walter Claus, Division of Biology and Medicine, for chemical analyses.

Samples were taken from the top inch of soil on March 26, 1954, from both Labaredj and Kabelle. Portions were ashed and then dissolved in dilute nitric acid. There was only a very small amount of insoluble residue containing less than 0.1 percent of the radioactivity of the solute. Aliquots of this solution were used to determine total activity and to provide samples for chemical separation.

Standard methods of separating fission products and calcium were followed. Counts obtained from the analyses for cerium, zirconium, niobium, strontium, ruthenium, and barium were corrected for chemical or spike yield. The chemical yield is the ratio of the weight of recovered carrier to added carrier. A yield for calcium was not determined because of the large amount of calcium carbonate in the sample. The radioactivity of seven fission products and calcium corrected for yield and adjusted to 100 percent recovery and expressed as a percentage of the total radioactivity is given in Table VI. The chemical yields and the observed counts from which these values were computed are tabulated in Appendix Table XI.

The results of radiostrontium analyses of biological samples from Rongelap Atoll are given in Table VII. Radiostrontium was

Table VI. Fission Products and Radio-calcium in Soil from Rongelap Atoll 1/

Per Cent Activity 2/

Element	Sample Number 7500 3/	7501 4/	7502 5/
cerium	37.	32.	30.
trivalent rare earths	24.	22.	24.
zirconium	16.	25.	24.
niobium	5.9	7.2	7.0
ruthenium	6.9	6.7	5.9
strontium	4.4	2.4	2.5
barium	5.5	4.1	6.2
calcium	$<$ .3	$<$ .6	.4
total	100.	100.	100.

1/ samples collected March 26, 1954 and analyzed May 11, 1954, activity as of counting date

2/ per cent activity corrected for yield and adjusted to 100% recovery

3/ Labaredj Island 100 feet above high tide line

4/ Labaredj Island, 150 feet above high tide line

5/ Kabelle Island, 150 feet above high tide line

Table VI. Fission Products and Radio-calcium in Soil from Rongelap Atoll 1/

Per Cent Activity 2/

Element	Sample Number 7500 3/	7501 4/	7502 5/
cerium	37.	32.	30.
trivalent rare earths	24.	22.	24.
zirconium	16.	25.	24.
niobium	5.9	7.2	7.0
ruthenium	6.9	6.7	5.9
strontium	4.4	2.4	2.5
barium	5.5	4.1	6.2
calcium	< .3	< .6	.4
total	100.	100.	100.

1/ samples collected March 26, 1954 and analyzed May 11, 1954, activity as of counting date

2/ per cent activity corrected for yield and adjusted to 100% recovery

3/ Labaredj Island 100 feet above high tide line

4/ Labaredj Island, 150 feet above high tide line

5/ Kabelle Island, 150 feet above high tide line

Table VII. Radio-strontium and Radio-cerium in Biological Samples from Rongelap Atoll

Values expressed in micro-microcuries per gram, wet

Group	Tissue	Date and Area of Collection		$Sr^{89}+Sr^{90}$ 1/	Sr^{90}	% of total activity $Sr^{89}+Sr^{90}$	Ce^{144} 2/	% of total activity Ce^{144}
Bird	Carcass	3/26/54	Labaredj	20.		11.3		
"	Skin	"	"	40.		2.9		
"	Carcass	"	Kabelle	5.1		3.9		
"	Skin	"	"	27.		3.5		
Squash	Fruit	1/26/55	Rongelap	2.2	2.1	1.5	1.1	1.4
Papaya	"	"	"	1.9	1.8	2.6	-	-
Pandanus	"	"	"	2.3	2.3	2.6	0.70	1.38
Coconut	Meat	"	"	0		0	0.11	0.38
"	Milk	"	"	0		0	0.05	0.24
"	"	1/28/55	Labaredj	0.11		0.38	0	0
"	"	1/29/55	Kabelle	-		-	0	0
"	"	1/30/55	Gejen	0.03		0.02	0	0
Coconut crab	Muscle	1/29/55	Kabelle	31.	27.	5.7	5.5	1.0
Tuna	"	12/27/54	Mellu	0		0	0.8	0.7
Mullet	"	1/26/55	Rongelap	0		0	2.4	4.4

1/ The 3/26/54 collection processed in December 1954; the January 1955 collection in June - July 1955. Values as of date of analyses.

2/ Processed in July 1955. Values as of date of analyses.

found in plants, birds, and crabs but not in fish muscle nor in some of the coconuts. The greatest amount of Sr^{90} found in the January 1955 samples was 27×10^{-6} uc/g wet weight of coconut crab muscle.

Method for Radiostrontium Separation. The fuming nitric acid precipitation method was used, the sample being dissolved in dilute nitric acid and strontium carrier then added. For the bird tissues the strontium was precipitated by increasing the acid concentration to 72 percent by the addition of 90 percent nitric acid and stirring for one-half hour. The precipitated strontium nitrate was dissolved in water, scavenged with ferric hydroxide and precipitated a second time from 72 percent nitric acid, then counted for strontium radioactivity. Three spikes run concurrently with the bird samples gave a yield of 59.2 ± 0.9 percent. Separation of Y^{90} from the strontium indicated that one-third to one-half of the total strontium was strontium-90 as of the counting date, December 1954.

Strontium analyses of samples of coconut meat and milk and pandanus fruit from the January 1955 collection were made June 14, 1955. The procedure was similar to that above except that 75 percent nitric acid was used and the scavenge with ferric hydroxide was followed by a scavenge with mixed sulfides in acid and in alkaline solution. Four spikes in non-radioactive fish meal ash run concurrently with these samples gave a yield of 65.6 ± 5.3 percent. Four blanks using the same fish meal and run as a check on the radioactivity in the meal, the reagents and on the glassware gave counts of 0, 1, 0, and 0. Yields from spikes run concurrently with the squash, papaya, crab and fish samples were 84 $\pm$ 3.1 percent. From the amount of Sr^{90} present which was determined by separation of Y^{90}, daughter of Sr^{90}, it is evident that only a small amount of Sr^{89} could be present (Table VII).

The results of the Ce^{144} analyses are given in Table VII. The maximum amount found was 5×10^{-6} uc in crab muscle, while none was found in some coconut samples. Cerium analyses were made of the filtrate from strontium nitrate precipitation of the coconut, pandanus fruit, squash, crab, and fish samples listed in the above table. The rare earths were extracted with tributyl phosphate, and cerium was separated from the trivalent rare earths by ceric iodate precipitation. Recovery from "spiked" samples of non-radioactive fish meal ash run concurrently were 73 percent for coconut and pandanus fruit, and 75 percent for all the others.

Determinations were made of the amount of radioiodine present in three land plants and two algae collected at Rongelap Atoll on March 26, 1954. These analyses made on April 24, 1954, followed the procedures as outlined by Glendenin, et al.*

The counts as obtained were corrected back to March 26, 1954. I^{131} was present in all five plant tissues counted, varying from 0.47 percent to 0.029 percent of the total activity found.

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* Glendenin et al., "Interchange of radioactive iodine with carrier iodine." In Coryell, C. D. and Sugarman, N., Radiochemical Studies: The Fission Products, Book 3, p. 1629, McGraw-Hill, 1951.

