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Record Number: 215

File Name (TITLE): Rad. Studies .. Before and After Mike Shot

Document Number (ID): WT-616

DATE: 11/1952

Previous Location (FROM): CIC

AUTHOR: JTF 132

Addditional Information:

OrMIbox: 13

CyMIbox: 9

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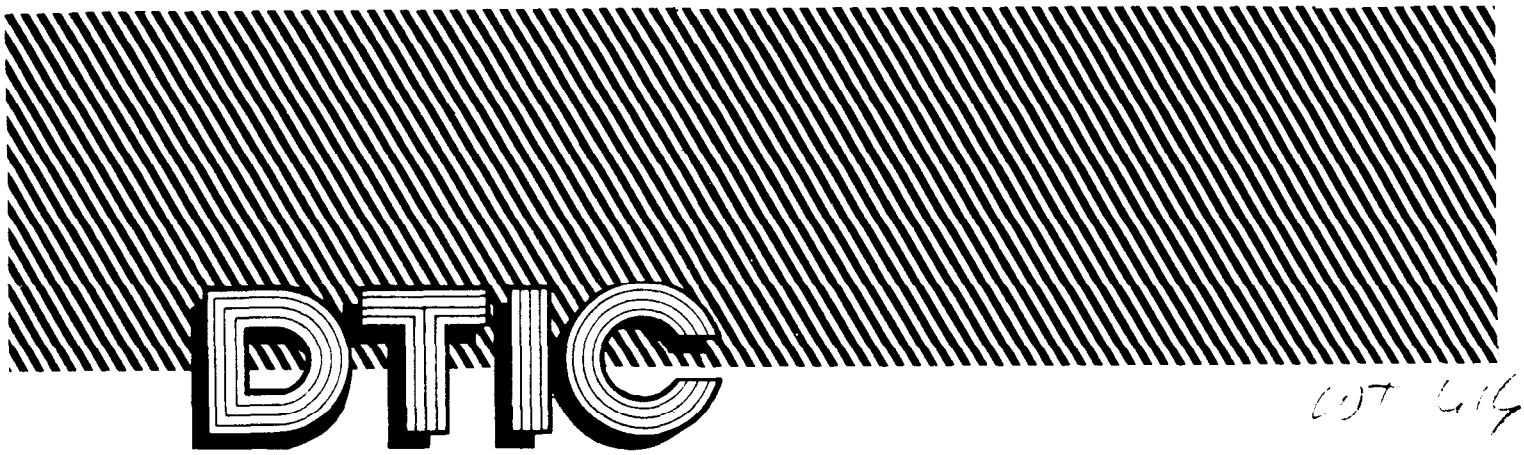

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PACIFIC PROVING GROUNDS

November 1952

Project 21.3

RADIOBIOLOGICAL STUDIES AT ENIWETOK BEFORE AND AFTER MIKE SHOT

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[redacted] DATA

[redacted] data as [illegible] of 1946. [illegible] authorized [illegible]

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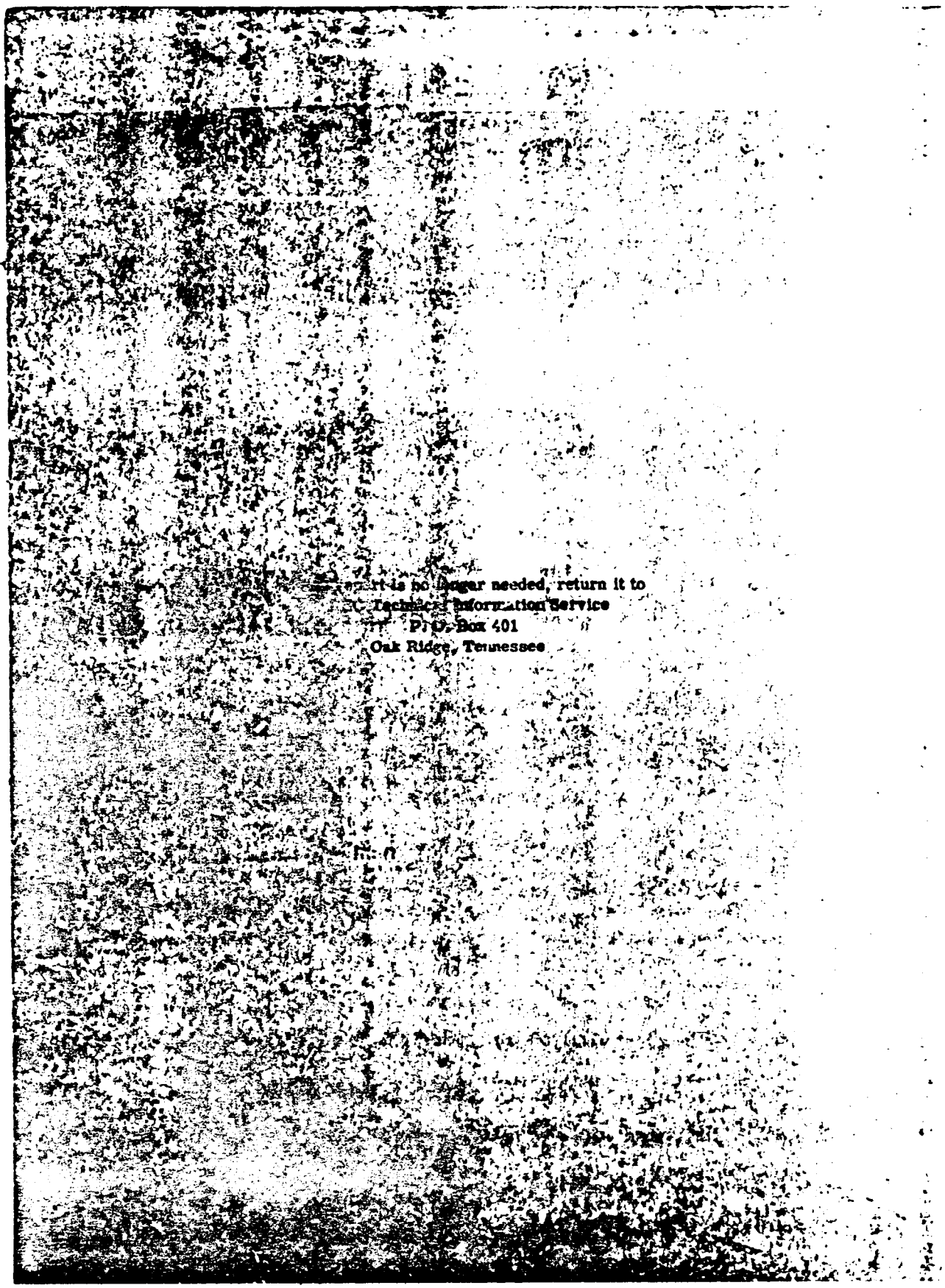
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Report to the Scientific Director

RADIOBIOLOGICAL STUDIES AT ENIWETOK BEFORE AND AFTER MIKE SHOT

By

Lauren R. Donaldson

Applied Fisheries Laboratory
University of Washington
Seattle, Washington
June 1953

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ABSTRACT

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

The field data were collected by seven specialists who collected plankton, algae, rats, birds, fish, plants, and invertebrate organisms from Oct. 20 to Nov. 11, 1952. The material collected was frozen for storage and shipment back to the Applied Fisheries Laboratory, where it was identified, dissected, weighed, ashed, and measured for radiation in disintegrations per minute per gram of wet sample.

The pretest 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 Mike shot the radiation level increased manyfold, especially along the northern and western portions of the Atoll.

The amount of radiation found on and in the specimens was sufficient to destroy or damage these forms over a very wide area.

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.

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PREFACE

The atomic energy weapons-testing program, initiated with the detonation of 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 a 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 are recorded in a number of reports prepared for the Atomic Energy Commission. A list of the reports is given in Appendix A.

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ACKNOWLEDGMENTS

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 cannot acknowledge the help and counsel of all those who aided us, but of especial help were the members of the AEC Division of Biology and Medicine staff in the Washington office. The AEC personnel at Hanford Engineer Works, in particular Kenneth Englund, were most helpful. The administrative staff of Operation Ivy, especially Duncan Curry, Jr., and Col P. L. Hooper, provided the support needed to carry out the operations in the field. CDR J. H. Barker, Jr., USN, acted as liaison officer; his services were invaluable in the preoperations planning, procurement of supplies, shipping of material, and arrangement for transportation of personnel and equipment. The officers and enlisted men of the USS Oakhill (LSD-7) supplied the necessary assistance for our operations and in many ways made our work and stay in the area enjoyable. To them we acknowledge our thanks.

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CONTENTS

	Page
ABSTRACT	3
PREFACE	5
ACKNOWLEDGMENTS	7
CHAPTER 1 OBJECTIVE AND BACKGROUND	15
CHAPTER 2 OPERATIONS	16
2.1 Areas Sampled	16
2.2 Time of Collections	18
CHAPTER 3 METHODS	19
3.1 Preservation of Specimens	19
3.2 Ashing	19
3.3 Counting	19
3.3.1 Counting Time	20
3.3.2 Distribution of Counts	20
3.3.3 Unit of Measurement	20
3.3.4 Significant Figures	20
3.4 Correction Factors	22
3.4.1 Geometry	22
3.4.2 Backscatter	22
3.4.3 Coincidence	22
3.4.4 Background	22
3.4.5 Decay	22
3.4.6 Self-absorption	25
CHAPTER 4 RESULTS AND ANALYSIS OF DATA	26
4.1 Water Samples	27
4.1.1 Sample Preparation	27
4.1.2 Results	27
4.2 Plankton	27
4.3 Algae	29
4.3.1 Analysis by Area	29
4.3.2 Analysis by Species	30
4.3.3 Radiochemical Analysis	30
4.4 Invertebrates	31
4.4.1 Pretest	31
4.4.2 Posttest	34

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CONTENTS (Continued)

		Page
4.5	Fish	38
4.5.1	Materials and Methods	38
4.5.2	Analysis by Area	38
4.5.3	Analysis by Species and Feeding Habits	41
4.5.4	Analysis by Tissues or Organs	41
4.6	Land Plants	47
4.6.1	Analysis by Area	47
4.6.2	Analysis by Species	48
4.6.3	Analysis by Organs	48
4.6.4	Radiochemical Analyses	48
4.6.5	Conclusions	49
4.7	Land Vertebrates	49
4.7.1	Collecting Methods	49
4.7.2	Results	50
4.7.3	Analysis of Organs and Tissues, Preshot	50
4.7.4	Analysis of Organs and Tissues, Postshot	55
4.7.5	Analysis by Island	55
4.7.6	Analysis by Feeding Habit	56
4.7.7	Conclusions	60
4.8	Radiochemical Analyses	60
4.9	Absorbed and Surface Contamination	62
4.9.1	Speck Contamination	67
4.9.2	Other Surface Contamination	73
CHAPTER 5	CONCLUSIONS	82
CHAPTER 6	RECOMMENDATIONS	84
APPENDIX A	BIKINI AND ENIWETOK RESURVEY REPORTS BY THE APPLIED FISHERIES LABORATORY	85
APPENDIX B	ALGAE COLLECTED AT ENIWETOK, 1952	86
APPENDIX C	INVERTEBRATE-SAMPLE DATA	89
APPENDIX D	COMMON NAMES, GENERA, AND SPECIES OF FISH USED FOR COUNTING AND NUMBER OF SPECIMENS	98
APPENDIX E	LAND PLANTS COLLECTED AT ENIWETOK, 1952	100
APPENDIX F	RADIOACTIVITY OF BIRDS, POSTSHOT	101
APPENDIX G	SURVEY-METER READINGS, POSTSHOT	102
APPENDIX H	PROCEDURES FOR PRECIPITATION OF FISSION PRODUCTS AND CALCIUM AND STRONTIUM	103
REFERENCES		104

