UNCLASSIFIED

407858

UNIVERSITY OF WASHINGTON

LABORATORY OF RADIATION BIOLOGY

SEATTLE, WASHINGTON 98105

REPORT NO. UWFL-33

UNCLASSIFIED

(This is a classified report)

UWFL-33

(WT-616)

Report to the Test (Scientific) Director

RADIOBIOLOGICAL STUDIES AT ENIWETOK ATOLL BEFORE AND FOLLOWING THE MIKE SHOT OF THE NOVEMBER 1952 TESTING PROGRAM

(Preliminary Marine Survey, Project 11.5)

June 10, 1953

Submitted by: Lauren R. Donaldson
Director

Applied Fisheries Laboratory
University of Washington
Seattle, Washington

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

UWFL-33

Effects of Atomic Weapons

Report to the Test (Scientific) Director

RADIOBIOLOGICAL STUDIES AT ENIWETOK ATOLL BEFORE AND FOLLOWING THE MIKE SHOT OF THE NOVEMBER 1952 TESTING PROGRAM

(Preliminary Marine Survey, Project 11.5)

June 10, 1953

Submitted by: Lauren R. Donaldson
Director

Applied Fisheries Laboratory
University of Washington
Seattle, Washington

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

CONTENTS

PREFACE

ABSTRACT

SECTION 1. OBJECTIVE AND BACKGROUND

SECTION 2. OPERATIONS

2.1 Areas Sampled

2.2 Time of Collections

SECTION 3. METHODS

3.1 Preservation of Specimens

3.2 Ashing

3.3 Counting

3.4 Correction Factors

SECTION 4. RESULTS AND ANALYSIS OF DATA

4.1 Water Samples

4.2 Plankton

4.3 Algae

4.4 Invertebrates

4.5 Fish

4.6 Land Plants

4.7 Land Vertebrates

4.8 Radiochemical Analyses

4.9 Absorbed and Surface Contamination

4.9.1 Speck Contamination

4.9.2 Other Surface Contamination

SECTION 5. CONCLUSIONS

SECTION 6. RECOMMENDATIONS

SECTION 7. APPENDIXES

TABLES

		Page
1.	Radioactivity of water samples	21
2.	Radioactivity of plankton	24
3.	Radioactivity of all algae	27
4.	Radioactivity of the seven most common algae, post shot	27
5.	Radioactivity of pre-test inveterbrate samples by groups	32
6.	Pre-test invertebrate samples with highest activity	33
7.	Frequencies of pre and post test invertebrate ashed sample counts by magnitudes	35
8.	Radioactivity of separate tissues or organs of different groups of post shot invertebrates	38
9.	Radioactivity of all post test invertebrate samples	40
10.	Radioactivity of whole fish	45
11.	Radioactivity of fish compared by feeding habit	50
12.	Radioactivity in fish tissues, pre-shot	54
13.	Radioactivity in fish tissues, post shot	55
14.	Radioactivity of land plants	
15.	Radiochemical analyses of soils and plants, post shot	
16.	(a)Radioactivity of pre-shot rats; (b)Radio-activity of post shot rats	66
17.	(a)Radioactivity of pre-shot birds; (b)Radio-activity of post shot birds	67
18.	Radiochemical analyses of sand, soil and biological samples, post test	80
19.	Comparison of radicactivity of two species of sea cucumbers, post shot	102
20.	Radioactivity of samples summarized by groups and islands	105

ILLUSTRATIONS

		Page
Figure 1.	Collecting stations	5
Figure 2.	Frequency distributions of counts of Engebi beach sand	10
Figure 3.	Decay curves	15
Figure 4.	Mass absorption curves	16
Figure 5.	Relative radioactivity of clam tissues, and soil or beach sand at each station	39
Figure 6.	Radioactivity in whole fish and fish tissues for all stations	47
Figure 7.	Injured goatfish from Engebi Island	49
Figure 8.	Radioactivity of fish by species for all stations	52
Figure 9.	Photograph of singed plover	64
Figure 10.	Photograph of singed noddy tern	64
Figure 11.	Radioactivity of pre-shot rats and birds	68
Figure 12.	Radioactivity of post shot terns with relation to distance of collecting site from ground zero	71
Figure 13.	Radioactivity in lungs of rats	75
Figure 14.	Mass absorption curves from bones of rat and tern samples	77
Figure 15.	Mass absorption curves of radiochemically-separated fractions of Rojoa dredged sand	83
Figure 16.	Decay curves of radiochemically-separated fractions of Rojoa dredged sand	84
Figure 17.	Photomicrographs of Engebi beach sand	87
Figure 18.	Autoradiograph, photograph and photomicrograph of Biijiri dredged sand	89
Figure 19.	Autoradiograph of eleven of the more radioactive post test samples	90

		Page
Figure 20.	Photograph of the eleven samples shown in Figure 19	91
Figure 21.	Autoradiograph of algae	93
Figure 22.	Corals showing white nodules of high specific activity	95
Figure 23.	(a)Autoradiograph of goatfish showing radioactivity in gills; (b) Photograph of fish in (a)	97
Figure 24.	(a)Composite photograph of fish used for autoradiograph (b)	98-99
Figure 25.	(a)Photograph of land plants used for autoradiograph (b)	100

PREFACE

The atomic energy weapons testing program, initiated with the detonation of the "Trinity" shot in New Mexico in 1945 and continued subsequently at Bikini, Eniwetok, and Nevada, has resulted in contamination of the test sites with varying amounts of radioactive materials. Some of these radioactive materials are absorbed or adsorbed by animal and plant life. To gain an understanding of the nature of such contamination, field studies in the test areas are essential. In the tests conducted at Bikini and Eniwetok the conditions are nearly ideal for study of the contamination of an aquatic environment. The Applied Fisheries Laboratory has been interested in the problems presented by disposal of radioactive wastes into water since the United States atomic energy program was initiated. Field studies have been conducted by the Laboratory at Bikini and Eniwetok since the inception of the test programs at these two atolls. The data from these studies is recorded in a number of reports prepared for the Atomic Energy Commission. A list of the reports is attached in the Appendix.

To complete a project such as the Marine Survey of Eniwetok Atoll for the purpose of evaluating radiological contamination requires the combined efforts of many persons and organizations. We are not able to acknowledge the help and counsel of all those who aided us but of especial help were the members of the A.E.C. Division of Biology and Medicine staff in the Washington office. The A.E.C. personnel at the Hanford Works, in

particular Mr. Kenneth Englund, were most helpful. The administrative staff of Operation Ivy, especially Capt. Duncan Curry and Col. P. L. Hooper, provided the support needed to carry out the operations in the field. Comdr. J. H. Barker, Jr., U.S.N., acted as liaison officer; his services were invaluable in the pre-operations planning, procurement of supplies, shipping of material and arranging for transportation of personnel and equipment. The officers and enlisted men of the Oakhill (LSD-7) supplied the necessary assistance for our operations and in many ways made our work and stay in the area enjoyable. We owe them our thanks.

ABSTRACT

The Marine Survey Unit had as its major objectives (1) the measurement of the residual radiation of Eniwetok Atoll as found in the living organisms as a result of previous weapons tests in this area, and (2) a resurvey of the area, following the Mike shot, to determine the change in amounts, kinds, and distribution of radioactive materials.

The field data were collected by a party of seven specialists who spent the time from October 20 to November 11, 1952, collecting plankton, algae, rats, birds, fishes, plants and invertebrate organisms. The material collected was frozen for storage and shipment back to the Applied Fisheries Laboratory where it was identified, dissected, weighed, ashed, and the amount of radiation measured as disintegrations per minute per gram of wet sample.

The pre-test survey showed measurable amounts of residual radiation on and in the living organisms collected from the stations along the eastern and northern portion of the atoll. Following the Mike shot the radiation level increased manyfold, especially along the northern and western portions of the atoll.

It was found that some of the organisms collected and studied had been exposed to sufficient external and/or internal radiation to eventually damage or destroy them.

Subsequent studies should determine the biological half life of the materials contaminating the area, their shift in position with the currents, and the results of the contamination from radioactive materials upon the living forms of the atoll.

1. OBJECTIVE AND BACKGROUND

For Operation Ivy, the Marine Survey Unit, Project 11.5 of Task Group 132.1, had as a major objective the evaluation of the contamination of living organisms following the Mike shot. An investigation of the residual radiation contamination of the fauna and flora of Eniwetok Atoll from the previous weapons tests was also undertaken.

As Eniwetok Atoll has been used for several tests of atomic weapons since the last resurvey by the Applied Fisheries Laboratory group in 1949, it was essential to establish the level and kinds of residual radiation from the previous tests before the detonation and resultant contamination of the Mike shot. The data on the pre-shot contamination were obtained from samples of flora and fauna of the atoll and lagoon. In addition to the data accumulated on the level of radioactive contamination, it was necessary to determine the condition of the animal and plant populations in the areas chosen for sampling stations. The extensive construction program on the atoll since 1949 changed not only the surfaces of the islands but also modified many of the marine areas.

Following Mike shot the studies were directed to the evaluation of:

1. The determination of the extent of the area contaminated.
2. The nature and kinds of the radioactive materials found in the various areas.

3. The amount and kinds of radioactive substances absorbed or adsorbed onto the plants and animals.
4. The more immediate effects of the Mike shot upon the plants and animals.

2. OPERATIONS

To carry out the field portion of the operations, representatives of the Applied Fisheries Laboratory, University of Washington, spent the period from October 20 to November 11, 1952, at Eniwetok. Field parties left the group headquarters on the Oakhill (LSD-7) each day for the collecting stations about the lagoon.

Collections were made by specialists in each of the several fields.

Kelshaw Bonham	Invertebrates
Edward E. Held	Invertebrates
Frank G. Lowman	Instrumentation and land vertebrates
Ralph F. Palumbo	Aquatic and land plants
Allyn H. Seymour	Plankton and water samples
Arthur D. Welander	Fishes
Lauren R. Donaldson	Project leader

The final processing of the material and the analysis of the data were accomplished by the combined efforts of the entire staff of the Laboratory. Each of the several specialists

supervised the work in his field of specialization and summarized the results for inclusion in this group report. Dorothy South was responsible for doing the chemical analyses on selected specimens of sand, soil and biological samples. The work on absorption and decay curves was handled by Paul Olson.

2.1 Areas Sampled

The locations of the collecting stations are shown in Figure 1. There were 7 major stations, 6 of which were approximately the same as those visited in 1948 and 1949 and the 7th, Bogombogo-Bogallua, was 2 to 3 miles west of the Mike test shot island. The same areas from which collections were made before the test were revisited after the test where circumstances allowed. Collections of fish, invertebrates and algae were generally made on the lagoon side from the intertidal zone down to a depth of about 12 feet. Occasionally the sampling area was extended to the ocean side of the collecting station, especially if there was a scarcity of specimens on the lagoon side. Terrestrial plants and animals were gathered from the islands and, while the reef and island collections were being made, plankton towing, dredging and water sampling operations were being carried on in contiguous waters. These operations on occasion extended 2 or 3 miles from the area of reef collections.

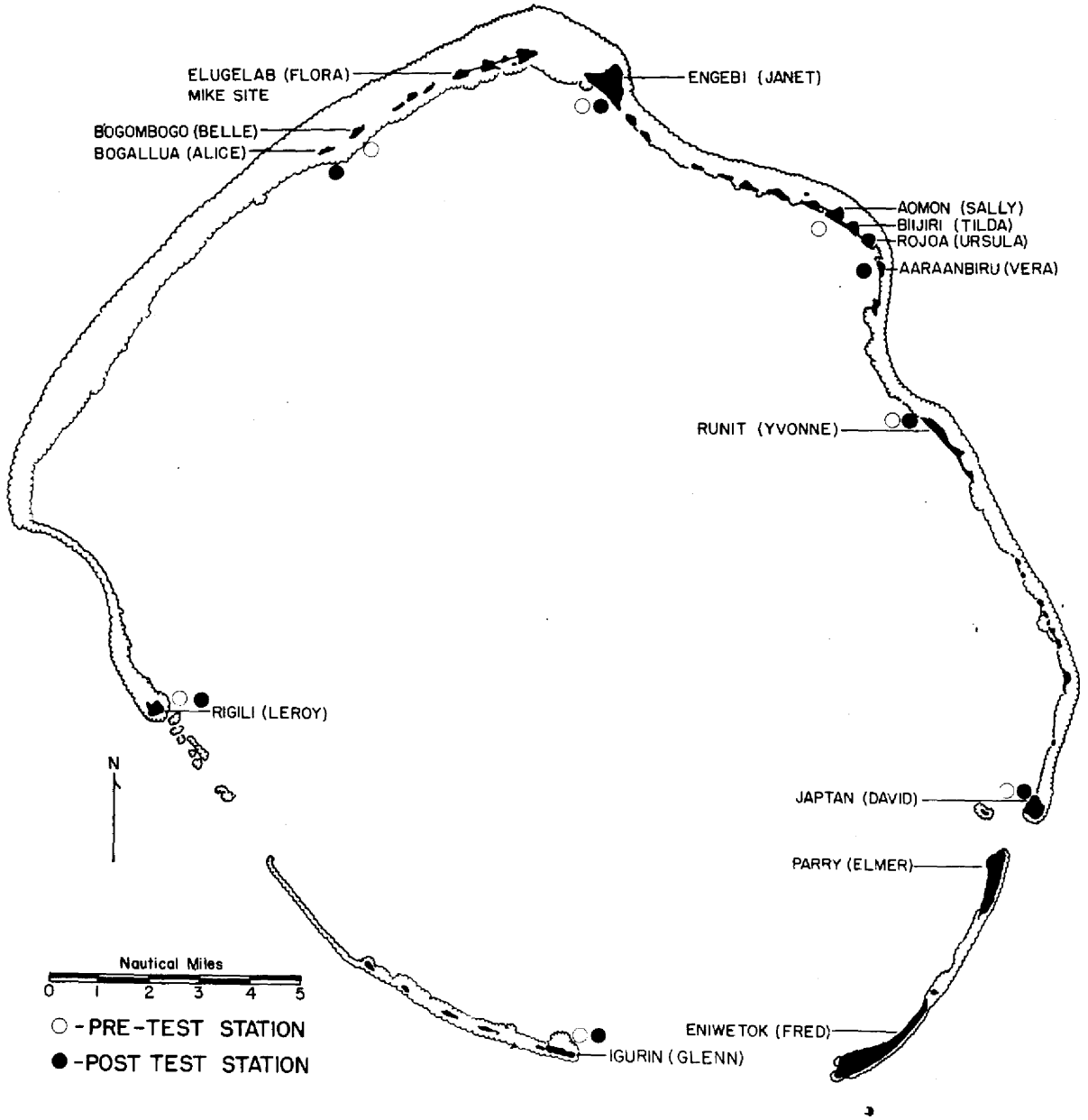


FIGURE I. PRE AND POST TEST COLLECTING STATIONS, ENIWETOK ATOLL, OCTOBER - NOVEMBER 1952

2.2 Time of Collections

Collections were made both before and after the Mike test of November 1. The pre-test samples were collected from October 21 to 28, and the post test samples from November 3 to 10. The collecting dates and distances from Mike shot by islands were as follows:

Month		Japtan	Igurin	Rigili	Bogombogo-Bogallua	Engebi	Aomon Aaraan.	Runit
Pre	Oct.	21	28	27	25	24	23	22
Post	Nov.	3	4	5	8	8	7	6
Nautical miles from Mike shot		18½	19½	14	2½-3	2½	7½-9	11½

3. METHODS

3.1 Preservation of Specimens

All biological material, with the exception of plankton and rats, that was to be used for radioactivity analyses was placed on ice in an insulated container as it was collected. After return to the Oakhill the collections were packaged in cellophane bags, labeled, and moved to a deep freeze box for freezing and storage. During the air flight from Eniwetok to Seattle the specimens were transported in an insulated container with dry ice. The specimens arrived at the University of Washington laboratory in a frozen condition

and were immediately stored in a deep freeze unit where they remained until time for processing. Algae and plants that were to be used for autoradiographs or as herbarium specimens were dried and pressed in the field. All plankton samples, as well as fish and algal specimens, that were to be used for identification were preserved in 4 percent formalin.

3.2 Ashing

The samples were ashed and plated in much the same manner as previously described (AECD-3446)[1]. Briefly the procedure was as follows: (1) Fish, invertebrates, birds, rats and land plants were dissected and approximately one-gram samples of various tissues were placed upon weighed 1½-inch stainless steel plates. Wet sample weights depended upon the amount of tissue available and the activity of the sample as determined by survey meter at the time of dissection. The mean sample weight of 145 randomly selected samples was 1.17 ± .074 grams.* (2) The plates with the wet samples were placed in a drying oven at 97°-99°C for 12 to 24 hours. (3) They were then cooled in a desiccator and dry weights determined. (4) The plates were next moved to the muffle furnace for about 12 hours, during which time the temperature was gradually raised to 300°C then more rapidly to a maximum of 550°C, except for

*In this report the value following the mean is the standard error.

clam shells and corals which were held at 600°C for thirty minutes. (5) After cooling, the ash was slurried with ethyl alcohol and a clean glass rod to distribute it evenly on the plate. Following drying, a weightless amount of formvar, in a ½-percent solution of ethylene dichloride was added to prevent ash from being blown off the plate. After drying under a heat lamp the plate was ready for counting.

3.3 Counting

The samples were counted in two Nucleometer internal gas flow (pure methane) counting chambers.

Counting time. A compromise was made as to length of counting time, since there were many plates to be counted, only two counters were available and it was desirable to keep the correction factor for decay to a minimum. The counting time for each plate was determined by its approximate counting rate, including a 50 c/m background, in accordance with the following schedule:

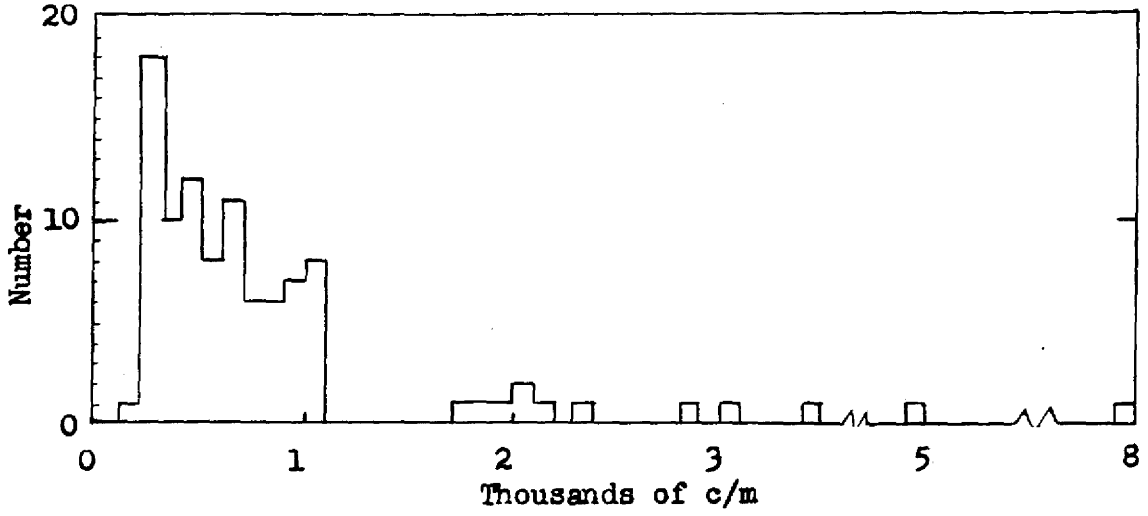
Counting Rate (c/m)	Counting time (minutes)
<500	20
500-1000	10
1000-2000	5
>2000	2

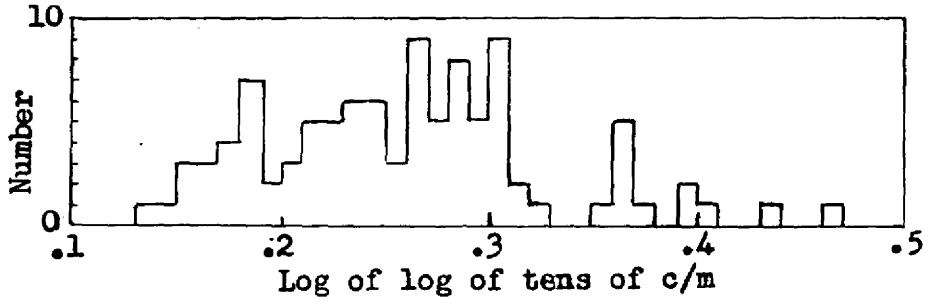
The counting period for practically all samples collected after the Mike test (Nov. 1) was from November 24 to December 12. Most of the samples from the pre-test collections were counted

after this period but before the end of December. During this period a 24-hour day, 7-day week counting schedule was maintained.

Distribution of Counts. The statistical distribution of sample counts appeared to be of a logarithmic or log-logarithmic nature. To further investigate the type of distribution two series of counts of 100 samples each of unashed post test Engebi sand were made. Sand in a jar was dried in the oven and mixed. Sampling cups for the two series held 6.1 $\pm$ .05 mg (n = 100) and 2990 $\pm$ 3 mg (n = 32), respectively. The small sample series was counted in the Nucleometer for 10 minutes per sample and the large samples in the end window counter for 1 minute each. The frequency distribution of the actual counts of the small samples was strongly skewed (Fig. 2, upper) but was approximately normal for the logarithms of the logarithms of these counts (Fig. 2, middle). For the large samples (Fig. 2, lower) the mode of the observed values was still to the left of the mean but the distribution was more nearly normal. It would appear that the distribution of counts is strongly skewed to the left when the chance of occurrence of "speck" contamination (see Section 4.9.1) is small, but as the number of specks increases the distribution approaches the normal curve. For biological samples, especially those with "surface" contamination, the distribution of counts could be expected to be similar to those of the sand samples.

Unit of Measurement. The unit of measurement for recording radioactivity is disintegrations per minute per gram (d/m/g) of wet sample (unless otherwise noted) although





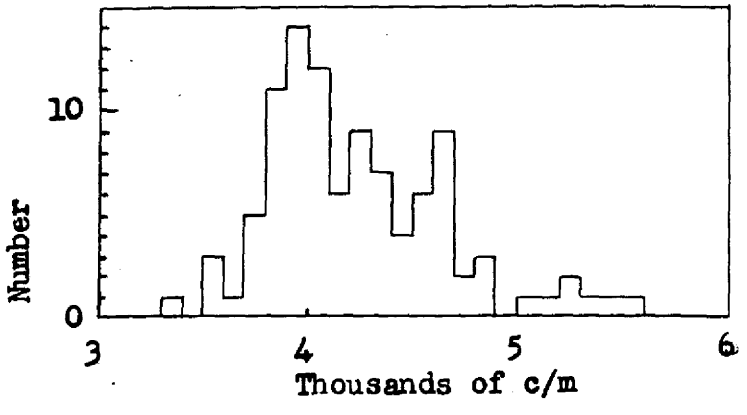


Figure 2. Histograms showing frequency distributions of counts of radioactivity of Engebi beach sand.
Upper, counts for 100 small (6 mg) samples.
Middle, logarithms of logarithms of the same counts.
Lower, counts for 100 large (3000 mg) samples.

it is realized that the actual disintegration rate is not practically attained. The actual disintegration rate was approximated by correcting the gross sample counts for background, sample weight, geometry, backscatter, self-absorption, coincidence and decay. Since it is desirable to express the amount of activity per sample in a weight unit comparable to that of living organism, wet weight was selected in preference to dried or ashed weight. Naturally the activity per unit of wet weight is lower than per unit of dried or ashed weight.

Significant Figures. Results have been recorded to two significant figures although three figures generally were used in the computations. The number of significant figures in the final answer was limited by the number of significant figures in the least accurate value in the computation. One source of limitation in the post test samples was the correction factor for decay which was changing approximately 4 percent per day and which was applied no closer than to the day the sample was counted. Another limitation occurred in the weight of the ash used to determine the correction for self-absorption. Samples were weighed to the nearest milligram and often the ashed weight was less than 100 milligrams and occasionally less than 10 milligrams. Also, the correction factors for backscatter and for geometry were not determined more accurately than to two significant figures.

3.4 Correction Factors

Geometry. Geometry is about 50 percent for an internal

gas flow counting chamber. Hence the correction factor was approximately 2.0.

Backscatter. Backscatter was previously determined for P^{32} in our Nucleometers as being 30 percent (see p. 24 of AECD-3446). The same correction factor, $\frac{100}{130} = 0.77$, was used again this year.

Coincidence. The loss of counts due to coincidence was determined empirically. Small amounts of P^{32} were dried on tinfoil and the pieces of the P^{32} tinfoil, for which the counting rates had been determined, were placed one at a time side by side on the counting plate. After each piece of the P^{32} tinfoil had been placed on the plate a count was made. The expected count, which was the sum of the individual counts, was divided by the observed count to determine the correction factor. For observed counts less than 80,000 c/m, no correction was made for coincidence; for counts of 80,000 to 160,000 per minute, the correction factor was 1.01; for counts of 382,000 to 392,000 per minute, the correction factor was 1.07. Correction factors were also determined for intermediate values. For small corrections the counting rate as determined theoretically from the formula $N = \frac{n}{1-nt}$ held true (N = true counting rate, n = observed counting rate, and t = recovery time of register = 5 microseconds).

Background. The background values were determined by interpolating between background counts at the point (i.e., time) when the sample count was made. Usually about five

20-minute background counts were taken during a 24-hour period. From November 24 to the end of December, 127 background counts were made with counter No. 185, and the mean value was 50.25 c/m with a standard deviation of 2.63; for the other counter, No. 184, 135 background counts were made during the same period with a mean value of 53.51 c/m and a standard deviation of 3.84. These background values are less than those recorded in the 1949 report because the counting chambers are now shielded with two inches of lead.

Decay. At the time of counting, the post test samples were decaying at an appreciable rate. Therefore these samples were corrected for decay and the date to which they were corrected arbitrarily chosen as December 1, one month after the Mike test and also near the mid-point of the counting period for these samples. Although the activity of the samples is corrected to that of December 1, the distribution of activity is that of the date of collection, November 2 to 10. In the period immediately following the shot the activity in the organisms would be expected to vary greatly within short periods, due to changes in geographical distribution of the radioactive materials and to length of time of exposure of the organisms.

The curve from which the correction factors were determined was the decay curve for a sand sample that had been dredged from Rojoa and Aaraanbiru on November 7 at a depth of 30 feet. The principal reason for selecting this curve was that, by inspection, the "composite" of 91 decay curves from various types of organisms and tissues closely resembled the sand

curve and, of the two curves, the data for the sand curve were more extensive and fitted more closely to a curve of low degree (see Fig. 3). However, there were a few curves that departed significantly from the sand curve and those are also shown in Figure 3. The decay correction factor was determined by dividing the value on the sand curve for December 1 by the value on the sand curve for the day the sample was counted. The range of these factors was from 0.68 for November 24 to 1.51 for December 12.

The samples from the pre-test collections were not corrected for decay since the change in counting rate during the period the samples were counted was slight. Maximum correction factors would have been about 1 percent. For differences between pre and post shot decay curves see Figure 3.