Study of the Rate of Physical Decay of Radiation in the Biological Samples

The Rongelap samples are now unique among our Marshall Islands collections since they were taken from an area - Rongelap Atoll - in which the radioactivity resulted primarily from a single time source - the March 1, 1954 Bikini experiment; whereas the activity at Eniwetok and Bikini derived from several experiments over a number of years.

Rongelap decay data were studied with three primary objectives: (1) to evaluate suitability of the decay correction factor based on soil by a comparison of biological and other materials, (2) to aid in extrapolating into past or future time beyond the period of the present survey, and (3) to compare decay rates with decline rates.

Eighty-four samples of fish, invertebrates, algae, land plants, plankton, birds, and soil were counted an average of 11.5 (range, 2-73) times for various intervals during the period from 38 to 500 days after the Bikini test of March 1, 1954.

When log of count is plotted on the ordinate against log of time after March 1, 1954, on the abscissa (here called a log-log plot), a more nearly straight line is usually obtained than when the abscissa is arithmetic (semi-log plot). A mixture of fission products is supposed (Coryell and Sugarman)* to give a straight line by log-log plot with a slope of about -1.25 for the period of time involved in this study. The decay of a single

* Coryell, C. D. and Sugarman, N., Radiochemical Studies: The Fission Products, Book 1, p. 456, McGraw-Hill, 1951

isotope is linear on a semi-log plot, exemplified by bird thyroid containing predominantly I^{131}, mentioned in the section on birds.

Among the 28 plates counted most often (10 - 73 times) and presumed to be counted frequently enough to detect the existence of a linear semi-log relationship, only one other sample was more nearly linear by semi-log than by log-log plot. This was the gastric mill of a crab, Grapsus grapsus, taken March 26, 1954, at Kabelle. The graph (Figure 11) was sufficiently curved to indicate the presence of more than one isotope. The early portion 50 - 300 days gave a half-life of 78 days, and the portion 300 - 430 days gave a half-life of 107 days. A section of the curve of another sample, muscle of sea cucumber (Figure 11), was typical of semi-log linearity. The radioactivity of this sample decayed over the period from 50 to nearly 200 days with a half-life of about 75 days, but more slowly later.

Although a single isotope displays a downwardly concave curvilinear plot by log-log presentation, a mixture of as few as two isotopes with half-lives of similar orders of magnitude, such as Ce^{141} and Ce^{144} of 30- and 280- day half-lives, may appear almost linear on a log-log plot over the period of 70 to 500 days.

Most decays were best suited to log-log plotting as seen in the seven examples in Figures 12 and 13. Although some appear slightly curved, straight lines were fitted and slopes were scaled graphically.

Definition of the curves requires evaluation not only of

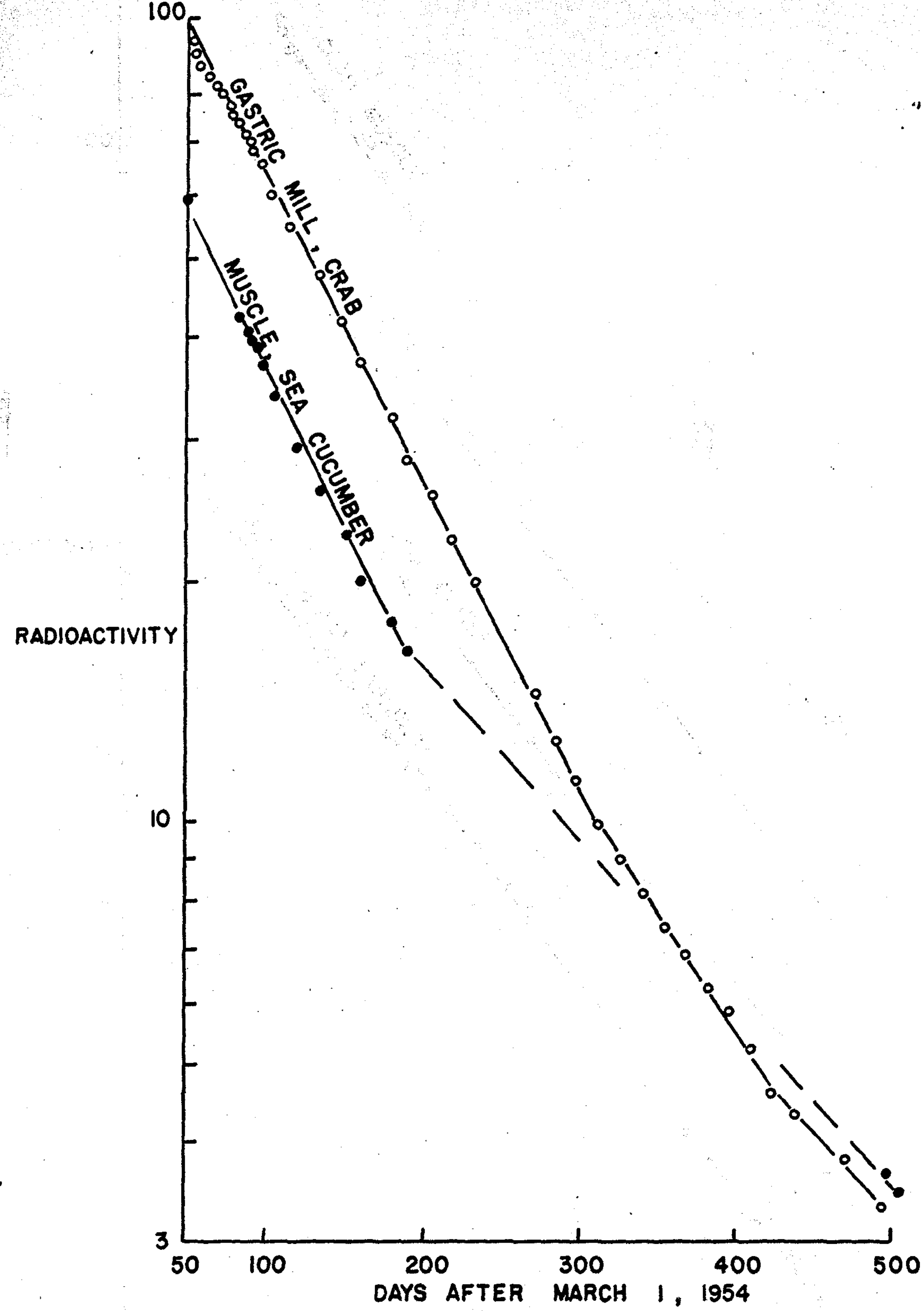

FIG. 11 SEMI-LOG PLOTS OF DECAY CURVES OF GASTRIC MILL OF CRAB, GRAPSUS GRAPSUS, AND MUSCLE OF SEA CUCUMBER, HOLOTHURIA ATRA, COLLECTED MARCH 26, 1954 AT KABELLE