UNCLASSIFIED

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ILLUSTRATIONS

Page

CHAPTER 2 OPERATIONS

2.1 Pre- and Posttest Collecting Stations, Eniwetok Atoll, October to November 1952 17

CHAPTER 3 METHODS

3.1 Histograms Showing Frequency Distributions of Radioactivity Counts of Engebi Beach Sand 21
3.2 Decay Curves 23
3.3 Mass-absorption Curves 24

CHAPTER 4 RESULTS AND ANALYSIS OF DATA

4.1 Relative Radioactivity of Soil or Beach Sand 35
4.2 Histograms Showing Radioactivity in Wet Weight of Whole Fish and of Fish Tissues for All Stations 39
4.3 Injured Goatfish, *M. auriflamma*, Collected at Engebi Nov. 8, 1952 . . . 42
4.4 Histograms Showing Radioactivity of Various Species of Fish 43
4.5 Photograph of a Singed Plover Taken on Bijiri (8¼ Nautical Miles from Ground Zero) Nov. 7, 1952 51
4.6 Photograph of a Singed Noddy Tern Taken on Rigili Nov. 5, 1952 . . . 52
4.7 Radioactivity of Preshot Rats and Birds, Wet Sample 53
4.8 Histograms Showing Radioactivity of Postshot Terns with Relation to Distance of Collecting Site from Ground Zero, Wet Sample 57
4.9 Photographs and Autoradiographs of 100-μ Sections of Lungs from Rats Collected at Bijiri Nine Days After Mike Shot Detonation . . . 59
4.10 Mass-absorption Curves from Bones of Rat and Tern Samples, Postshot 61
4.11 Mass-absorption Curves of Radiochemically Separated Fractions of Rojoa Dredged Sand 63
4.12 Decay Curves of Radiochemically Separated Fractions of Rojoa Dredged Sand 64
4.13a Photomicrographs of Engebi Beach Sand on Ashing Plates Counted May 1953 68
4.13b Photomicrographs of Engebi Beach Sand on Ashing Plates Counted May 1953 68
4.13c Photomicrographs of Engebi Beach Sand on Ashing Plates Counted May 1953 69
4.13d Photomicrographs of Engebi Beach Sand on Ashing Plates Counted May 1953 69
4.14 Autoradiograph, Photograph, and Photomicrograph of Bijiri Dredged Sand 70
4.15 Actual-size Autoradiographs of Eleven of the More Radioactive Posttest Ashed Samples 71
4.16 Approximately Actual-size Photographs of Eleven of the More Radioactive Posttest Ashed Samples 72
4.17 Autoradiographs of Algae Exposed to Super XX Pan Film 74
4.18 Corals Found on Bogallua Nov. 8, 1952 75
4.19 Autoradiograph of Goatfish, *M. auriflamma*, Showing Radioactivity in the Gills 76

UNCLASSIFIED

ILLUSTRATIONS (Continued)

		Page
4.20	Photograph of Fish Used in Autoradiograph of Fig. 4.19	76
4.21	Photographs of Fish Collected at Bogallua Nov. 8, 1952	77
4.22	Autoradiograph of Fish Shown in Fig. 4.21	78
4.23	Land Plants from Engebi, Postshot	79

TABLES

CHAPTER 2 OPERATIONS

2.1	Collection Data, Mike Shot	18

CHAPTER 4 RESULTS AND ANALYSIS OF DATA

4.1	Radioactivity of Water Samples	28
4.2	Radioactivity of Plankton Samples	29
4.3	Radioactivity of All Algae Samples by Island	30
4.4	Radioactivity of the Seven Most Common Algae by Island, Postshot	31
4.5	Radioactivity of Invertebrate Samples by Animal Groups, Pretest	32
4.6	Invertebrate Samples with Highest Activity, Pretest	33
4.7	Frequencies of Invertebrate Ashed-sample Counts by Magnitudes, Pre- and Posttest	33
4.8	Radioactivity of Separate Tissues or Organs of Different Groups of Invertebrates, Postshot	36
4.9	Radioactivity of All Invertebrate Samples Counted at Each Collecting Station, Posttest	37
4.10	Radioactivity of Whole Fish by Stations	40
4.11	Radioactivity of Fish from All Stations Compared by Feeding Habits	44
4.12	Radioactivity of Fish Tissues Compared by Stations, Preshot	45
4.13	Radioactivity of Fish Tissues Compared by Stations, Postshot	46
4.14	Radioactivity of Land Plants by Stations	48
4.15	Radiochemical Analyses of Soils and Plants, Postshot	49
4.16	Radioactivity of Rats	54
4.17a	Radioactivity of Birds, Preshot	54
4.17b	Radioactivity of Birds, Postshot	55
4.18	Radioactivity in Rats and Shore Birds Compared by Feeding Habits	56
4.19	Radioactivity in Terns and Shore Birds Compared by Feeding Habits	58
4.20	Coefficients of Variability for Organs of Rats, Postshot	58
4.21	Radiochemical Analyses of Sand, Soil, and Biological Samples, Posttest	65
4.22	Comparison of Radioactivity of Two Species of Sea Cucumbers Collected at Aaraanbiru, Postshot	80
4.23	Comparison of Specific Activity Found in Shrimp and Algae	81

CHAPTER 5 CONCLUSIONS

5.1	Radioactivity of Samples Summarized by Groups and by Islands	83

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TABLES (Continued)

Page

APPENDIX C INVERTEBRATE-SAMPLE DATA

C.1 Individual Values of Invertebrate Samples, Pretest 91
C.2 Radioactivity of Invertebrate Organs and Tissues by Food Habits, Postshot 92
C.3 List of Specific Activity of Invertebrate Samples, Postshot 93

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CHAPTER 1

OBJECTIVE AND BACKGROUND

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

Since Eniwetok Atoll has been used for several tests of atomic weapons since the last resurvey by the Applied Fisheries Laboratory group in 1948, it was essential to establish the level and kinds of residual radiation from the previous tests before the detonation and resultant contamination of Mike shot. The data on the preshot contamination were obtained from samples of flora and fauna of the Atoll and the lagoon. In addition to the data accumulated regarding 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 not only changed 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 Mike shot upon the plants and animals.

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CHAPTER 2

OPERATIONS

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

Collections were made by the following 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	Fish
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 Fig. 2.1. There were seven major stations, six of which were approximately the same as those visited in 1948 and 1949. The seventh station, Bogombogo-Bogallua, was 2 to 3 miles west of the Mike shot test 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 ft. 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.

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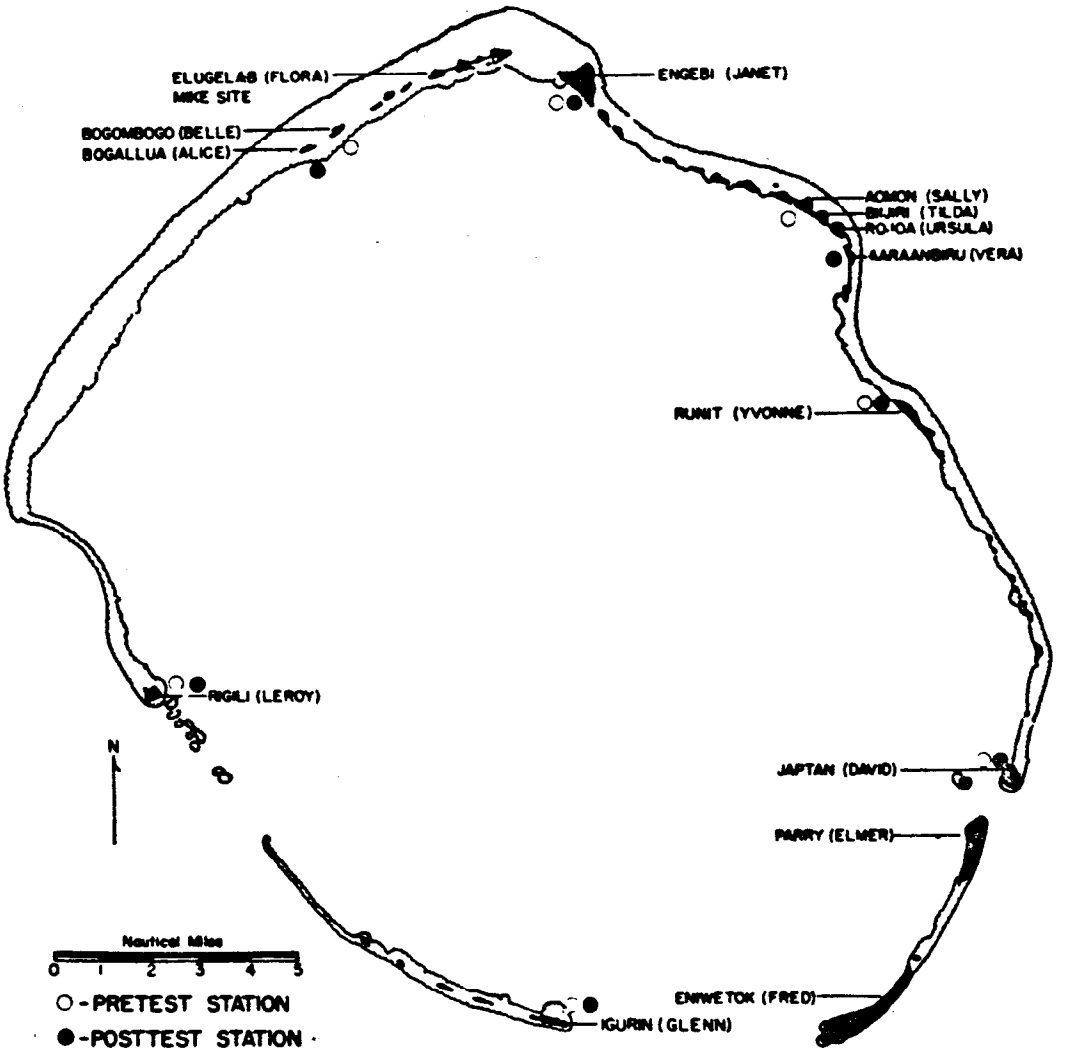

Fig. 2.1—Pre- and posttest collecting stations, Eniwetok Atoll, October to November 1952.

2.2 TIME OF COLLECTIONS

Collections were made both before and after the Mike test of November 1. The pretest samples were collected from October 21 to 28, and the posttest samples were collected from November 3 to 10. The collecting dates and distances from Mike shot by islands are given in Table 2.1.