Self-absorption. This year sample counts were corrected for self-absorption. In 1949 no correction for self-absorption was determined but an attempt was made to keep the ash on the plate thin and constant in amount. Although it was recognized that the types and the proportions of isotopes varied from sample to sample, the decay and mass absorption curves (see Figs. 3 and 4) indicate that the sand sample approximates the mean of all the curves. Hence the same sand that was used to determine the correction factor for decay was also used to determine the self-absorption correction factor. A few of the actual values, based on the total weight of ash on $1\frac{1}{2}$-inch plate, are as follows: 100 mg, 2.6;

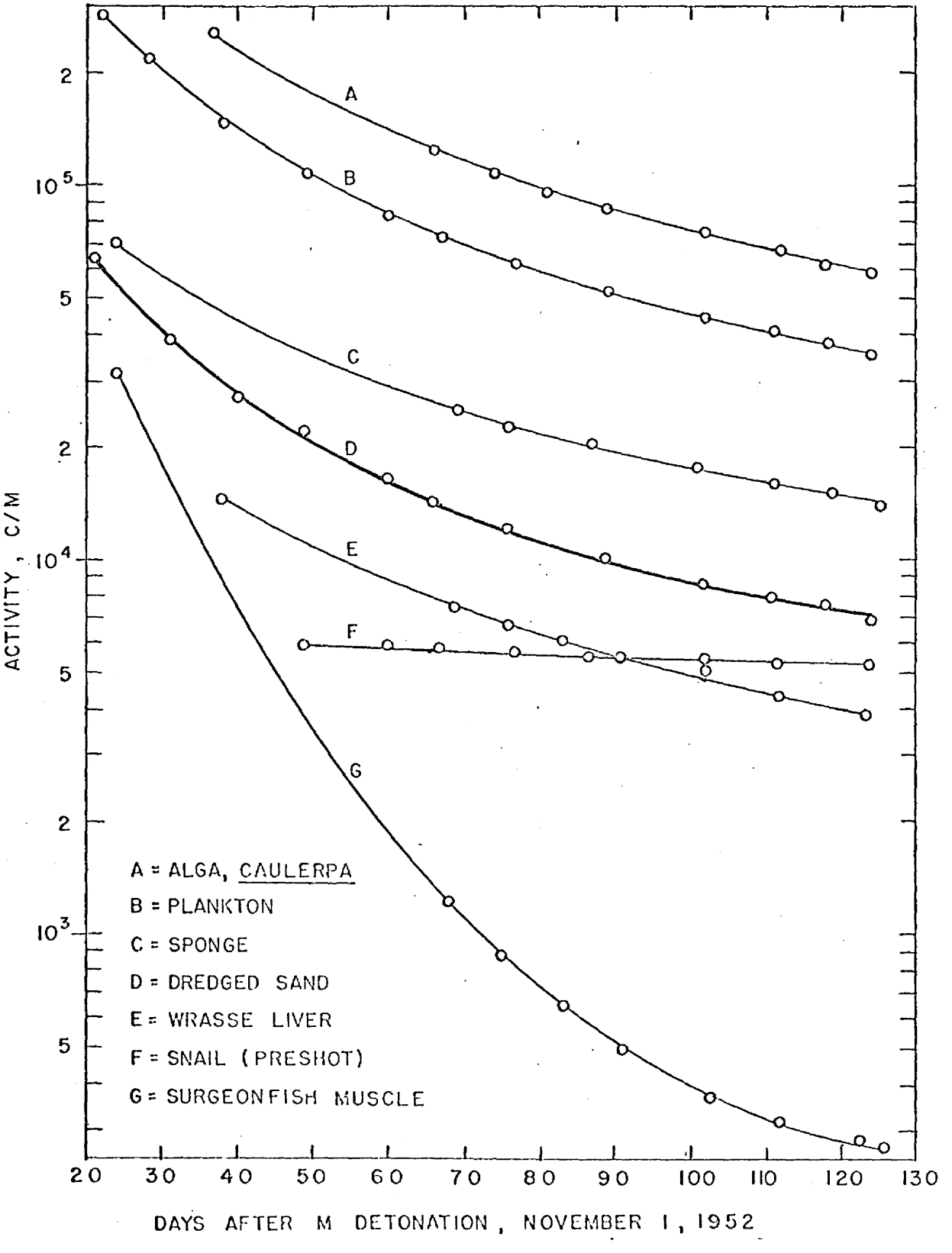


Figure 3. Decay curves.

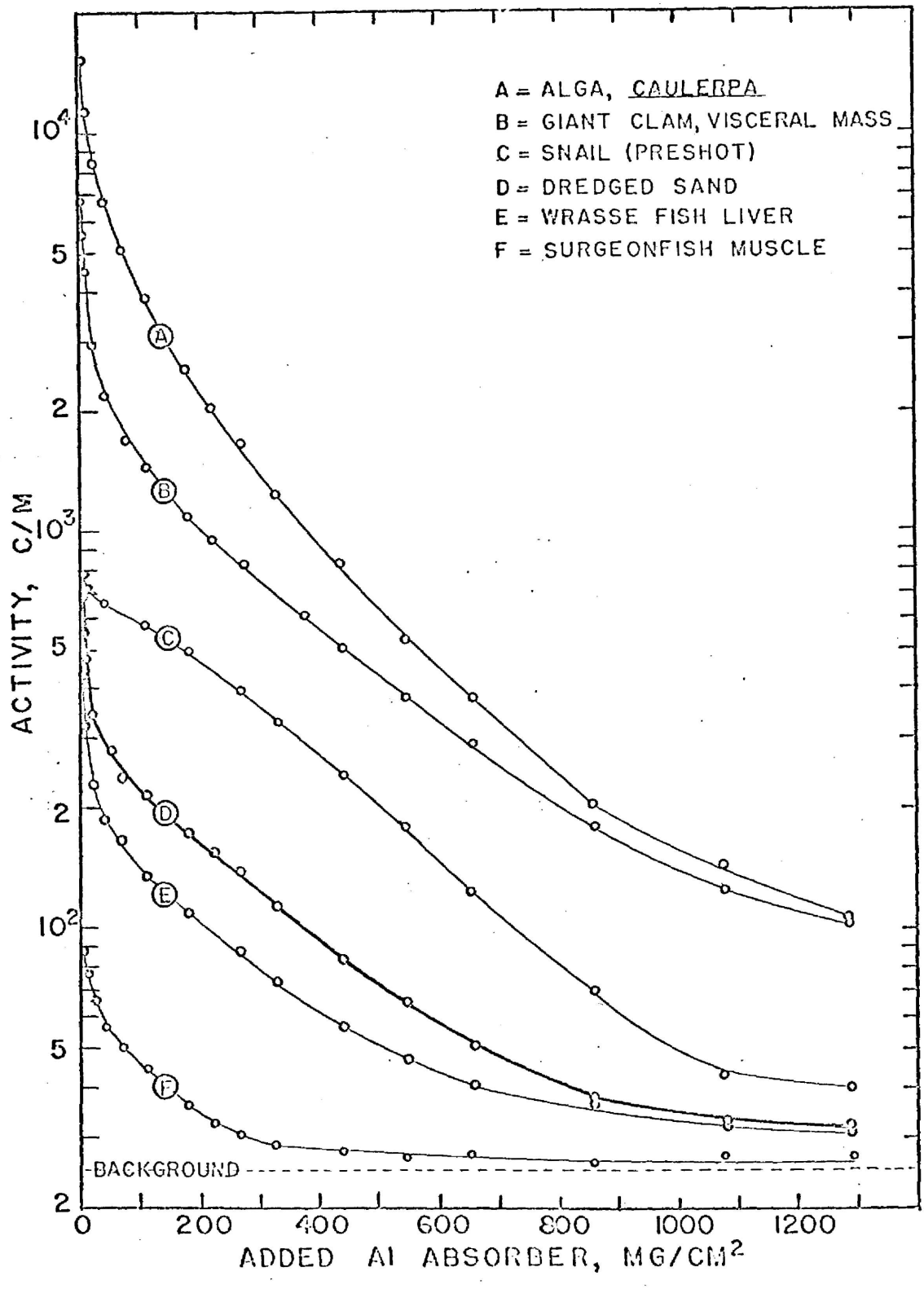


Figure 4. Mass Absorption curves.

300 mg, 4.0; 600 mg, 5.2; and 1100 mg, 6.9. The average self-absorption correction factor from 135 randomly selected plates was 2.23 ± 0.023.

Total correction factor for 68 pre-test samples was 3.93 ± 0.21, and for 64 post test samples was 5.98 ± 0.62.

4. RESULTS AND ANALYSIS OF DATA

The reliability of the results of certain average values as used in this report to express the radioactivity of a group of organisms is subject to the following considerations:

(1) Non-random selection of specimens. In the field, collection of specimens was directed towards obtaining certain species at all stations, if possible, and supplementing this collection with whatever other species were available. When a large number of a single group of organisms was available only a small percentage of the specimens was collected, whereas all of the specimens may have been collected for another group of organisms which were less abundant. Hence, the specimens are represented qualitatively rather than quantitatively in the field collection and also in the samples used for counting.

(2) Random selection of tissues. In some instances the activity of pre-shot invertebrates for a collecting station was estimated by averaging all the samples counted irrespective of tissue or species. Such an estimate is an average of plate counts and not an average of the pre-shot invertebrates.

For some of the fish the total activity of individuals was determined, not by randomly selecting by tissues, but by using weighted samples of all tissues. The activity of the group (fish) was then determined by averaging the values for the individuals. Although the two methods for determining the group average differ in the degree of refinement of the data, one viewpoint is that the method used for the pre-shot invertebrates adequately describes the trends and that for these organisms further refinement is not warranted because of the nature of the errors in the data.

(3) Variance of sample counts. Variance both within groups and between groups was often great. The greatest variance and also the highest specific activity were found in th those tissues with radioactivity from "surface" contamination, e.g., algae in the digestive tract of fish, sand in the gut content of the sea cucumber, algae growing on the carapace of the crab, or fallout particles on the surface of land plants. On the other hand the radioactivity of tissues with absorbed isotopes only, such as muscle, bone and liver, was less variable and was usually lower. Consequently, it is believed that the greatest cause of variance in the sample counts was due to the amount and type of food in the digestive tract and/or the materials on external surfaces.

(4) Number of items in a sample. Small samples resulted from breaking down the collection into small groups such as species. The combination of a few samples and a large value

for the variance considerably impairs the reliability of results.

In view of these considerations, the best estimate of the absolute value of the radioactivity of a group of organisms at a collecting station is an average of the values for the individual organisms. However, for comparison of activities by collecting stations the best estimate is made by comparing similar species and tissues. Because the variance both between and within species was often great and the number of samples was limited, the most that can be obtained from these data is trends and certain relative values.

4.1 Water Samples

While the land and reef collections were being made, the "M-boat" that had transported the field crew from the Oakhill to the collecting station was used for dredging, plankton towing, and water collecting in contiguous waters. Because of the expected difference in specific activity, the volume of the pre-shot water samples was 6 liters and of the post shot samples, ½ liter. The samples were collected with a Foerst-type water bottle.

Sample Preparation. Since it was impractical to bring six-liter water samples to the laboratory for processing, a precipitation method was used in the field for the pre-shot samples and only the precipitate was returned to the laboratory for counting and analysis. The procedure used in the

field was determined from experimentation in the laboratory with "spiked" sea water samples and in general was a double precipitation process in which most fission products were brought down in a ferric hydroxide scavenge. Calcium and strontium were precipitated as oxalates. The specific procedures are outlined in the Appendix.

Results. Results are presented in Table 1. It is to be noted that the values in this table are in terms of milliliters of water sample and that the disintegration rate is as stated and not in thousands as has been used in other tables in this report. Also the values for both the "$Fe(OH)_3$ scavenge" and the "Ca-Sr oxalate", even though small, have considerable reliability because the values have been based on large samples. The total sample activity was divided by the number of milliliters in the sample, which was 6,000 for the pre-test samples and 500 for the post test samples. The values for "whole sample" (post shot) were based on a 3-milliliter sample that was withdrawn before precipitation and hence would be expected to be less reliable.

From inspection of Table 1 the following conclusions can be drawn. For the pre-test samples radioactivity of the Bogombogo sample was considerably greater than for other stations. Why it was greater is not known, but activity of plankton samples was also greatest from this station. There were small but measurable amounts of activity in water samples from other stations. For the post test samples the amount of activity in the samples was closely and inversely related to

Table 1 - RADIOACTIVITY OF WATER SAMPLES
d/m/ml

ISLAND		PRE-TEST			POST TEST			
		Sample depth	$Fe(OH)_3$ scavenge	Ca-Sr oxalate	Sample depth	Whole sample	$Fe(OH)_3$ scavenge	Ca-Sr oxalate
Japtan	S			-		25.	0.09	0.48
	B			-	4'	Bg.	0.17	Bg.
Igurin	S		Bg.	-		16.	0.32	0.30
	B	40'	0.01	-	60'	Bg.	0.72	0.14
Rigili	S		0.07	-		19.	2.3	0.83
	B	62'	0.04	-	55'	Bg.	1.8	0.66
Bogombogo and Bogallua	S		0.35	0.05		350.	96.	18.
	B	45'	1.11	0.26	25'	330.	92.	16.
Engebi	S		0.02	-		46.	20.	2.7
	B	55'	0.04	-	25'	70.	22.	3.1
Aomon and Rojoa	S		0.01	-		Bg.	5.0	1.0
	B	84'	0.02	-	25'	Bg.	7.0	1.0
Runit	S		0.13	-		40.	0.84	0.35
	B	20'	0.25	-	20'	Bg.	0.04	0.22

S = Surface
B = Bottom

distance of sample from test site. For stations nearest the test site, values for the post test samples were several hundred times greater than for the pre-test samples. Since the counts of "$Fe(OH)_3$ scavenge" and "Ca-Sr oxalate" do not equal the count of "whole sample" evidently all of the radioactive materials were not removed by these processes.

A rain water sample was collected 33 hours after the Mike shot in the lagoon off Eniwetok Island. A 450-cc sample was evaporated and counted on November 4, 87 hours after Mike, using a Victoreen survey meter with a one-inch end window tube, window thickness 1.8 mg/cm^2. The maximum count was 10,000 per minute.

4.2 Plankton

The plankton nets were ½ meter in diameter and 2 meters long. The anterior section was cylindrical, the posterior section conical with a detachable net end. The plankton tows were made in pairs, at the surface and during daylight hours. One net of each pair was constructed with No. 6 silk (74 meshes per inch) and the other of No. 12 silk (173 meshes per inch). Towing time was usually one hour and the distance towed was about 1½ miles. Catches of plankton were small. Exclusive of jelly fish the greatest volume of plankton in a one-hour tow was 28 cc. This value was obtained by decanting and measuring the preservative and then subtracting this amount from the volume of preservative and plankton.

A gross examination of the types of organisms present

in the catches was made to determine if the difference in counts between net hauls and between stations could be accounted for by the type of organism in the catch. Although the catches varied considerably both quantitatively and qualitatively, there was strong evidence that activity of the samples was not associated with the presence of any one group of organisms. Autoradiographs of a dried plankton sample showed that the activity was usually associated with inanimate objects, but even when the organisms were active the association was not with any one particular group (see Section 4.9.1). Further evidence was obtained from the paired hauls, in which the activity of the samples often varied but the composition of the catch was similar. For example, the catch in net B and net D at Bogallua appeared similar in composition - foraminiferans principally, and some snails, copepods and a few miscellaneous eggs and arrow worms - but the sample from net B was 7 times more active than the sample from net D (1,160,000 d/m/g ÷ 155,000 d/m/g). Since net B was of finer mesh than D (173 and 74 meshes per inch respectively) it might be thought that some small radioactive organism was escaping the D net and was being caught in B, but microscopic examination of the catches did not demonstrate this to be true. It is believed that the fine-meshed net was more efficient in capturing suspended, inanimate radioactive particles.

Results. The radioactivity in plankton samples is recorded in Table 2.

Table 2 - RADIOACTIVITY OF PLANKTON SAMPLES
Thousands of d/m/g Wet Sample

Island	PRE-SHOT		POST SHOT	
	Net A or B	Net D	Net A or B	Net D
Igurin	0.79	1.1	140	34
Rigili	--	1.3	71	19
Bogallua			1100	160
Bogombogo	2.9	2.4		
Engebi	0.31	0.28	--	--
Rojoa	0.34	0.10		
Aaraanbiru			100	24
Runit	0.12	0.11	48	67

Nets A or B: #20 silk, 173 meshes per inch
Net D: #6 silk, 74 meshes per inch

From inspection of Table 2 the following conclusions are made. There were measurable amounts of radioactivity in all the pre-shot samples, especially those from Bogombogo. For similar areas, the post shot samples were more radioactive than the pre-test samples by 200-300 times. The post shot samples from Igurin were higher than those at Rigili, Aaraan-biru and Runit, which were closer to the shot island. Usually the catch in the fine-meshed net was considerably more radioactive than the catch from a coarser-meshed net for paired hauls from the same station, especially in the post shot samples.

Some radioactivity was also found in the plankton preservative. The activity of the preservative from the Bogallua collection that was filtered through No. 42 Whatman paper was 10,000 d/m/cc as compared to 11,000 d/m/cc for the unfiltered sample. The plankton for the same sample was 100 times greater (1,100,000 d/m/g wet). The activity of the preservative suggests that some radioactive isotopes associated with the plankton are partly soluble in a 4 percent formalin solution or that some of the adsorbed particles are washed off the organisms.

4.3 Algae

The algae collections included five species of blue-green algae, 14 species of green, 3 species of brown, and 7 species of red algae. A check list of species collected for assay is given in the Appendix.

Analysis by Area. Because of the paucity of samples and non-randomness of sampling, the best evaluation of the data

can be made by comparing the averages of the radioactivity of all the samples collected at each station. In Table 3 the average radioactivity of the algae at each collecting station is given.

In the pre-test collection the samples from those islands close to, or upon which previous atomic tests had been conducted were the most radioactive. One sample in particular, collected in a stagnant pool 250 yards east of Lake George on Eberiru Island had a count of 54,000 d/m/g wet weight. Three others collected on the tide flats at the western tip of Runit Island averaged 31,000 d/m/g. In the post shot series, for stations within 9 miles of the shot island (Bogallua, Engebi, Aomon), the average of all the algae samples from one station was not significantly different from a similar average for any other station. The samples collected at the islands beyond this area contained significantly less radioactivity, the least radioactivity being found at Japtan.

Analysis by Species. Of the 7 most common species of algae collected there is no species showing activity which is consistently higher than that of any of the others. The radioactivity of the coralline algae, which contain a large amount of calcareous matter, does not differ from that of succulent forms for specimens at the same station. These data are presented in Table 4. When the samples were combined into phylogenetic groups still no difference in radioactivity between groups could be shown. This observation was also noted in the 1949 survey report (AECD-3446).

Table 3 - RADIOACTIVITY OF ALL ALGAE SAMPLES BY ISLANDS
Thousands of d/m/g Wet Sample

Island	PRE n	PRE Ave.	PRE Max.	PRE Min.	POST n	POST Ave.	POST Max.	POST Min.
Japtan	6	0.066	0.099	0.041	6	0.3	0.70	0.22
Igurin	5	0.19	0.51	0.075	6	15.	38.	6.8
Igurin*	3	0.16	0.22	0.067	4	16.	40.	4.1
Rigili	4	0.46	0.97	0.14	6	550.	2100.	28.
Rigili*	4	0.36	0.58	0.21				
Bogombogo	7	1.6	4.3	0.24				
Bogombogo*	2	0.74	1.1	0.37				
Bogallua					8	5200.	14,000.	1200.
Engebi	7	8.2	21.	0.18	3	4000.	6800.	2500.
Engebi*	3	8.4	11.	6.2				
Aomon-Aaraanbiru	12	7.7	54.	1.7	5	1400.	3900.	56.
Aomon*					4	3600.	6200.	400.
Runit	12	9.8	51.	0.087	9	110.	250.	13.
Runit*	6	3.5	9.8	0.20	4	92.	250.	26.

*dredged samples

Table 4 - RADIOACTIVITY OF THE SEVEN MOST COMMON ALGAE, POST SHOT BY ISLANDS
Thousands of d/m/g Wet Sample

Island	Halimeda**	Caulerpa	Lyngbia	Cladophora	Bryopsis	Dictyota	Jania**
Engebi			6800	2600.	2500		
Bogallua	1700.	2500.	14,000	6400.			
Aomon	240.	150.	2400	56.	3900		
Aomon*	2500.					5300	6200
Igurin	9.					10	
Igurin*	4.	22.				16	
Rigili	700.		820				
Runit	13.	120.	36	69.			240
Runit*					130	38	
Japtan	0.59	0.33		0.25			

*dredged samples
**coralline algae

Radiochemical Analysis. Radiochemical analysis of the pre-test sample from the Lake George area (Section 4.8) showed that Ce^{144}, with a half life of 280 days, contributed 74 percent of the radioactivity. Results of radiochemical analyses of post test samples of sand dredged off Rojoa Island and of 3 algae collected in the lagoon 200 yards off Bogallua Island are given in Table 18.

From 85 to 96 percent of the total activity of the algal samples is accounted for by the presence of the highly insoluble fission products - cerium, ruthenium, zirconium, and the trivalent rare earths. Since the algae are not likely to take up these insoluble materials in their normal physiological processes, it seems very probable that most of the activity is present on the surface of the algae, rather than in the cells themselves. This does not, however, rule out the presence of some radioactive salts in the cell structure or in the cell sap. It has been shown that Sr^{90} is absorbed by plants (UCLA-247)[2], and it is generally known that calcium is an essential element in plant metabolism. Thus it is highly probable that a portion of the calcium-strontium fraction found in the analyses is in the protoplasm of the algae.

4.4 Invertebrates

In this section the pre and the post test sampling are reported separately since the collection and analyses of the data were made by different individuals.

Pre-test

Methods of collection were the same as for previous surveys, that is, hand pries and gloves were used when necessary to obtain specimens found while wading or swimming. The contents of the small dredge were examined on the stern of the "M-boat" from which the dredge was towed. Special attention was given to locating certain common animals intended to serve as a basis for comparing localities. These were primarily sponges, corals, sea urchins, sea cucumbers, ghost crabs, rock crabs, red-eyed crabs, hermit crabs, snails, clams, and oysters. While collecting these primary kinds, other invertebrates were also sought to obtain a collection that would be representative of the locality. While most of the collecting was done on the lagoon side of the islands, approximately one-third was on the outer side, chiefly at Engebi, Runit, Japtan, and Igurin. Specimens from Piiraai were collected by the crew of "M-boat" No. 38.

In preparing specimens for ashing, small specimens were ashed entire while large ones were dissected and the tissues ashed separately. In the case of intermediate-sized specimens, hard parts such as exoskeleton or shell were separated from soft parts for ashing. Smaller samples of hard parts than of soft parts were used in order to equalize the quantity of ash on the plates. Animals from which tissues were dissected and ashed were: sea cucumbers, sea urchins, large crabs, snails, and giant clams.

Analysis of the data was based on sample counts of one or

more tissues rather than on counts of the entire organism, as was done for certain treatments of the fish data. Attempts to compare species by areas on the basis of the ratios of activity of their tissues were thwarted by a lack of some samples and by the presence of many samples with only background counts, i.e., net sample counts of zero. Also, the method of ranking was considered but was believed to be inadequate because of the great effect of surface contamination upon the average of a limited number of sample counts (see p.18).

Results. Appendix Table 1 gives individual sample values. Table 5, page 32, shows average amounts of radioactivity in the main invertebrate groups at the collecting localities. Blanks indicate no specimens were found. These values bear out the inverse relationship of radioactivity to distance from the test sites for operations previous to Ivy, which extended from Runit Island to Engebi Island. Within this range the only significantly low counts came from a small collection made by navy personnel on Piiraai Island. However, it is probable that because of this island's position relative to the prevailing winds, waves, and current it neither initially received nor retained large amounts of radioactivity, in spite of its intermediate position between two shot islands. Igurin and Japtan Islands were almost equally low, and Rigili higher.

Because of their marked influence upon the averages, the high-counting samples included in Table 5 and Appendix Table are listed separately in Table 6.

Table 5 - RADIOACTIVITY OF PRE-TEST INVERTEBRATE SAMPLES BY ANIMAL GROUPS
Thousands of d/m/g Wet Sample

	Japtan	Igurin	Rigili	Bogombogo	Bogombogo*	Engebi inner	Engebi outer	Engebi inner and outer	Engebi*	Aomon	Aomon*	Piiraai	Runit	Runit*
Sponge	0.2	0.2	3.	10.	0.4	-	48.	48.	-	3.	-	-	1.	-
Worm	0	-	-	0.3	-	-	0.9	0.9	-	-	-	-	17.	3.
Hydroid	-	-	-	-	-	-	-	-	-	2.	-	-	7.	-
Coral	0	-	0	0.04	0.02	-	-	-	0.3	0	0.1	-	-	-
Starfish	0	-	0.5	4.	-	-	0.8	0.8	0.5	-	8.	-	0.3	2.
Urchin and Sand dollar	0	-	0.2	-	2.	-	4.	4.	4.	1.	0.3	0.02	-	3.
Cucumber	0	0.02	0.1	2.	-	-	0.08	0.08	0.3	1.	0.6	-	0.5	-
Crustacea	0	0.04	0.03	0.5	-	0.08	2.	0.6	1.	0.7	0.9	0.02	1.	2.
Gastropod	0.07	0.03	0.2	0.6	-	-	5.	5.	1.	1.	-	-	14.	7.
Bivalve	0	0	0.2	0.6	0.1	0.5	8.	5.	-	0.1	0.6	0.01	2.	1.
Cephalopod	-	-	-	-	-	-	-	-	-	0.2	-	-	0	-
Tunicate	-	-	-	-	0.5	-	-	-	6.	-	-	-	-	-

*dredged samples

Table 6 - PRE-TEST INVERTEBRATE SAMPLES WITH HIGHEST ACTIVITY
Thousands of d/m/g Wet Sample

Organism	Tissue or organ	Locality	d/m/g
Snail, *Nerita polita*	Soft parts	Runit	80
Sponge	Entire	Engebi, outer	48
Sea hare, *Dolabrifera*	Gut with much sand	Engebi, outer	22
Urchin, *Echinometra*	Gut and contents	Engebi, outer	18
Snail, *Polinices*	Egg collar, mostly sand	Runit dredge	17
Worm, sipunculid	Entire	Runit	17
Snail, *Cymatium*	Soft parts	Engebi, outer	16
Sponge, black	Entire	Bogombogo	16
Snail, *Strombus maculatus*	Soft parts	Engebi, outer	15
Clam, *Pinna*	Shell and byssus	Engebi, outer	14
Clam, *Pinna*	Soft parts	Engebi, outer	9

The variability that may be expected from two collections taken in close proximity is pointed out in the comparison of two collecting areas on Engebi. Tide pool collecting at the west tip on the lagoon side yielded invertebrates containing significantly less radioactivity than did those collected on the outer, north shore. The average of all samples as well as counts of comparable tissues were alike in this respect. See Table 1 in the Appendix.

The relationship of radioactivity to animal group is not so clear as it is to locality. Comparison with 1949 findings at Eniwetok shows mutual tendencies toward high activities in samples of hydroids, sponges, starfish, and oysters, in descending order of magnitude, with crustaceans and corals containing relatively little radioactivity.

Table 7 gives frequencies of counts by magnitudes for the major collecting areas for both pre and post shot material exclusive of dredged samples. The trend for high counts to predominate near shot areas is almost the same both pre and post test.

Table 7 also serves to demonstrate that the frequency of distribution of logarithms of counts in the post test series is approximately of the normal form, whereas the distribution of the observed counts would be strongly skewed. In the pre-test series the distribution of the logarithms of the counts is normal only in the "hotter" areas and then only if background counts are excluded.