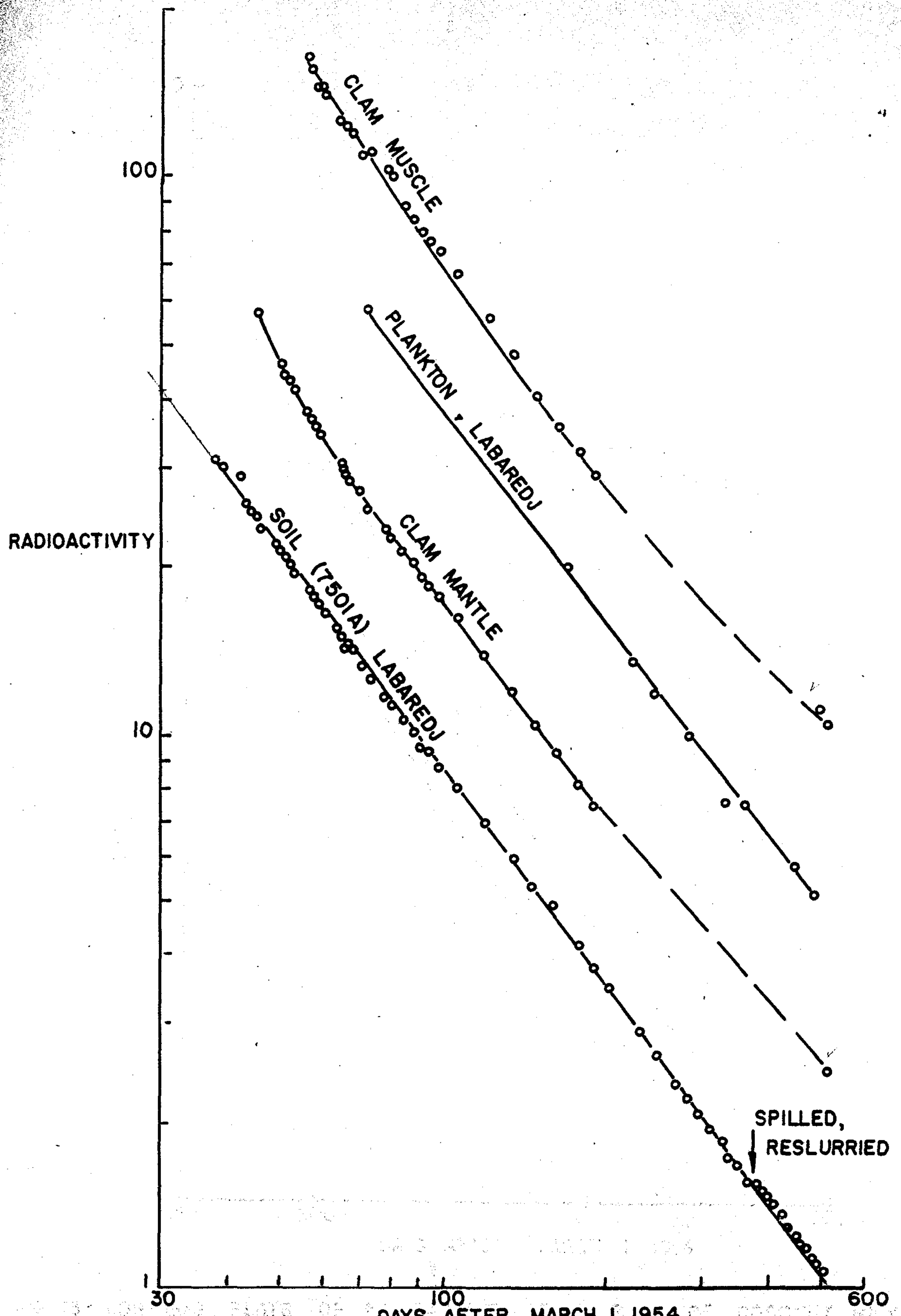

FIG. 12 LOG-LOG PLOTS OF RONGELAP DECAY SAMPLES OF MARCH 26, 1954: PLANKTON FROM LABAREDJ; MUSCLE AND MANTLE OF GIANT CLAM, HIPPOPUS, FROM KABELLE; AND SOIL ON WHICH DECAY CORRECTION FACTORS WERE BASED

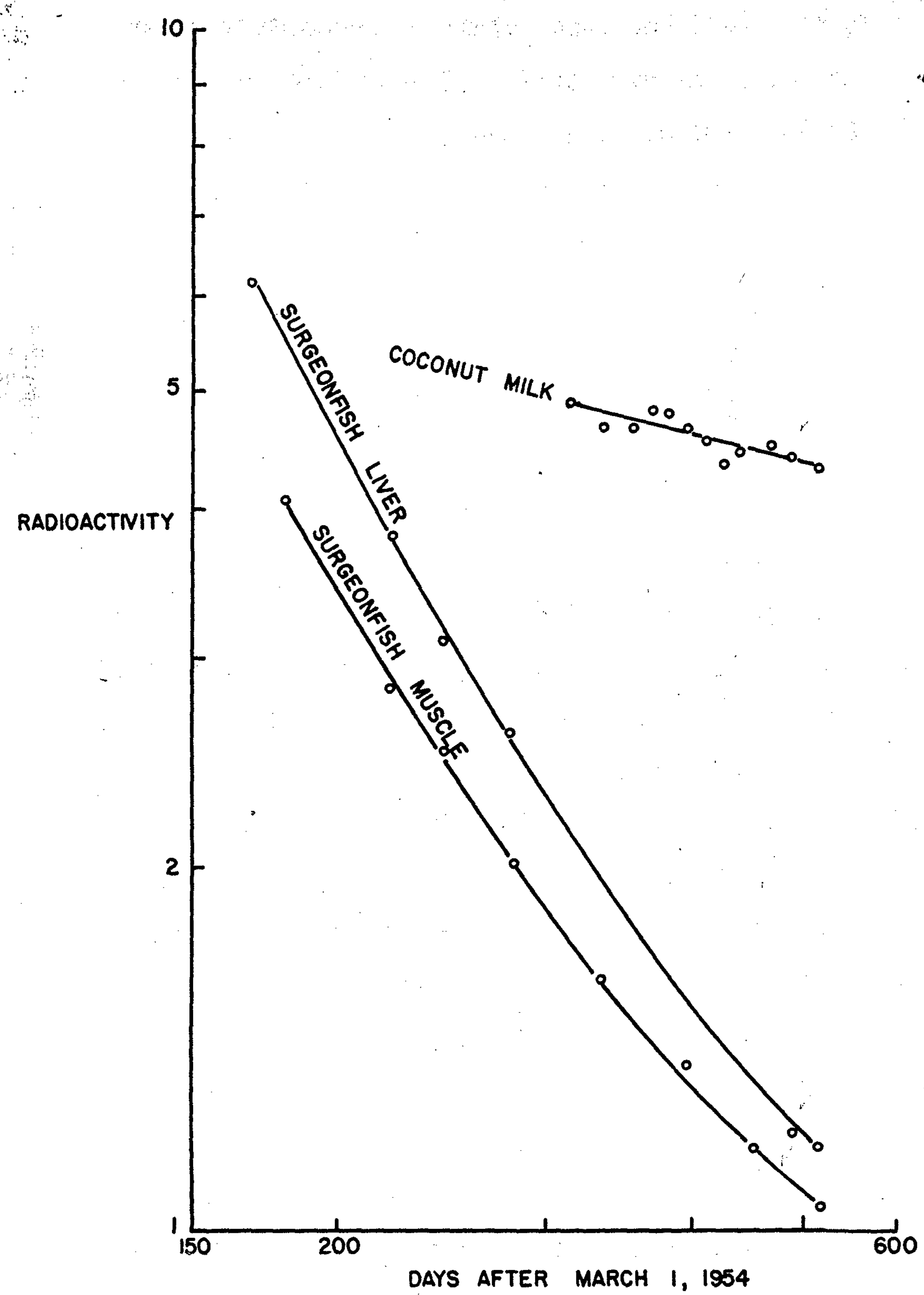

FIG. 13 LOG-LOG PLOTS OF RADIOACTIVE DECAY RATE OF COCONUT MILK, (COCOS) COLLECTED DECEMBER 8, 1954 AT KABELLE, AND OF LIVER AND MUSCLE OF SURGEON FISH (ACANTHURUS ELONGATUS) COLLECTED JULY 16, 1954