Table 2.1—COLLECTION DATA, MIKE SHOT

Island	Date		Nautical miles from Mike shot
	Preshot	Postshot	
Japtan	Oct. 21	Nov. 3	18½
Igurin	Oct. 28	Nov. 4	19½
Rigili	Oct. 27	Nov. 5	14
Bogombogo-Bogaliua	Oct. 25	Nov. 6	2½–3
Engebi	Oct. 24	Nov. 8	2½
Aomon-Aaraanbiru	Oct. 23	Nov. 7	7½–9
Runit	Oct. 22	Nov. 6	11½

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CHAPTER 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 USS 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 per cent formalin.

3.2 ASHING

The samples were ashed and plated in much the same manner as previously described.[1] Briefly, the procedure was as follows: (1) Fish, invertebrates, birds, rats, and land plants were dissected, and approximately 1-g samples of various tissues were placed upon weighed $1\frac{1}{2}$-in. stainless-steel plates. Wet-sample weights depended upon the amount of tissue available and the activity of the sample at the time of dissection as determined by survey meter. The mean sample weight of 145 randomly selected samples was 1.17 ± 0.074 g.* (2) The wet-sample plates were placed in a drying oven at 97 to 99°C for 12 to 24 hr. (3) They were then cooled in a desiccator, and the dry weights were determined. (4) The plates were next moved to the muffle furnace for about 12 hr, during which time the temperature was gradually raised to 300°C then more rapidly to a maximum of 550°C; clam shells and corals were held at 600°C for 30 min. (5) After cooling, the ash was slurried with ethyl alcohol, and a clean glass rod was used to distribute it evenly on the plate. Following drying, a weightless amount of formvar in a 0.65 per cent 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.

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

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3.3.1 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, min
<500	20
500–1000	10
1000–2000	5
>2000	2

The counting period for practically all samples collected after the Mike test (November 1) was from November 24 to December 12. Most of the samples from the pretest collections were counted after this period but before the end of December. During this period a 24-hr-day 7-day-week counting schedule was maintained.

3.3.2 Distribution of Counts

The statistical distribution of sample counts appeared to be of a logarithmic or log-log nature. To further investigate the type of distribution, two series of counts of 100 samples each of unashed posttest Engebi sand were made. Sand, in a jar, was dried in the oven and mixed. Sampling cups for the two series held 6.1 ± 0.05 mg (n = 100) and 2990 ± 3 mg (n = 32), respectively (n is number of samples counted). The small-sample series was counted in the Nucleometer for 10 min per sample, and the large samples were counted in the end-window counter for 1 min each. The frequency distribution of the actual counts of the small samples was strongly skewed (Fig. 3.1a) but was approximately normal for the logarithms of the logarithms of these counts (Fig. 3.1b). For the large samples (Fig. 3.1c), 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 (Sec. 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.

3.3.3 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 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 the activity per unit of dried or ashed weight.

3.3.4 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 lim-

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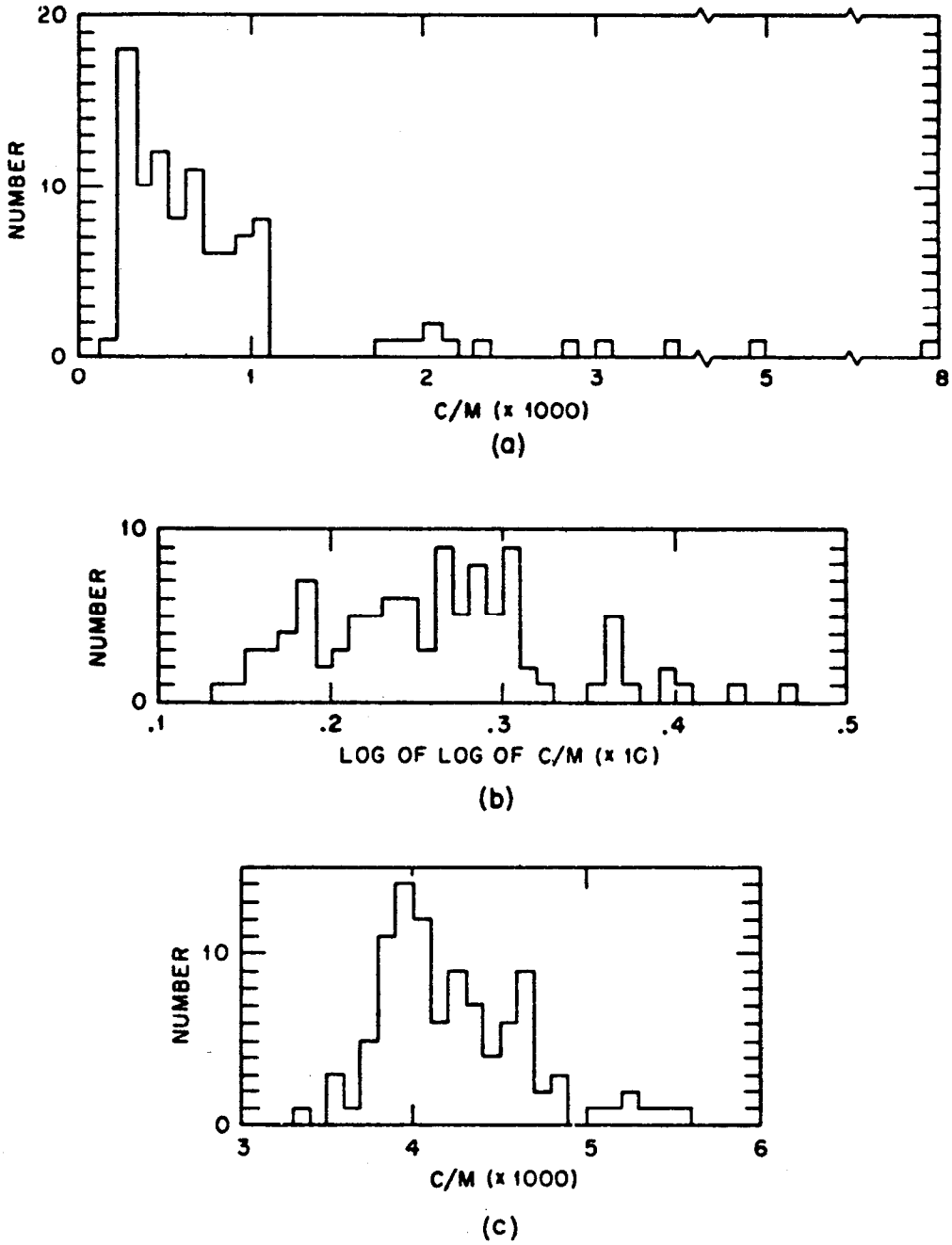

Fig. 3.1—Histograms showing frequency distributions of radioactivity counts of Engebi beach sand. (a) Counts for 100 small (6-mg) samples. (b) Logarithms of logarithms of the same counts. (c) Counts for 100 large (3000-mg) samples.

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ited by the number of significant figures in the least accurate value in the computation. One source of limitation in the posttest samples was the correction factor for decay, which was changing approximately 4 per cent 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 mg and occasionally less than 10 mg. Also the correction factors for backscatter and for geometry were not determined more accurately than to two significant figures.

3.4 CORRECTION FACTORS

3.4.1 Geometry

Geometry is about 50 per cent for an internal-gas-flow counting chamber. Hence the correction factor was approximately 2.0.

3.4.2 Backscatter

Backscatter was previously determined for P^{32} in our Nucleometers as being 30 per cent (see p. 24 of reference 1). The same correction factor, 100/130 = 0.77, was used again this year.

3.4.3 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 c/m, the correction factor was 1.01; for counts of 382,000 to 392,000 c/m, 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 $N = n/(1 - nt)$, held true (N = true counting rate, n = observed counting rate, and t = recovery time of register, or 5 μsec).

3.4.4 Background

The background values were determined by interpolating between background counts at the point (time) when the sample count was made. Usually about five 20-min background counts were taken during a 24-hr period. From November 24 to the end of December, 127 background counts were made with counter 185, and the mean value was 50.25 c/m, with a standard deviation of 2.63; for counter 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 2 in. of lead.

3.4.5 Decay

At the time of counting, the posttest samples were decaying at an appreciable rate. Therefore these samples were corrected for decay, and the date to which they were corrected was arbitrarily chosen as December 1, one month after 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

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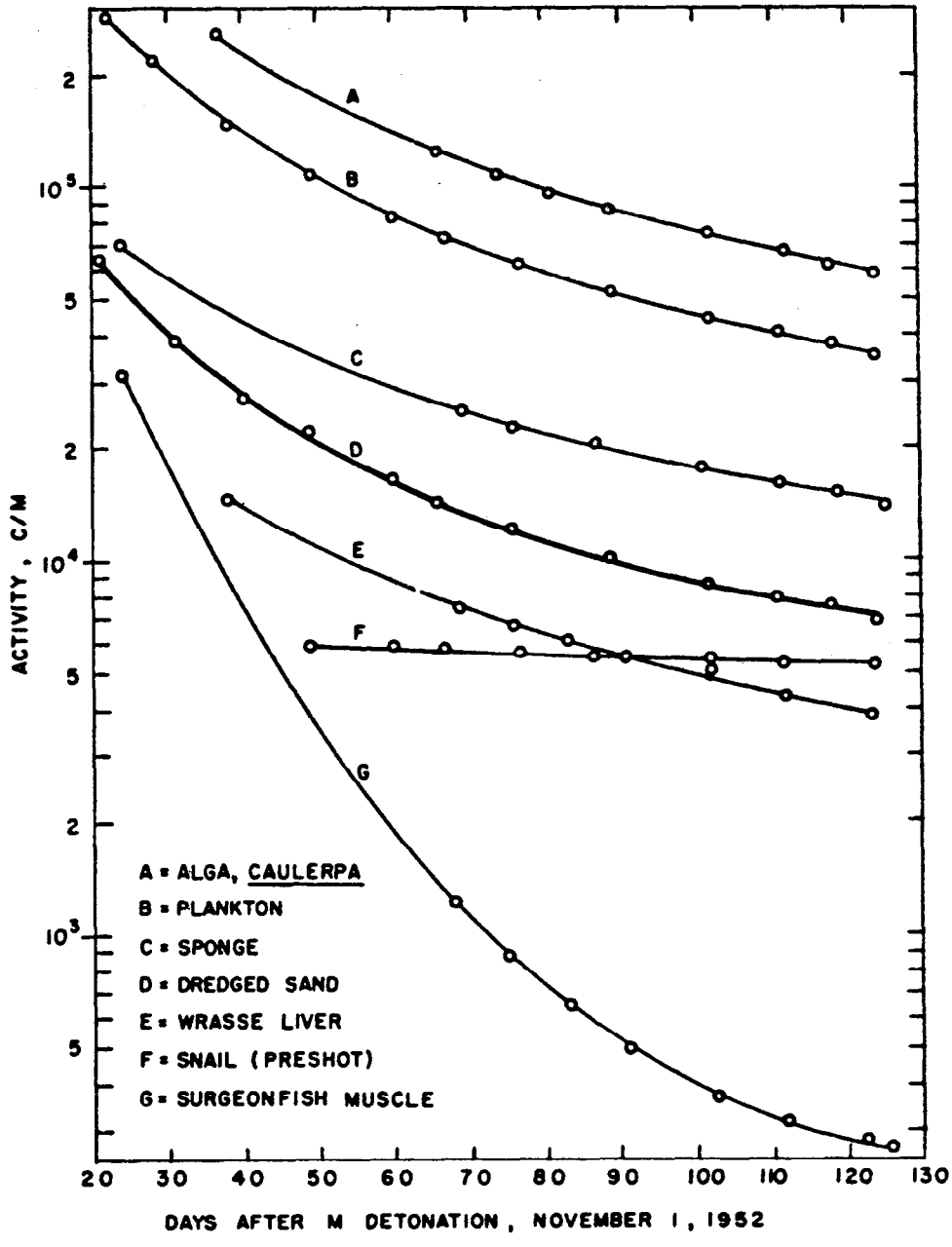

Fig. 3.2—Decay curves.