Table 7 - FREQUENCIES OF PRE AND POST TEST INVERTEBRATE ASHED SAMPLE COUNTS BY MAGNITUDES FOR MAJOR COLLECTING LOCALITIES, EXCLUSIVE OF DREDGED MATERIAL
Thousands of d/m/g Wet Sample

Magnitude	Japtan	Igurin	Rigili	Bogom-bogo	Engebi	Aomon Aaraan-biru	Runit
			PRE-TEST				
Background	44	15	11	11	9	6	3
0.01-0.1	1	6	8	3	2	2	1
0.1-1	4	2	13	20	23	15	18
1-10			1	11	17	9	11
10-100				1	6		2
			POST TEST				
Background	13	1					
0.01-0.1	21	2					
0.1-1	15	34	5				3
1-10		25	34			9	20
10-100		4	37	5	8	9	24
100-1,000			14	14	9	4	3
1,000-10,000				4	3	2	
10,000-100,000					1		

A comparison of the activity in different organs of crabs was made using the court found in muscle as unity. The values relative to muscle for other tissues in pre and post test crabs respectively were: digestive system, 6 and 30; gills, 3 and 22; and exoskeleton 6 and 16. In 40 comparisons of the shell and soft parts of pre-test molluscs, the shells were more radioactive than the soft parts for 25 percent, and for the other 75 percent the reverse was true.

Post Test

Invertebrates collected after Mike test are listed in Table 2 of the Appendix. Limitation of time made it impractical to search thoroughly for specimens that would have made possible a complete comparison of collection stations according to species. Since the collections were made soon after the shot (2 to 8 days) it may be presumed that the distribution of radioactive materials was still in a state of flux in the waters of the lagoon, with consequent variability in the degree of radioactive contamination even between local areas at a given station.

The specific activity of individual samples of invertebrates ranged from background at Japtan to 15,000,000 d/m/g wet (sand from sea cucumber gut) at Engebi. One exceptional piece of coral detected from an autoradiograph (Fig.22b) had a specific activity of approximately 100,000,000 d/m/g.

Analysis by Area. Differences in activity between organisms at various collecting stations depend upon the species

and organ or tissue being considered. When compared by ranking within each of the nineteen classes of items in Table 8, the stations fall into the following decreasing order of radioactivity: Bogallua, Engebi, Aaraanbiru, Rigili, Runit, Igurin, Japtan. The giant clam, Tridacna, was the only species collected at every station. Comparison of individual tissues of this clam at each station is made in Figure 5. The specific activity relative to Igurin is shown for gill, mantle, muscle, and digestive gland ("liver"). Whichever tissue is considered, the ranking of the stations remains the same. Japtan is not included since several of the counts were background, hence the ratios are meaningless, and the relative activity was in every case less than one. Included in Figure 5 are the relative activities of beach sand or soil and bottom sand from each station. The latter has a higher relative, specific activity at Engebi than at Bogallua while the reverse is true with the giant clam tissues. No landing was made at Bogallua, consequently no beach sand is available from that station. Bottom sand was taken from sea cucumber guts, usually Holothuria atra. This can be considered a random sample of the bottom sand since H. atra shows no selectivity in its ingestion of bottom materials.[3] This difference between Engebi and Bogal-

Table 8 - RADIOACTIVITY OF SEPARATE TISSUES OR ORGANS OF DIFFERENT GROUPS OF POST SHOT INVERTEBRATES
Thousands d/m/g Wet Sample
(Refer to Appendix Table 2 for n, max. and min.)

	Collecting Stations						
	Japtan	Igurin	Rigili	Bogallua	Engebi	Aaraanbiru	Runit
Digestive Tract and Contents							
Clams	0.076	3.7	74.	530	460	220.	31.
Crabs	0.081	9.7	-	-	7600	-	-
Sea Cucumbers	0.14	64.	200.	5900	15000	4300.	110.
Muscle							
Clams	0.055	0.15	0.76	54	10	2.3	2.0
Snails	-	0.25	3.4	-	-	-	4.3
Crabs	0.049	0.10	1.8	-	410	3.1	1.3
Mantle							
Clams	0.39	0.25	1.5	120	22	4.8	3.1
Oysters	-	-	15.	-	-	120.	-
Snails	-	0.52	4.1	-	-	-	4.3
Body Wall							
Sea Cucumbers	0.057	3.8	15.	110	52	59.	12.
Gill							
Clams	0.12	0.22	-	190	51	9.8	-
Crabs	0.015	0.64	49.	-	-	-	-
Sea Cucumbers	0.063	0.48	3.6	-	100	-	12.
"Liver"							
Clams	0.33	1.1	3.9	120	24	8.8	-
Crabs	0.050	0.61	29.	-	-	-	-
Shell or Exoskeleton							
Clams	Bg.	2.2	9.1	123	45	18.	3.9
Snails	Bg.	0.60	8.0	-	-	-	3.1
Crabs	0.16	1.2	23.	-	750	20.	17.
Entire Coral	Bg.	0.55	15.	3000	2700	-	35.

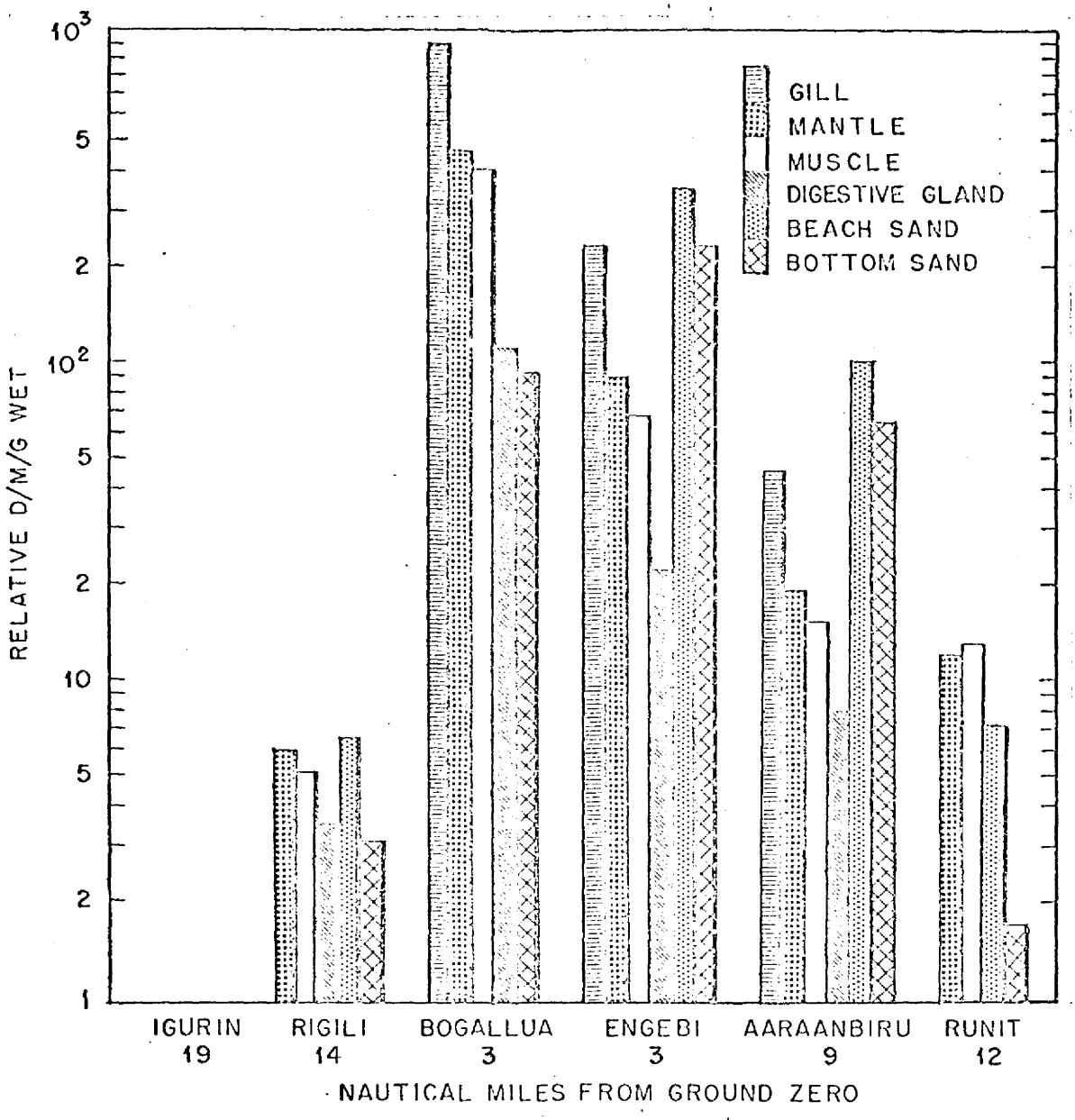


Figure 5. Relative radioactivity of soil or beach sand, bottom sand taken from sea cucumber guts and giant clam gill, mantle, muscle and digestive gland. The relative activity of each type of sample at Igurin is taken as 1.

lua may well be a matter of sampling. One such sample collected from each of the two stations differed by a factor of less than three, while the maximum and minimum specific activities of a series of nine sea cucumber guts taken from an area of less than one thousand square feet at Aaraanbiru differed by a factor of more than six.

The average values of all invertebrate samples from each station are given in Table 9. The limited usefulness of these values is discussed on page 17. They were not considered in the ranking of stations discussed in the preceding paragraph.

Table 9 - RADIOACTIVITY OF ALL POST TEST INVERTEBRATE SAMPLES COUNTED AT EACH COLLECTING STATION
Thousands of d/m/g Wet Sample

	Japtan	Igurin	Rigili	Bogallua	Engebi	Aaraanbiru	Runit
Max.	0.47	75.	400.	7,700.	15,000.	6,800.	160.
Min.	0	0	0.35	25.	10.	2.1	0.63
Ave.	0.083	4.0	44.	1,200.	1,700.	1,100.	26.

Tissue and Organ Differences. General statements can be made as to tissue and organ differences in specific activity although there were not sufficient specimens of any one species of invertebrates to warrant statistical analysis. The relative rankings presented here are based on comparison of the specific activity of each tissue or organ in individual specimens.

However, the same relationship can be found in Table 8 , which is based on the average values of similar species.

1. Muscle consistently has the lowest specific activity regardless of species.
2. "Liver" or digestive gland is the only tissue sampled, other than muscle, which is not subject to external contamination. It rarely has a higher specific activity than the digestive tract and is always more radioactive than muscle.
3. The relative specific activity of the gill varies with the species. In the clams the gills, which are the food gathering organ, have the highest activity, exclusive of the digestive tract with its content. In those snails with a gill the "liver" is the more active. The liver is also more active than the gill in the crabs.
4. The digestive tract with its content is usually the most radioactive portion. Its activity is highly variable, however, even within a species from the same station.
5. Shell and carapace are also highly variable in specific activity.
6. The following rankings of tissues in descending order of specific activity with individual exceptions are:

   a. Clams: (1) digestive tract (visceral mass with contents)
   (2) gill
   (3) "liver"
   (4) mantle
   (5) muscle

shell variable in position

b. Snails: (1) "liver"
(2) gill
(3) mantle
(4) muscle

c. Octopus (one specimen): (1) "liver"
(2) gill
(3) muscle

d. Hermit crabs: (1) digestive tract with contents
(2) "liver"
(3) gill
(4) muscle
carapace variable in position

e. True crabs: (1) digestive tract with contents
(2) and (3) liver or gill
(4) muscle
carapace variable in position

Species Differences. There were not enough samples at any one island to reliably determine species differences. It is probable, however, that both species and individual differences are considerable as is indicated by the data from the two similar species of sea cucumbers presented in Table 8.

At Rigili and Igurin where several specimens of crabs were taken (not more than two of one species), differences within a species are as great as between species. Tissue for tissue the land hermit crabs, Cenobita, may have a higher specific activity than the shore crabs.

Conclusions. The most obvious and striking conclusion is that there was great variability in the amount of radioactivity found in invertebrates at every station sampled. The distribution of radioactive materials was evidently still in a state of considerable flux eight days after the shot. Surface contamination or the presence of radioactive material

in the contents of the digestive tract accounted for most of the radioactivity found in the invertebrates. An appreciable amount, however, was absorbed into the tissues. Muscle consistently had the lowest specific activity and digestive tract with its content the highest. Other tissues or organs varied in ranking depending on the species. In general invertebrates taken at the northern stations were the most radioactive. The decrease in radioactivity from north to south appeared to be more rapid on the east than on the west side of the lagoon.

4.5 Fish

Materials and Methods. The fish specimens were collected in water poisoned with derris root powder in depths up to 12 feet, usually on the lagoon side of each of the station islands. Areas selected for poisoning had a minimum of current combined with adequate coral and substrate to support the typical reef population of fishes.

The number of fish collected varied from 26 to over 300 per station depending on the success of the poisoning operation and the number of species present. These fish represented from 10 to over 30 families and varied in weight from less than a gram to 1589 grams (average 51.1 grams).

Although there were several hundred species of fish living on the reef, the species selected for analysis of radioactivity were those most common to all stations and those that were representative of the various types of feeding habits.

Most of the species selected were reef dwellers and more or less sedentary; however, a few which prefer open sandy bottom, such as goatfish, jacks and flatfish, were also taken and ashed for counting.

The fish which best fulfilled the criteria listed above were the damsel fish (Pomacentridae), surgeon fish (Acanthuridae), groupers (Serranidae) and wrasse (Labridae). Appendix Table 3, which summarizes the material used in the analysis for radioactivity, shows that these four families were taken at all stations. Certain species such as the grouper, Epinephalus merra, the damsel fish, Abudefduf biocellatus, the surgeon fish, Acanthurus triostegus, and the wrasse, Halichoeres trimaculatus, were taken at a majority of the stations.

A total of 237 specimens representing 58 species, 33 genera and 22 families of fishes were counted for radioactivity on 768 plates.

The following organs of the large specimens selected were analyzed for radioactivity: muscle, skin, bone, liver, and gut (including contents). In small fish the following were combined for analysis: (1) muscle, skin, and bone; (2) gut and liver; or (3) entire fish. Omnivores and carnivores were selected in approximately equal numbers at each station.

In order to compare the activity found in various samples of entire fish, the total activity per gram of an individual fish was calculated as the sum of the activity of all tissues, the procedure followed in 1949 (AECD-3446). The results are recorded in Table 10. The tissues listed in this

Table 10 - RADIOACTIVITY OF WHOLE FISH BY STATIONS
Thousands of d/m/g Wet Sample

Common Name	Japtan			Igurin			Rigili			Bogombogo-Bogallua			Engebi			Aomon-Aaraanbiru			Runit		
	Pre	n	Post	Pre	n	Post	Pre	Post	n	Pre	n	Post	Pre	n	Post	n	Pre	n	Post	n	Pre	Post	n
Damsel	.020	5	.22	.024		.74	2	.10	26.	3	.21	2	520.	4	.43	4	800.	5	.31	3	272.	4	1.5	8.2	6
Surgeon	.031		.31	.024	2	.56		.052	3.6		.079		1,100.		.030		110.		.094		45.		.11	2.9	2
Butterfly	.021		.27	.024		.30		.083	3.6		.082		571.		.24		130.		.35		---		---	3.8	
Parrot	---		.091	---		.20		.067	12.		.15		---		.49		340.		.25		62.	5	2.3	16.	
Blenny	.02	2	.044	.013	2	---		.042	18.		---		---		.85		370.		---		---		---	---	
Brotulid	---		---	---		---		---	---		---		2.8		---		---		---		---		---	---	
Mullet	0	4	---	---		---		---	---		---		---		---		---		---		---		.57	---	
Puffer	.022		---	---		---		---	---		---		160.		---		---		---		11.	2	---	---	
Filefish	---		---	---		---		---	---		---		220.		---		---		---		---		---	---	
Grouper	.037		.64	.017		.46		.040	.32		.030		22.	2	.064		7.0		.035		1.7		.051	.33	
Squirrel	---		.22	---		.14		---	17.	3	.035	2	16.		.29	2	24.	2	.072	3	2.4		---	1.6	2
Wrasse	.020	4	.22	.017		.17		.055	1.5		.035	2	79.	9	.15		22.	4	.073		6.8	7	.33	2.3	6
Goatfish	.031		---	.032		.14		.064	.40		.064		---		.042		7.6		---		---		.69	1.0	
Eel	---		.11	---		---		.032	---		.022		61.	3	---		---		.032		---		---	---	
Goby	---		.21	---		---		---	1.3		---		98.	4	---		---		.079	3	1.0		.13	---	
Cardinal	---		---	.012	2	.10		.004	---		.018	2	23.	2	.45		4.7		.057		.72		---	---	
Snapper	---		---	---		2.0		---	---		---		2.0		.026		---		.066		2.4		---	---	
Halfbeak	---		---	---		---		---	---		---		---		.073		---		---		1.3		---	---	
Jack	---		---	---		---		---	---		---		---		---		---		---		.86		.041	.17	
Smelt	---		---	---		---		---	---		---		---		---		---		---		---		.044	---	
Flatfish	---		---	.013		---		---	---		---		---		---		---		---		---		---	---	
Reeffish	---		---	---		---		---	---		---		47.	5	---		---		---		---		---	---	
n	20		10	12		11		10	14		14		36		16		18		17		26		10	21	
Ave.	.018		.23	.019		.51		.054	12		.073		160		.55		280		.14		59		.58	4.4	
s	.012		.16	.007		.56		.027	42		.068		240		1.9		370		.12		210		.76	4.5	

table made up at least 95 percent of the total weight of the fish. Gills, glands, and nervous tissue were assumed to be similar in activity to bone, skin, and muscle.

Analysis by Area. Comparisons of averages for entire fish indicate the greatest amount of radioactivity was in post shot samples collected at Engebi Island, followed by Bogallua, Aaraanbiru, Rigili, Runit, Igurin and Japtan in descending order (Table 10 and Fig. 6).

If the tissues are analyzed by stations a slightly different order is indicated. Activity in muscle is greatest at Bogallua, followed by Engebi, Aaraanbiru, Rigili, Igurin, Japtan and Runit. The sequence is similar for the activity in bone, skin, and liver except for a shifting in the last four islands. Japtan generally appears to be lowest in activity with Igurin next lowest and Rigili and Runit alternating in position. The activity in the gut had a sequence similar to that of entire fish because the gut and contents were the greatest contributing factor.

The greatest increase of radioactivity in post test fish over pre-shot levels was in the islands to the west and south of Elugelab where it was especially noticeable in muscle, skin, bone and liver. In spite of the fact that Bogallua fish had slightly less activity in the gut, several times as much activity appears in the liver, bone, skin and muscle as in post shot fish from Engebi. These data seem to indicate that the metabolized, and to some extent the adsorbed (onto the skin), radio-

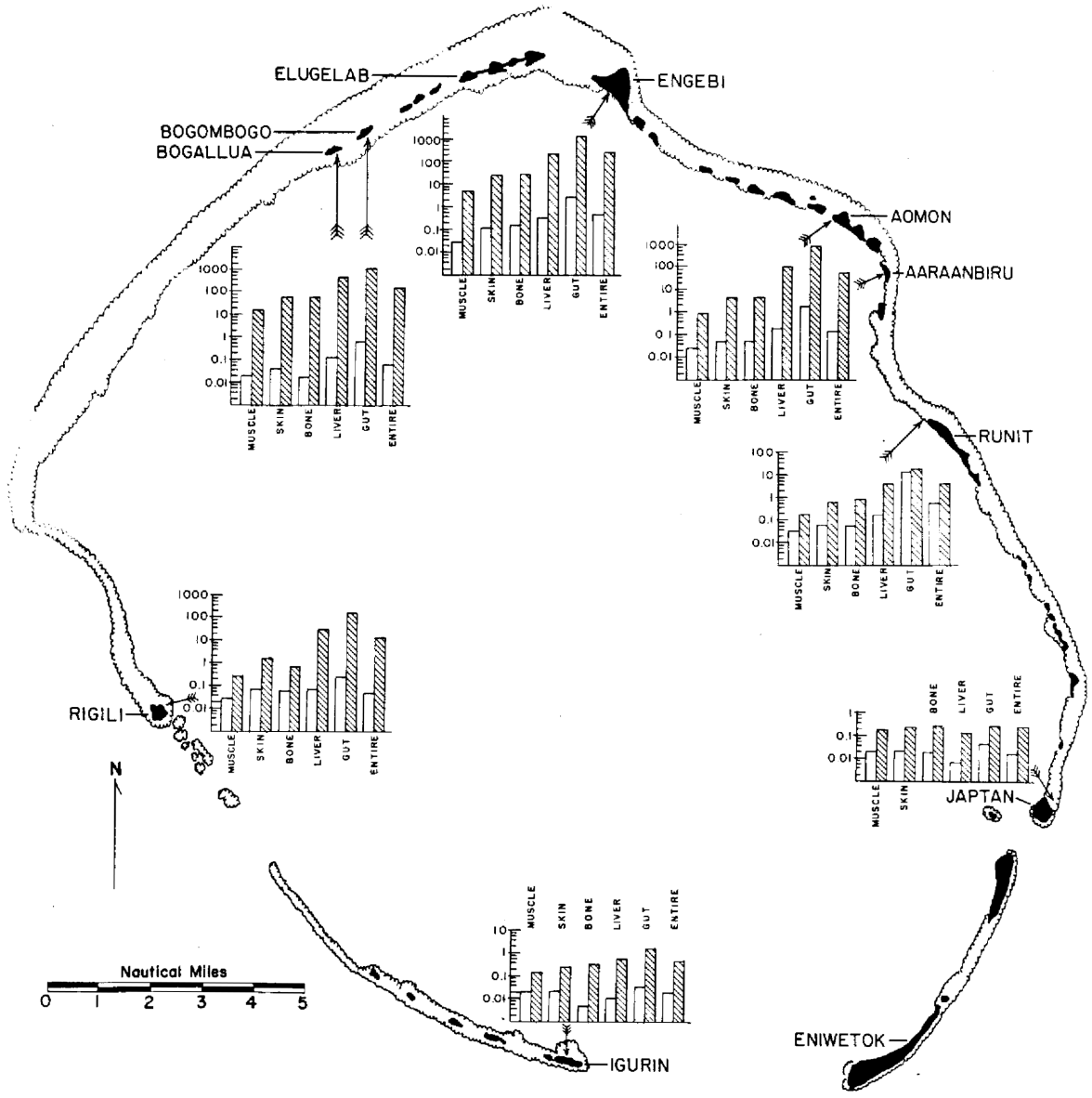


Figure 6. Pre-shot (open histograms) and post shot (shaded histograms) radioactivity in thousands of d/m/g wet weight of whole fish and of fish tissues.

isotopes were available in greater amounts at Bogallua - carried westward from the target area by currents and wind in the lagoon. This is partially substantiated by the presence of turbid water west and southwest of the target area. It must be noted also that much of the activity at Engebi was pre-shot and probably made up of considerable inert material, biologically speaking.

A large number of dead and dying fish were seen in and close to the turbid water flowing from the target area westward inside the lagoon between Elugelab and Bogallua eight days after the blast. There were some injured fish at Engebi also and two or three badly injured goatfish were collected near the shore (Fig. 7).

Analysis by Species and by Feeding Habits. Among those fish which are fairly well represented in the samples, damsel fish appear to ingest the greatest amount of active material, followed by surgeon fish, butterfly fish, parrot fish, gobies, wrasse, squirrel fish, cardinal fish and groupers. Other species, of which we have only a few samples, and which indicate their ability to absorb active materials, are filefish, blennies, puffers and eels (Table 11). As the range of d/m/g indicates, there is great variation from species to species, island to island, and even from specimen to specimen, especially evident in the post shot fish.

Omnivorous species almost invariably showed more activity than carnivorous species from the same area. Exceptions were

Figure 7. Goatfish, Mulloidichthys auriflamma, collected at Engebi Island, November 8, 1952. One of many seen along the shore in an injured condition. Note absence of skin and scales on right side and back above lateral line. Left side of fish apparently normal.

Table 11 - RADIOACTIVITY OF FISH FROM ALL STATIONS COMPARED BY FEEDING HABIT
Thousands of d/m/g Wet Sample

Common name	PRE-SHOT n	Range	Ave.	POST SHOT n	Range	Ave.
Omnivores						
Damsel	16	0.024 - 1.5	0.30	24	0.22 - 800	300.
Surgeon	8	0.024 - 0.11	0.056	8	0.31 - 1100	150.
Butterfly	6	0.021 - 0.35	0.13	6	0.27 - 570	120.
Parrot	4	0.067 - 2.3	0.70	11	0.091 - 340	62.
Blenny	6	0.013 - 0.085	0.16	3	0.042 - 367	130.
Brotulid				1	2.8	2.8
Mullet	5	0 - 0.57	0.11			
Puffer	1	0.022	0.022	3	11. - 160	60.
Filefish				1	220.	220.
All Omnivores	46	0 - 2.3	0.22	57	0.042 - 1100	190.
Carnivores						
Grouper	7	0.017 - 0.064	0.039	8	0.32 - 22.	6.8
Squirrel	7	0.035 - 0.14	0.120	11	0.14 - 24.	11.
Wrasse	11	0.017 - 0.33	0.070	29	0.17 - 79.	30.
Goatfish	6	0.031 - 0.69	0.16	4	0.14 - 7.6	2.3
Eel	3	0.022 - 0.032	0.029	4	0.11 - 61.	46.
Goby	4	0.079 - 0.130	0.092	7	0.22 - 98.	56.
Cardinal	7	0.004 - 0.450	0.082	5	0.10 - 23.	10.
Snapper	2	0.026 - 0.066	0.046	3	2.0 - 12.	5.5
Halfbeak	1	0.073	0.073	1	1.3	1.3
Jack	1	0.041	0.041	2	0.17 - .86	.52
Smelt	1	0.044	0.044			
Flatfish	1	0.013	0.013			
Reeffish				5	13. - 167.	47.
All Carnivores	51	0.004 - 0.69	0.081	79	0.10 - 98.	24.
Omnivores & Carnivores	97	0 - 2.3	0.15	136	0.042 - 1100.	92.

found at Igurin and Japtan (Fig. 8) where activity was more or less similar in the two groups. Comparisons of pre-shot activity at other stations indicate the omnivores to be 2 to 7 times as radioactive as the carnivores. Comparisons of post shot activity indicate the greatest difference existed at Engebi, where omnivores were about 32 times as radioactive as carnivores, and at Aaraanbiru where omnivores were about 30 times as active.

The data indicate that ratio of radioactivity, omnivores to carnivores, was greater at Aaraanbiru and Engebi than at Japtan and Igurin, which is further substantiated by comparing like tissues of carnivores and omnivores. At Japtan and Igurin comparatively small amounts of pre-shot radioactive material were taken into the gut of either omnivores or carnivores, and approximately equal amounts were retained in the muscle, skin, bone and liver. On the other hand, at pre-shot and post shot islands, where the activity was comparatively high, the omnivores took in considerably more radioactive material in feeding than the carnivores but retained proportionately less in the liver, bone, skin and muscle. For example, at Engebi and Aaraanbiru the activity in the gut of omnivores was approximately 21 times and 125 times as great, respectively, as in carnivores, yet the radioactive materials retained in the muscle, skin, and bone ranged from only 2.5 to 7.2 times as much in omnivores. It should be pointed out, however, that because of the great variation in activity of the gut both within and between species, any conclusions made should take this factor into consideration.