the degree of variance or scatter about the line, but also by the nature of the deviation from linearity among the smooth, curvilinear plots. Those curves which were concave upward were fish tissues, none of which had been counted more than seven times.

The average slope of 83 decays on log-log plots was -1.43. Table VIII shows a breakdown into groups by types of organisms and by tissues, and all samples grouped by collecting dates are recorded in Appendix Table XII.

Differences in decay rates of tissues of the animals are not great, although the liver rate of decay is steepest to a degree that is of borderline significance. Comparison of rate of decline of food items, -1.75, with rate of decay of all samples, -1.43, shows that food items, with the exception of such plants as the coconut, decline more rapidly in their radioactive content than can be accounted for solely on the basis of their physical decay. However, the steep trend of decline may result from the inadequacies of sampling. The January 1955 collection may reflect variability in the effects of currents or season. Future sampling will show whether the indicated decline is truly unusually steep, or a vagary of sampling.

From a study of the decay curves it is seen that most biological samples follow the soil trend sufficiently well to justify use of the soil decay rate in correcting sample counts back to the time of collection over short periods. However, some samples diverge widely.[a] Of greatest concern is the coconut, in the milk of which the radioactivity may decay very

Table VIII

Decay Rates of Rongelap Samples Expressed as the Slope of the Log-log Relationship of Activity to Time after March 1, 1954

Fish, invertebrate, and bird tissues

	Skin & Mantle	Muscle	Bone	Liver	Gut or Viscera	Gill
n	11	12	10	12	11	1
$\bar{x}$	-1.34	-1.39	-1.40	-1.68	-1.45	-1.28
$s/\bar{x}$	0.16	0.11	0.11	0.16	0.30	0

Miscellaneous

	Kidney of bird		Plankton	Algae	Coconut	Other land plants	Soil
	<90d	>90d					
n	2	2	3	3	3	2	7
$\bar{x}$	-1.25	-1.71	-1.35	-1.20	-0.60	-1.30	-1.31
$s/\bar{x}$	0.08	0.12	0.05	0.12	0.56	0.01	0.04

n = number of relationships
$\bar{x}$ = mean slope
s = standard deviation
$s/\bar{x}$ = coefficient of variation of slope

slowly ($r = t^{-.24}$). At the other extreme are occasional samples of fish gut, the radioactivity of which decays fast ($r = t^{-2.4}$).

A P P E N D I X

Table I. Radioactivity of Fish from Rongelap Atoll, 1954-55

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

APPENDIX

Date and Island	Common Name 1/		Skin	Muscle	Bone	Liver	Viscera	Entire
[illegible]	damsel	4	41.5	[illegible]	14.6	289.	3,590.	
[illegible]	"	"	60.5	[illegible]	25.8	1,020.	3,690.	
	parrot	1	107.	11.4	74.3	361.	[illegible]	
	"	1	106.	11.3	[illegible]	160.	[illegible]	
	squirrel	1	74.5	7.54	21.5	680.	604.	
	"	"	55.5	6.24	10.2	390.	[illegible]	
	grouper	5	12.4	[illegible]	9.53	98.2	180.	
	"	4	20.3	[illegible]	7.50	141.	417.	
	"	1	[illegible]	1.75	5.19	25.5	69.8	
	shark		22.7	2.35	17.3	71.9	21.1	
	"		23.1	2.90	7.73	27.7	5.66	
	"		36.5	2.52	19.5	70.3	15.1	
7/16/54 Kabelle	mullet		13.6	3.15	9.59	39.3	328.	
	surgeon	1	3.09	.903	5.35	23.7	89.1	
	butterfly	2	4.04	.974	8.82	60.2	16.3	
	"	"	4.78	1.12	4.31	23.2	13.3	
	"	"	2.55	.335	3.80	28.1	12.2	
	"	1	4.27	.796	5.31	70.1	23.9	
	damsel	2						10.9
	"	4						7.42
	"	1	6.03	.364	5.07	97.8	34.4	
	"	2						7.54
	"	2						21.1
	parrot	2						20.4
	"	"						18.4
	"	"						15.0
	herring							17.6
	"							12.5
	halfbeak		4.81	.540	2.66	28.7	13.8	
	"		4.80	.353	2.97	38.6	14.6	
	"		5.41	1.05	4.27	45.6	15.9	
	"		3.65	.970	2.80	71.2	11.7	
	goatfish	2	9.78	1.46	30.1	152.	50.4	
	"	"	11.7	2.00	12.4	91.2	101.	
	"	"	6.96	1.08	15.2	58.3	39.2	
	"	"	6.05	.933	6.83	53.8	29.2	
	wrasse	2						10.0
	"	"						9.75
	"	"						4.67
	"	"						6.24
	"	"						4.67
	grouper	2	1.41	.246	.473	14.8	6.39	
	"	4	3.55	.767	3.86	39.1	29.6	
	"	"						6.43

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Table I. Radioactivity of Fish from Rongelap Atoll, 1954-55

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

Date and Island	Common Name 1/	Skin	Muscle	Bone	Liver	Viscera	Entire
3/26/54 Kabelle	damsel 4	41.5	4.85	14.8	889.	3,590.	
	" "	52.5	10.3	26.8	1,820.	3,890.	
	parrot 1	102.	11.4	79.9	381.	332.	
	" "	106.	13.3	96.0	780.	4,020.	
	squirrel 2	74.0	8.44	21.5	680.	645.	
	" "	35.6	6.25	12.5	399.	331.	
	grouper 5	12.4	3.45	9.53	98.2	180.	
	" 4	20.9	4.22	7.50	141.	417.	
	" 1	16.5	1.75	5.19	15.3	69.8	
	shark	28.7	2.95	17.3	71.2	21.1	
	"	23.1	2.90	7.73	27.7	5.68	
	"	36.5	2.52	19.5	70.3	15.1	
7/16/54 Kabelle	mullet	13.6	3.15	9.59	59.3	328.	
	surgeon 1	3.09	.903	5.35	23.7	89.1	
	butterfly 2	4.04	.974	8.82	60.2	16.3	
	" "	4.78	1.12	4.31	23.2	13.8	
	" "	2.55	.335	3.80	28.1	12.2	
	" 1	4.27	.796	5.31	70.1	23.9	
	damsel 3						10.9
	" "						7.42
	" 5	6.03	.564	5.07	97.8	84.4	
	" 2						7.64
	parrot 2						21.1
	" "						22.4
	" "						18.4
	" "						15.0
	herring						17.6
	"						12.5
	halfbeak	4.81	.540	2.86	24.7	13.8	
	"	4.80	.353	2.95	36.6	14.5	
	"	5.41	1.09	4.27	45.6	18.9	
	"	3.62	.970	2.80	21.2	11.7	
	goatfish 2	9.78	1.46	30.1	152.	59.4	
	" "	11.7	2.00	12.4	91.2	101.	
	" "	6.96	1.08	15.2	58.3	39.2	
	" "	6.05	.933	6.83	83.8	29.2	
	wrasse 2						10.0
	" "						9.75
	" "						4.67
	" "						6.24
	" "						4.67
	grouper 2	1.41	.246	.473	14.8	6.39	
	" 4	3.55	.767	3.86	39.1	29.6	
	" "						6.48

1/ see page 33 for scientific name

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(Table I cont.)