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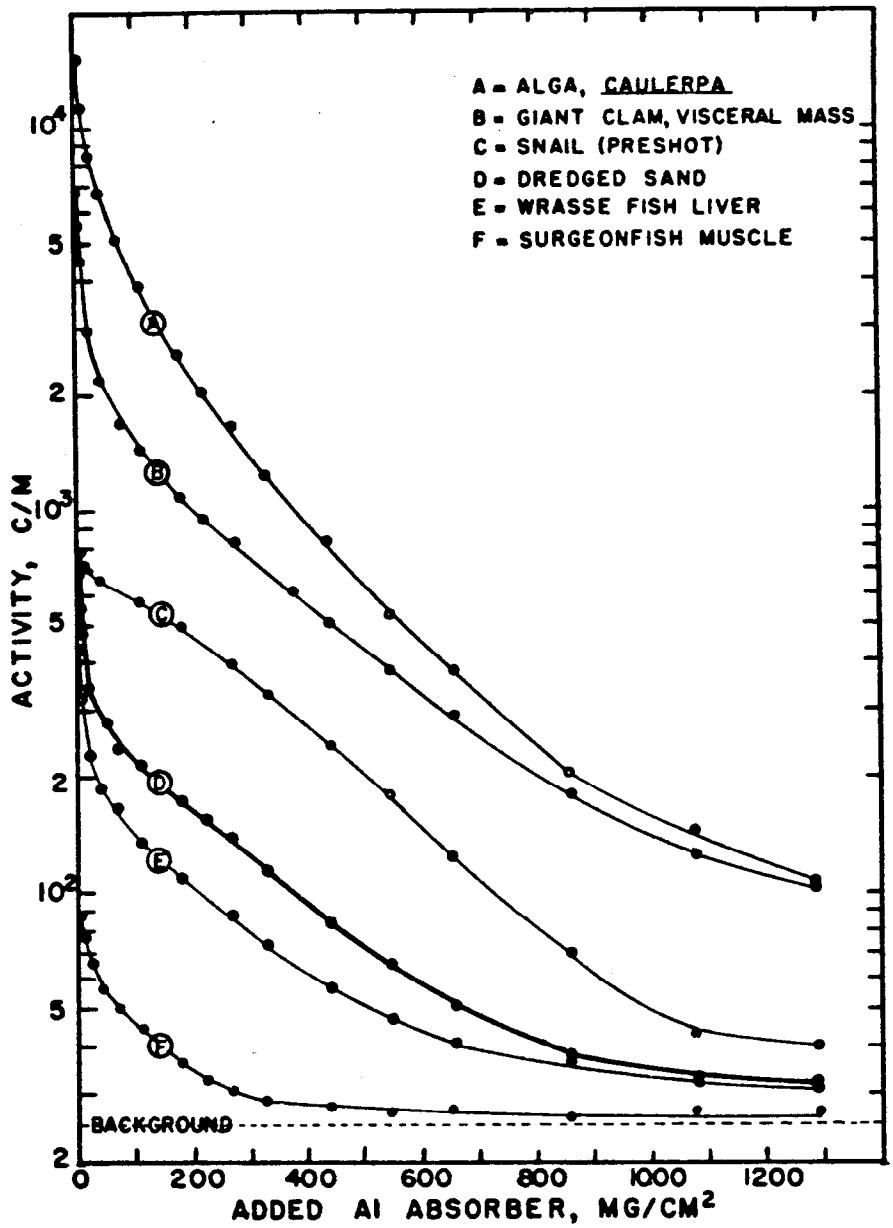

Fig. 3.3—Mass-absorption curves.

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10. In the period immediately following the shot, the activity in the organisms would be expected to vary greatly within short periods owing to changes in geographical distribution of the radioactive materials and to length of exposure time 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 ft. 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 (Fig. 3.2). However, there were a few curves that departed significantly from the sand curve; those are also shown in Fig. 3.2. 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 pretest 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 per cent. For differences between pre- and postshot decay curves, see Fig. 3.2.

3.4.6 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 (Figs. 3.2 and 3.3) 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 1½-in. plate, are as follows: 100 mg, 2.6; 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.

The total correction factor for 68 pretest samples was 3.93 ± 0.21, and for 64 posttest samples it was 5.98 ± 0.62.

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CHAPTER 4

RESULTS AND ANALYSIS OF DATA

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

1. Nonrandom selection of specimens: In the field, collection of specimens was directed toward 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 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 courting.

2. Random selection of tissues: In some instances the activity of preshot 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 preshot 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 preshot 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 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 fall-out 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 are trends and certain relative values.

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4.1 WATER SAMPLES

While the land and reef collections were being made, the M-boat that had transported the field crew from the USS 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 preshot water samples was 6 liters, and that of the postshot samples was ½ liter. The samples were collected with a Foerst type water bottle.

4.1.1 Sample Preparation

Since it was impractical to bring 6-liter water samples to the laboratory for processing, a precipitation method was used in the field for the preshot 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 Appendix H.

4.1.2 Results

Results are presented in Table 4.1. Note that the values in this table are in terms of milliliters of water samples 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 6000 for the pretest samples and 500 for the posttest samples. The values for whole sample (postshot) were based on a 3-ml sample that was withdrawn before precipitation; hence it would be expected to be less reliable.

From inspection of Table 4.1 the following conclusions can be drawn: For the pretest samples radioactivity of the Bogombogo sample was considerably greater than that for other stations. Why it was greater is not known, but the 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 posttest samples the amount of activity was closely and inversely related to distance of sample from test site. For stations nearest the test site values for the posttest samples were several hundred times greater than those for the pretest samples. Since the counts of $Fe(OH)_3$ scavenge and Ca-Sr oxalate do not equal the count of whole sample, evidently all the radioactive materials were not removed by these processes.

A rain-water sample was collected 33 hr after Mike shot in the lagoon off Eniwetok Island. A 450-cc sample was evaporated and counted on Nov. 4, 87 hr after Mike, using a Victoreen survey meter with a 1-in. end-window tube, the window thickness being 1.8 mg/sq cm. The maximum count was 10,000 per minute.

4.2 PLANKTON

The plankton nets were 0.5 m in diameter and 2 m long. The anterior section was cylindrical, and the posterior section was conical with a detachable net end. The plankton tows were made in pairs at the surface during daylight hours. One net of each pair was constructed with No. 6 silk (74 meshes/in.) and the other of No. 12 silk (173 meshes/in.). Towing time was usually 1 hr, and the towing distance was about 1½ miles. Catches of plankton were small. Exclusive of jellyfish, the greatest volume of plankton in a 1-hr 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.

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Table 4.1 — RADIOACTIVITY OF WATER SAMPLES*

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

*Measured in disintegrations per minute per milliliter.

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 the 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 Sec. 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 (foraminifers, principally, and some snails, copepods, and a few miscellaneous eggs and arrowworms), but the sample from net B was seven times more active than the sample from net D (1,160,000 d/m/g as compared to 155,000 d/m/g). Since net B was of finer mesh than net D (173 and 74 meshes/in., 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-mesh net was more efficient in capturing suspended inanimate radioactive particles.

The radioactivity in plankton samples is recorded in Table 4.2.

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Table 4.2—RADIOACTIVITY OF PLANKTON SAMPLES*†

Island	Preshot		Postshot	
	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

*Measured in disintegrations per minute per gram (× 1000), wet sample.

†Nets A and B: No. 20 silk, 173 meshes/in.; net D: No. 6 silk, 74 meshes/in.

From an inspection of Table 4.2 the following conclusions are made: There were measurable amounts of radioactivity in all the preshot samples, especially those from Bogombogo. For similar areas the postshot samples were 200 to 300 times more radioactive than the pretest samples. The postshot samples from Igurin were higher than those at Rigili, Aaraanbiru, or Runit, which were closer to the shot island. Usually the catch in the fine-mesh net was considerably more radioactive than the catch from a coarser mesh net for paired hauls from the same station, especially in the postshot samples.

Some radioactivity was also found in the plankton preservative. The activity of the preservative from the Bogallua collection which was filtered through No. 42 Whatman filter 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 per cent formalin solution or that some of the adsorbed particles are washed off the organisms.

4.3 ALGAE

The algae collections included 5 species of blue-green, 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 Appendix B.

4.3.1 Analysis by Area

Because of the paucity of samples and the nonrandomness 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 4.3 the average radioactivity of the algae at each collecting station is given.

In the pretest collection the samples from those islands close to previous atomic tests or upon which previous atomic tests had been conducted were the most radioactive. One sample in particular, collected in a stagnant pool 250 yd 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 postshot series, for stations within

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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.

Table 4.3 — RADIOACTIVITY OF ALL ALGAE SAMPLES BY ISLAND*

Island	Preshot				Postshot			
	n	Av.	Max.	Min.	n	Av.	Max.	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	2,100	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	5,200	14,000	1,200
Engebi	7	8.2	21	0.18	3	4,000	6,800	2,500
Engebi†	3	8.4	11	6.2				
Aomon-Aaraanbiru	12	7.7	54	1.7	5	1,400	3,900	56
Aomon†					4	3,600	6,200	400
Runit	12	9.8	51	0.087	9	110	250	13
Runit†	6	3.5	9.8	0.20	4	92	250	26

* Measured in disintegrations per minute per gram (× 1000), wet sample.
† Dredged samples.

4.3.2 Analysis by Species

Of the seven 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 4.4. 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.[1]

4.3.3 Radiochemical Analysis

Radiochemical analysis of the pretest sample from the Lake George area (Sec. 4.8) showed that Ce^{144}, having a half life of 280 days, contributed 74 per cent of the radioactivity. Results of radiochemical analyses of posttest samples of sand dredged off Rojoa Island and of three algae collected in the lagoon 200 yd off Bogallua Island are given in Table 4.21.

From 85 to 96 per cent of the total activity of the algal samples is accounted for by 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,[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.

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Table 4.4—RADIOACTIVITY OF THE SEVEN MOST COMMON ALGAE BY ISLAND, POSTSHOT*

Island	*Halimeda*†	*Caulerpa*	*Lyngbya*	*Cladophora*	*Bryopsis*	*Dictyota*	*Jania*†
Engebi			6,800	2,600	2,500		
Bogallua	1,700	2,500	14,000	6,400			
Aomon	240	150	2,400	56	3,900		
Aomon‡	2,500					5,300	6,200
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			

* Measured in disintegrations per minute per gram (× 1000), wet sample.
† Coralline algae.
‡ Dredged samples.

4.4 INVERTEBRATES

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

4.4.1 Pretest

Methods of collection were the same as those for previous surveys; i.e., 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. During the collection of these primary kinds, other invertebrates were also sought to obtain a collection that would be representative of the locality. Whereas 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 38.