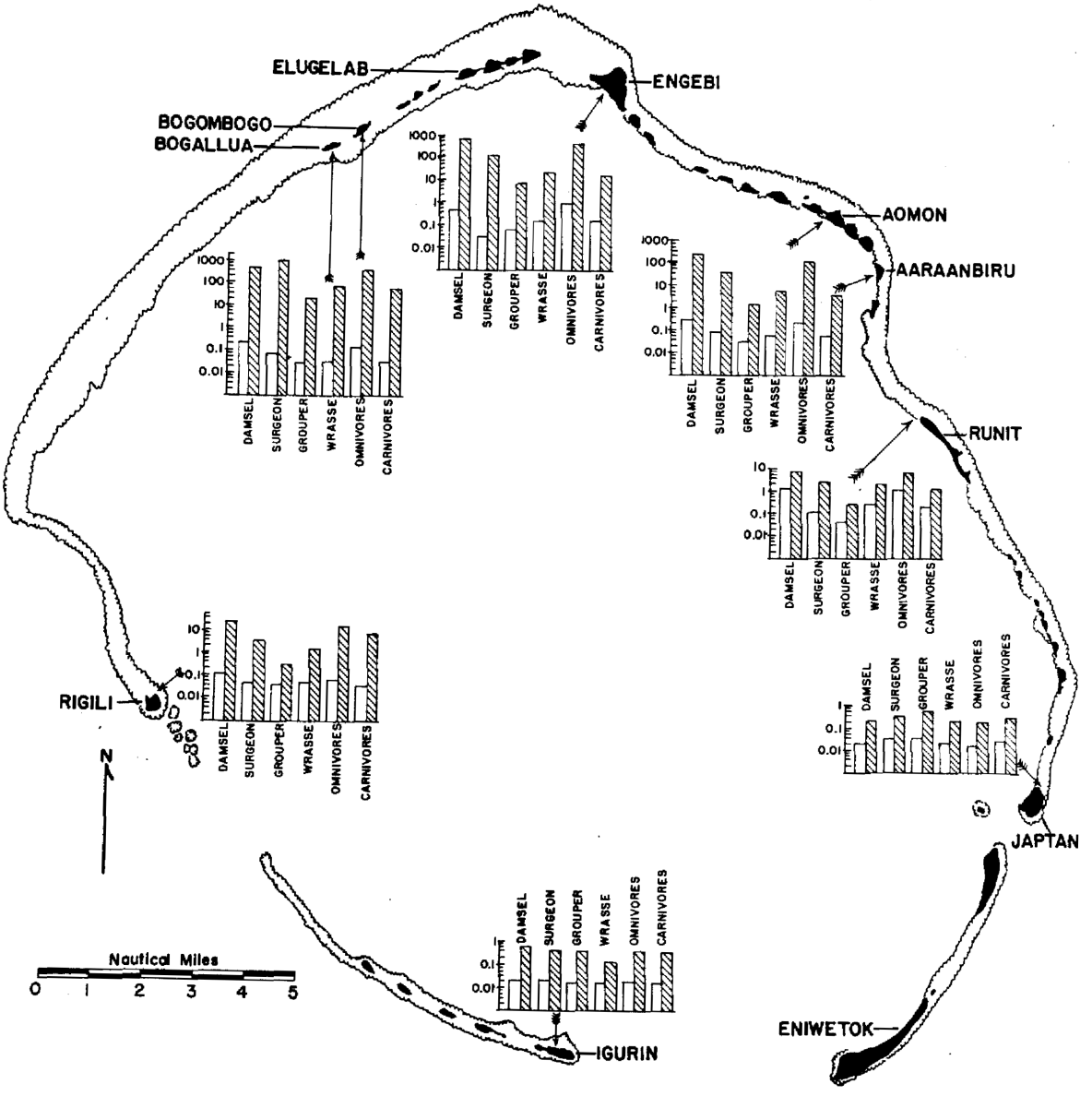


Figure 8. Pre-shot (open histograms) and post shot (shaded histograms) radioactivity of various species of fish representing omnivores and carnivores, and of all omnivores and carnivores combined.

Analysis by Tissues or Organs. The data for the analysis of tissues or organs are summarized in Tables 12 and 13, in which the d/m/g wet weight of tissues is compared by islands and by feeding habits. Part of the material has been discussed on the preceding pages.

Generally, in both pre-shot and post shot fish, the greatest amount of activity was found in the gut with liver, skin, bone, and muscle having lesser amounts in descending order of magnitude. Exceptions to this sequence were most numerous in skin and bone counts, in which the disintegration rates were about the same. Omnivores usually had slightly more activity in the bone than in the skin, whereas the reverse was generally true in the carnivores. Other exceptions occurred in most of the fish at Japtan and in the pre-shot samples from Igurin, where the activity in the livers was usually lower than in other tissues, while muscle radioactivity was comparatively high in proportion to other tissues and when compared with other stations.

Counts in skin and bone averaged about twice muscle in pre-shot omnivores and carnivores. In post shot omnivores the skin and bone counts were about 5 times muscle and in carnivores about 2 to 3 times muscle. Differences between these three tissues seemed to be greatest at Rigili, Engebi, and Aaraanbiru in post shot fish.

Aside from the exceptions at Japtan and Igurin mentioned above, the liver was usually much more radioactive than skin, bone, and muscle. The average for all fish livers combined

Table 12 - RADIOACTIVITY IN TISSUES OF FISH COMPARED BY PRE-SHOT STATIONS
Thousands of d/m/g Wet Sample

	JAPTAN	IGURIN	RIGILI	BOGOMBOGO	ENGEBI	AOMON	RUNIT	AVE.	RANGE
Omnivores, n	7	6	5	5	4	6	4	37	
Muscle	0.019	0.022	0.040	0.021	0.040	0.030	0.036	0.028	0.014 - 0.092
Skin	0.023	0.013	0.048	0.058	0.14	0.064	0.081	0.055	0 - 0.24
Bone	0.011	0	0.059	0.032	0.23	0.064	0.10	0.060	0 - 0.56
Liver	0	0.020	0.065	0.18	0.50	0.24	0.29	0.16	0 - 0.71
Gut	0.063	0.040	0.34	1.1	6.2	2.0	20.	3.4	0.026 - 45.
Carnivores, n	4	6	5	8	5	7	6	41	
Muscle	0.022	0.018	0.018	0.020	0.025	0.023	0.038	0.027	0 - 0.057
Skin	0.019	0.030	0.11	0.033	0.10	0.050	0.053	0.054	0 - 0.33
Bone	0.028	0.010	0.067	0.009	0.098	0.049	0.034	0.040	0 - 0.16
Liver	0.018	0	0.084	0.095	0.11	0.15	0.090	0.082	0 - 0.24
Gut	0.031	0.033	0.097	0.44	0.77	1.4	7.6	1.6	0 - 33.
All Fish, n	11	12	10	13	9	13	10	78	
Muscle	0.020	0.020	0.029	0.020	0.032	0.025	0.037	0.026	0 - 0.092
Skin	0.021	0.021	0.077	0.042	0.12	0.056	0.064	0.055	0 - 0.33
Bone	0.018	0.005	0.063	0.018	0.16	0.056	0.060	0.049	0 - 0.56
Liver	0.007	0.010	0.075	0.13	0.28	0.19	0.17	0.12	0 - 0.71
Gut	0.051	0.037	0.22	0.70	3.2	1.7	13.	2.4	0 - 45.

Table 13- RADIOACTIVITY IN TISSUES OF FISH COMPARED BY POST SHOT STATIONS
Thousands of d/m/g Wet Sample

	JAPTAN	IGURIN	RIGILI	BOGOLLUA	ENGEBI	AARAANBIRU	RUNIT	AVE.	RANGE
Omnivores, n	5	5	6	7	5	2	4	34	
Muscle	0.12	0.12	0.33	22.*	7.8	2.4	0.26	6.5*	0 - 35
Skin	0.16	0.31	2.3	120.	46.	12.	0.90	33.	0.080 - 166
Bone	0.33	0.24	0.90	130.	56.	11.	1.0	35.	0 - 182
Liver	0.15	0.57	66.	1,200.	540.	370.	8.0	340.	0 - 2,100
Gut	0.32	2.4	130.	3,000.	3,300.	3,500.	26.	1400.	0.13 - 6,800
Carnivores, n	5	6	6	10	5	6	5	43	
Muscle	0.26	0.13	0.16	8.0	3.2	0.40	0.14	2.5	0.032 - 18
Skin	0.35	0.24	0.86	22.	9.6	2.3	0.47	6.9	0 - 31
Bone	0.30	0.38	0.46	16.	7.7	1.8	0.66	5.1	0 - 45
Liver	0.11	0.59	4.0	89.	15.	5.2	1.1	24.	0 - 190
Gut	0.26	0.76	140.	520.	160.	28.	11.	160.	0.051 - 890
All Fish, n	10	11	12	17	10	8	9	77	
Muscle	0.19	0.13	0.25	15.*	5.5	0.89	0.19	4.3*	0 - 35
Skin	0.26	0.27	1.6	63.	28.	4.8	0.66	18.	0 - 166
Bone	0.32	0.32	0.68	61.	32.	4.1	0.83	18.	0 - 182
Liver	0.13*	0.58	35.	550.	220.	97.	4.2	160.*	0 - 2,100
Gut	0.29	1.5	140.	1,600.	1,700.	890.	18.	690.	0.31 - 6,800

* n ≠ 1

was about twice that of skin and bone at pre-shot stations, increasing to about 9 times in the post shot fish. The increase in activity in post shot carnivores over pre-shot was less than that of omnivores. Of the pre-shot fish samples, omnivores from Engebi had the highest count in liver tissue. After the shot, Bogallua omnivores had the most radioactive liver tissue.

The gut averaged about twice as high as the liver at all pre-shot stations, increasing to 4 times in post shot fish; the greatest increase was found in omnivores at Engebi. Post shot carnivores at Bogallua had 3 times as much activity in the gut as carnivores at Engebi. Comparatively high counts were found in the gut of pre-shot fish at Runit and Engebi and to some extent at Bogombogo and Aomon. Fish with the lowest activity in the gut were collected at Japtan.

Distribution of radioactive materials throughout the tissues from gut to muscle was fairly uniform in pre-shot and post shot fish from Japtan and Igurin. For example, by comparing the radioactivity in the gut with that of muscle of all fish, the pre-shot activity in the gut was about 2.5 times and 1.8 times that of muscle at Japtan and Igurin respectively (Fig. 6). At other islands the ratios between gut and muscle were markedly greater: about 10.3 times at Rigili, 35 times at Bogombogo, 100 times at Engebi, 68 times at Aomon and 352 times at Runit. Post shot ratios were as follows: Japtan about 1.5 times, Igurin 42, Rigili over 3,000, Bogallua 107, Engebi 310, Aaraanbiru 1,000 and Runit 940. Ratios between tissues thus seem proportionately

less with distance from shot islands, with the exception of Rigili, and were least to the south and southeast within the atoll.

The average increase in all tissues from pre-shot to post shot activity was greatest by far at Bogallua (Fig. 6 and Table 10). Although Engebi and Bogallua were about equidistant from the target center, the amount of radioactivity in fish tissues at Bogallua showed an increase of from 4 to 18 times that of the fish tissues at Engebi. The data indicate that, of the radioactive materials taken into the gut at Engebi or Bogallua, a greater proportion reached the four other tissues (muscle, skin, bone, liver) of fish at Bogallua than at Engebi.

4.6 Land Plants

The plants collected before and after the shot included 15 species of flowering plants, 4 species of fungi, and 1 species of lichen. Some of the plants were collected at only a few of the stations. A check list is given in the Appendix. In general, collections were made in the areas where rat traps were set (p.62), but a few were made along the beach or wherever it was possible to obtain certain of the species. Some plants were pressed directly in the field for future use in autoradiography; others were preserved for identification. Radiological assay of the plants followed the same procedure used for the other organisms. Counts were made on leaves, stems, roots, flowers, fruits, and fungi.

Analysis by Area. Table 14 is a summary of the activity found in all the plants collected at each station before and after the Mike shot. Counts of all plant parts are included in the averages.

Table 14 - RADIOACTIVITY OF LAND PLANTS BY STATION
Thousands of d/m/g Wet Sample

Island	PRE SHOT Mean	n	Max.	Min.	POST SHOT Mean	n	Max.	Min.
Japtan	0.014	14	0.074	Bg.	0.24	6	0.33	0.13
Igurin	0.28	22	3.7	Bg.	16.	11	39.	0.83
Rigili	0.56	17	8.6	Bg.	100.	20	820.	1.0
Bogombogo	0.12	22	1.6	Bg.	---	--	---	---
Engebi	0.83	24	3.4	0.092	1900.	6	4000	280.
Aomon-Rojoa	0.28	30	1.3	Bg.	89.	12	370.	4.9
Runit					40.	2	60.	20.

The greatest amount of activity was found at Engebi Island, both before and after the Mike test. Since landings were not made at either Bogallua or Bogombogo after the shot, there were no collections at these islands. In general, the activity levels of the land plants were lower than those of the algae collected at the same island, but the trend is similar. Plants from those islands closest to and west of the shot island contained the highest activity. Most of the plants at Engebi and Rojoa as well as some at Rigili were either burned or physically damaged after Mike shot. Comparison of counts of damaged and healthy leaves from Rigili plants showed no marked differences between the two, indicating that most of the activity was on the surface of the leaves.

Analysis by Species. Because of the incompleteness of the collections and the great variation within species, it is not reasonable to attempt to determine whether significant differences in the amount of activity exist between species. From the data available, it appears that bunch grass, Lepturus repens, had the highest activity of the plants collected at Rigili and Rojoa after the shot. On the other hand, Mycena, a fungus, was among the highest at Rigili, but lowest at Igurin. Because of inconsistencies of this nature conclusions as to species differences are not justifiable.

Analysis by organs. No specific conclusions can be made regarding radioactivity in the organs of the land plants collected before and after the Mike shot because of the inconsistencies encountered. At some collecting areas the roots had the highest activity, at others the lowest. In general the leaves were highest. An insufficient number of flower and fruit samples were assayed from the post Mike series to warrant comparison.

Radiochemical analyses. Radiochemical analyses of post Mike soils from Rigili, Rojoa, and Runit and of post Mike plants from Engebi were made in order to determine the identity and relative amounts of fission products present. By comparing the relative percentages of specific fission products in plants with those found in the soil, and knowing the solubility of these fission products in water, it is possible to estimate which isotopes have entered the plant via the normal processes of mineral

absorption. The results, given in Table 15, are tabulated as percent of total recovered activity in the sample, although actual chemical yield was approximately 75 percent of the total radioactivity in the samples. If the percentages of the radioisotopes in plant and soil samples are approximately the same, then it may be assumed that the radioactive material is adsorbed onto the surfaces of the plants. The radiochemical analyses and the analytical procedures are described on page 81 of this report.

Table 15 - RADIOCHEMICAL ANALYSES OF SOILS AND PLANTS, POST SHOT
Percentage of Total Recovered Activity

Fission Product	Soil				Plants	
	Rigili	Rojoa	Runit	Engebi	Engebi	
					Triumfetta	Sedge
Cerium	32.2	25.0	24.5	31.2	24.6	25.7
Trivalent rare earths	18.5	21.2	16.0	13.5	24.6	24.2
Zirconium	20.8	24.5	25.5	19.8	13.7	12.9
Ruthenium	20.8	19.3	19.3	31.5	16.6	22.0
Barium	4.0	6.5	3.6	--	4.5	4.0
Calcium-Strontium	3.2	3.6	11.1	3.0	16.8	11.3
Cesium-Rubidium	0	0	0	--	0	0

The radiochemical content of the soils from the four islands is fairly uniform with some exceptions noted in the Engebi soil. As in the soil samples, 80 to 85 percent of the radioactivity in the land plants from Engebi was found in the highly

insoluble fission products that are absorbed by the plants in minimal amounts under normal conditions. The remaining portion of the radioactivity is found in the more soluble calcium-strontium fraction which is known to be actively absorbed by living plants. The marked difference between the percent of calcium-strontium fraction found in the plants from Engebi and that found in the soils indicates that the plants absorbed more of this fraction than any of the other radioactive materials present in the soil.

Conclusions. Analysis of the data obtained from counts made of 57 samples of land plants collected after Mike detonation shows a correlation between distance of collection area from ground zero and amount of radioactivity in the samples. On the basis of these data no clear cut differences can be pointed out as to the relative activity between species or between organs of a plant. The problems presented by surface contamination make further interpretations unreliable.

4.7 Rats and Birds

Collecting Methods. Attempts were made to collect rodents and birds at each of the principal collecting stations although they were not always successful.

Collections of rats (Rattus exulans) were made by setting live traps in the runways near the openings of the rat burrows. The traps were left overnight since these rats are, for the most part, nocturnal in their feeding habits. Openings to the

burrows are found under and around clumps of grass or under beach magnolia bushes (Scaevola frutescens). These rats do not inhabit areas containing no plants.

Rats were found on Engebi, Biijiri, and Rojoa prior to Mike detonation. After the shot they were taken on Biijiri only and were ill and lethargic. There is little probability that any rats survived on Engebi; for it was denuded by the heat and shock wave, then partly inundated by water waves from the blast, and had a radiation reading of 11 r/hr two inches from ground level for beta-gamma seven days after the detonation. That there was little chance of animals surviving is illustrated by the fact that the sole bird found on Engebi post shot had been blown to pieces by the shock wave.

Birds were collected at two stations, Igurin and Rigili, prior to Mike detonation. After the shot they were taken at eight stations and, with the exception of two stations, consisted entirely of terns (fam. Laridae). Within this group the fairy tern (Gygis alba) and the common noddy tern (Anous stolidus) were taken when available. These two species usually remain close to the nesting grounds, although they may forage over a range of several islands in search of food. Other terns taken included the sooty tern (Sterna fuscata), the crested tern (Sterna bergii) and the arctic tern (Sterna paradisaea). All birds were collected with a shotgun.

The food of the terns inhabiting Eniwetok Atoll consists almost entirely of small live fish caught near the surface

of the water. Occasionally small octopi are eaten. Terns are not scavengers and do not eat refuse. The food of the shore birds is composed mostly of insects and small crustacea found on the beaches.

At Aaraanbiru one shore bird was taken in addition to the terns, and at Rojoa the collection consisted entirely of shore birds. The shore birds taken included the golden plover (Pluvialis dominica fulva), the wandering tattler (Heteroscelus incanus), and the turnstone (Arenaria interpes morinella). Shore birds are not desirable specimens for the purposes of this survey because of their extensive migratory habits, but were collected when terns were not available. In the instances where shore birds were taken, however, the factor of migration was of little consequence. It was apparent that these birds were on the island where collected at the time of the detonation, as they were injured and burned to such an extent they were unable to fly.

Rojoa was the closest island to ground zero on which live birds were seen or taken. The birds at Runit, Rigili, and especially at Rojoa had been burned, sometimes to the bone, and were ill (Figs. 9 and 10). Birds with dark colored feathers were burned more severely than were the white fairy terns.

The birds were placed on ice as soon as they were shot. The rats were returned alive in the traps. Upon return to the Oakhill the traps, with the rats, were placed in a deep freeze unit so that death occurred from freezing.

Figure 9. Photograph of a singed plover taken on Biijiri (8¼ nautical miles from ground zero) November 7, 1952. The bird had apparently been flying with its left side toward ground zero at the time of detonation as indicated by the configuration of the burns on the remiges and the coverts.

Figure 10. Photograph of a singed noddy tern taken on Rigili November 5, 1952. The bird was flying in a direction away from ground zero at the time of detonation. The rectrices had been burned and the bird was unable to fly. The contour feathers of the back of the head and neck were also singed.

The following tissues were taken: for rats, skin, muscle, bone, liver, stomach, gut, kidney, and lung (in post shot specimens); for birds, skin, muscle, bone, liver, proventriculus, gizzard, gut, and lung (in some specimens). Special care was taken in all dissections to prevent cross contamination between organs. The dissection instruments were washed and wiped after each step, and the digestive tract with its contents dissected out last to prevent general cross contamination by the more or less fluid digestive tract contents.

Results. The specific activity of the organs and tissues of the rats is given in Tables 16a and 16b. In Tables 17a and 17b the disintegration rate for activity within the organs and tissues of the birds is given.

Analysis of Organs and Tissues, Pre-shot. The amount of radioactivity found in the organs and tissues of rats and birds in the pre-shot collections is small (Tables 16a and 17a) with a maximum of 47 d/m/g in the terns and 26 d/m/g in the rats. However, there are similarities in the distribution of the activity according to the different tissues and organs of the rats and birds. In Figure 11, a histogram of the average d/m/g for the organs and tissues of all of the pre-shot birds and rats is given. Similarities in radioactivity levels for like organs or tissues in the birds and rats are apparent with gut, muscle, liver, skin, and stomach in both groups containing measurable amounts of radioactivity. In bone none was detected. If the organs and tissues are arranged in descending order of average

activity the order is identical in the two groups.

Table 16a - RADIOACTIVITY OF PRE-SHOT RATS
Thousands of d/m/g Wet Sample

Island	Wt in gms	Skin	Muscle	Bone	Liver	Stomach & contents	Gut & contents	Lung	Kidney
Engebi	175	0	0.011	0	0	0	0.018	0	0.015
Biijiri	57	0	0.020	0	0.012	0.016	0.026	0	0
Rojoa	82	0.026	0.014	0	0.012	0.010	0.016	0	0
	77	0	0.016	0	0.012	0	0.011	0	0
	63	0	0.020	0	0.016	0	0.014	0	0

Table 16b - RADIOACTIVITY OF POST SHOT RATS
Thousands of d/m/g Wet Sample

Island	Wt in gms	Skin	Muscle	Bone	Liver	Stomach & contents	Gut & contents	Lung	Kidney
Biijiri	58	6.4	0.48	13.	1.9	0.94	34.	1.2	2.2
	66	9.0	1.6	8.3	2.2	16.	11.	1.4	3.4
	69	14.	1.1	18.	2.3	3.7	3.2	1.0	3.8
	72	8.8	1.0	12.	1.5	0.20	5.8	0.94	2.2
	95	9.1	0.68	7.0	1.9	1.2	1.4	0.75	2.7
	120	7.6	0.76	46.	1.5	3.5	16.	0.79	4.1
Average		9.2	0.94	17.	1.9	4.3	12.	1.0	3.1

Part of the activity in some of the tissues may be due to naturally occurring K^{40}. However, the amount of potassium per unit wet weight in the skin and muscle is approximately the same and in either instance would amount to 5 d/m/g or less. If K^{40} were mainly responsible for the increase in activity in the tissues then one would expect skin and muscle

Table 17a - RADIOACTIVITY OF BIRDS, PRE-SHOT
Thousands of d/m/g Wet Sample

Island	Type of tern	Skin	Muscle	Bone	Liver	Proven-triculus and contents	Gizzard and contents	Gut and contents
Igurin	fairy	0.046	0.018	0	0.016	0.020	0.019	0.047
	noddy	0	0.012	0	0	0.013	0	0.021
Rigili	fairy	0	0.014	0	0.019	0	0	0.016
	fairy	0	0.016	0	0.012	0	0	0.026
	sooty	0	0.032	0	0.029	0	0.038	0.027

Bogombogo noddy tern egg: shell - 0; embryo - 0.

Table 17b - RADIOACTIVITY OF BIRDS, POST SHOT
Thousands of d/m/g Wet Sample

Island	Type of bird	n	Skin	Muscle	Bone	Liver	Proven-triculus and contents	Gizzard and con-tents	n	Gut and con-tents	n	Lung
Igurin	tern	3	1.2	0.26	1.0	0.083	0.15	0.23	3	0.41	-	-
Eniwetok	tern	1	0.85	0.16	0.55	0.12	0.40	0.21	1	0.12	-	-
Japtan	tern	4	0.37	0.22	0.37	0.13	0.14	0.20	4	0.18	-	-
Rigili	tern	4	14.	0.72	23.	3.6	2.1	4.7	4	13.	1	1.9
Runit	tern	3	0.75	0.54	0.74	1.1	0.83	10.	3	3.7	-	-
Aaraan-biru	tern	2	1.1	0.36	0.86	0.78	0.89	1.5	3	3.9	-	-
Aaraan-biru	shore bird	1	14.	2.0	6.6	8.5	28.	96.	1	220.	-	-
Rojoa	shore bird	2	19.	0.63	7.6	2.5	3.2	94.	2	73.	2	0.86
Engebi	tern*	1	17,000.									

*Bird had been blown to pieces by the shock wave. Radioactivity is that of surface contamination.

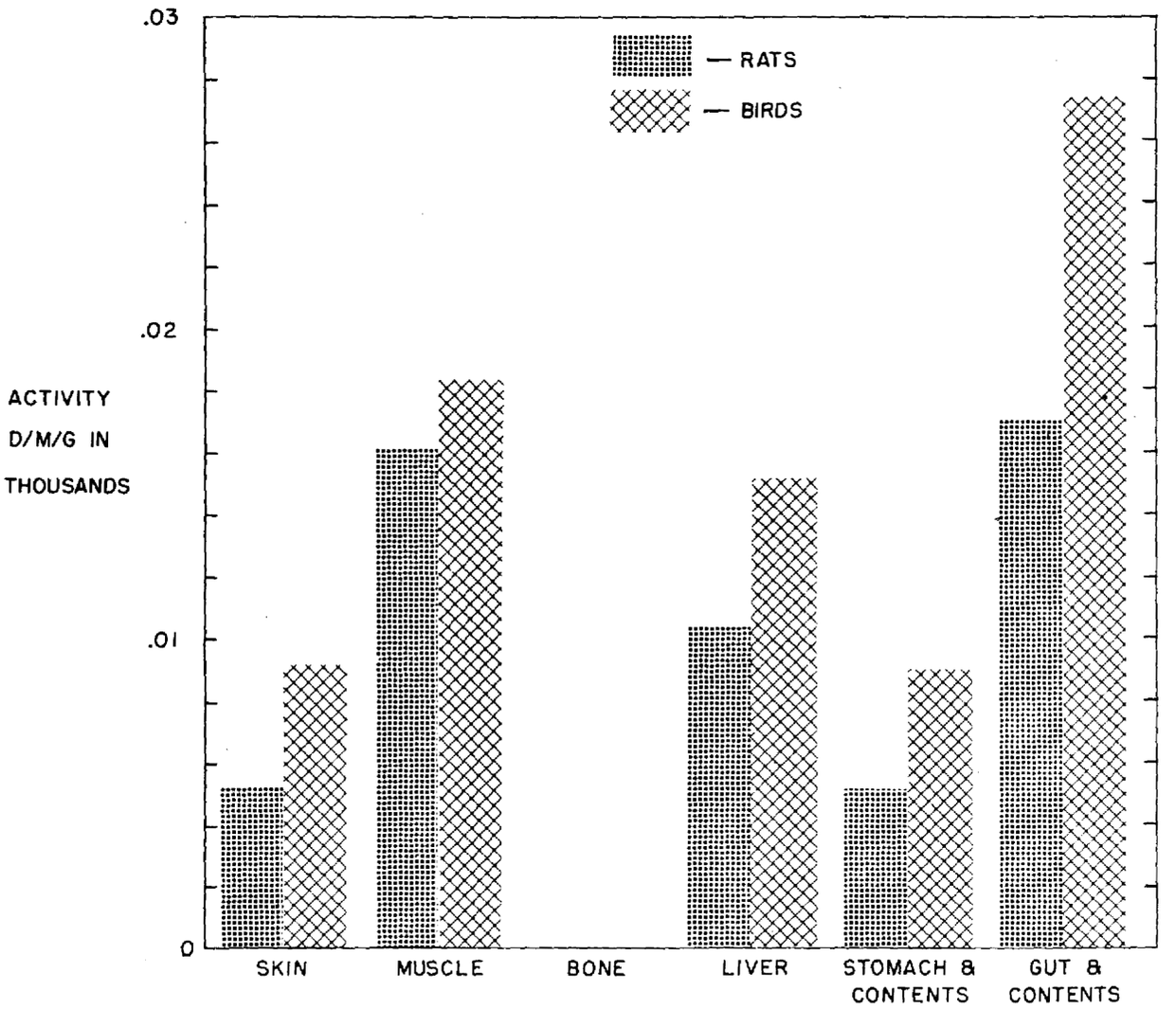


Figure 11. Radioactivity of pre-shot rats and birds, d/m/g wet sample.

to be approximately equal in activity. Muscle, however, is more radioactive.