Date and Island	Common Name	Skin	Muscle	Bone	Liver	Viscera
7/16/54 Kabelle (cont'd)	squirrel 1	.596	.399	.850	10.5	48.2
	" "	1.32	.454	5.95	54.2	17.7
	" "	1.37	.467	4.25	61.1	12.1
12/27/54 Lagoon	tuna	5.73	.079	.770	5.76	1.28
	"	3.86	.139	.251	3.09	.972
12/8/54 Lagoon	snapper	.960	.218	.724	4.70	1.14
1/25/55 Rongelap	surgeon 2	.209	.061	1.81	3.15	1.02
	" "	.196	.068	.214	1.04	1.04
	blenny 2	.097	.026	.073	.545	2.77
	" "	.084	.038	.195	1.13	3.36
	" "	.062	.031	.140	.998	9.34
	damsel 1	.561	.040	.304	2.80	5.91
	" "	.347	.061	.449	2.92	5.37
	" "	.418	.052	.295	3.15	6.27
	" "	.668	.065	.487	5.54	7.08
	goatfish 2	.399	.063	.907	3.89	1.96
	" "	.298	.085	.352	1.59	1.01
	" "	.509	.103	.981	2.99	2.50
	" "	.514	.091	.734	7.07	3.91
	squirrel 1	.487	.106	1.44	4.01	1.59
	" "	.447	.082	1.32	9.63	2.87
	" "	.685	.084	.378	11.0	3.64
	grouper 3	.473	.138	.682	9.23	2.21
	" "	.721	.144	1.11	8.02	5.09
	" 1	.752	.093	.879	3.30	.986
	jack	.216	.052	.395	3.48	.766
1/26-29/55 Lagoon	grouper		.072		3.84	
	"		.089		1.91	
	" 4	1.25	.191	.671	10.6	1.86
	snapper 1	1.52	.375	.694	3.98	4.53
	" "	2.20	.386	.682	5.07	1.30
	" "	1.62	.165	.490	2.75	7.32
	" 2		.074		3.63	
1/28/55 Labaredj	damsel 2	2.08	.728	3.08	21.6	8.85
	" "		.374	2.62		
	" "		.436			
	" 1	.721	.133	1.16	7.00	10.9
	" "	2.05	.251	1.65	1.73	12.8
	surgeon 1	2.10	.145	2.10	18.0	27.1
	" "	1.90	.149	1.21	1.41	9.45
	" 2	.932	.115	.815	7.26	3.20
	parrot 1	.977	.201	1.06	7.88	45.7
	" "	1.68	.147	1.59	25.8	29.1
	" "	.725	.184	.818	3.79	38.5

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(Table I cont.)

Date and Island	Common Name	Skin	Muscle	Bone	Liver	Viscera
1/28/55	mullet	1.05	2.49	1.91	8.22	286.
Labaredj	"	.564	.265	.637	4.35	6.86
(cont'd)	"	1.35	.513	1.97	5.50	47.0
	"	.789	.496	1.09	28.3	54.3
	"	.611	.236	.758	4.81	19.5
	blenny 2	1.65	.264	1.29	10.1	37.5
	" "	.614	.306	1.41	8.74	24.3
	" "	.782	.408	1.50	14.8	25.1
	" "	.577	.278	1.84	14.4	43.8
	" "		.269			
	wrasse 2	1.63	.348	1.43	3.97	18.2
	" "	1.47	.401	1.76	4.05	14.8
	grouper	1.08	.175	1.50	2.75	4.68
	"	.828	.447	1.05	15.1	3.25
	goatfish	2.34	.353	3.88	17.5	26.4
	lizard	2.13	.300	1.83	6.51	1.52
	"	1.61	.386	1.13	14.5	4.51
	"	1.92	.252	2.08	3.81	1.93
1/29/55	mullet	1.19	.181	.952	5.74	9.35
Kabelle	"	.382	.166	.612	3.45	16.9
	"	.587	.184	.926	4.80	11.2
	surgeon 2	.641	.125	.944	4.05	2.30
	" "	.649	.139	.906	3.63	3.76
	damsel 1	1.46	.246	1.70	10.2	15.8
	" 5	1.11	.168	.683	9.02	4.06
	blenny 1	.509	.167	1.02	3.35	11.6
	" 2	.525	.253	1.92	6.54	11.2
	goatfish 2	1.36	.299	2.23	8.00	14.4
	" "	1.78	.436	2.97	1.34	10.3
	" "	1.05	.264	1.36	18.1	9.85
	shark	.687	.125	.191	2.67	.490
	grouper 4	.433	.110	.504	6.94	2.77
	" "	.826	.117	.726	12.2	6.24
	" "	.622	.108	.606	13.0	.249
1/30/55	damsel 1	3.44	.350	2.40	27.4	37.6
Gejen	wrasse 1	1.37	.215	1.42	15.3	8.62
	grouper 4	1.34	.279	1.79	21.9	5.02
	" "	1.39	.273	1.15	38.1	6.65
	" "	.591	.118	.368	2.32	1.21
	" "	.861	.268	1.13	4.38	2.36
	" 6	1.20	.396	1.42	4.77	1.78
	goatfish 1	2.54	.405	4.95	18.0	17.5
	flatfish	3.18	.248	1.96	3.70	5.30

Scientific Names of Fishes

blenny 1	Istiblennius edentulus
" 2	" paulus
butterfly 1	Chaetodon collaris
" 2	" lunula
damsel 1	Abudefduf sordidus
" 2	Dascyllus aruanus
" 3	Chromis caeruleus
" 4	Pomacentrus nigricans
" 5	" vaiuli
flatfish	Bothus mancus
goatfish 1	Mulloidichthys auriflamma
" 2	" samoensis
grouper 1	Epinephalus elongatus
" 2	" fario
" 3	" hexagonatus
" 4	" merra
" 5	" spilotoceps
" 6	Variola louti
halfbeak	Hyporhamphus laticeps
herring	Spratelloides delicatulus
jack	Caranx melampygus
lizard	Synodus variegatus
mullet	Neomyxus chaptalii
parrot 1	Scarus purpureus
" 2	" sp.
shark	Carcharhinus melanopterus
snapper 1	Lethrinus sp.
" 2	Lutianus sp.
squirrel 1	Holocentrus sammara
" 2	Myripristis multiradiatus
" 3	" sp.
surgeon 1	Acanthurus elongatus
" 2	" triostegus
tuna	Gymnosarda nuda
wrasse 1	Gomphosus varius
" 2	Halichoeres trimaculatus