In the preparation of specimens for ashing, small specimens were ashed entirely, whereas large ones were dissected, and the tissues were ashed separately. In the case of intermediate-size 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, as previously stated.

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Results. Table C.1 gives individual sample values. Table 4.5 shows the average amounts of radioactivity in the main invertebrate groups at the collecting localities. Blanks indicate that no specimens were found. These values bear out the inverse relation 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 the position of this island 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 was higher.

Because of their marked influence upon the averages, the high-counting samples included in Table 4.5 and Table C.1 are listed separately in Table 4.6.

Table 4.5 — RADIOACTIVITY OF INVERTEBRATE SAMPLES BY ANIMAL GROUPS, PRETEST*

Organism	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	
Crustacean	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					

* Measured in disintegrations per minute per gram (× 1000), wet sample.
† Dredged samples.

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. Collections from the tide pool 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 (Table C.1).

The relation 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 4.7 gives frequencies of counts by magnitudes for the major collecting areas for both pre- and postshot material, exclusive of dredged samples. The trend for high counts to predominate near shot areas is almost the same in both pre- and posttest samples.

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Table 4.6—INVERTEBRATE SAMPLES WITH HIGHEST ACTIVITY, PRETEST

Organism	Tissue or organ	Locality	Activity, d/m/g (× 1000)*
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

*Wet sample.

Table 4.7—FREQUENCIES OF INVERTEBRATE ASHED-SAMPLE COUNTS BY MAGNITUDES, PRE- AND POSTTEST*

Magnitude, d/m/g (× 1000), wet sample	Japtan	Igurin	Rigili	Bogombogo	Engebi	Aomon and Aaraanbiru	Runit
			Pretest				
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
			Posttest				
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
100–1000			14	14	9	4	3
1,000–10,000				4	3	2	
10,000–100,000					1		

*Frequencies are for major collecting localities, exclusive of dredged material.

Table 4.7 also serves to demonstrate that the frequency of distribution of logarithms of counts in the posttest series is approximately of the normal form, whereas the distribution of the observed counts would be strongly skewed. In the pretest series the distribution of the logarithms of the counts is normal only in the hotter areas and then only if background counts are excluded.

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A comparison of the activity in different organs of crabs was made using the count found in muscle as unity. The values relative to muscle for other tissues in pre- and posttest 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 pretest molluscs, the shells were more radioactive than the soft parts for 25 per cent, and for the other 75 per cent the reverse was true.

4.4.2 Posttest

Invertebrates collected after Mike test are listed in Table C.2. 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. 4.18b) had a specific activity of approximately 100,000,000 d/m/g.

(a) 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 19 classes of items in Table 4.8, the stations, given in decreasing order of radioactivity, are: Bogallua, Engebi, Aaraanbiru, Rigili, Runit, Igurin, and 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 Fig. 4.1. The specific activity relative to Igurin is shown for gill, mantle, muscle, and digestive gland (liver). Regardless of the tissue 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 1. Included in Fig. 4.1 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, whereas 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 Bogallua may well be a matter of sampling. One such sample collected from each of the two stations differed by a factor of less than 3, whereas the maximum and minimum specific activities of a series of nine sea-cucumber guts taken from an area of less than 1000 sq ft at Aaraanbiru differed by a factor of more than 6.

The average values of all invertebrate samples from each station are given in Table 4.9. The limited usefulness of these values was discussed earlier in this chapter. The values were not considered in the ranking of stations discussed in the preceding paragraph.

(b) Tissue and Organ Differences. General statements can be made regarding 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 a comparison of the specific activity of each tissue or organ in individual specimens. However, the same relation can be found in Table 4.8, 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 contents. In those snails having a gill, the liver is the more active. The liver is also more active than the gill in the crabs.

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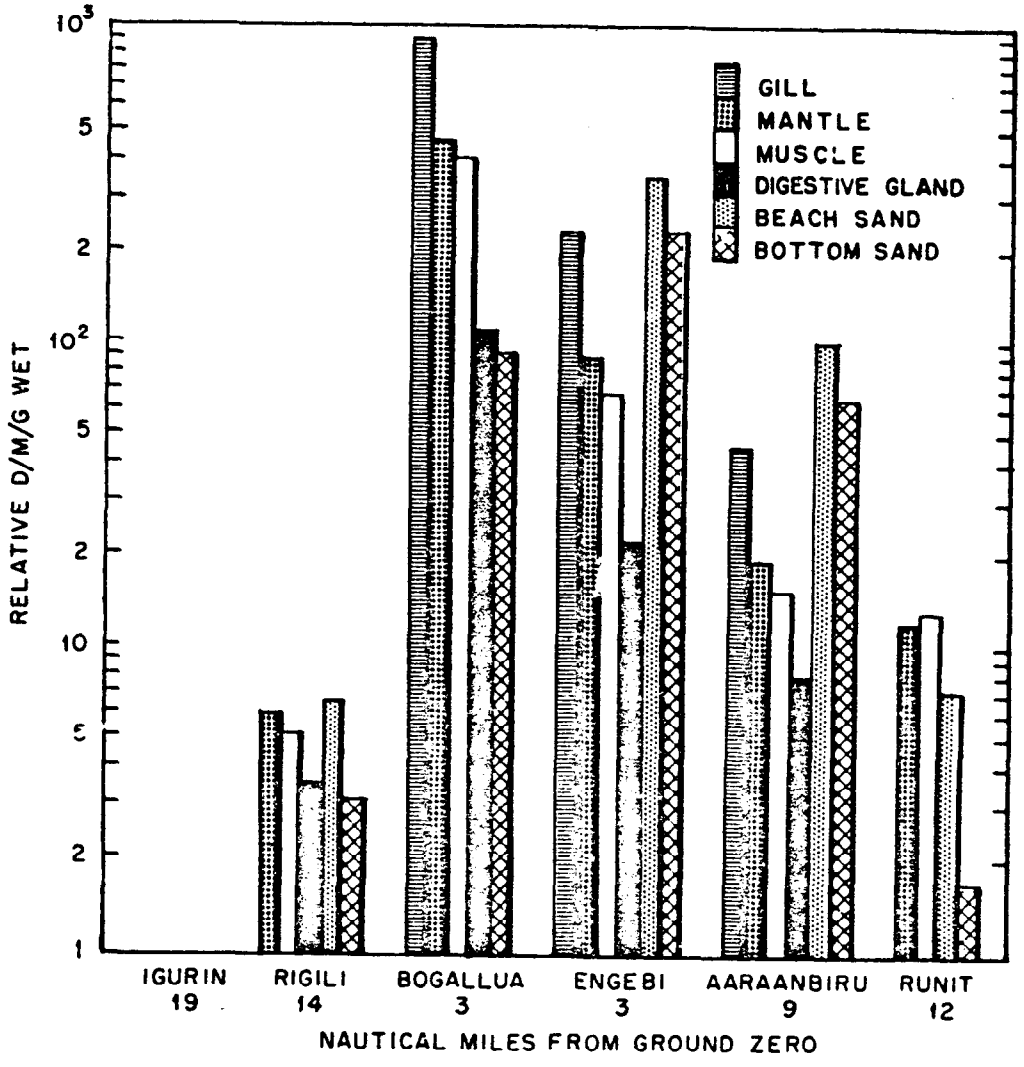

Fig. 4.1—Relative radioactivity of soil or beach sand. Bottom sand taken from sea-cucumber guts and giant-clam gill, mantle, muscle, and digestive gland. The relative activity of each type of sample at Igurin is taken as 1.

Table 4.8 — RADIOACTIVITY OF SEPARATE TISSUES OR ORGANS OF DIFFERENT GROUPS OF INVERTEBRATES, POSTSHOT*†

Invertebrate, organ, and tissue	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			7,600		
Sea cucumbers	0.14	64	200	5,900	15,000	4,300	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	Background	2.2	9.1	123	45	18	3.9
Snails	Background	0.60	8.0				3.1
Crabs	0.16	1.2	23		750	20	17
Entire coral	Background	0.55	15	3,000	2,700		35

* Measured in disintegrations per minute per gram (× 1000), wet sample.
† For n, maximum, and minimum, refer to Table C.2.

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Table 4.9—RADIOACTIVITY OF ALL INVERTEBRATE SAMPLES COUNTED AT EACH COLLECTING STATION, POSTTEST*

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

*Measured in disintegrations per minute per gram (× 1000), wet sample.

4. The digestive tract with its contents 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 rankings of tissues in descending order of specific activity with individual exceptions are as follows:

a. Clams: (shell variable in position)
   (1) Digestive tract (visceral mass with contents)
   (2) Gill
   (3) Liver
   (4) Mantle
   (5) Muscle

b. Snails:
   (1) Liver
   (2) Gill
   (3) Mantle
   (4) Muscle

c. Octopus (one specimen):
   (1) Liver
   (2) Gill
   (3) Muscle

d. Hermit crabs: (carapace variable in position)
   (1) Digestive tract with contents
   (2) Liver
   (3) Gill
   (4) Muscle

e. True crabs: (carapace variable in position)
   (1) Digestive tract with contents
   (2)
   (3) } Liver or gill
   (4) Muscle

(c) 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 4.8.

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.

(d) 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

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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 contents, the highest. Other tissues or organs varied in rank, 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

4.5.1 Materials and Methods

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

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 more than 30 families and varied in weight from less than 1 to 1589 g (average 51.1 g).

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, such as goatfish, jacks, and flatfish, which prefer an open sandy bottom were also taken and ashed for counting.

The fish which best fulfilled the criteria listed above were the damselfish *(Pomacentridae)*, surgeonfish *(Acanthuridae)*, grouper *(Serranidae)*, and wrasse *(Labridae)*. Table C.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, *Epinephelus merra*, the damselfish, *Abudefduf biocellatus*, the surgeonfish, *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 fish 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[1] followed in 1949. The results are recorded in Table 4.10. The tissues listed in this table made up at least 95 per cent of the total weight of the fish. Gills, glands, and nervous tissue were assumed to be similar in activity to bone, skin, and muscle.

4.5.2 Analysis by Area

Comparisons of averages for entire fish indicate that the greatest amount of radioactivity was in postshot samples collected at Engebi Island, followed by Bogallua, Aaraanbiru, Rigili, Runit, Igurin, and Japtan in descending order (Table 4.10 and Fig. 4.2).