The fact that the activity within the bone was zero in both the birds and rats is of interest. In the 1949 radiobiological resurvey of Eniwetok, the amount of activity in the bone samples of rats was positively correlated with the radioactivity of the habitat as indicated by survey meter readings. The habitat of the rat specimens at the time of the present preshot collections had a low reading, in all cases being less than 1 mr/hr.

Analysis of Organs and Tissues, Post Shot. In Table 16b the data for the post shot rat collections are given. In a comparison of the same organs and tissues in six specimens (except for the digestive tract) the disintegration rate does not differ in any instance by more than a factor of 7.

In a comparison of the same organ or tissue in the different specimens of birds collected at any one station (Table 4, Appendix) greater variations in disintegration rates are found than were evident in the rats. The maximum variation occurred in the livers of the Rigili terns where the greatest difference was by a factor of 470.

Analysis by Island. In general, the variability of activity for specific organs between individual birds precludes the possibility of significant differences existing between average values for various collecting stations. However, when the average values for the different organs for individual stations are

plotted against distance collected from ground zero (Fig. 12), the effect of the site of collection upon the amount of activity within the organs or tissues is apparent.

Meter readings were taken at each collecting site with a Juno ionization type instrument at the time the collections were made. These values for Runit, Aaraanbiru and Rigili are given in Table 5 in the Appendix.

On the basis of the meter readings the activity levels in the terns from Runit and Rigili should be similar, but those of the terns from Aaraanbiru higher. This was not found to be true, however (Fig. 12). At Rigili, downwind from ground zero, there were higher average levels of activity in the terns than at either Runit or Aaraanbiru in which the levels were almost equal (Table 17b). The terns taken at Runit may have flown from neighboring northerly islands since, although singed, they were able to fly. The birds taken at Rigili, however, probably did not fly from islands closer to the target area, because all of the birds observed during the post shot collections at Rigili were singed or ill and not inclined to fly. They would walk away or flutter with effort from the beach to the water when anyone came near.

Analysis by Feeding Habit. The shore birds and rats have similar feeding habits; both subsist mainly on insects, seeds, and grasses so that a comparison of average levels of activity in diverse forms with similar feeding habits can be made. The results are as follows:

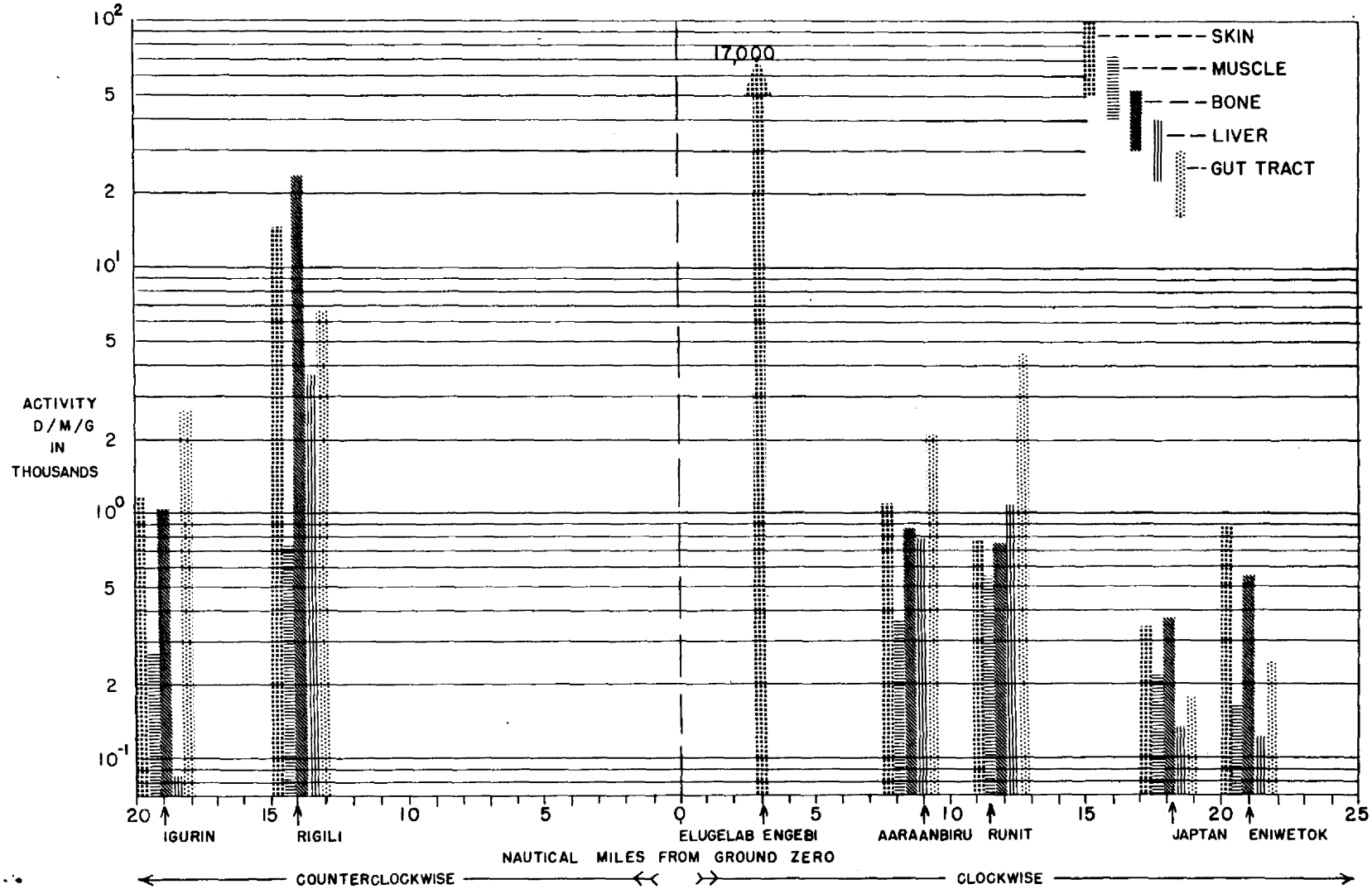


Figure 12. Histogram showing radioactivity of post shot terns with relation to distance of collecting site from ground zero, thousands of d/m/g wet sample.

Organs or tissues	Rats - Biijiri n	d/m/g in thousands	Shore birds - Rojoa n	d/m/g in thousands	Ratio of d/m/g of shore birds to rats
Skin	6	9.2	2	19.	2.06
Muscle	6	0.94	2	0.63	0.67
Bone	6	17.	2	7.6	0.45
Liver	6	1.9	2	2.5	1.32
Digestive tract	12	8.1	6	57.	7.04
Lung	6	1.0	2	0.86	0.87

Only in the activity of the digestive tract do the two forms differ by more than a factor of three, also the differences are not consistently in favor of either of the forms.

Differences in activity levels between birds of different feeding habits were found. Average values for the shore birds of the Rojoa-Aaraanbiru area and those for the terns in the Aaraanbiru area are as follows:

Organs or tissues	Terns - Aaraanbiru n	d/m/g in thousands	Shore birds - Rojoa n	d/m/g in thousands	Ratio of d/m/g of shore birds to terns
Skin	2	1.1	3	17.	15.45
Muscle	2	0.36	3	1.1	3.05
Bone	2	0.86	3	4.0	4.65
Liver	2	0.78	3	4.5	5.77
Digestive tract	6	2.1	9	76.	36.18

Shore birds and rats appear to be more alike in relation to uptake of radioactive materials than do the shore birds and terns. It appears likely, however, that the shore birds and rats are different regarding retention of radioactive materials

within the different organs and that the differences between the terns and shore birds were caused by differences in feeding habits.

Although variations within the tissue or organ samples of birds were great enough to preclude analyses of the radioactive disintegration rates by organ, a few conclusions can be drawn from the available data on birds in light of the findings with the post shot rats. In the latter, individual variation between samples was small enough that the differences between organs was significant, except for those of the GI tract. In addition to this, all of the post shot rat specimens were collected within a 50-yard square area so that the environmental conditions may be considered identical for practical purposes.

The coefficients of variability for the organs of the post shot rats were determined and the results are as follows:

	Skin	Muscle	Bone	Liver	Stomach & contents	Gut & contents	Lung	Kidney
Mean	9.2	.94	17.	1.9	4.3	12.	1.0	3.1
Coefficient of variation in percent	28.	42.	84.	18.	140.	100.	24.	27.

The lack of marked variability in activity between the lungs of the six rats probably depends mainly upon the effect of particle size and density as related to deposition within lung tissue. Stokinger et al.[4] working with albino rats found

that particle size greatly affected the amount of deposition in the areolar spaces with increases of as much as 10-fold with a reduction of mass-median diameter from 2.6 to .45 μ. Taplin et al.[5] found that in rats lung retention of particles with a mean size of ~1μ was strongly dependent upon density of the particles.

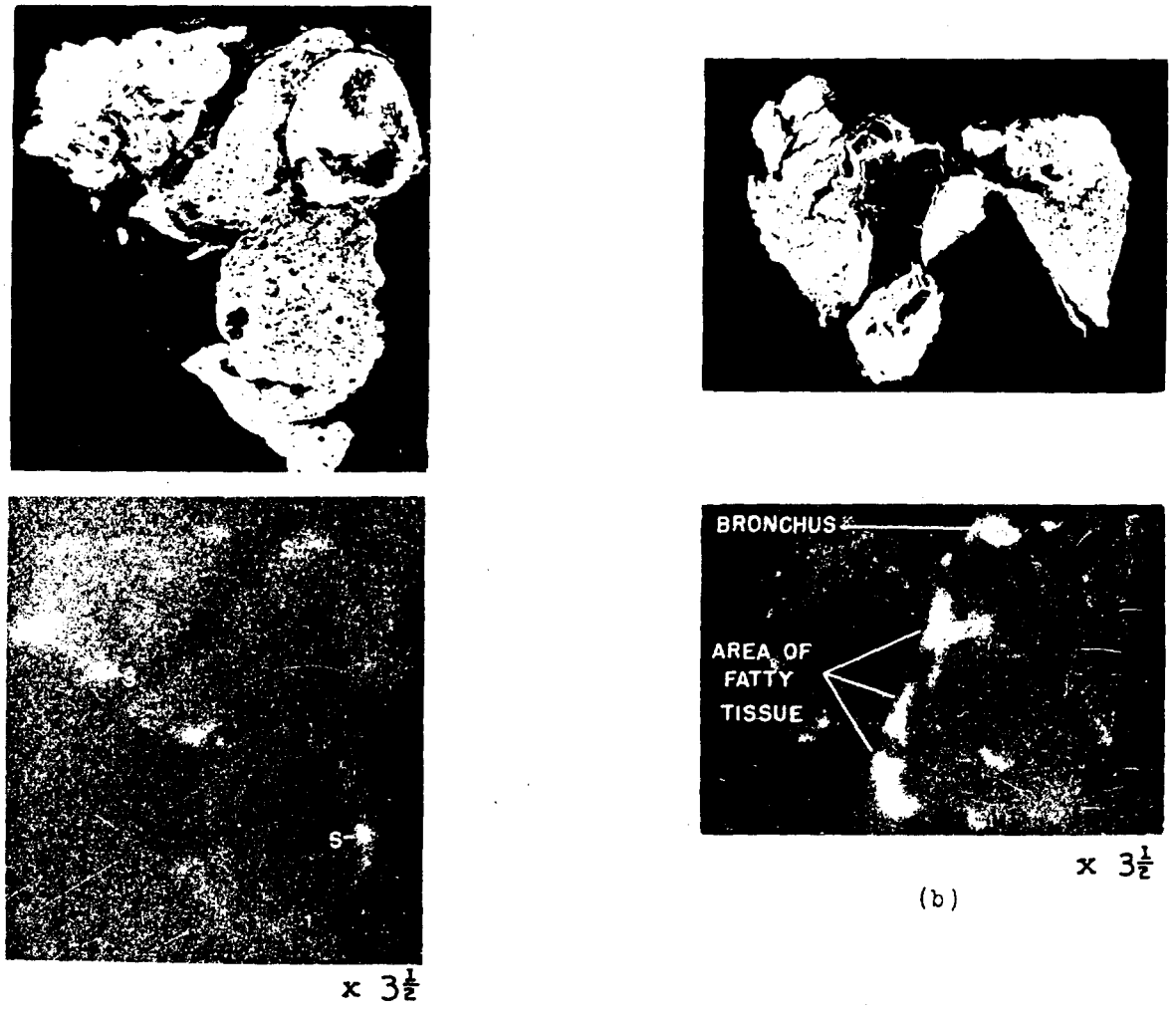
Autoradiographs of lungs of rats collected for the present work indicate a diffuse deposition of the radioactive material within the lungs except for the bronchii, where the activity is more concentrated and irregular (Fig. 13).

The results found in the autoradiographs as well as the lack of appreciable variation in samples may well be dependent upon the factors of selection and retention of particles by size and density, especially since the particles retained by the lungs are of a small mean diameter and are more nearly the density of the heavier Nevada sand and $BaSo_4$ particles than the dye particles Taplin found to be retained to a greater degree in lungs of rats.

The least variability in organs and tissues of the post shot rats was found in the liver, the variability of kidney and lung being slightly greater.

When the average values for each organ or tissue of the post shot rats are compared, muscle is the lowest and bone the highest in activity of the samples taken. Lung tissue, however, is almost as low as that of muscle tissue.

In the birds from Rigili, Rojoa, Aaraanbiru, and Runit



x 3½ (a)

x 3½ (b)

Figure 15. Photograph and autoradiograph of 100 u sections of lungs from rats collected at Biijiri 9 days after M detonation. (a) Blue Brand X-ray film exposed 39 days; exposure started November 29, 1952. Activity within the lung is diffuse in distribution except for spots from limited speck contamination. (b) Super XX film exposed 45 days; exposure started November 22, 1952. Radioactivity within the lung is diffuse except in the bronchus where it is more concentrated and irregular in deposition, thus suggesting limited speck contamination. In areas containing fatty tissue, greater exposure is indicated. Whether this is from chemical fogging or from exposure to radiation is not known.

the lowest activity was found in the muscle. In the same birds the highest levels of activity were in the "gut" or "digestive tract" with the exception of Rigili in which the bone contained the greatest amount of activity. In birds from the southern islands of Igurin, Japtan and Eniwetok the lowest levels of activity were found in the liver. The highest levels for birds of these islands were found in both the skins and bones and were approximately the same.

Judging from the data from both birds and rats muscle either takes up or retains a lesser amount of radioactive material than any other tissue or organ sampled.

In rats, radioactive materials are deposited in the bone with greater facility than in any other organ or tissue sampled. Evidence that this is not a general uptake by the bone but rather a selective action is indicated by a mass absorption curve of one of the six specimens taken at Biijiri (Fig. 14). Inflections in the curve indicate that the beta particles having maximum energies of approximately .2, .8, and 1.3 Mev are present.

A mass absorption curve of a noddy tern bone specimen (Fig. 14) gives some indication of selective deposition in uptake by bone. Well defined inflections which were evident in the rat bone sample are not found; however, the presence of beta particles having maximum energies of approximately .4, .95, and 1.3 Mev are suggested.

Conclusions. Food habit as well as range of activity of

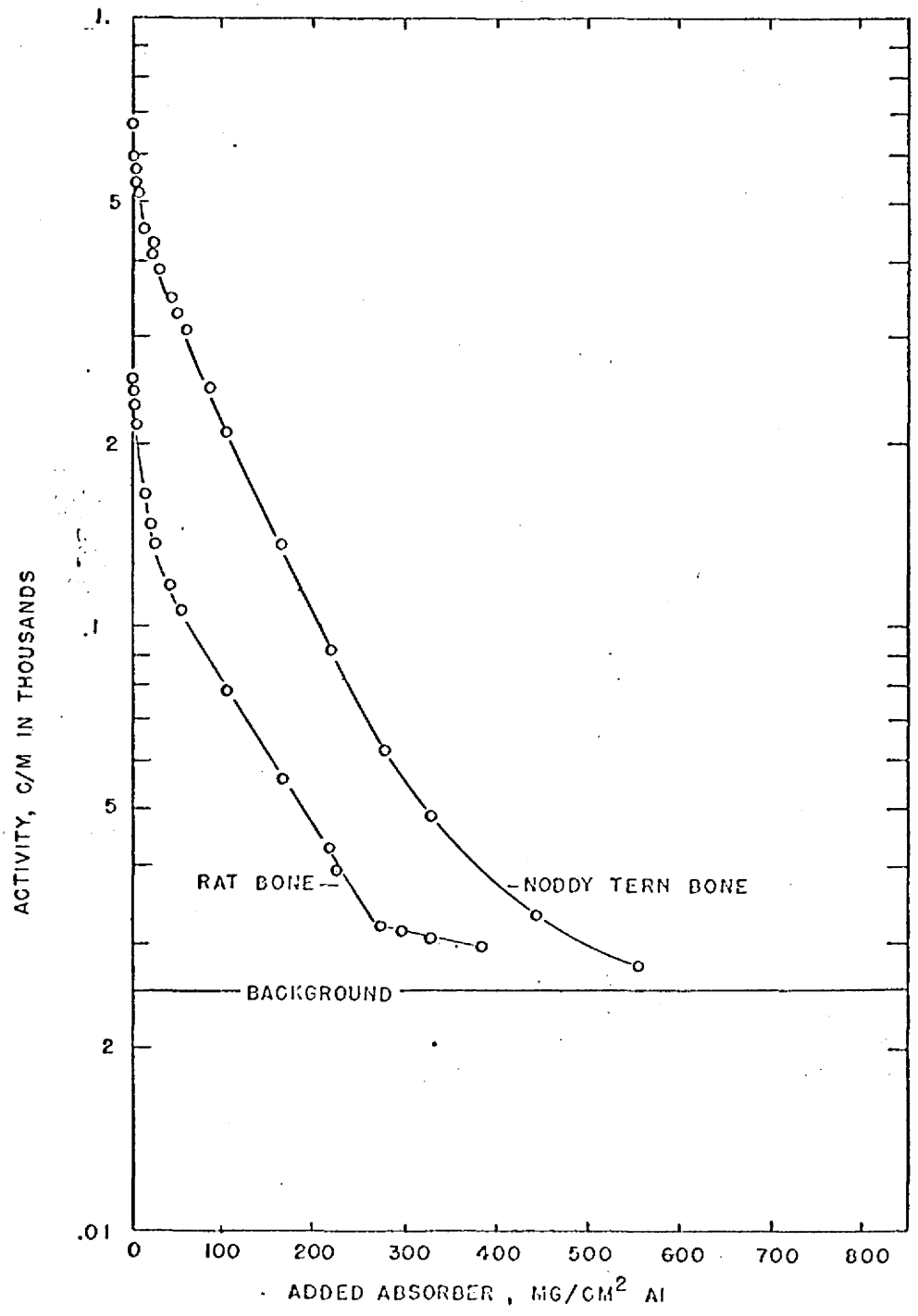


Figure 14. Mass absorption curves from the bones of a rat and a tern, post shot.

birds and rats have a marked effect upon the uptake of radioactive materials both in absolute quantity and in variability with different specimens. In those vertebrates where feeding is confined to the shore or a relatively restricted area the variability is less than where food is obtained from the water or over a relatively large area of the waters of the lagoon. In an area of strong water currents the variability in the specific activities in fish-eating birds increases greatly.

The uptake of radioactivity by land vertebrates, however, does not appear to be in a state of flux as a result of the greatly modified environment as does that of the invertebrates. Rather the differences in amount and variability in uptake of radioactive materials is probably directly related to food habits. However, in areas of relatively great contamination, a tendency for saturation of the organs by radioactive materials rather than selective action upon the materials by the organs may confuse the interpretation of the latter.

4.8 Radiochemical Analyses

Radiochemical analyses of post test samples of sand dredged from the bottom of the lagoon between Rojoa and Aaraanbiru, of beach sand from Engebi, and of soil from Rigili, Rojoa, and Runit were undertaken to provide a basis for comparison with results of similar analyses of biological samples. These analyses show the presence in about the expected ratio of all the important isotopes formed in fission except strontium, cesium,

and rubidium. Cesium and rubidium are water soluble and could be expected to be leached out of the sand and soil samples. A probable reason for the absence of strontium in the expected amount is not clear.

Radiochemical analyses were made of the following ashed biological samples: plankton, algae, octopus gill and digestive gland, fish tissues and land plants. These specimens were from the post test collections except for one alga that was collected before the Mike test. Little selective absorption of isotopes by these species so soon after the shot is observed except for concentration of zirconium in an octopus gill and of rare earths by plankton and by a surgeon fish and a butterfly fish. Results of these analyses are shown in Table 18.

Method Used. Twenty to fifty-gram portions of sand or soil samples were ashed at 700°C to destroy organic matter and the ash dissolved in dilute nitric acid. Filtering the solutions and counting the filters showed that solution of the active material was complete. Biological samples were also ashed and dissolved in dilute nitric acid. Filtering the solutions and counting the filters for these samples showed that in most cases the small insoluble residue contained less than 10 percent of the activity of the sample. Duplicate portions of the filtrates were taken and analyzed by the following methods.

Rare earths and zirconium were separated as hydroxides by precipitation with ammonium hydroxide. The resulting precipitate was dissolved in nitric acid and rare earths separated

Table 18 - RADIOCHEMICAL ANALYSES OF SAND, SOIL AND BIOLOGICAL SAMPLES, POST TEST
Values percent of total recovered activity.

Sample	Sand		Soil			Plank-ton	Algae			Octo-pus				Fish				Land Plants	
Area	Rojoa Dredged	Engebi Beach	Rigili	Rojoa	Runit	Bogallua	Bogallua			Lake George area (Pre-Test)	Bogallua			Bogallua				Engebi	
"Species"							(1)	(2)	(3)	(4)			(5)	(6)	(7)	(7)	(7)	(8)	(9)
Tissue											A	B	C	C	C	D	E	F	G
Date Counted	Dec. 12 '52	Apr. 14 '53	Jan.13,'53			April 14 '53	Feb.1,'53			Apr. 14 '53	April 14 1953			May 5, 1953				Feb.1,'53	
Cerium	30	31.	32	25.	24.5	51.5	29.5	35	19	73.5	18	43	49	29.	46.	34.	20.	26	24.5
Trivalent rare earths	22	13.5	19	21.	16.	20.	27.	14	32	14.	3	16	17	15.	16.	16.	12.5	24	24.5
Zirconium	14	20.	21	24.5	25.5	9.5	19.	26	14	1.	44	19	5	15.	14.5	11.	32.	13	14.
Ruthenium	19	31.5	21	19.	19.	15.	20.	24	21	5.	2	8	23	33.	17.5	5.5	17.	22	16.5
Barium	6	—	4	6.5	4.	—	3.5	1	8	—	—	—	—	—	—	—	—	4	4.5
Calcium & strontium	8	3.	3	4.	11.	4.	1.	1	6	6.5	34	14	2	4.5	3.	3.	7.	11	16.
*	0	—	0	0	0	—	0	0	0	—	—	—	3.5	3.	2.	30.	11.	0	0

(1) Udotea (2) Lyngbia (3) Halimeda (4) Rhizoclonium and Enteromorpha (5) Butterfly (6) Grouper (7) Surgeon (8) Sedge (9) Triumfetta

A Gill B Digestive Gland C Gut D Muscle E Skin F Stems and Leaves G Stem

* Activity remaining in solution after precipitation of rare earth hydroxide and alkaline earth carbonates and presumed to be cesium. Level of activity too low to pursue further analysis.

from zirconium by precipitation as fluorides. Cerium was separated from trivalent rare earths by precipitation as ceric iodate. In analysis of Rojoa dredged sand an attempt was made to separate trivalent rare earths from yttrium by precipitating them on lanthanum carbonate, but absorption curve study showed that this separation was not complete. A large fraction of other trivalent rare earth isotopes had carried on yttrium instead of on lanthanum. The two results were added together and reported as trivalent rare earths. This separation was not attempted in other analyses. Trivalent rare earths were counted together on yttrium carrier. The rare earths were weighed as oxalates. Zirconium was recovered from the flouride supernate by precipitation first as barium fluozirconate and than as zirconium mandelate, which was ignited and weighed as zirconium oxide. The supernate from the hydroxide precipitation contained barium, strontium, and calcium which were precipitated as carbonates. Barium was separated as barium chromate and strontium and calcium precipitated together as oxalates. Chemical separation of strontium and calcium was not attempted. A separate aliquot of Rojoa dredged sand solution was analyzed for cesium by the standard cesium perchlorate method and no detectable radiocesium was found. Since rubidium also is carried on this precipitate it is evident that rubidium was also absent. In most samples the absence of cesium was indicated by the absence of activity in the solution remaining after precipitation of rare earth hydroxides and alkaline earth carbonates. Ruth-

enium was determined in separate aliquots by the standard perchloric acid distillation method and by subsequent reduction to ruthenium metal by magnesium powder.

Chemical yield factors were determined and applied to the results of all analyses except barium and strontium-calcium. Spiked samples prepared by mixing appropriate carriers and corresponding radioisotopes were run concurrently with samples. The results are shown in Table 18 as percent of total recovered activity. Total activity recovered varied from 60 to 100 percent of total activity in the aliquot of sample solution used, as determined by plating and counting triplicate one ml-aliquots of the solution.

Absorption curves were made of each fraction separated from the Rojoa dredged sand and in each case showed the energy characteristic of the particular isotope separated. The curve of calcium-strontium shows that about three fourths of the activity has the energy corresponding to calcium^{45}. The remaining one fourth may be Sr^{90}, Y^{90} and Sr^{89}. These mass absorption curves and decay curves for the same fractions are presented in Figures 15 and 16.