Table II. Radioactivity of Invertebrates Other Than Corals Collected at Rongelap Atoll, 1954-55

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

Date and Island	Organism[1]	Muscle	Gut	Integument	Gill	Mantle	Gonad	Liver	Kidney	Misc.
3/26/54 Kabelle	sea cucumber	251		227			877			
		592	3,170	684			416			
		166	8,700	531			1,440			
		394	8,500	537			1,140			
		509	5,900	635			811			
		112	950	291			510			
		590	940	1,080			1,300			
		1,400	343	650						
		530	760	500			3,000			
	giant clam		16		350	122			190	
		47	740		840	116			780	720[2]
			1,050		410	98			740	1,890[2]
	spider snail	140	3,600			440		13,000		7,500[2]
	crab	182	2,800	1,600	3,000			5,400		
Labaredj	hermit crab	260	2,500	1,500	1,400			9,400		
	coconut crab	21	6,300	990	1,300			790		
			3,700							
7/16/54 Kabelle	sea cucumber	11.	90	24			8.4			
	giant clam	2.9	62		25	6.5			120	20[2]
	hermit crab	5.6	112	122	22			65		
		6.8	240	190	99			88		
		7.0	119	90	30			106		
	coconut crab	2.6	58	61	22			51		
		4.3	480	67	36			33		
12/8/54 Kabelle	sea cucumber	3.4	21	1.9			7.8			
		7.1	20	9.6			4.6			
		1.2	25	6.3			10.5			
	spider snail	14.	66; 64			50		280		13[2]
		9.8	58; 62			46		250		22[2]
		24.	150; 92			88		320		3.4[2]

(Table II cont.)

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Date and Island	Organism 1/	Muscle	Gut	Integ-ument	Gill	Mantle	Gonad	Liver	Kidney	Misc.
1/26-30/55 Rongelap	snail									19 3/; 25 3/; .68 2/
	ghost crab	.081	2.0	1.6	1.6			.50		
	redeye crab	.47	.87	.13	1.7			1.9		
		.79	1.7	.21	1.6			.71		.45 4/
	rock crab	.25	.43	.073	.85			.61		
		.23	.55	.30	.79			.59		
	hermit crab	.76	1.4	5.8	.93			.95		
	coconut crab	.66								
		.53								
Labaredj	giant clam	.49	5.4		1.8	1.6			27	2.4 2/
Kabelle	sea cucumber	4.8	7.4	1.2			7.6			
	coconut crab	.39	45.	9.2	3.8			4.7		
		1.0	15.	12.	4.9			5.0		
	orange sponge									65. 5/
	sea urchin									.95 6/
Gejen	giant clam	.86	19.		6.1	6.1			38	12. 2/
	octopus	1.4	12.			2.2		26.		3.9 2/
	coconut crab	6.9	5.1	.90	3.2			3.3		
	spiny lobster	1.2	2.0	.53	2.4			4.4		
Eniaetok	yellow sponge									1.7 5/

1/ sea cucumber, Holothuria atra; giant clam -1, Hippopus; giant clam -2, Tridacna crocea; spider snail, Pterocera; crab, Grapsus grapsus; hermit crab, Cenobita; coconut crab, Birgus; snail, Nerita; ghost crab, Ocypode ceratophthalma; redeye crab, Eriphia; sea urchin, Echinothrix; octopus, Polypus; spiny lobster, Panulirus.

2/ shell

3/ soft parts

4/ egg

5/ entire

6/ spines

Table III. Radioactivity of Coral
from Rongelap Atoll, 1954-55

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

Date and Island	Acro-pora	Fungia	Helio-pora	Lept-astrea	Milli-pora	Pocillo-pora	Porites
3/26/54 Kabelle	960.	140.				240.	39.
7/16/54 Kabelle	8.4 14.	3.0 3.6	33. 49.		9.7 7.8		
1/29/55 Kabelle	.70 .50 3.5 4.1 .44						.22 3.2
1/28/55 Labaredj	3.1 2.1			.88	1.3	1.9	2.6

Rongelap Atoll, 1954-55

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

Date and Island	Milk	Meat	Skin	Husk	Shell	Misc.	
3/26/54	1.42	2.55	87.8	14.7	3.13	215.	primary leaf
Kabelle	3.14		3.77	53.	1.73	142.	old leaf, external
	1.48					34.4	" " , internal
	3.02					393.	secondary root
						110.	primary "
7/16/54	.101	.251	1.96	.279		.281	entire fruit
Kabelle	.116	.249	11.3	.306		.201	" "
		.310				.688	" flower
						.466	pedicel
12/8/54	.030	.070	.155	.094	.095	.163	entire flower
Kabelle	.066	.174	1.76	.253	.137	.156	pedicel
	.051	.166	2.43	.285			
12/18/54	.032	.064		.063			
Rongelap	.033	.051		.043			
1/26/55	.035	.031					
Rongelap	.032	.031					
	.025	.043					
	.066	.058					
	.034	.051					
1/29/55	.172	.082				.434	primary leaf
Kabelle	.120	.109					
	.111	.151					
	.131	.099					
	.029	.056					
Labaredj	.062	.046					
	.038	.031					
	.035	.057					
	.054	.048					
1/30/55	.125	.263					
Gejen	.230						
	.154						
Lukuen	.107	.120					

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Table V. Radioactivity of Edible Plants other than Coconuts from Rongelap Atoll, 1954-55

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

Date and Island	Name	Edible Portion	Seeds	Skin	Leaves	Misc.
3/26/54 Labaredj	Morinda	24.8			1,070	
12/18/54 Rongelap	squash	.034	.168	.070		.066 pulp
	papaya	.044	.174	.088		
	"	.033	.123	.105		
	arrowroot	.052; .042; .052		.048	.182	
	Morinda	.062	.093	.071		
	Pandanus	.059	.048	.103		
1/29/55	arrowroot	.066				
Kabelle	Pandanus	.124		.133		
Labaredj	arrowroot	.015				
Lomuilal	"	.362				
	Pandanus	.175	.175	.189		
Gejen	arrowroot	.110		.211		
Rongelap	papaya	.029	.141			
	"	.190	.129			
	arrowroot	.117; .061; .135				
	"	.018; .022				
	Pandanus	.074				
	squash	.223; .012	.029			
	spinach				.033	
	"				.040	