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,

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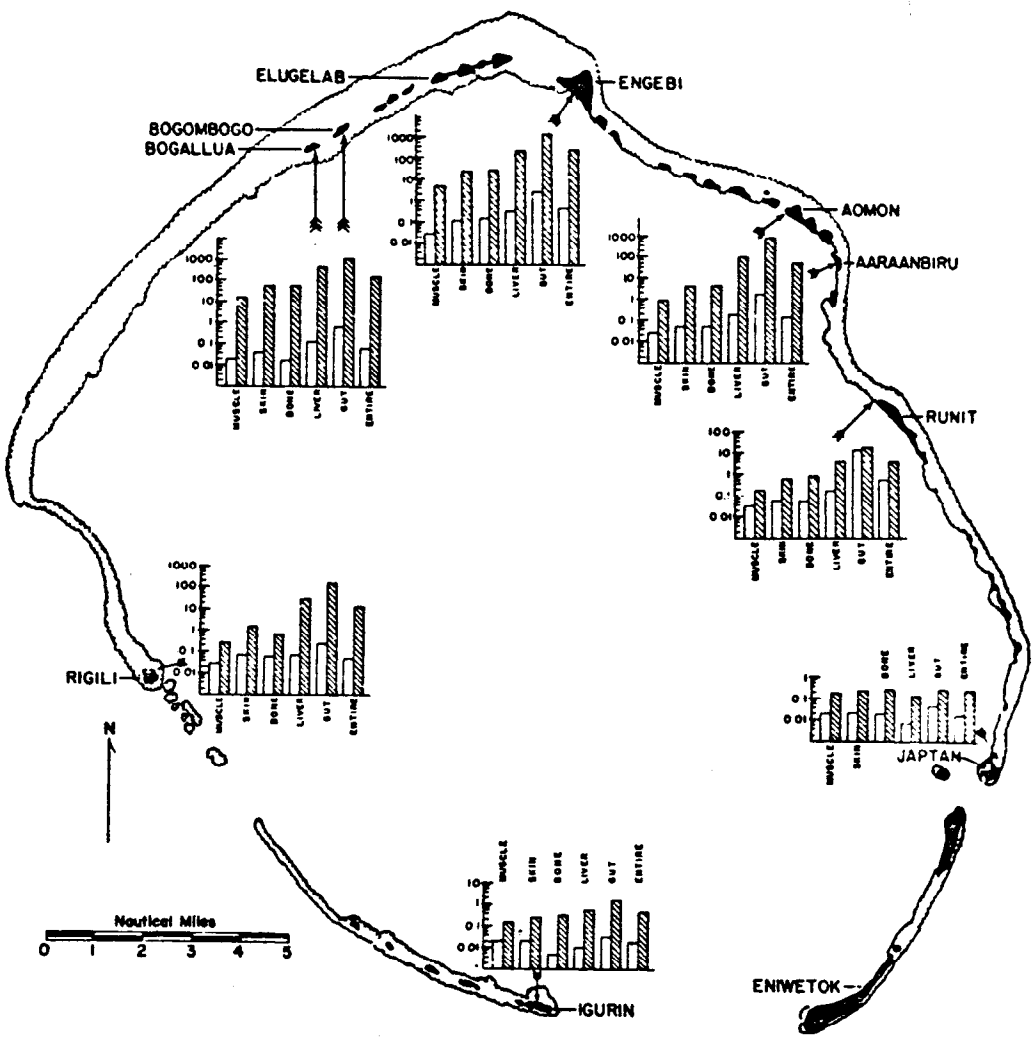

Fig. 4.2—Histograms showing radioactivity in wet weight [d/m/g (x 1000)] of whole fish and of fish tissues for all stations. Open histograms, preshot. Shaded histograms, postshot.

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Table 4.10—RADIOACTIVITY OF WHOLE FISH BY STATIONS*

Common name	Japtan			Igurin			Rigili			Bogombogo and Bogallua			Engebi			Aomon and Aaraanbiru			Runit		
	Pre-shot	n	Post-shot	Pre-shot	n	Post shot	n	Pre-shot	Post-shot	n	Pre-shot	n	Post-shot	n	Pre-shot	n	Post-shot	n	Pre-shot	n	Post-shot	n	Pre-shot	Post-shot	n
Damsel	0.020	5	0.22	0.024		0.74	2	0.10	26	3	0.21	2	520	4	0.43	4	800	5	0.31	3	272	4	1.5	8.2	6
Surgeon	0.031		0.31	0.024	2	0.56		0.052	3.6		0.079		1100		0.030		110		0.094		45		0.11	2.9	2
Butterfly	0.021		0.27	0.024		0.30		0.083	3.6		0.082		571		0.24		130		0.35					3.8	
Parrot			0.091			0.20		0.067	12		0.15				0.49		340		0.25		62	5	2.3	16	
Blenny	0.02	2	0.044	0.013	2			0.042	18						0.85		370								
Brotulid													2.8												
Mullet	0	4																					0.57		
Puffer	0.022												160								11	2			
Filefish													220												
Grouper	0.037		0.64	0.017		0.46		0.040	0.32		0.030		22	2	0.064		7.0		0.035		.7		0.051	0.33	
Squirrel			0.22			0.14			17	3	0.035	2	16		0.29	2	24	2	0.072	3	2.4			1.6	2
Wrasse	0.020	4	0.22	0.017		0.17		0.055	1.5		0.035	2	79	9	0.15		22	4	0.073		6.8	7	0.33	2.3	6
Goatfish	0.031			0.032		0.14		0.064	0.40		0.064				0.042		7.6						0.69	1.0	
Eel			0.11					0.032			0.022		61	3					0.032						
Goby			0.21						1.3				98	4					0.079	3	1.0		0.13		
Cardinal				0.012	2	0.10		0.004			0.018	2	23	2	0.45		4.7		0.057		0.72				
Snapper						2.0							2.0		0.026				0.066		2.4				
Halfbeak															0.073						1.3				
Jack																					0.86		0.041	0.17	
Smelt																							0.044		
Flatfish				0.013																					
Reeffish													47	5											
n	20		10	12		11		10	14		14		36		16		18		17		26		10	21	
Average	0.018		0.23	0.019		0.51		0.054	12		0.073		160		0.55		280		0.14		59		0.58	4.4	
s†	0.012		0.16	0.007		0.56		0.027	42		0.068		240		1.9		370		0.12		210		0.76	4.5	

* Measured in disintegrations per minute per gram (× 1000), wet sample.
† Standard deviation.

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 factors.

The greatest increase of radioactivity in posttest fish over preshot 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 postshot fish from Engebi. These data seem to indicate that the metabolized and, to some extent, the adsorbed (onto the skin) radioisotopes were available in greater amounts at Bogallua; i.e., they were 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 preshot 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. 4.3).

4.5.3 Analysis by Species and Feeding Habits

Among those fish which are fairly well represented in the samples, the damselfish appear to ingest the greatest amount of active material, followed by surgeonfish, butterfly fish, parrot fish, gobies, wrasses, squirrelfish, 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 4.11). As the range of disintegrations per minute per gram indicates, there is great variation from species to species, island to island, and even from specimen to specimen, especially evident in the postshot fish.

Omnivorous species almost invariably showed more activity than carnivorous species from the same area. Exceptions were found at Igurin and Japtan (Fig. 4.4), where activity was more or less similar in the two groups. Comparisons of preshot activity at other stations indicate that the omnivores are two to seven times as radioactive as the carnivores. Comparisons of postshot activity indicate that 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 the omnivores to carnivores ratio of radioactivity was greater at Aaraanbiru and Engebi than at Japtan and Igurin. This is further substantiated by comparing like tissues of carnivores and omnivores. At Japtan and Igurin comparatively small amounts of preshot 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 preshot and postshot 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 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.

4.5.4 Analysis by Tissues or Organs

The data for the analysis of tissues or organs are summarized in Tables 4.12 and 4.13, in which the wet weight of tissues (disintegrations per minute per gram) is compared by islands and by feeding habits. Part of the material has been discussed on the preceding pages.

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Fig. 4.3—Injured goatfish, *M. auriflamma*, collected at Engebi Nov. 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.

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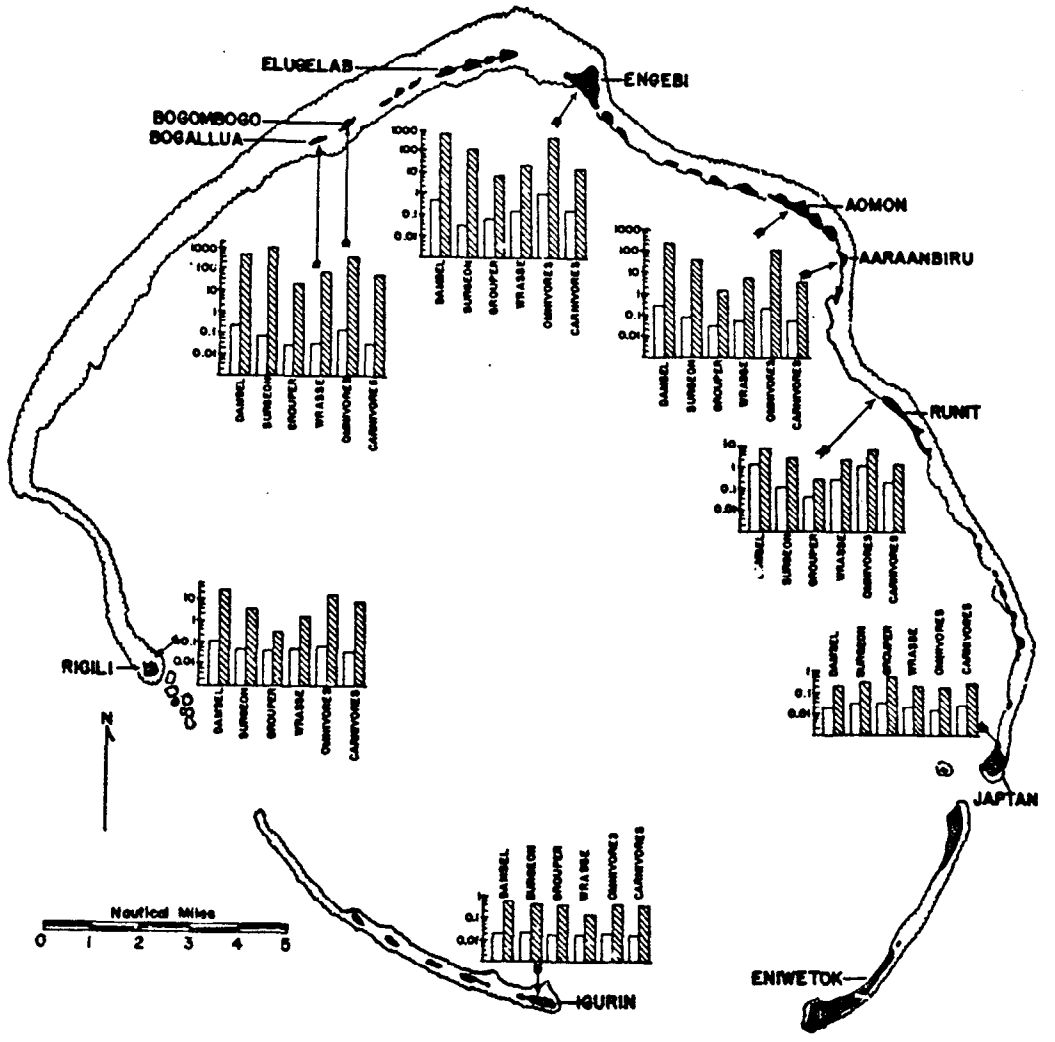

Fig. 4.4—Histograms showing radioactivity of various species of fish. Omnivores and carnivores and all omnivores and carnivores combined are represented. Open histograms, preshot. Shaded histograms, postshot.

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Table 4.11 — RADIOACTIVITY OF FISH FROM ALL STATIONS COMPARED BY FEEDING HABITS*

Common name	Preshot n	Preshot Range	Preshot Av.	Postshot n	Postshot Range	Postshot Av.
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	0.17–0.86	0.52
Smelt	1	0.044	0.044			
Flatfish	1	0.013	0.013			
Reeffish				5	13–107	47
All carnivores	51	0.004–0.69	0.081	79	0.10–98	24
Omnivores and carnivores	97	0–2.3	0.15	136	0.042–1100	92

* Measured in disintegrations per minute per gram (× 1000), wet sample.