4.9 Absorbed and Surface Contamination

In a discussion of results, the path of the radioactive materials to the tissue and the source from which they are taken into the organism are important considerations. If injury to the individual organism is being considered, the proximity of

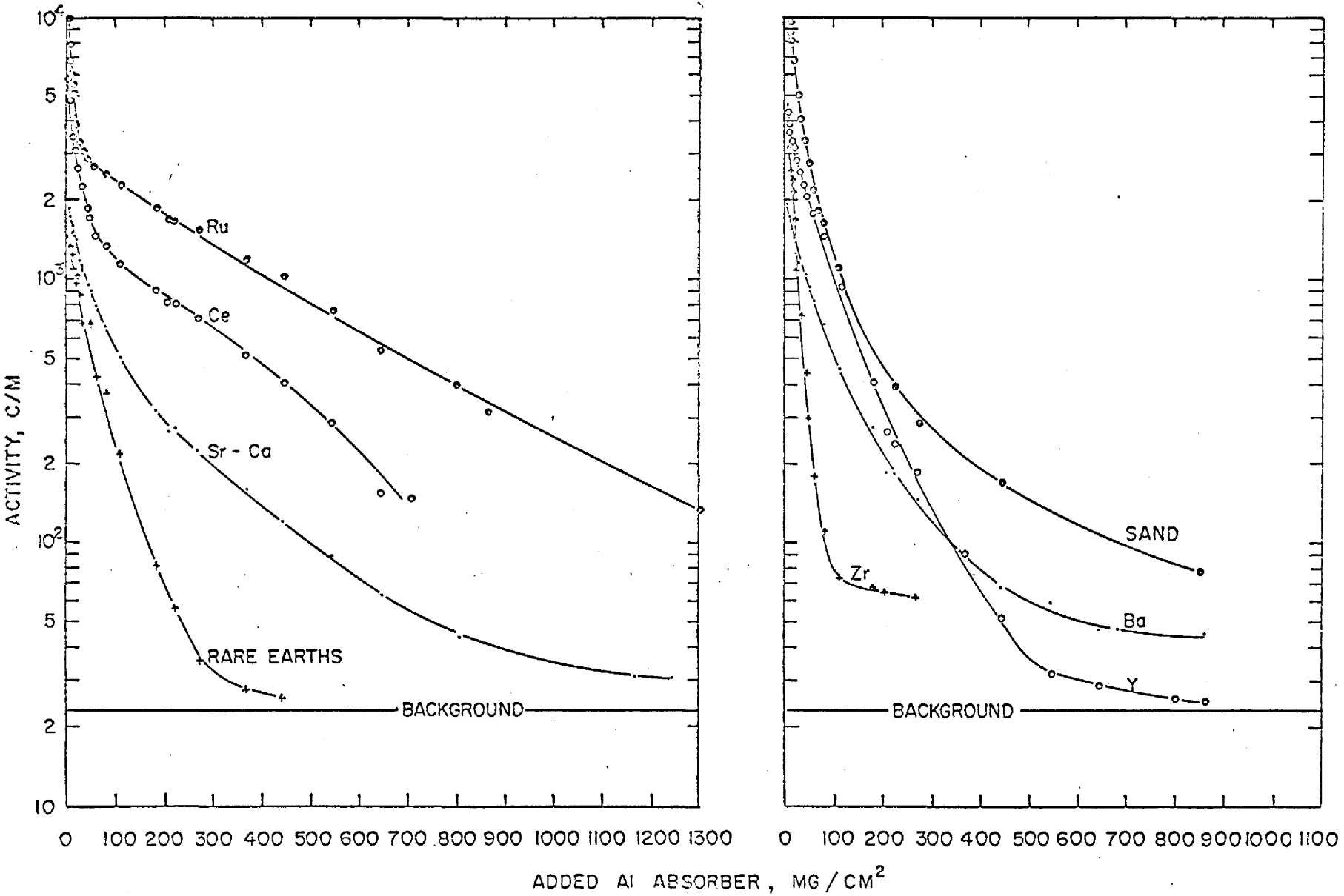


Figure 15. Mass absorption curves of radiochemically-separated fractions of Rojoa dredged sand

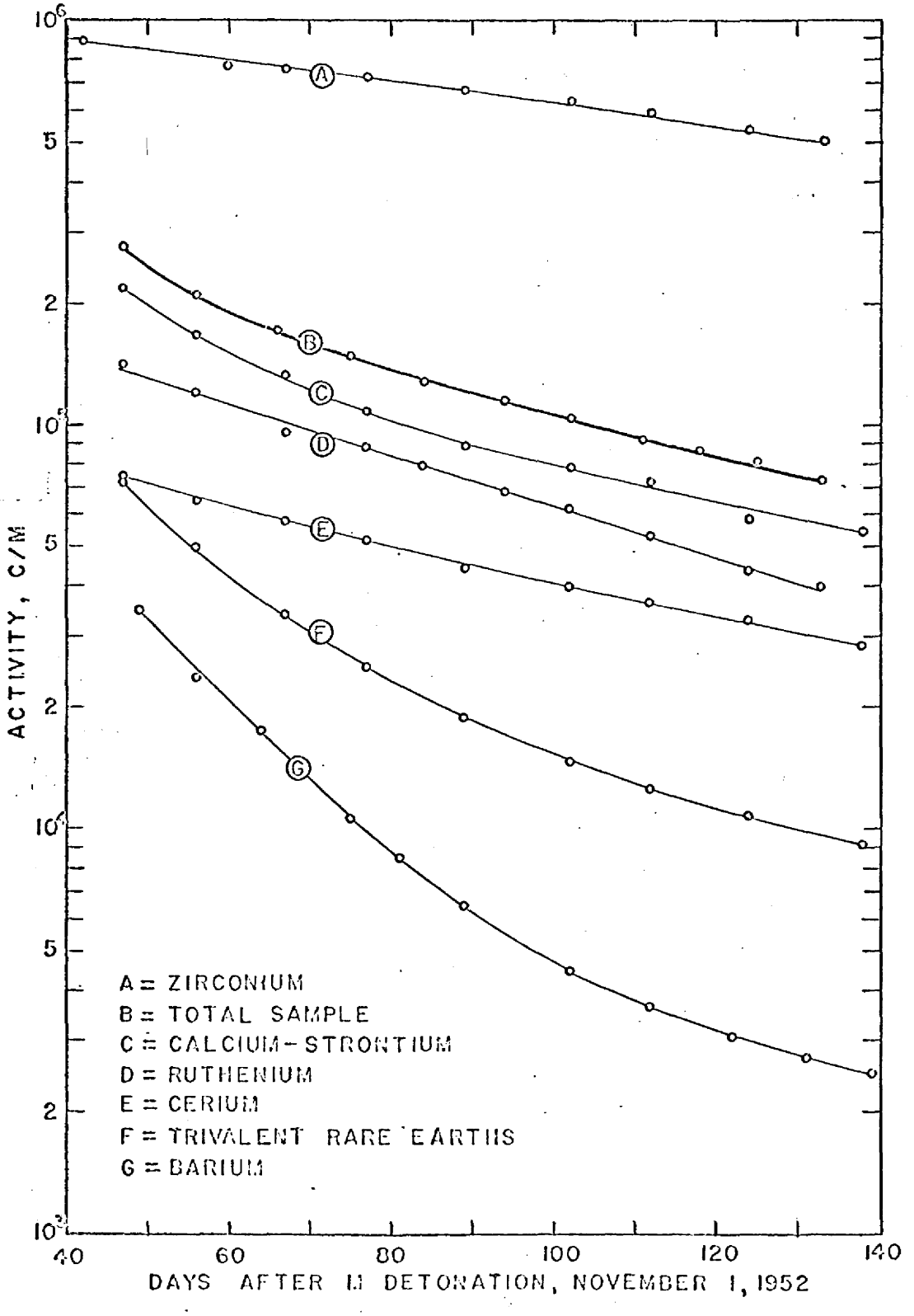


Figure 16. Decay curves of radiochemically-separated fractions of Rojoa dredged sand.

the radioactive material to sensitive cells and the potential duration of contamination are important and are in part dependent on the source of the contamination. If biological cycling is considered, the nature of the contamination of each organism in the food chain affects the availability of the radioactive materials to the next higher organism in the chain, i.e., materials which have been absorbed or metabolized once are more likely to be absorbed in the next step than are surface contaminants.

In an evaluation of the sources of radioactive contamination, the tissues of an organism may be grouped into the following categories: (1) tissues, such as liver, bone and muscle, which have only those isotopes absorbed from the blood and (2) tissues such as skin, gill, shell and digestive tract, which may have "surface" contamination from externally adsorbed or adhering materials in addition to absorbed isotopes. (Radioactive materials in the digestive tract are considered surface contaminants as long as they have not been absorbed).

The immediate sources of surface contamination are direct and indirect. The direct sources are the fallout particles and the induced radioactive materials in the sea water, air, or substrate, and isotopes of those materials that are soluble in water. Indirect sources are other radioactive organisms which are ingested by the specimen or commensal with it.

4.9.1 Speck Contamination

Autoradiographs have shown that the distribution of

radioactivity in the samples is often limited to isolated areas or "specks", most of which are assumed to be fallout particles. The term "speck" contamination is used to denote spotty activity on organisms, presumably caused from insoluble radioisotopes. The identification and distribution of "specks" in sand, plankton, algae, invertebrates, fish and land plants are discussed below.

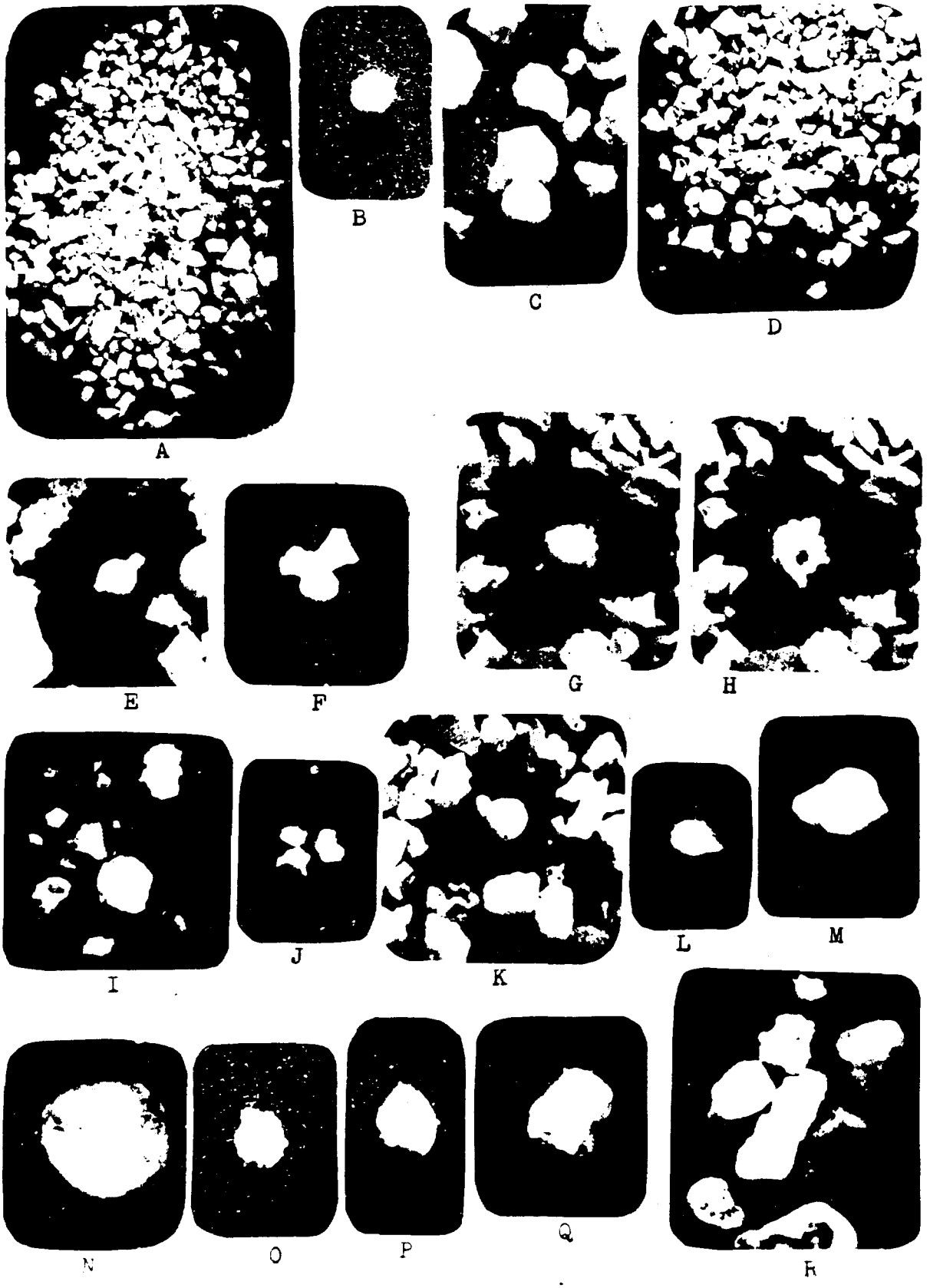
Sand. An autographic technique found useful for locating these radioactive particles involved spreading sand on scotch tape, inverting to remove loose particles, and exposing with firm contact against fast film. After developing, a positive transparency was printed on the film to be placed beneath the sand sample so that when in perfect registry the radioactive particles would be illuminated if viewed by transmitted light.

Engebi beach sand showed spots that were associated apparently with only the finer sand particles. Some of the active particles were isolated by successive dichotomous division of a sample of sand and retention of the more active half, as determined by the end window survey meter, until the individual particles which contribute most of the radioactivity could be picked out under the microscope. In Figure 17 sand samples and active and non-active particles which have been separated from the samples are shown. Counting rates for the particles are given in the legend for the same figure.

In Biijiri dredged sand radioactive particles were different in appearance from inactive particles. Active particles

Figure 17. Photomicrographs of Engebi beach sand on ashing plates counted May, 1953. Magnification 23x, except for A and D which are 8x.

Photo	c/m	Description or remarks
A	1,970	Entire sample weighing 6.2 mg typical of plates 1 through 100.
B	1,680	White sphere from upper right portion of A.
C	930	Another white sphere fused to a larger irregular particle.
D	1,130	Most of sample showing sphere of C near bottom.
E	3,300	Central, white sphere bearing two protrusions. Total plate 3,800 c/m.
F	1,160	White sphere fused to irregular particles. Total plate 2,900 c/m.
G	2,900	Spheroid with equatorial protrusions. Total plate 3,200 c/m.
H	2,900	Other side of same particle (G) showing a dark inclusion.
I	4,000-5,000	estimated using end window survey meter. Fragments of a white, hollow sphere broken in handling. Total plate 5,500 c/m.
J	1,400	Three irregular particles. Total plate 2,100 c/m.
K	1,900	Central, white sphere with protrusions. Total plate 2,200 c/m.
L	8,000	"Hottest" particle encountered; sphere with protrusion. Plate 8,600 c/m.
M	2,000	Irregular particle with heat-smoothed appearance.
N	7,800	End view of mottled, gray cylinder 1mm long.
O	450	Unsmoothed, chalky fragment.
P	6,000	Particle with heat-smoothed appearance of upper surface.
Q	1,300	Mottled, irregular particle.
R	300	Eight particles some of which were suspected of being radioactive from their appearance, but which gave no reading on end window survey meter.


A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R

were chalky looking and lacked even the slight hyaline luster characteristic of most inactive sand particles. One of the larger of these, as well as the sand sample and autoradiograph by means of which it was located, are shown in Figure 18.

Autoradiographs of plates of ashed biological samples were made to compare the nature of the distribution of the activity found in these specimens with that of the Engebi and Biijiri sand samples (see Fig. 19). Activity of the tissues with absorbed radiation was diffuse. For those tissues with possible "surface" contamination the distribution of activity was spotty and similar to the sand samples. Photographs of the plates (Fig. 20) show that the ash is evenly distributed and that the unexposed portions of the autoradiographs are not due to the absence of ash.

Plankton. The spots on plankton autoradiographs from samples dried on filter paper were associated primarily with a white, amorphous material of cheesy consistency, which may be the counterpart in the water of the chalky material in the sand. The autoradiographs also showed some activity associated with organisms. However, almost every kind of organism that showed activity in one individual would in another case fail to show it. Thus, among foraminifera, gastropods, mysids, and other crustacea there could be found some radioactive and some non-radioactive individuals. Activity tended to be proportional to mass of organisms. This suggests that minute particles suspended in the water, or possibly even a certain amount of dis-

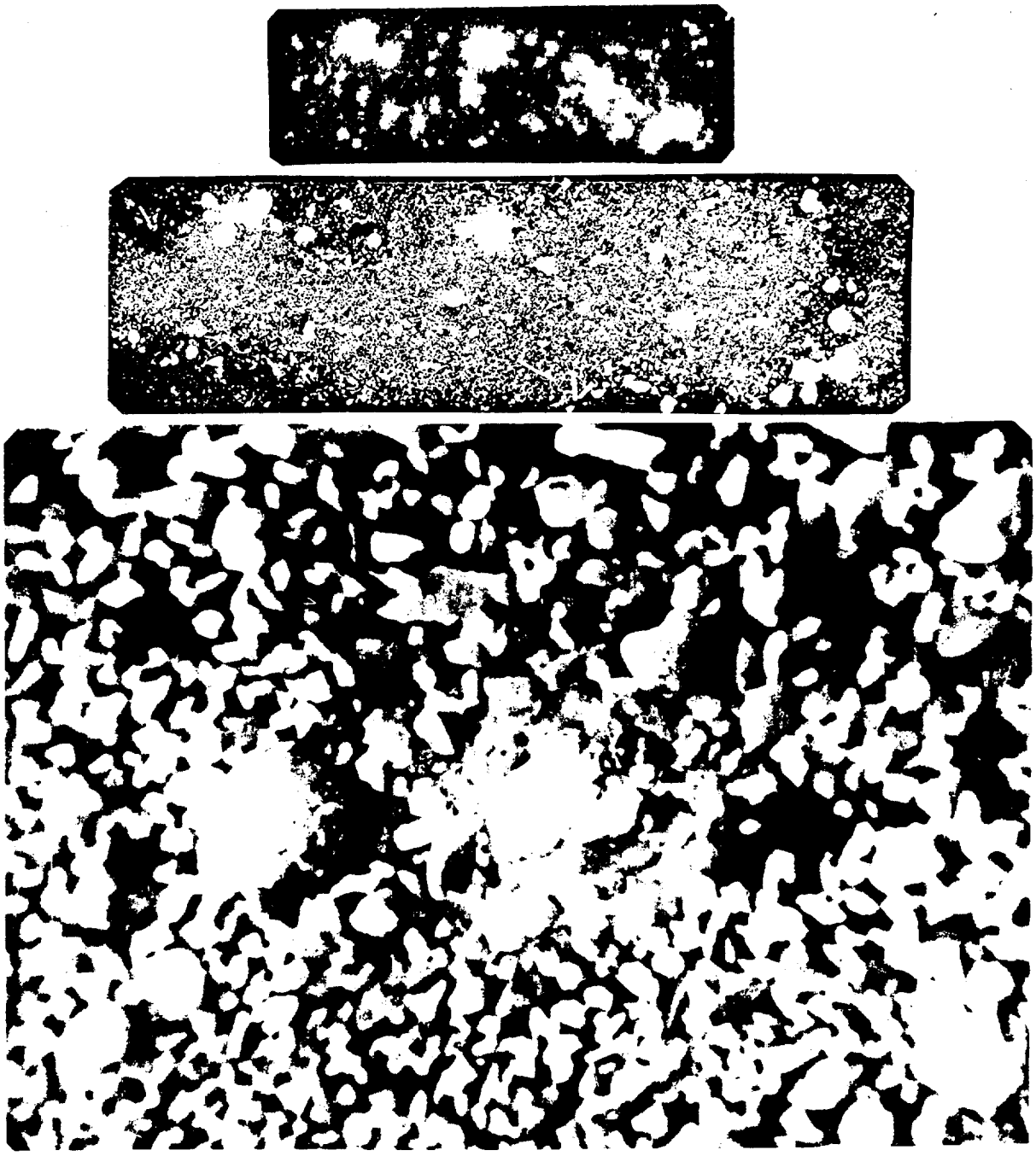


Figure 18, (upper). Autoradiograph actual size of Biijiri-Kojoa dredged sand on 3/4-inch scotch tape.
Figure 18, (middle). Photograph, 1.8x, of the same sand preparation partially illuminated from below through a positive transparency of its own autograph.
Figure 18, (lower). Photomicrograph, 20x, of the large radioactive particle near top center of preceding figure. This irregular, chalky particle weighing 0.6 mg, when removed to a plate on May 18, 1953, counted 5,300/m in the Nucleometer.

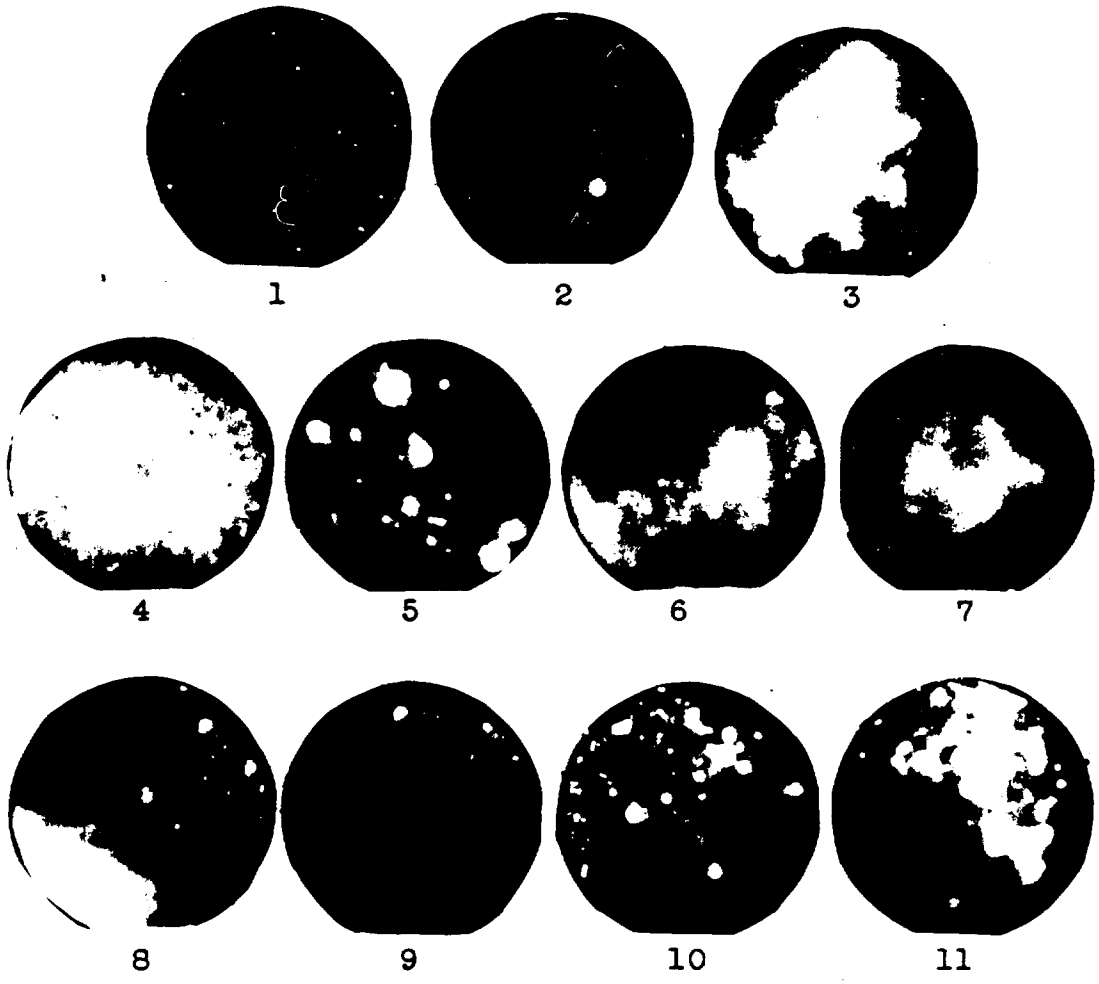


Figure 19 - Autoradiographs actual size of eleven of the more radioactive post test ashed samples. Pictures should not be compared because of different photographic treatment.

Number	Plate	Locality	Organism and tissue
1	423	Bogallua	Damselfish muscle
2	407	"	Tridacna (clam) muscle
3	403	"	Octopus digestive gland
4	427	"	Damselfish viscera
5	353	"	Plankton
6	354	"	"
7	483	Engebi	Hermit crab viscera
8	500	"	H. atra (cucumber) gut & contents
9	676	Aaraanbiru	Tattler (bird) gizzard
10	816	"	Lyngbia (alga), entire
11	819	"	Jana-like alga, entire

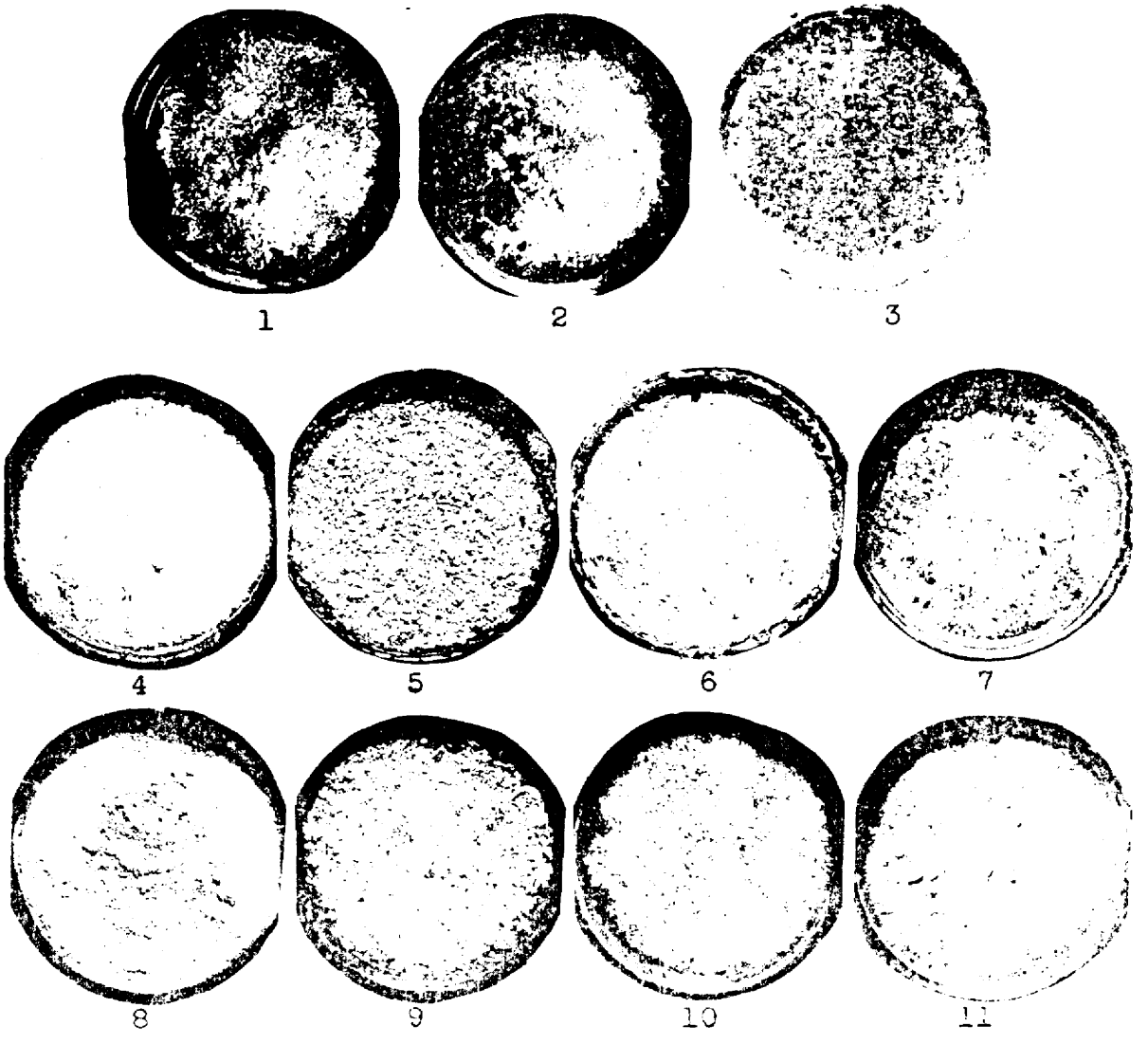


Figure 20 - Photographs approximately actual size of 11 of the more radioactive post test ashed samples whose autoradiographs are shown in Figure 19. Orientations do not necessarily correspond in the two figures.

solved radioactive material, may accumulate on the surface of plankton organisms, and that in addition there are larger particles (the cheesy material) suspended in the water.

Algae. In order to evaluate the "speck" contamination of algae, autoradiographs of washed and unwashed specimens were made. Washing was done by scrubbing with a brush and detergent and was followed by rinsing with running tap water.

Autoradiographs of an alga, Udotea, before and after washing, are shown in Figure 21a and b. Some of the radioactive spots were removed by washing, but most of them were not, showing that a major portion of the radioactivity is actually present within the alga. The even distribution of radioactivity in the filaments of Lyngbia and in the ramuli of Bryopsis, shown in c and d of this figure, indicate that "speck" contamination is of minor importance in these specimens. In one alga of the pre-shot collection (Fig. 21e) adhering soil particles were responsible for numerous hot spots in the autoradiograph. The autoradiographic method has indicated the presence of both surface and absorbed contamination in the algae collected before and after Mike shot. The relative amount of speck contamination was high in some cases and low in others; however, a quantitative estimation cannot be made.