Table VI. Radioactivity of Plants [illegible]
Eaten from Rongelap Atoll, 1954-55

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

Date and Island	Name 1/	Fruit Flower	Leaves Apical-Bud	Leaves Old Green	Leaves Mixed	Stems Entire	Stems Debarked	Stems Bark	Roots
3/26/54 Labaredj	tree 1							1,630	
	tree 2	62.7			2,070	1,630	41.9	302	
	shrub 1	800.			1,080		14.0	440	
	herb 1				3,260; 1,030	1,240			
3/26/54 Kabelle	herb 1				874	782			
	herb 2	469. 2/			153; 12,200	129; 154			
	grass 1				3,990				336
7/16/54 Kabelle	tree 1		1.42	1.71		32.4		72.3	
	tree 2		1.08; 2.04	1.25		7.71	.968	12.3 !	
	shrub 1		1.55; 1.56	1.48		3.15	.554	6.36	
	shrub 2				25.3; 19.4 3/	126.; 4.87 3/	.365	17.8	
	herb 1				3.53; 3.66 3/	2.35; 2.78 3/			
	herb 2				5.92; 2.95 3/	7.25; 1.41 3/			
	grass 1				14.1; 18.4 3/				
12/8/54 Kabelle	tree 1	.511	.943	1.08		.634	.405	.830	
	tree 2			3.30		1.85	.760	2.53	
	shrub 1	.164; .325 2/	.413	.496		.172	.164	.266	
	herb 1			2.60		1.25			
	herb 2			.887		.944	.917	4.59	
	herb 3	2.68 2/	1.71	2.92		.990	.494	1.60	
	grass 1				4.77				14.8; 13.2
1/29/55 Kabelle	tree 1		4.73	1.33			2.07		
	tree 2		.338	.318					
	shrub 1	.151	.336	.525			.148		
	herb 1			1.48					
	herb 2				.499	1.42			
	herb 3		1.74	4.20		2.60			
	grass 1				10.3				12.1

1/ 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, *Truimfetta procumbens*; grass 1, *Lepturus repens*.

2/ flower

3/ sample washed before counting

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Table VII. Radioactivity of Marine Algae
from Rongelap Atoll, 1954-55

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

Date and Island	Udotea indica	Micro-dictyon spp.	Halimeda spp.	Caulerpa spp.	Dictyo-sphaeria cavernosa	Gracilaria sp.
3/26/54 Kabelle	1,480	5,100	735 450	1,360		
7/16/54 Kabelle		43.4; 41.7 38.4; 48.6 61.5; 113.	8.02; 10.7 19.5; 10.0 15.0	53.4; 15.3 8.12; 13.7 7.10; 6.08 33.7; 82.2 45.4		
12/8/54 Kabelle			3.75; 3.52 4.90	2.31; 2.96 7.66		
1/27-30/55 Eniaetok		5.22	3.42 1.58 4.18 7.53	11.1	2.40	
lagoon off Rongelap, 150' lagoon off Kabelle, 60'	7.99	11.7; 9.69	.695; 1.52 2.26; 2.12 .454; 1.49	.350; .840 1/ 1.53; 4.77 1/ .537 2/; 5.76 1/	4.23	9.57
Gejen	3.78 9.09 8.61		.849 1.63 .854	2.48 5.58 3.63		

1/ leaves
2/ stems

Table VIII. Radioactivity of Birds Collected at Rongelap Atoll, 1954-55

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

Date	Island	Name[1]	Skin	Muscle	Bone	Thyroid	Lung	Liver	Kidney	Ileum
3/26/54	Labaredj	noddy tern	482.	9.16	121.		23.4	72.0	53.0	65.0
"	Kabelle	" "	51.0	17.0	68.7		14.0	59.0	65.0	643.
"	"	fairy tern	555.	6.71	61.4	39.0	13.8	27.0	12.8	793.
"	"	" "	380.	9.40	110.	298.	15.8	42.0	31.0	73.0
"	"	curlew	4,970.	17.0	354.	15.0	37.0	79.0	291.	66.0
7/16/54	Kabelle	noddy tern	1.58	.693	1.29	9.00	4.38	6.58	3.06	1.99
"	"	" "	1.29	1.22	1.33	20.0	11.0	6.77	8.28	2.08
"	"	fairy tern	1.20	1.02	.823	14.0	8.34	7.71	6.10	1.18
"	"	" "	.621	.573	1.57	3.70	3.88	4.85	3.79	1.25
"	"	crested tern	6.78	3.15	2.39	20.0	150.	13.5	8.68	10.3
"	"	" "	5.84	1.81	2.53	24.0	11.2	8.05	5.52	5.93
"	"	curlew	1.57	.403	3.72	14.7	1.75	2.26	3.29	21.8
12/8/54	Kabelle	noddy tern	.789	.060	.118		.255	.314	.391	.147
"	"	" "	1.88	.074	.140		.351	.508	.435	.124
"	"	fairy tern	.951	.102	.330		.447	.698	.291	.132
"	"	" "	.384	.111	.266		.435	.349	.394	.112
1/26/55	Rongelap	fairy tern	1.21	.591	1.09		2.07	2.52	2.98	.995
"	"	" "	1.31	.912	3.16		4.11	2.54	2.53	1.10
"	"	" "	1.16	.334	.357		1.58	1.51	1.63	1.21
"	"	" "	.556	.361	1.56		2.05	.585	.585	.652
"	"	" "	2.19	.623	1.04		2.27	1.79	1.91	1.40
"	"	turnstone	.430	.107	.248		.387	.558	.566	.800
"	"	plover	.331	.090	.552		.157	.437	.490	1.07
1/28/55	Labaredj	noddy tern	.829	.045	.345		.430	.213	.295	.085
"	"	" "	.776	.358	.740		1.74	.934	1.04	.395
"	"	fairy tern	.279	.041	.061		.258	.243	.182	.154
"	"	" "	6.92	.049	.125		.394	.217	.258	.069
1/30/55	Gejen	noddy tern	.150	.054	.042			.196		
"	"	fairy tern	.851	.108	.078		.317	.223	.240	.167

1/ Noddy tern, *Anous stolidus*; fairy tern, *Gygis alba*; curlew, *Numenius sp.*; crested tern, *Sterna bergii*; turnstone, *Arenaria interpres morinella*; plover, *Pluvialis dominica*.

Table IX. Radioactivity of Tern Eggs

from Rongelap Atoll, 1954-55

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

Date and Island	Eggshell	Yolk	White	Embryo
7/16/54	1.14	.804		.508
Kabelle	2.15	2.03		.795
	1.42	2.08		.905
	1.48	4.92	.056	
	.956	.409		
12/8/54	.575	.421	.018	
Kabelle	.581	.147	.023	
	.789			
1/29/55	.376	.065		
Kabelle	.272	.030		
	.280	.045		
		.035		

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Table X Radioactivity of Plankton, Soil-Sand, and Water Samples from Rongelap, 1954-55

Plankton - Values expressed in thousands of d/m/g of wet sample

	3/26/54	7/16/54	12/8/54	12/18/54	1/26-30/55
Off Lukuen					3.39; 9.61
" Kabelle		4.73; 5.84	13.7; 22.8		4.01; 12.8
" Labaredj	306.			11.0; 8.54	2.04; 0.90
" Rongelap					1.18; 2.10

Soil-Sand - Values expressed in thousands of d/m/g

	Island Soil				Beach Sand	
	3/26/54	7/16/54	12/8/54	1/25-30/55	12/8/54	1/25-30/55
Lomuilal				166		35.9
Gejen				830		6.16
Kabelle	2,000	312	315	106	20.5 1/	13.7
"		421		596	5.04	3.04
Labaredj	17,000					
"	13,000					
Rongelap				2.34		1.16