Generally, in both preshot and postshot 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 preshot samples from Igurin, where the activity in the livers was usually lower than in other tissues, whereas muscle radioactivity was comparatively high in proportion to other tissues and when compared with other stations.

Counts in skin and bone averaged about twice the counts in muscle in preshot omnivores and carnivores. In postshot omnivores the skin and bone counts were about five times those

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Table 4.12—RADIOACTIVITY OF FISH TISSUES COMPARED BY STATIONS, PRESHOT*

	Japtan	Igurin	Rigili	Bogombogo	Engebi	Aomon	Runit	Av.	Range
Omnivores:									
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	9.29	0.16	0–0.71
Gut	0.063	0.040	0.34	1.1	6.2	2.0	20	3.4	0.026–45
n	7	6	5	5	4	6	4	37	
Carnivores:									
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
n	4	6	5	8	5	7	6	41	
All fish:									
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
n	11	12	10	13	9	13	10	78	

* Measured in disintegrations per minute per gram (× 1000), wet sample.

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Table 4.13 — RADIOACTIVITY OF FISH TISSUES COMPARED BY STATIONS, POSTSHOT*

	Japtan	Igurin	Rigili	Bogallua	Engebi	Aaraanbiru	Runit	Av.	Range
Omnivores:									
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	1200	540	370	8.0	340	0–2100
Gut	0.32	2.4	130	3000	3300	3500	26	1400	0.13–6800
n	5	5	6	7	5	2	4	34	
Carnivores:									
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
n	5	6	6	10	5	6	5	43	
All fish:									
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	0–2100
Gut	0.29	1.5	140	1600	1700	890	18	690	0.31–6800
n	10	11	12	17	10	8	9	77	

*Measured in disintegrations per minute per gram (× 1000), wet sample.
†n + 1.

of the muscle, and in carnivores about two to three times those of the muscle. Differences between these three tissues seemed to be greatest at Rigili, Engebi, and Aaraanbiru in postshot 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 was about twice that of skin and bone at preshot stations, increasing to about nine times in the postshot fish. The increase in activity in postshot over preshot carnivores was less than that of omnivores. Of the preshot 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 preshot stations, increasing to four times in postshot fish; the greatest increase was found in omnivores at Engebi. Postshot carnivores at Bogallua had three times as much activity in the gut as carnivores at Engebi. Comparatively high counts were found in the gut of preshot 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 preshot and postshot fish from Japtan and Igurin. For example, by comparing the radioactivity in the gut with that of muscle of all fish, the preshot activity in the gut was about 2.5 and 1.8 times that of muscle at Japtan and Igurin, respectively (Fig. 4.2). 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. Postshot ratios were as follows: Japtan, about 1.5 times; Igurin, 42; Rigili, over 3000; Bogallua, 107; Engebi, 310; Aaraanbiru, 1000; 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 preshot to postshot activity was greatest by far at Bogallua (Fig. 4.2 and Table 4.10). Although Engebi and Bogallua were about equidistant from the target center, the amount of radioactivity in fish tissues at Bogallua showed an increase of 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 muscle, skin, bone, and 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 of land plants collected is given in Appendix E. In general, collections were made in the areas where rat traps were set (Sec. 4.7.1), 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.

4.6.1 Analysis by Area

Table 4.14 is a summary of the activity found in all the plants collected at each station before and after Mike shot. Counts of all plant parts are included in the averages.

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

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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.

Table 4.14 — RADIOACTIVITY OF LAND PLANTS BY STATIONS*

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

*Measured in disintegrations per minute per gram (× 1000), wet sample.

4.6.2 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.

4.6.3 Analysis by Organs

No specific conclusions can be made regarding radioactivity in the organs of the land plants collected before and after 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 was assayed from the post-Mike series to warrant comparison.

4.6.4 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 (Table 4.15) are tabulated as percentage of total recovered activity in the sample, although actual chemical yield was approximately 75 per cent 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 in Sec. 4.8 of this report. 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 per cent 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

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soluble calcium-strontium fraction, which is known to be actively absorbed by living plants. The marked difference between the percentage of the 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.

4.6.5 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.

Table 4.15 — RADIOCHEMICAL ANALYSES OF SOILS AND PLANTS, POSTSHOT*

Fission product	Soil				Engebi plants	
	Rigili	Rojoa	Runit	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 and strontium	3.2	3.6	11.1	3.0	16.8	11.3
Cesium and rubidium	0	0	0		0	0

*Measured as the percentage of the total recovered activity.

4.7 LAND VERTEBRATES

4.7.1 Collecting Methods

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

Rats, *Rattus exulans*, were collected 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 because 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 2 in. 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 postshot had been blown to pieces by the shock wave.

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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 (Laridae family). 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, *S. bergii*, and the arctic tern, *S. 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 crustaceans 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 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 since they were injured and burned to such an extent that 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 4.5 and 4.6). 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. When the traps with the rats were returned to the USS Oakhill, they were placed in a deep-freeze unit so that death occurred from freezing.

The following tissues were taken: for rats, skin, muscle, bone, liver, stomach, gut, kidney, and lung (in postshot specimens); and 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 was dissected out last to prevent general cross contamination by the more or less fluid digestive-tract contents.

4.7.2 Results

The specific activity of the organs and tissues of the rats is given in Table 4.16. In Tables 4.17a and b the disintegration rate for activity within the organs and tissues of the birds is given.

4.7.3 Analysis of Organs and Tissues, Preshot

The amount of radioactivity found in the organs and tissues of rats and birds in the preshot collections is small (Tables 4.16 and 4.17a), with a maximum of 17 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 Fig. 4.7, histograms of the average disintegration per minute per gram for the organs and tissues of all the preshot birds and rats are 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.

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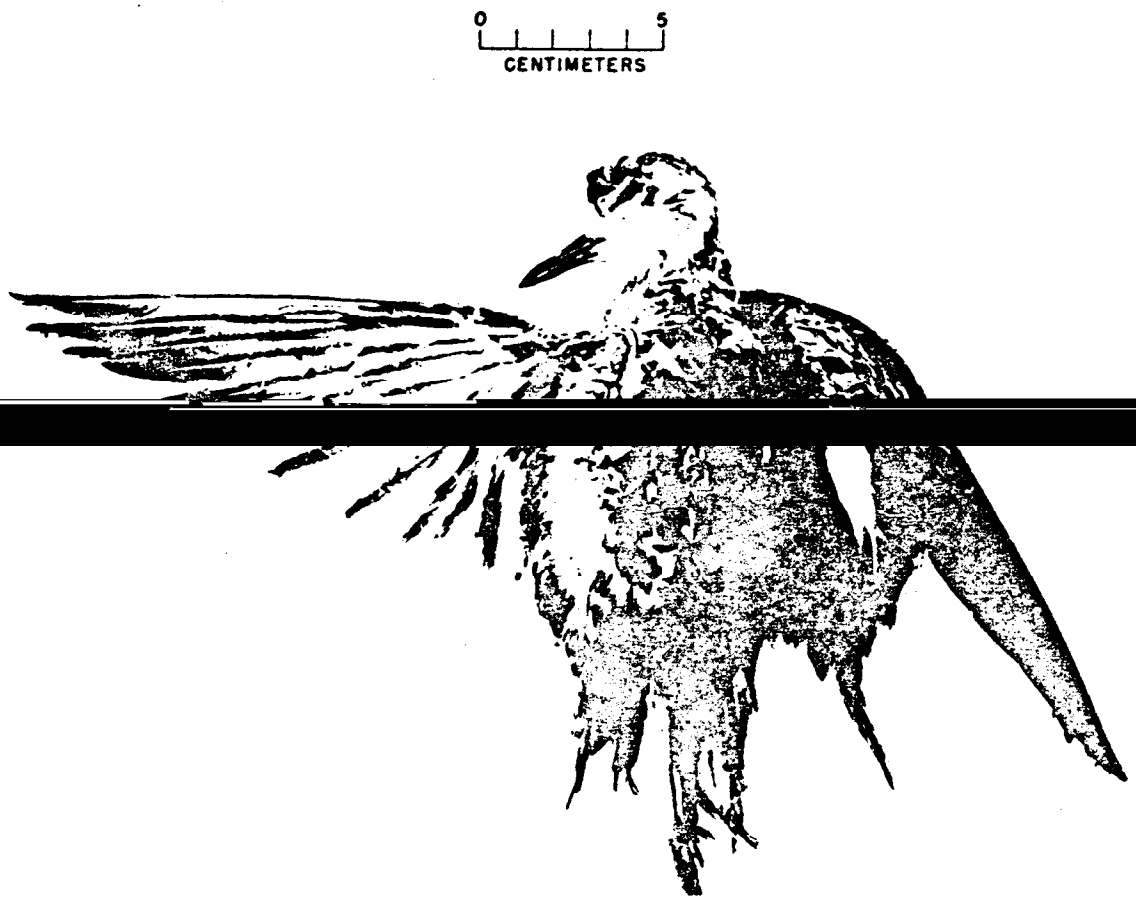

Fig. 4.5—Photograph of a singed plover taken on Bijiri ($8\frac{1}{4}$ nautical miles from Ground Zero) Nov. 7, 1952. The bird had apparently been flying with its left side toward Ground Zero at the time of detonation, as indicated by the configuration of burns on the remiges and the coverts.

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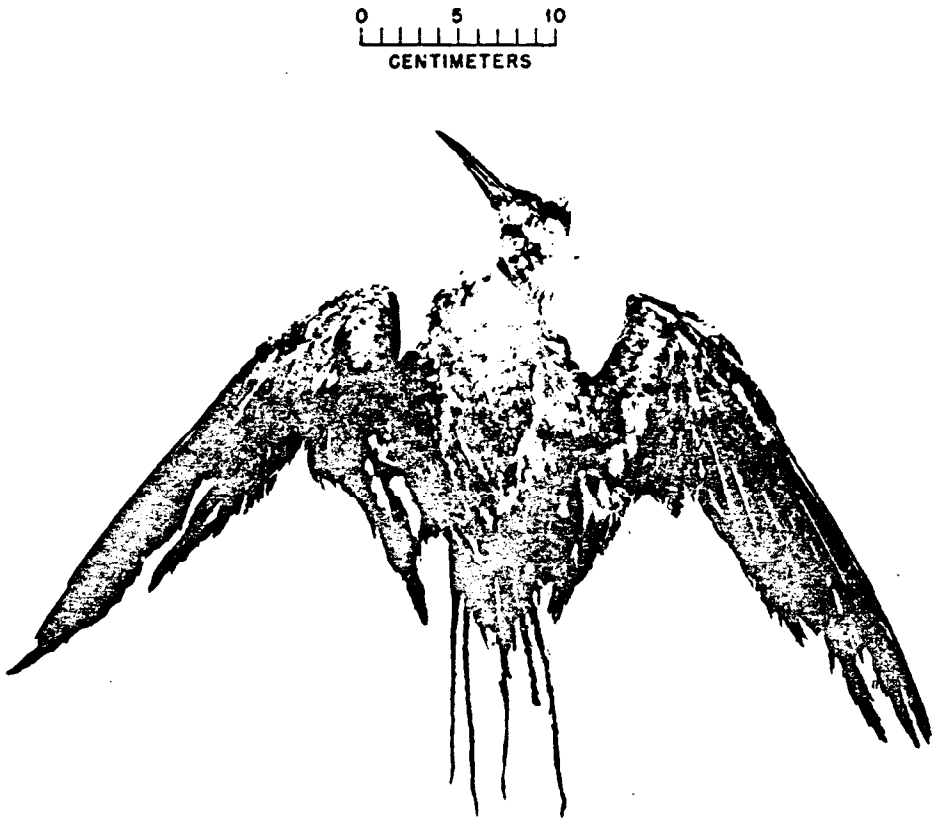

Fig. 4.6—Photograph of a singed noddy tern taken on Rigili Nov. 5, 1952. The bird was flying away from Ground Zero at the time of detonation. The retrices were burned, and the bird was unable to fly. The contour feathers on the back of the head and neck were also singed.