Invertebrates. Among the invertebrates, an outstanding example of spotty distribution of activity was the occurrence on a piece of coral of the genus Acropora, taken at Bogallua November 8, 1952, of 3 highly radioactive nodules firmly at-

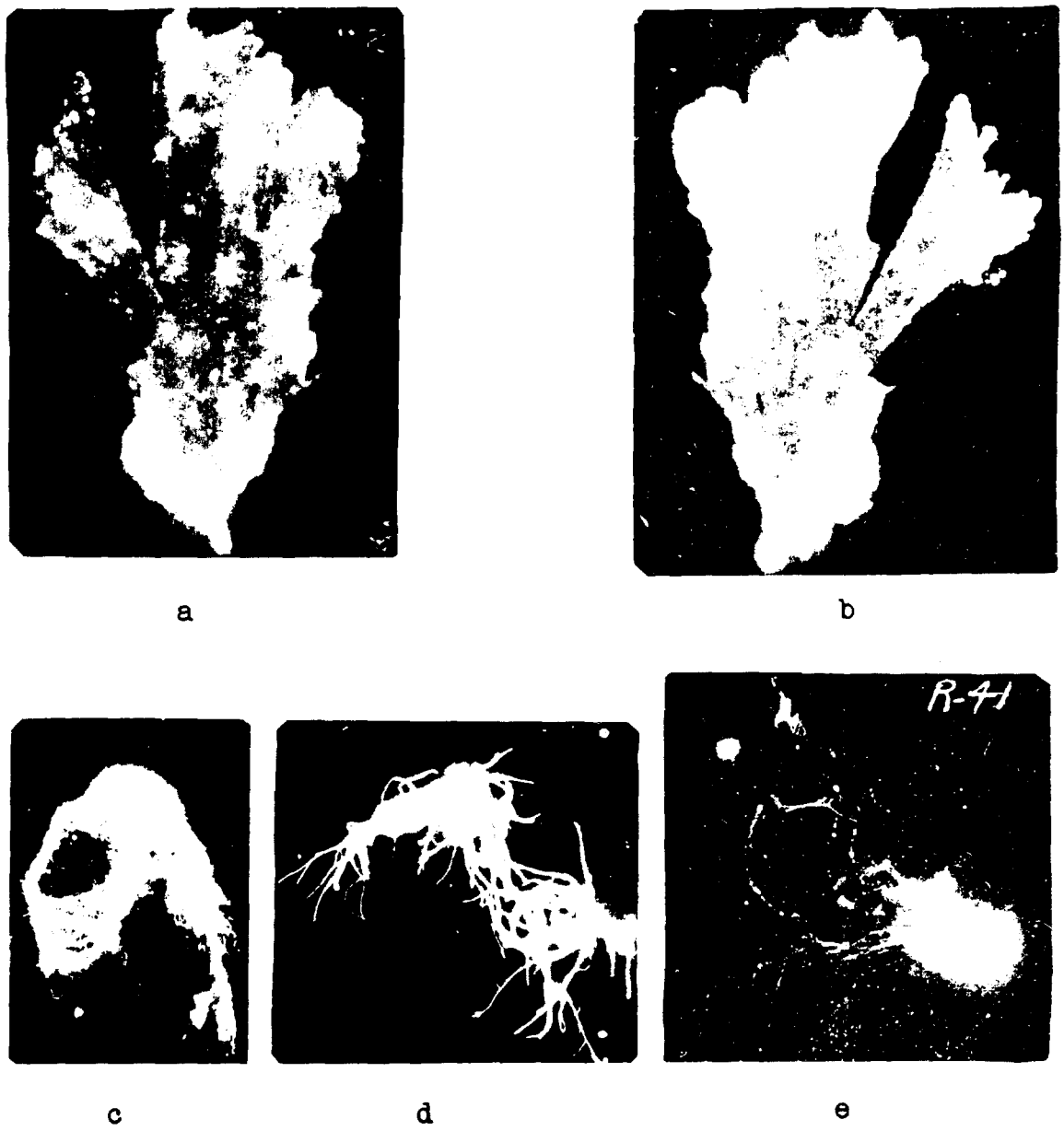


Figure 21. Autoradiographs of algae exposed to Super xx Pan Film. (a) Udotea before washing, 2½ hours exposure; (b) Udotea, same plant after washing with detergent, 60 hours; (c) Lyngbia and (d) Bryopsis, 52 days; (e) Enteromorpha and Rhizoclonium, 60 days. (a) to (d) post shot, (e) pre-shot.

tached and probably of foreign origin. The nodules did not appear to be part of the coral but were so well attached that when one of them was removed for counting it could not be separated from the coral without being broken. This unashed hollow sphere weighing 1 mg yielded 100,000 d/m. It is possible that these bodies were cysts produced by the coral itself, either for the purpose of walling off irritating, highly radioactive particles, or that they were rapidly-growing neoplastic growths which had concentrated a great amount of radioactivity since the time of the blast. See Figure 22c.

Photographs and autoradiographs of Heliopora and of the above samples of Acropora collected at Bogallua are shown in Figure 22a and b. The specific activity of the Acropora was 7,000,000 d/m/g and of the nodule 100,000,000 d/m/g, i.e., 100,000 d/m/mg. After the autoradiographs were made another piece from the same sample of Heliopora was used in an attempt to complement the results with quantitative data. The thin outer layer, about one millimeter thick, the dense median portion corresponding to the least dense portion in the autoradiograph, and the relatively porous central portion were separated from one another and ashed for counting. The resulting specific activities were 3,400,000 d/m/g, 160,000 d/m/g and 1,000,000 d/m/g respectively. It seems likely that the radioactivity found in the median portion lined small cavities which are present in the skeleton rather than actually being incorporated in the coralline material.

a b

c

Figure 22. Corals found on Bogallua November 8, 1952. (a) Photograph of Acropora (top) and Heliopora (bottom), actual size; (b) autoradiographs of corals shown in (a); (c) enlargement of marked area in (a) - the white nodules were firmly attached to the coral - arrow indicates nodule which was broken open showing hollow nature (x-13).

Fish. In fish a fairly even distribution of active material is seen in muscle, liver, gut, and to some extent in bone. Most of the activity was in the gut and liver as indicated by counts as well as by autoradiographs. The activity is less evenly distributed on or in the skin, in that more"specks" were in evidence in this tissue. In some fish a concentration of activity was noted in the gills (Fig. 23) or in the teeth (surgeon fish, Fig. 24). Carnivores and omnivores showed striking differences in the amount within the body cavity (Fig. 24).

Land plants. Washing with running tap water removed 10 to 20 percent of the activity on the land plants in most cases, although a much higher percentage of the "speck" contamination was removed by this method from the leaves of a grass collected at Engebi (Fig. 25). The remainder of the radioactivity was partly spotty and partly homogeneous in distribution. The spotty activity was probably due to material that was not washed from the external surfaces of the plants, and the homogeneous activity was the result of dissolved radioactive material that had been actively absorbed and metabolized by the plant. In leaves radioactivity was highest in the veins, the conductors of absorbed materials throughout the leaves.

4.9.2 Other Surface Contamination

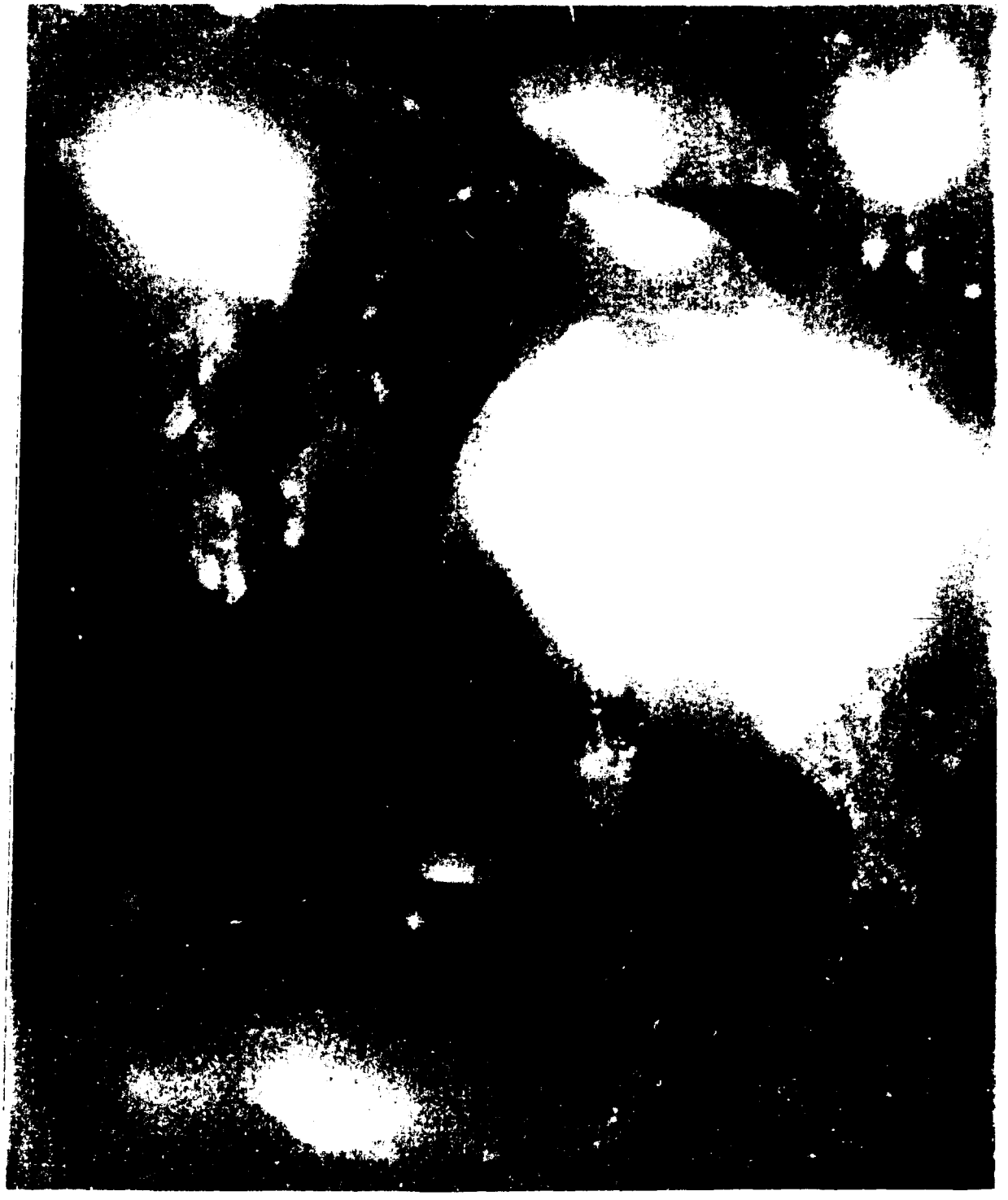
The general problem of surface contamination from indirect sources is illustrated by specific examples such as the contamination found on the carapace of a crab, on the shell of a clam,

Figure 23a. Autoradiograph of goatfish, Mulloidichthys auriflamma, showing radioactivity in the gills. Blue Brand Dec. 3, 1952 to Jan. 5, 1953.

Figure 23b. Photograph of fish used in above autoradiograph. Section of vertebrae removed for counting. Counts in tissues were as follows : muscle, 1,660; skin, 17,500; bone, 16,000; liver, 29,900; gut, 75,600.

Figure 24a. Photograph of the right half of a butterfly fish, Chaetodon citrinellus (omnivore, upper left, both halves of a damsel fish, Abudefduf glaucus (omnivore, top center), both halves of a wrasse, Halichoeres margaritaceus (carnivore, upper right), left half of a grouper, Epinephalus merra (carnivore, extreme left), right half of a cardinal, Apogon bandanensis (carnivore, left center), left and right halves of a surgeon, Acanthurus elongatus (omnivore, right center and extreme right), and a squirrel fish, Myripristis pralinius (carnivore, bottom). All fish collected at Bogallua, Nov. 8, 1952.

Figure 24b. Autoradiograph of the fish pictured in Figure 24a. Activity is greatest in the surgeon fish, moderate in the butterfly, wrasse and damsel fish, and slight in the grouper and squirrel fish. Counts in d/m/g of the tissues of the surgeon fish were as follows: muscle 26,000, skin 150,000, bone 120,000, liver 400,000, and gut 6,800,000. Counts in the squirrel fish were: muscle 10,000, skin 31,000, bone 16,000, liver 30,000, and gut 21,000. (Autoradiograph produced by 8 days exposure, Jan. 6 to 14, 1953).



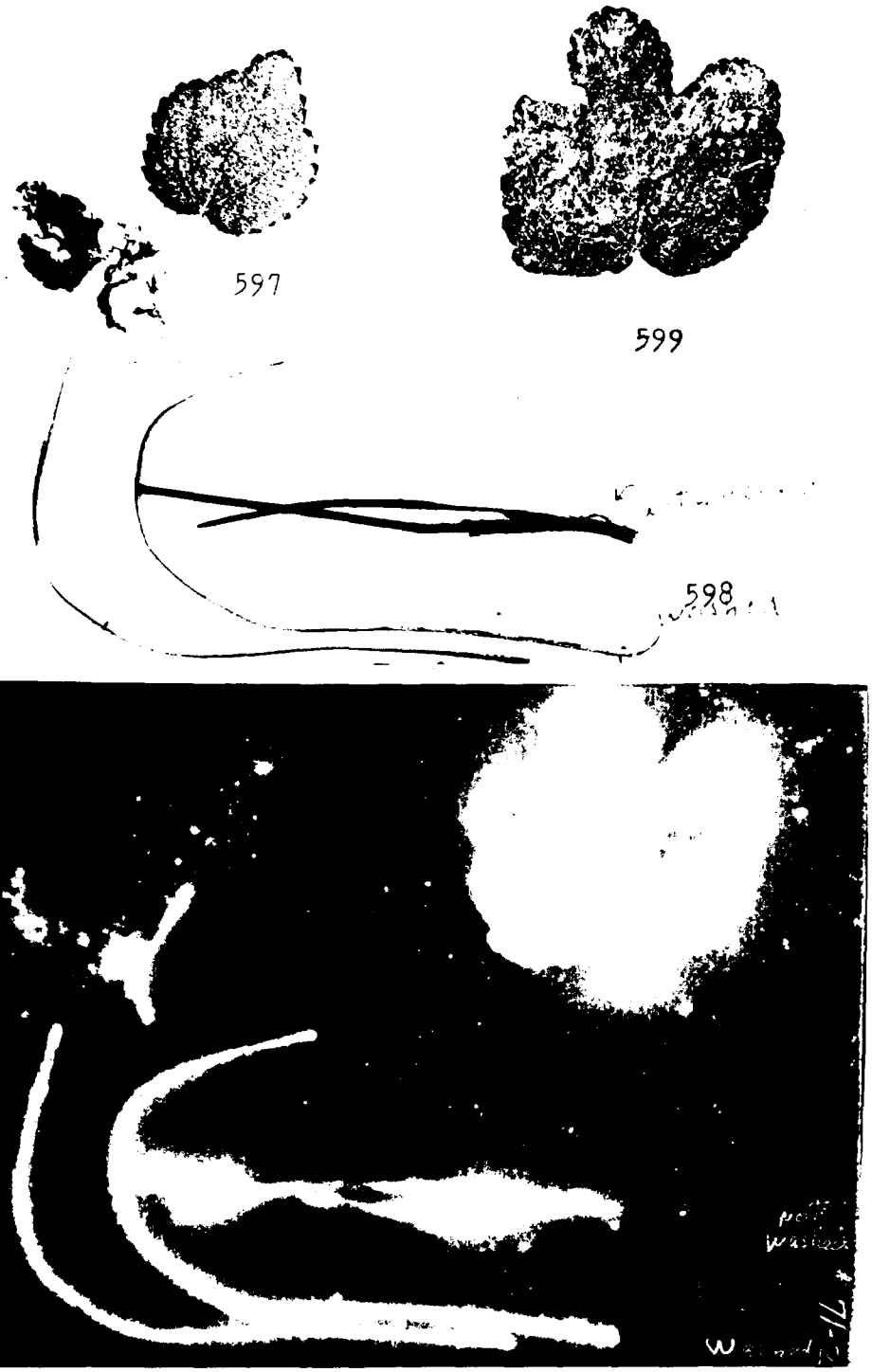


Figure 25. Land plants from Engebi, post shot. (a) Photographs No. 597 and 599, portions of Triumfetta procumbens; No. 598, Fimbristylis cymosa, upper portion not washed, lower portion washed with running tap water. (b) Autoradiographs of the plants in (a), 7 days exposure to Super xx Pan film.

in the skin and gut of the sea cucumber, and on the outer surfaces of algae and land plants.

Usually the crab carapace was prepared for ashing without any attempt to scrub or scrape the surface. In one instance, however, one half of the carapace was prepared as usual while small amounts of algae and unidentified material were scraped from the surface of the other half. These scrapings were found to have a specific activity more than ten times that of the carapace as a whole (150,000 d/m/g compared with 14,000 d/m/g). When the small proportion of the total weight of the carapace represented by the surface material is considered, it is clear that little if any of the radioactivity was actually deposited in the exoskeleton.

A similar situation was found with clam shell, where material scraped from the surface had a specific activity 68 times that of a portion of the shell taken as a whole (6800 d/m/g compared to 100 d/m/g). In this case the surface material makes up an even smaller proportion of the total weight than it does in the crab carapace.

Contamination of the skin of a species of sea cucumber, H. atra, is evident from a comparison with a second species, Stichopus sp., collected at Aaraanbiru (Table 19). A total of nine specimens was collected in four to seven feet of water within an area of less than one thousand square feet. The two species live side by side and are both detritus feeders. H. atra, however, has a habit of coating itself with sand while

ever be omnivorous, since a similar Pacific Coast species is known to stun prey with the violent snapping of a specialized claw, hence the name, "pistol shrimp." It is difficult to conceive how, living encased in a cylinder of highly enmeshed filaments of algae, it could feed on anything larger than very small plankton, if that, in addition to the algae. The similarity of the specific activities found in the viscera of the shrimp and in the algae, as shown below, indicate the effect of food habit upon the radioactivity of the digestive tract.

	Rigili d/m/g wet	Runit d/m/g wet
Shrimp		
muscle	15,000	7,000
viscera	110,000	31,000
Algae	210,000	36,000

5. CONCLUSIONS

The radioactivity of the six groups of organisms by islands is summarized in Table 20.

The individual counts for pre-shot samples ranged from 0 to 80,000 d/m/g of wet sample and the distribution of counts was strongly skewed to the left. A count of zero was obtained from samples collected at all islands and for most of the groups.

For the post test samples, individual counts ranged from 0 to 14,000,000 d/m/g wet. The few zero counts were from Japtan or Igurin. Counts of 1,000,000 d/m/g or greater were obtained from all groups of living organisms other than land vertebrates. The distribution of post test counts was also skewed to the left.

The average values (Table 20) are those of all samples prepared for counting and may include more than one sample from one specimen. A comparison of one group with another is limited by the differences between species and tissues as well as by the variations in sampling; however, the number of samples processed warrants the belief that trends are indicated. Although the range in values for one group of organisms at one station may be considerable, the order of magnitude of differences between islands and between groups is great enough to clearly indicate a constant order in the ranking of the groups and a definite pattern of distribution by stations.

Ranking of the groups for both the pre and post shot collections (1) by the station with the greatest activity or (2)

Table 20 - RADIOACTIVITY OF SAMPLES SUMMARIZED BY GROUPS AND BY ISLANDS
Thousands of d/m/g Wet Sample

	WATER		PLANKTON		ALGAE				INVERTEBRATES				FISH				LAND PLANTS				LAND VERTEBRATES			
	n*	Ave.	n*	Ave.	n*	Max.	Min.	Ave.	n*	Max.	Min.	Ave.	n*	Max.	Min.	Ave.	n*	Max.	Min.	Ave.	n*	Max.	Min.	Ave.
PRE-TEST																								
Japtan					6	.099	.041	.066	49	.47	0	.024	45	.074	0	.022	14	.074	0	.014				
Igurin	2	.000005	2	.94	8	.51	.067	.18	23	.46	0	.041	50	.105	0	.021	22	3.7	0	.28	16'	.047	0	.013
Migili	2	.000055	1	1.3	8	.97	.14	.40	33	2.8	0	.24	50	.73	0	.092	17	8.6	0	.56	24'	.038	0	.010
Bogombogo	2	.00073	2	2.6	9	4.3	.24	1.4	55	16.	0	.99	50	2.5	0	.19	22	1.6	0	.12	2'	0	0	0
Bugobi	2	.000030	2	.30	10	21.	.18	8.3	72	48.	0	3.2	50	72.0	0	2.0	24	3.4	.092	.83	8"	.018	0	.004
Aomon-Bojoa	2	.000015	2	.22	12	54.	1.7	7.7	45	8.5	0	1.12	50	4.2	0	.34	30	1.3	0	.28	32"	.026	0	.008
Runit	2	.00019	2	.12	18	51.	.087	7.6	52	80.	0	3.9	50	45.	0	2.6								
Ave.		.00014		.32				3.7				1.4				.76				.35				.002
POST TEST																								
Japtan	2	.00013			6	.70	.22	.30	49	.47	0	.083	50	.86	0	.22	6	.33	.13	.24	28'	.54	.070	.23
Igurin	2	.00052	2	88.	10	40.	4.1	15.	66	75.	0	4.0	50	4.1	0	.50	11	39.	.83	16.	21'	1.7	.044	.48
Migili	2	.0020	2	45.	6	2100.	28.	550.	92	400.	.35	44.	54	380.	.10	21.	20	820.	1.0	100.	19'	53.	.019	8.6
Bogallua	2	.094	2	650.	8	14000.	1200.	5200.	23	7700.	25.	1180.	79	6800.	.46	310.								
Bugobi	2	.021			3	6800.	2500.	4000.	21	15000.	10.	1670.	66	7500.	.37	590.	6	4000.	280.	1900.				
Aaraanbiru	2	.0060	2	64.	9	6200.	56.	2400.	38	6800.	2.1	1090.	70	6800.	.22	160.					21'	280.	.28	23.
Aomon-Bijiri																	12	370.	4.9	89.	48"	46.	.48	6.2
Runit	2	.00044	2	58.	13	250.	13.	103.	50	160.	.63	26.	68	72.	.10	8.3	2	60.	20.	40.	21'	23.	.17	2.5
Ave.		.016		180.				1800.				570.				160.				360.				6.9

*n refers to plates counted, not to specimens.

' = birds
" = rats

by the three stations with the greatest activity, or (3) by all stations gave the same order, with one exception, and was as follows: algae, invertebrates, plankton, fish, land plants and land vertebrates. The exception was that of the post shot land plants, which ranked third.

The pattern of distribution of activity of the pre-shot collections clearly indicates the areas of former test sites - Engebi, Aomon-Biijiri, and Runit. Pre-test collections at other stations had considerably less activity, which decreased with distance from the test site in the following order: Bogombogo, Runit, Igurin, and Japtan. The activity at Japtan Island was not much greater than that which would be expected from naturally occurring isotopes. An exception was the counts of plankton samples, which were greatest on the western side of the atoll. This distribution might be expected because of the movement of the surface currents from east to west.

For the post test collections the center of distribution was shifted toward the site of the Mike shot. For the outlying stations there was again a marked decrease in activity but with greater activity, as related to distance from Mike site, on the western side of the atoll than on the eastern side. There was a slight but definite increase in activity at Japtan.

The ratio of post shot to pre-shot activity as determined by the averages for each group of organisms was approximately 300 for the aquatic organisms and 1,000 for the land plants and vertebrates.

6. RECOMMENDATIONS

(1) For subsequent studies of radiological contamination at weapons test sites it would be advantageous to all concerned to start the program planning sufficiently far in advance of the tests to insure better coordination with the task force.

(2) A laboratory should be established on Parry Island, Eniwetok, to serve as headquarters for persons working on radiological studies of the fauna and flora of the atolls.

(3) Continuity in the study of problems of radiological contamination is essential at Eniwetok and Bikini in order to formulate a basis for understanding the scope, direction, and duration of the problems involved.

(4) Studies by a staff of specialists should be conducted at Eniwetok. These specialists might serve on a rotation plan so that, although the number of persons at the atoll at any one time might be limited, the total observational, collecting and study contributions made by such individuals would be great.

(5) Laboratory-type experiments, both at Eniwetok and at laboratories on the mainland, are essential to an evaluation of the phenomena observed during and following the test programs.

(6) Increased emphasis is needed to evaluate the physical nature of the radioactive materials and the mode of contamination.

REFERENCES

1. Applied Fisheries Laboratory, Radiobiological Survey of Bikini, Eniwetok, and Likiep Atolls - July-August 1949, AECD-3446, 1950

2. Neel, J.W., Soil-Plant Interrelationships with Respect to the Uptake of Fission Products: I. The Uptake of Sr^{90}, Cs^{137}, Ru^{106}, Ce^{144}, and Y^{91}, UCLA-247, 1953

3. Yamanouti, T., Ecological and Physiological Studies on the Holothurians in the Coral Reef of Palao Islands 1939. Contributions from Palao Trop. Biol. Station, No. 25, Palao Trop. Biol. Station Studies, Vol. 1, No. 4, 1939

4. Stokinger, H.E. et al., "Lobar Deposition and Retention of Inhaled Insoluble Particulates," p. 41, Quarterly Technical Report Jan. 1, 1951 through Mar. 31, 1951, UR-164, 1951

5. Taplin, G.V. et al., "Dust Distribution and Absorption from the Pulmonary Tree," p. 31, Quarterly Progress Report for Period Ending Dec. 31, 1952, UCLA-238, 1953 (Confidential)

6. Taylor, W.R., Plants of Bikini and Other Northern Marshall Islands, p. 111, Univ. of Michigan Press, Ann Arbor, 1950

APPENDIX

Bikini-Eniwetok Resurvey Reports by the Applied Fisheries Laboratory

Donaldson, L.R., Radiobiological Resurvey of Bikini Atoll During the Summer of 1947, UWFL-7, 1947 (Secret).

Donaldson, L.R., Preliminary Outline of a Program for the Second Radiobiological Resurvey of Bikini Atoll During the Summer of 1948 to be Sponsored by the Atomic Energy Commission and the United States Navy, UWFL-10, 1948 (Confidential)

Donaldson, L.R. et al., Concentration of Active Materials by Hydroids in the Bikini Lagoon During the Summer of 1947, UWFL-11, 1948 (Secret)

Applied Fisheries Laboratory, Bikini Radiobiological Resurvey of 1948, UWFL-16, 1949 (Secret)

Donaldson, L.R., A.H. Seymour, and J. Donaldson, Radiological Analysis of Biological Samples Collected at Eniwetok May 16, 1948, UWFL-18, 1949 (Secret)

Applied Fisheries Laboratory, Eniwetok Radiological Resurvey July 1948, UWFL-19, 1949 (Secret)

Applied Fisheries Laboratory, Proposed Program of Study of Radiation-Biology at Bikini and Eniwetok During the Summer of 1949, UWFL-20, 1949 (Confidential)

Donaldson, L.R., Suggestions for Program of Radiological Resurvey of the Bikini-Eniwetok Area During July and August of 1950, UWFL-22, 1950 (Restricted)

Applied Fisheries Laboratory, Radiobiological Survey of Bikini, Eniwetok, and Likiep Atolls - July-August 1949, UWFL-23 (AECD-3446), 1950

Biddulph, S.F., and O.Biddulph, A description of Tumors in Ipomoea tuba from the A-Bomb Test Sites on Eniwetok Atoll,(UWFL-23 - App.) AECD-3446 (App.), 1953

Applied Fisheries Laboratory, The Need for Continuation of Studies of Radiation Contamination of Biotic Forms at the Bikini and Eniwetok Testing Grounds, UWFL-28, 1952

Applied Fisheries Laboratory, Biological Monitoring Program for Eniwetok Prepared for the Bio-Medical Test Planning and Screening Committee, UWFL-30, 1952

Biddulph, O. and R.Cory, The Relationship Between Ca^{45}, Total Calcium and Fission Product Radioactivity in Plants of Portulaca oleracea Growing in the Vicinity of the Atom Bomb Test Sites of Eniwetok Atoll, UWFL-31, 1952

List of algae collected at Eniwetok, 1952 arranged in phylogenetic sequence.