Lagoon bottom, 1/29-30/55

	0-¼"	¼-¾"	¾-1¼"	1¼-1¾"	1¾-2¼"	2¼-3"	
Lomuilal, 55'	22.9	27.2	17.8	16.3	17.9	14.5	
	0-1"	1-2"	2-3"	3-4"	4-5"	5-6"	6-7"
Kabelle, 60'	19.2	16.9	16.9	16.2	20.0	7.47	
" 40'	20.3	16.9	21.4	21.8	10.3	3.35	3.29
Labaredj, 150'	16.2						

Water - Values expressed in d/m/ml ± 0.95 counting error

	Lagoon Water		Fresh Water	
	7/16/54	1/26-30/55	12/18/54	1/26-30/55
Lomuilal		5.6 ± 3.0		
Kabelle	3.3 ± 3.1	3.3 ± 2.7		48. ± 3.2 5/
"	2.3 ± 3.0			
"	4.1 ± 3.2			
"	4.8 ± 3.4			
Labaredj		6.8 ± 3.0		25. ± 2.2 2/
Eniaetok				17. ± 2.2 4/
Rongelap		5.6 ± 3.0	3.4 ± .20 2/	4.2 ± 1.8 2/
"			2.6 ± .18 2/	
"			1.9 ± .15 3/	
"			1.8 ± .21 3/	

1/ at high tide line
2/ cistern water
3/ filtered well water
4/ standing water
5/ ground

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Table XI. Data for Computing Per Cent Activity of Fission Products and Calcium in Rongelap Soil Samples Based on 1 Milliliter Replicates

Sample Number:	7500			7501			7502		
	a = c/m	b = % chemical yield	$\frac{a}{bc} \times 10^4$ = %	a	b	$\frac{a}{bc} \times 10^4$	a	b	$\frac{a}{bc} \times 10^4$
cerium	21,005 27,154	40 48	44.	10,014 9,909	62 58	35.	16,719 17,946	83 83	30.
trivalent rare earths	26,297 25,535	75 1/ 75	28.	8,562 8,992	75 1/ 75	24.	13,507 12,353	75 1/ 75	25.
zirconium	19,099 18,809	99 69	19.0	9,337 9,532	73 72	27.	13,439 13,200	75 72	26.
niobium	7,584 7,192	96 79	6.9	3,618 3,386	93 95	7.8	4,857 4,488	100 79	7.7
ruthenium	10,289 9,518	97 2/ 97	8.2	3,019 3,321	87 2/ 97	7.2	5,247 3,664	100 2/ 97	6.6
strontium	1,574 1,440	21 26	5.2	253 612	20 30	3.4	551	29	2.8
barium	6,192 4,971	85 62	6.2	2,158 1.372	83 85	4.4	3,019 3,494	64 74	6.9
calcium	527 538	3/	0.4	278 221	3/	0.5	356 487	3/	.6
total			118.			109.			111.
c = c/m, non separated aliquot	123,558 123,904 124,561			47.992 48,282 47,370			68,758 69,692 67,304		
average	124,008			47,882			68,585		

1/ from previous experiments; yields for these analyses greater than 100%

2/ spike yields; chemical yields greater than 100%

3/ no yield was determined

Table XII. Physical Decay Rates of Rongelap Samples

$r = t^{-x}$; t_o = March 1. 1954

Plate No.	Date and Island	Substance or Organism	Tissue	No. of Times Counted	X, Decay Rate
4032	3/26/54	damsel fish	skin	2	1.49
4033	Kabelle	" "	muscle	3	1.42
4034		" "	bone	2	1.33
4035		" "	liver	2	1.64
4036a		" "	gut	2	1.11
4044		squirrel fish	skin	3	1.62
4045		" "	muscle	4	1.59
4046		" "	bone	2	1.53
4047		" "	liver	3	1.86
4048		" "	gut	2	1.61
4049		" "	gill	2	1.28
4050		" "	skin	2	1.30
4051		" "	muscle	4	1.63
4052		" "	bone	2	1.45
4053		" "	liver	3	1.71
4054		" "	gut	2	1.58
4055		parrot fish	gill	2	1.47
4056		" "	skin	2	1.30
4057		" "	muscle	4	1.77
4058		" "	bone	2	1.95
4059		" "	liver & gut	2	2.96
5000		giant clam	mantle	33	1.28
5006		" "	muscle	28	1.27
5008a		" "	visceral mass	18	1.14
5016		spider snail	mantle	13	1.15
5017		" "	muscle	13	1.24
5023		sea cucumber	"	14	1.38
5057a		shore crab	gastric mill	46	($\frac{1}{2}$-life ~80-d)
5078		coconut crab	gastric mill	15	1.13
6009		<u>Messerschmidia</u>	debarked stem	34	1.31
6018		<u>Boerhaavia</u>	leaves	33	1.29
7002	Labaredj	sooty tern	bone	17	1.60
7003	Kabelle	" "	liver	13	1.28
7021		fairy tern	"	13	1.31
7030		sooty tern	"	13	1.36
7032		" "	kidney	31	1.17, < 90 days 1.59, >90 days
7040		curlew	"	15	1.83, >90 days

Plate No.	Date and Island	Substance or Organism	Tissue	No. of Times Counted	X, Decay Rate
7500a	3/26/54	soil	top inch	40	1.35
7501 (glass)	Labaredj	"	" "	38	1.34
7501a		"	" "	73	1.33
7502a	Kabelle	"	" "	40	1.28
8203	Labaredj	plankton		8	1.28
8240	Kabelle	"		8	1.41
6844	7/16/54	<u>Halimeda</u>	entire	8	1.05
6859	Kabelle	3/4-inch coconut	"	6	0.54
12151		goatfish	skin	7	0.99
12152		"	muscle	7	1.12
12153		"	bone	7	1.14
12154		"	liver	7	1.75
12155		"	viscera	7	1.12
12186		herring	entire	7	1.30
12201		butterfly fish	skin	5	1.70
12202		" "	muscle	8	1.42
12203		" "	bone	5	1.39
12204		" "	liver	4	1.74
12205		" "	viscera	5	2.14
12231		surgeon fish	skin	5	1.49
12232		" "	muscle	7	1.22
12233		" "	bone	6	1.26
12234		" "	liver	5	1.54
12235		" "	viscera	5	1.25
12236		damsel fish	skin	5	1.21
12237		" "	muscle	7	1.44
12238		" "	bone	5	1.63
12239		" "	liver	6	2.06
12240		" "	viscera	5	1.25
12241		mullet	skin	5	1.31
12242		"	muscle	7	1.55
12243		"	bone	5	1.34
12244		"	liver	5	1.79
12245		"	viscera	5	1.25
12251		grouper	skin	6	1.26
12252		"	muscle	6	1.41
12253		"	bone	6	1.36
12254		"	liver	6	2.09
12255		"	viscera	6	2.40
71		tern	eggshell	40	1.76
9947	12/8/54	soil	mid-island	10	1.36
9949	Kabelle	"	intertidal	11	1.23
10700		coconut	meat	12	0.96
10706		"	milk	11	0.24
10745		<u>Halimeda</u>	entire	11	1.22
10748		<u>Caulerpa</u>	entire	11	1.33
19006		plankton		10	1.36