	Name	Family	Islands at which Collected										
			Japtan	Igurin	Figili	Bogombogo	Bogallua	Engebi	Aomon	Aaraanbiru	Runit	USS Oakhill	
1.	Entophysalis crustacea (J.Ag.)Dr.&Daily	Chroococcaceae											
2.	Lyngbya sordida Gom.	Oscillatoriaceae		x	x	x	x				x		
3.	Lyngbya sp.	"			x		x		x	x			
4.	Symploca hydnoides Gom.	"									x		
5.	Plectonema Wollei Gom.	Scytonematoceae						x					
6.	Calothrix sp.	Rivulariaceae	x					x					
7.	Ulothrix implexa	Ulotrichaceae							x				
8.	Enteromorpha prolifera (Fl.Dan) J.Ag.	"											x
9.	Enteromorpha sp.	"							x				
10.	Rhizoclonium riparum Harv.	Cladophoraceae							x				
11.	Caulerpa racemosa var. clavifera (Turn) Weber	Caulerpaceae	x	x			x			x	x		
	uvifera (Turn) van Bosse	"	x	x			x			x	x		
12.	Caulerpa serrulata var. typica Tseng.	"		x		x	x	x	x		x		
13.	Caulerpa sp.	"	x										
14.	Vaucheria sp.	Vaucheriaceae									x		
15.	Avrainvillea lacerata (Harv.) J.Ag.	Codiaceae									x		
16.	Codium sp.	"							x				
17.	Halimeda monile (Ellis & Sol.) Lamx.	"		x	x		x		x		x		
18.	Halimeda stuposa W. R. Taylor	"	x	x	x	x	x		x	x			
19.	Halimeda sp.	"	x	x	x	x	x	x	x	x	x		
20.	Udotea sp.	"		x			x				x		
21.	Bryopsis pennata Lamx.	Bryopsidaceae	x					x		x	x		
22.	Bryopsis sp.	"	x						x				
23.	Dictyosphaeria cavernosa (Forrsk) Borgs.	Valoniaceae									x		
24.	Microdictyon sp.	"				x					x		
25.	Valonia sp.	"	x		x				x	x			
26.	Dictyota pinnatifida Kutz.	Dictyotaceae		x	x	x		x	x	x	x		
27.	Dictyota sp.	"									x		
28.	Padina Commersonnii Bory	"						x					
29.	Pocockiella Papenfussii W. R. Taylor	"					x						
30.	Asparagopsis Sanfordiana Harv.	Bonnemaisoniaceae	x										
31.	Jania rubens (L.) Lamx.	Corallinaceae							x				
32.	Jania sp.	"							x		x		

Groups: 1 to 6, blue-green; 7 to 25, green; 26 to 29, brown; 30 to 32, red.

List of algae collected at Eniwetok, 1952 arranged in phylogenetic sequence, con't.

Name	Family	Islands at which Collected									
		Japtan	Igurin	Rigili	Bogombogo	Bogallua	Engebi	Aomon	Aaraanbirud	Runit	USS Oakhill
33. Ceramium sp.	Ceramiaceae	x		x		x					
34. Centroceras clavulatum (C.Ag.) Montagne	"			x							
35. Centroceras sp.	"									x	
36. Laurencia sp.	Rhodomelaceae					x					
37. Polysiphonia sp.	"						x			x	
38. Roschera calodictyon (Harv) W.v.Bosse	"		x							x	

Group: 33 to 38, red.

Appendix Table 1. INDIVIDUAL VALUES OF PRE-TEST INVERTEBRATE SAMPLES
Thousands of d/m/g Wet Sample

(When the same value occurs more than once in a cell the number of occurrences follows the parenthesis. Gut includes contents except where otherwise noted)

Sample	Japtan	Igurin	Rigili	Begombogo	Begombogo dredge	Engebi Inner	Engebi Outer	Engebi dredge	Aomon	Aomon dredge	Pii-raai	Runit	Runit dredge
Sponge	.14;.22	.15	2.8	3.2; 16	.42		48		3.0			.88;.96;1.1	
Worms	0			.30			.92					17	3.2
Hydroid									.96;3.6			7.2	
Coral, hard	0(5		0(3	0(4; .20	0(3; .07			.26(2	0	0(2;.32			
Starfish	0(2		.42	3.9			.76	.52		8.5			
Brittle stars			.57									.30	1.6
Urchins, entire	0(5												3.2(2
test			0				.35;.42;.86		.81		0		
gut			.57				6.6;7.1;18		2.5		.05		
other tissue			0;.13				.14;.20;.99;6.5		.40		.02		
Heart urchin, entire					2.3			3.9					.52
test										.51			.92
gut													2.2
other tissue										0			1.9
Sand doller test													7.3
soft parts		0											
Cucumber, entire													
integument	0	.03	.10;.26	.05; .66			.11	.05;.58	.88	.30		.30;.55	
gut	0	0*	.05*; .36	3.6; 3.9					.53*;3.2	.69*		.44;.78	
other tissue		.05	.03; .04				.06	.28	.76	.81		.29	
Barnacle								2.4					
Shrimp, entire	0											.59	.89
soft parts							.82						
exoskeleton							.35						
Hermit crab, entire			0						.16				2.4
digest. system	0(2	.08											
muscle	0(2	0		.08									
exoskeleton	0(2	.46		.68									
cephalothorax	0			1.7		.23	1.8	.73			0	.63	
abdomen	0	.03		.15		.10	.55	.80				1.2	
Crab, misc; entire	0(3	0(2		.19;.20(2;.64;.88		0	2.8; 6.5					4.5	2.5
exoskeleton				0					.44	.79;1.1			
gills										.78			
digest. system				1.5					1.4				
muscle				0									
Ocypode, dig. system		.08				0						.51	
gills		0				0							
muscle		0				0						.06	
exoskeleton		0				0						1.6	
G. grapsus, dig. sy.	0	0(2				.06;.13						.88	
gills	0	0				.23						1.3	
muscle	.06	0				0						.16	
exoskeleton	0	0				0						.12	
Eriphia, dig. syst.	0		.05			.11					0		
gills			.08			.13					.06		
muscle	0		.02			0					0		
exoskeleton	0		0			.22					0		
eggs											.03		
Snail, egg collar													17
soft parts	0(4	.06	0;.03;.13;.51	.16;.19;.50;.93	3.5	2.1	3.6;4.2;15;16	.14;3.3	.52;.53	1.6;8.3	.33;1.7;80		3.2
foot	0						2.2						
liver	0		.57				2.0						
shell	0(3;.27;.47	0	0(2;.55	0(4; 1.1		0;.63	.94;1.1;2.4;3.2	0;.52	0(3;.79			0(2;.63	1.7
sea hare gut							22						
Clams, entire													.76;1.5
soft parts			.07		.21		9.2		.28	1.1		.73;4.3	
foot											0(2		
visceral mass				.32;1.0;1.4							.06;.07		
siphons											.03		
mantle				.25;.30							0(2		
muscle				.10;.14							0		
shell			0	.24	0		14		.26	0	0	.74;1.4	
Isognomon, entire		0											
soft parts	0		.27	.40		.56	2.0		1.2			2.8	
shell	0		.27	1.7		.53	6.4		2.5			5.0	
Cephalopod, entire									.26			0	
lymph heart									.58				
gill									.10				
mantle									.02				
tentacle									0				
Tunicate					.29;.69		Engebi Inner & Outer	5.8					
Number	4?	23	33	45	10	18	39	57	15	31	14	18	35	17
Mean	.024	.011	.239	1.117	.398	.128	5.405	3.73*	1.303	1.148	1.064	.018	3.971	3.663
Standard deviation	.084	.049	.503	2.53	.706	.174	8.94	7.77	1.74	1.67	2.18	.026	13.6	4.11

* Without gut contents.

List of Specific Activity of Post Shot Invertebrate Samples

JAPTAN

Soft coral	Bg.
Corals	
Montipora	Bg.
Porites	Bg.
Pocillopora	Bg.
Heliopora	Bg.
Anemone	Bg.
Starfish	
Asterid	0.16
Asterid	0.47
Sea cucumber	
H. atra	
body wall	0.057
gut	0.14
resp.tree	0.063
Hermit crabs	
Cenobita	
carapace	0.17
gills	Bg.
gastric mill & gut	0.081
liver	0.044
muscle	0.088
Cenobita	
carapace	0.20
gills	Bg.
gastric mill & gut	0.39
liver	0.062
muscle	0.051
Calcinus	
cephalothorax	0.11
appendages	0.26
viscera	0.062
integument	0.082
Pagurus	
carapace & integument	0.061
gill	Bg.
gastric mill	0.12
liver	0.055
Hermit crabs (Continued)	
Pagurus (Continued)	
muscle	0.029
Xanthid	
carapace & muscle	0.14
viscera & gills	0.050
Xanthid	
carapace	0.20
gill	0.058
gastric mill	0.098
liver	0.039
muscle	0.068
True crabs	
Grapsid	
carapace & muscle	0.10
viscera	0.13
Snails	
Vasum	
shell	Bg.
soft parts	0.059
Clams	
Tridacna	
shell	Bg.
mantle	0.039
muscle	0.055
liver	0.33
visceral mass	0.076
gill	0.12

IGURIN

Soft coral	1.1
Soft coral	0.20
Corals	
Porites	0.59
Pocillopora	0.28
Heliopora	0.96
Acropora	0.38

IGURIN (Continued)

Sea cucumbers	
H. atra	
body wall	0.087
gut	53.
resp.tree	0.48
H. atra	
body wall	0.28
gut	75.
H. sp.	
body wall	3.4
viscera	19.
Hermit crabs	
Cenobita	
carapace	1.1
gills	0.39
gastric mill	3.8
gut	5.0
liver	0.41
muscle	0.29
Cenobita	
carapace	1.4
gill	0.83
gastric mill	8.0
gut	8.7
liver	0.99
muscle	0.46
Pagurus	
liver	3.2
abdomen	3.7
legs	1.4
eggs	1.5
True crabs	
Ocypode	
carapace	1.2
gills	0.19
gastric mill	0.93
liver	0.40
muscle	0.069
green gland	Bg.
Grapsus	
carapace	1.5
gills	1.0
gastric mill	9.7
liver	0.81
muscle	0.12
green gland	0.52
eggs	0.17

True crabs(Continued)	
Eriphia	
carapace	0.84
gills	0.79
gastric mill	1.7
liver	0.45
muscle	0.11
Snails	
Turbo	
shell	0.21
mantle	0.52
gill	2.5
foot	0.25
viscera	4.4
Purpura	
shell	0.70
soft parts	0.75
Morula	
shell	0.28
soft parts	0.35
C. moneta	
shell	1.2
soft parts	6.5
Clams	
Tridacna	
shell	0.10
mantle	0.25
muscle	0.15
liver	1.1
visceral mass	3.7
gill	0.22
algae, sponge & sand scraped from shell	6.8
Oysters	
Isognomon	
shell	2.2
soft parts	14.

RIGILI

Sponge	
Red	41.
White	69.
Black	15.

RIGILI (Continued)

Corals	
Montipora	7.4
Porites	12.
Pocillopora	2.5
Acropora	8.9
Leptastrea	46.
Starfish	
Linkia	19.
Sea cucumbers	
H. sp.	
body wall	8.8
gut	120.
resp.tree	2.9
H. fuscorubra	
body wall	22.
gut	260.
resp.tree	4.2
Shrimp	
Crangon	
muscle	15.
viscera	110.
Hermit crabs	
Dardanus	
carapace	4.9
gill	5.5
gastric mill & gut	16.
muscle	2.0
liver	13.
integument	7.4
eggs	2.3
Pagurus	
thorax	82.
viscera	140.
integument	140.
legs	43.
eggs	49.
True crabs	
Grapsus	
carapace	13.
gills	42.
gastric mill	6.4
gut	3.2
liver	34.
muscle	1.7

True crabs (Continued)	
Grapsus (Continued)	
green gland	6.1
swimmerettes	88.
Eriphia	
carapace	43.
gills	74.
gastric mill	76.
liver	22.
muscle	1.1
eggs	9.9
Eriphia	
carapace	20.
gills	6.2
gastric mill	9.5
liver	12.
muscle	3.3
green gland	2.9
eggs	8.3
Snails	
Turbo	
shell	4.4
mantle & gill	41.
gut	55.
liver	220.
foot	3.5
Abalone	
mantle	7.7
*viscera	140.
*viscera	160.
foot	2.1
Drupa	
shell	10.
foot & mantle	11.
viscera	400.
Vasum	
shell	0.56
mantle	0.56
viscera	1.2
foot	0.35
Morula	
shell	6.0
soft parts	3.0
Planaxis	
shell	23.
soft parts	3.3

*Two samples from the same animal.

RIGILI (Continued)

Snails (Continued)	
C. moneta	
shell	3.8
foot & mantle	16.
viscera	150.
Clams	
Tridacna	
mantle	1.5
muscle	0.76
liver	3.9
visceral mass	0.75
Oysters	
Isognomon	
shell	17.
soft parts	45.
Spondylus	
shell	1.1
mantle	15.
muscle	7.7
viscera	110.
gonad	23.

BOGALLUA

Sponges	
Red	3100.
Soft coral	770.
Corals	
Pocillopora	700.
Heliopora	680.
Acropora	7,700.
Sea cucumbers	
Stichopus	
body wall	110.
gut	5,900.
True crabs	
Xanthid	780.
Octopus	
tentacle	25.
gill	110.
liver	4,100
Clams	
Tridacna	
shell	75.
mantle	140.
muscle	56.
liver	110.
visceral mass	350.
gill	120.
Tridacna	
shell	170.
mantle	92.
muscle	52.
liver	130.
visceral mass	700.
gill	330.

ENGEBI

Corals	
Pocillopora	770.
Heliopora	220.
Acropora	7,100.
Fungia	45.
Sea cucumbers	
H. atra	
body wall	52.
gut	15,000.
resp.tree	100.
Shrimp	
Crangon	330.
Hermit crabs	
Dardanus	
gastric mill & gut	7,600.
muscle	410.
leg	750.
True crabs	
Xanthid	1,800.
Grapsid	450.
Snails	
Morula	
shell	190.
soft parts	100.

ENGEBI (Continued)

Clams	
Tridacna	
shell	45.
mantle	22.
muscle	10.
liver	24.
visceral mass	460.
gill	51.

AARAANBIRU

Hydroids	
Pennaria	980.
Sea cucumbers	
H. atra	
body wall	140.
gut	4,600.
H. atra	
body wall	230
gut	1,100.
H. atra	
body wall	17.
gut	5,800.
H. atra	
body wall	64.
gut	6,800.
Stichopus	
body wall	8.5
gut	2,600.
Stichopus	
body wall	5.4
gut	5,800.
Stichopus	
body wall	7.2
gut	4,400.
Stichopus	
body wall	6.1
gut	4,200.
Stichopus	
body wall	5.4
gut	3,600.
Hermit crabs	
Calcinus	
thorax	42.
abdomen	23.
True crabs	
Ocypode	
carapace	20.
gills	19.
muscle	3.1
viscera	29.
Clams	
Tridacna	
shell	18.
mantle	6.6
muscle	2.1
liver	11.
visceral mass	21.
Tridacna	
mantle	2.9
muscle	2.5
liver	6.5
visceral mass	2.3
gill	9.8
Oysters	
Spondylus	
mantle	120.
viscera	620.
gill	75.

RUNIT

Sponges	
White	120.
White	7.
Corals	
Porites	35.
Starfish	
Linkia	32.
Sea urchins	
Echinometra	
test	5.5
"jaws"	3.4
gut	85.
caeca	87.
ovary	11.
Sea cucumbers	
H. atra	
body wall	12.

RUNIT (Continued)

Sea cucumbers (Continued)	
H. atra (Continued)	
gut	130.
resp.tree	12.
Shrimp	
Crangon	
muscle	7.0
viscera	31.
carapace	32.
gill	30.
eggs & swimmerettes	9.9
Hermit crabs	
Calcinus	
thorax	23.
abdomen	30.
appendages	8.6
True crabs	
Ocypode	
carapace	3.9
muscle	1.2
viscera	5.9
Grapsus	
carapace	29.
gills	56.
muscle	1.8
viscera	160.
Eriphia	
carapace	13.
gills	36.
muscle	0.76
*viscera	15.
*viscera	26.
swimmerettes	19.
Snails	
Turbo	
shell	2.9
foot & mantle	5.1
viscera	42.
Nerita	
shell	5.2
mantle	3.0
viscera	45.
foot	3.4
Snails (Continued)	
C. moneta	
shell	1.2
foot & mantle	6.6
viscera	43.
Clams	
Tridacna	
mantle	5.6
muscle	3.1
viscera & gill	18.
Hippopus	
shell	3.9
mantle	0.63
muscle	0.94
viscera & gill	31.

ADDENDA

JAPTAN

Sea Urchin	
Echinodermata	
test	bg.
viscera	bg.

RIGILI

Grapsus	
carapace	14.
gills	62.
gastric mill	280.
gut	240.
liver	62.
muscle	0.90
swimmerettes	110.

*Two samples from the same animal.

Appendix Table 3 - COMMON NAMES, GENERA AND SPECIES OF FISH USED FOR COUNTING AND NUMBER OF SPECIMENS

Common Name	Genus	Species	No. of Specimens
CARNIVORES			
Grouper	Epinephalus	merra	11
	"	elongatus	3
	"	macrospilos	1
Wrasse	Halichoeres	trimaculatus	17
	"	margaritaceus	4
	"	kallochroma	1
	"	notopsis	1
	Thalassoma	quinquevittata	5
	Stethojulis	axillaris	9
	Gomphosus	varius	1
	Cheilinus	sp.	1
	Pseudocheilinus	hexatania	1
Squirrel	holocentrus	microstomus	6
	"	lacteo-guttatus	5
	"	diadema	4
	Myripristus	argyromus	2
	"	pralinius	1
Goatfish	Mulloidichthys	samoensis	6
	"	auriflamma	3
	Parupeneus	barberinus	1
Cardinal	Apogon	snyderi	5
	"	novemfasciata	6
	"	doryssa	1
Eel	Gymnothorax	buroensis	4
	"	picta	1
	"	undulata	2
Goby	Valenciennea	strigata	3
	"	sexguttata	3
	Gobiodon	citrinus	5
Snapper	Lethrinus	microdon	2
	Lutianus	janthinuropterus	2
	"	monostigma	1

Appendix Table 3 (continued)

Common Name	Genus	Species	No. of Specimens
CARNIVORES (Con't.)			
Jack	Caranx	sexfasciata	3
Smelt	Parapercis	montillae	1
Halfbeak	Hyporhamphus	dussumieri	2
Reeffish	Pseudochromis	nigricans	5
Flatfish	Bothus	mancus	1
OMNIVORES			
Damsel	Abudefduf	biocellatus	30
	"	lacrymatus	4
	"	sordidus	3
	"	vaiuli	1
	Pomacentrus	jenkensi	4
Surgeon	Acanthurus	triostegus	12
	"	elongatus	3
	Naso	litturatus	1
Butterfly	Chaetodon	citrinellus	3
	"	lunula	3
	"	auriga	5
	"	ephippium	1
Parrot	Scarus	erythrodon	10
	"	sordidus	5
Blenney	Istiblennius	edentulus	6
	"	paulus	3
	"	coronotus	1
Mullet	Neomyxis	chaptalli	5
Puffer	Canthigaster	solandri	4
Brotulid	Dinemathichthys	iluocoeteoides	1
Filefish	Oxymonacanthus	longirostris	1

List of land plants collected at Eniwetok, 1952 arranged in phylogenetic sequence.

	Name	Family	Islands at which Collected								
			Japtan	Igurin	Higli	Bogombogo	Engebi	Aomon	Kojoa	Runit	
1.	Calocera sp.	Dacromycetaceae		x							
2.	Marasmius sp.	Agaricoae							x		
3.	Mycena sp.	"		x	x						
4.	Xylaria sp.	"							x		
5.	Physcia picta (Swartz) Nylander	Physciacoae				x					
6.	Pandanus sp.	Pandanaceae	x								
7.	Tacca leontopetaloides (L.) Merrill	Taccaceae	x								
8.	Lepturus repens (Forster) R. Brown	Poaeceae		x	x				x	x	
9.	Fimbrystilis cymosa R. Brown	Cyperaceae					x				
10.	Cocos nucifera L.	Palmaceae		x	x	x					
11.	Cassytha filiformis L.	Lauraceae				x					
12.	Sida fallax Walpole	Malvaceae						x			
13.	Triumfetta procumbens Forster	Tiliaceae	x	x	x		x		x		
14.	Portulaca lutea Solander	Portulacaceae						x			
15.	Portulaca oleracea L.	"	x								
16.	Portulaca quadrifica L.	"									
17.	Portulaca sp.	"				x	x				
18.	Boerhaavia tetranda Forster	Nyctaginaceae	x								
19.	Boerhaavia sp.	"	x								
20.	Ipomoea alba L.	Convolvulaceae	x	x			x		x		
21.	Cordia subcordata Lamarck	Boraginaceae	x		x						
22.	Tournefortia argentea L.	"	x	x	x	x	x	x	x		
23.	Canavalia microcarpa (DeCandolle) Piper	Leguminosae		x							
24.	Guettarda speciosa L.	Rubiaceae				x					
25.	Morinda citrifolia L.	"	x	x							
26.	Scaevola frutescens (Mill.) Krause	Goodeniaceae	x	x	x	x	x		x		

1 to 4, fungi; 5, lichens; 6 to 26, flowering plants.

Table 4 - RADIOACTIVITY OF BIRDS, POST SHOT
Thousands of d/m/g Wet Sample

F.T. = fairy tern
N.T. = noddy tern
A.T. = arctic tern
G.P. = golden plover
T. = turnstone
W.T. = wandering tattler
C.T. = crested tern
S.T. = sooty tern

Island	Type of Bird	Skin	Muscle	Bone	Liver	Proventriculus and contents	Gizzard and Contents	Gut and contents	Lung
Igurin	F.T.	0.93	0.35	1.3	0.044	0.18	0.22	0.77	----
	F.T.	1.7	0.34	0.82	0.064	0.18	0.16	0.22	----
	N.T.	0.94	0.087	1.0	0.14	0.10	0.30	0.24	----
	Ave.	1.2	0.26	1.0	0.083	0.15	0.23	0.41	----
Rigili	F.T.	0.23	0.26	0.65	0.019	0.16	0.12	0.23	----
	N.T.	0.59	0.80	0.90	3.4	2.3	3.3	10.	----
	N.T.	53.	1.2	90.	9.0	4.4	13.	38.	1.9
	A.T.	3.0	0.63	1.8	2.2	1.4	2.2	5.3	----
	Ave.	14.	0.72	23.	3.6	2.1	4.7	13.	1.9
Engebi*	N.T.	17000.	---	---	---	---	---	---	---
Rojoa	G.P.	10.	0.53	4.3	1.6	1.0	37.	6.6	0.43
	T.	28.	0.73	11.	3.4	5.4	150.	140.	1.3
	Ave.	19.	0.63	7.6	2.5	3.2	94.	73.	0.86
Aaraanbiru	W.T.	14.	2.0	6.6	8.5	28.	96.	220.	---
Aaraanbiru	F.T.	1.6	0.44	0.81	0.64	1.2	1.8	6.2	---
	N.T.	0.59	0.28	0.90	0.92	0.58	1.2	3.1 2.4	---
	Ave.	1.1	0.36	0.86	0.78	0.89	1.5	3.9	---
Runit	N.T.	0.22	0.45	0.72	0.83	0.76	23.	4.8	---
	N.T.	0.44	1.0	0.78	2.2	1.4	6.2	3.9	---
	C.T.	1.6	0.17	0.71	0.22	0.34	6.7	2.4	---
	Ave.	0.75	0.54	0.74	1.03	0.83	10.	3.7	---
Japtan	F.T.	0.22	0.22	0.40	0.11	0.14	0.15	0.16	---
	F.T.	0.51	0.24	0.37	0.14	0.14	0.16	0.07	---
	N.T.	0.54	0.20	0.33	0.17	0.16	0.26	0.10	---
	N.T.	0.20	0.23	0.39	0.099	0.12	0.22	0.40	---
	Ave.	0.37	0.21	0.37	0.13	0.14	0.20	0.18	---
Eniwetok (Oakhill anchorage)	S.T.	0.85	0.16	0.55	0.12	0.40	0.21	0.12	---

*Bird had been killed by blast.

Appendix Table 5 - POST SHOT SURVEY METER READINGS

Island	Date 1952	Distance to ground in inches	Type of Radiation* mr/hr			Remarks
				and hard	, soft and hard	
Rigili	Nov.5	12	8	9	11	Lagoon side 10' out into the water
		2	120	370	700	Inshore 15 yards at edge of vegetation
		36	80	120	140	Inshore 15 yards
Runit	Nov.6	24	11	--	--	Water washed rocks
		2	--	25	28	on lagoon beach
		36	16	--	--	Sandy beach 10 yards
		2	16	16	16	inshore from water's edge
		36	55	--	--	Sandy beach inshore
		2	75	75	75	30 yards from water's edge
		36	60	--	--	North end
		2	90	380	1,200	of island
Rojoa	Nov.7	36	500	--	--	On beach at edge
		2	750	1,250	2,250	of water and on shore
Aaraanbiru	Nov.7	36	420	--	--	On beach at edge of
		2	620	1,050	2,050	water and on shore
Engebi	Nov.8	36	2,500	--	--	On beach above water line
		2	3,000	6,000	11,000	and on shore

*Readings taken with a Juno ionization rate meter enclosed in a 4.25 mg/cm^2 polyethylene bag.

Procedures for Precipitation of Fission Products and Calcium-Strontium

(1) The sea water was acidified and stirred to remove bicarbonates.

(2) Ferric chloride was added and precipitated by addition of ammonium hydroxide. The precipitate was allowed to coagulate.

(3) Saturated ammonium oxalate solution was added to the solution to precipitate oxalates and the solution allowed to stand several hours.

(4) The combined precipitates were filtered and the filter paper with precipitate returned to the laboratory.

Processing in the laboratory was as follows:

(5) The filter paper and precipitate was ashed at 600°C to destroy the paper and convert oxalates to oxides.

(6) The ash was dissolved in dilute hydrochloric acid. Solution was complete.

(7) The iron which had previously been added was reprecipitated by addition of ammonium hydroxide. This precipitate, which is believed to contain most of the fission products of the sample, was plated and counted.

(8) The alkaline filtrate was diluted to 100 mls and duplicate 20-ml aliquots taken.

(9) The aliquots were diluted to 100 mls and calcium and strontium reprecipitated by addition of saturated ammonium oxalate solution. The precipitate was plated and counted.

The half-liter post shot samples were brought to the Laboratory for all the processing. The method was slightly different from that used in the field and was as follows:

(1) The sample was acidified and stirred to remove bicarbonates.

(2) Ferric chloride was added and reprecipitated as ferric hydroxide by addition of ammonium hydroxide. The

precipitate was filtered out, dissolved and washed through the filter paper with dilute acid, reprecipitated from a smaller volume, centrifuged, plated and counted.

(3) Calcium and strontium were precipitated from the alkaline filtrate by addition of saturated ammonium oxalate solution to the "hot" solution. The precipitate was filtered out, dissolved and washed through the paper with acid, reprecipitated from a smaller volume, centrifuged, plated, and counted.