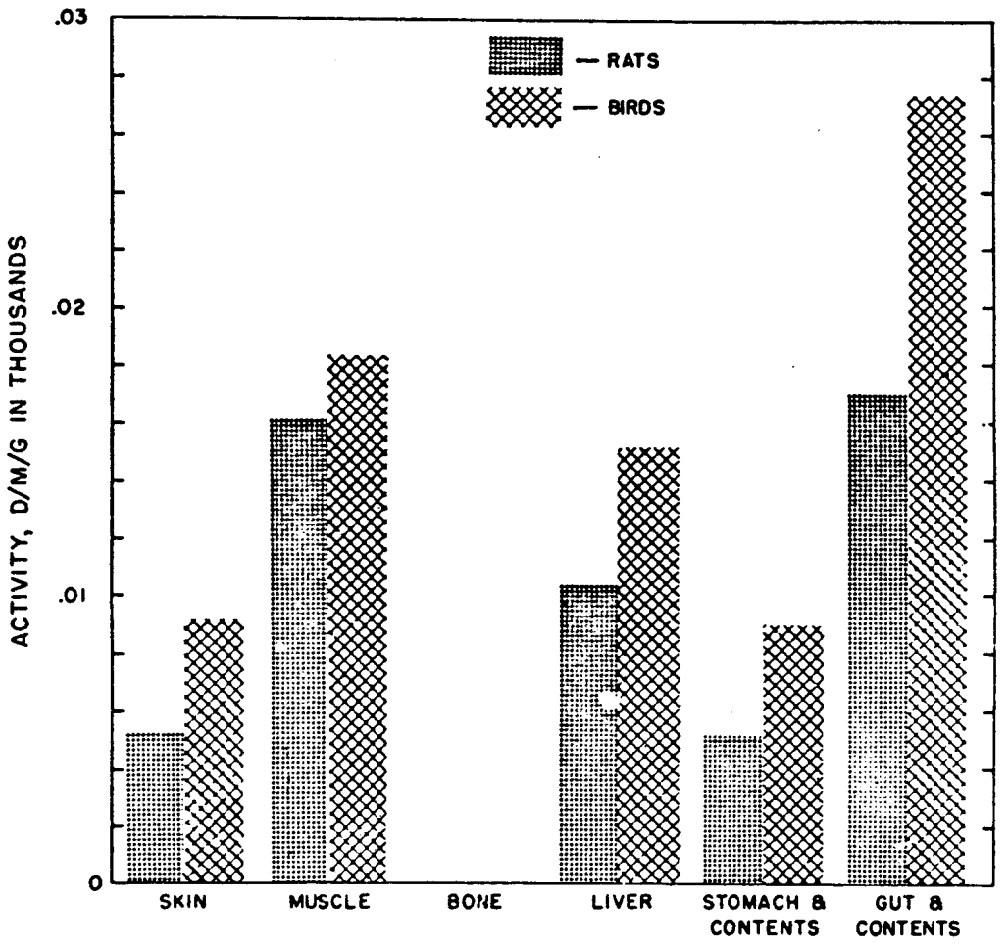

Fig. 4.7—Radioactivity of preshot rats and birds, wet sample.

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Table 4.16 — RADIOACTIVITY OF RATS*

Island	Weight, g	Skin	Muscle	Bone	Liver	Stomach and contents	Gut and contents	Lung	Kidney
					Preshot				
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
					Postshot				
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
Av.		9.2	0.94	17	1.9	4.3	12	1.0	3.1

*Measured in disintegrations per minute per gram (× 1000), wet sample.

Table 4.17a — RADIOACTIVITY OF BIRDS, PRESHOT*

Island	Type of tern	Skin	Muscle	Bone	Liver	Proventriculus 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†							

*Measured in disintegrations per minute per gram (× 1000), wet sample.
†Egg: shell, 0; embryo, 0.

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

Table 4.17b — RADIOACTIVITY OF BIRDS, POSTSHOT*

Island	Type of bird	n	Skin	Muscle	Bone	Liver	Proventriculus and contents	Gizzard and contents	n	Gut and contents	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									

*Measured in disintegrations per minute per gram (× 1000), wet sample.

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

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.

4.7.4 Analysis of Organs and Tissues, Postshot

In Table 4.16, the data for the postshot 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 (Appendix F), 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.

4.7.5 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

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stations are plotted against distance collected from Ground Zero (Fig. 4.8), 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 Appendix G.

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 should be higher. This was not found to be true, however (Fig. 4.8). 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 4.17b). 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 the birds observed during the postshot 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.

4.7.6 Analysis by Feeding Habit

The shore birds and rats have similar feeding habits; both subsist mainly on insects, seeds, and grasses; therefore a comparison of average levels of activity in diverse forms with similar feeding habits can be made. The results are given in Table 4.18.

Table 4.18—RADIOACTIVITY IN RATS AND SHORE BIRDS COMPARED BY FEEDING HABITS

Organ or tissue	Rats (Biijiri) n	Rats (Biijiri) Activity, d/m/g (× 1000)	Shore birds (Rojoa) n	Shore birds (Rojoa) Activity, d/m/g (× 1000)	Ratio of activity 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 3; 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 given in Table 4.19.

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 the 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

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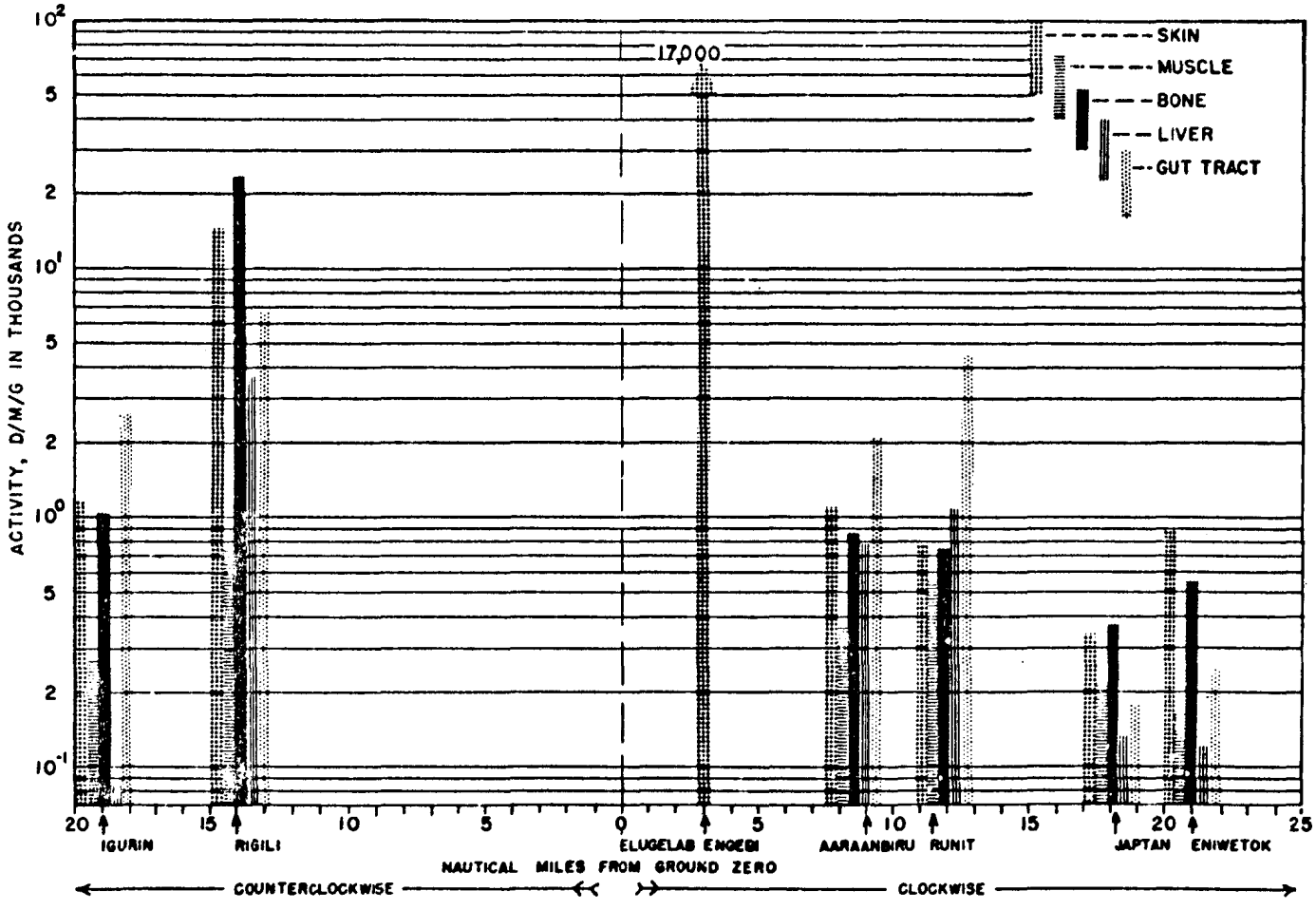

Fig. 4.8—Histograms showing radioactivity of postshot terns with relation to distance of collecting site from Ground Zero, wet sample.

be drawn from the available data on birds in light of the findings with the postshot rats. In the latter, individual variation between samples was small enough that the differences between organs were significant, except for those of the gastrointestinal tract. In addition to this, all the postshot rat specimens were collected within an area 50-yd square; so the environmental conditions may be considered identical for practical purposes.

Table 4.19 — RADIOACTIVITY IN TERNS AND SHORE BIRDS COMPARED BY FEEDING HABITS

Organ or tissue	Terns (Azraanbiru) n	Terns (Azraanbiru) Activity, d/m/g (× 1000)	Shore birds (Rojoa) n	Shore birds (Rojoa) Activity, d/m/g (× 1000)	Ratio of activity 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

The coefficients of variability for the organs of the postshot rats were determined, and the results are given in Table 4.20.

Table 4.20 — COEFFICIENTS OF VARIABILITY FOR ORGANS OF RATS, POSTSHOT

	Organ or tissue							
	Skin	Muscle	Bone	Liver	Stomach and contents	Gut and contents	Lung	Kidney
Mean	9.2	0.94	17	1.9	4.3	12	1.0	3.1
Coefficient of variation, %	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 as much as 10-fold with a reduction of mass median diameter from 2.6 to 0.45 μ. Taplin et al.[5] found that in rats lung retention of particles with a mean size of approximately 1 μ was strongly dependent upon the 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. 4.9).

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.

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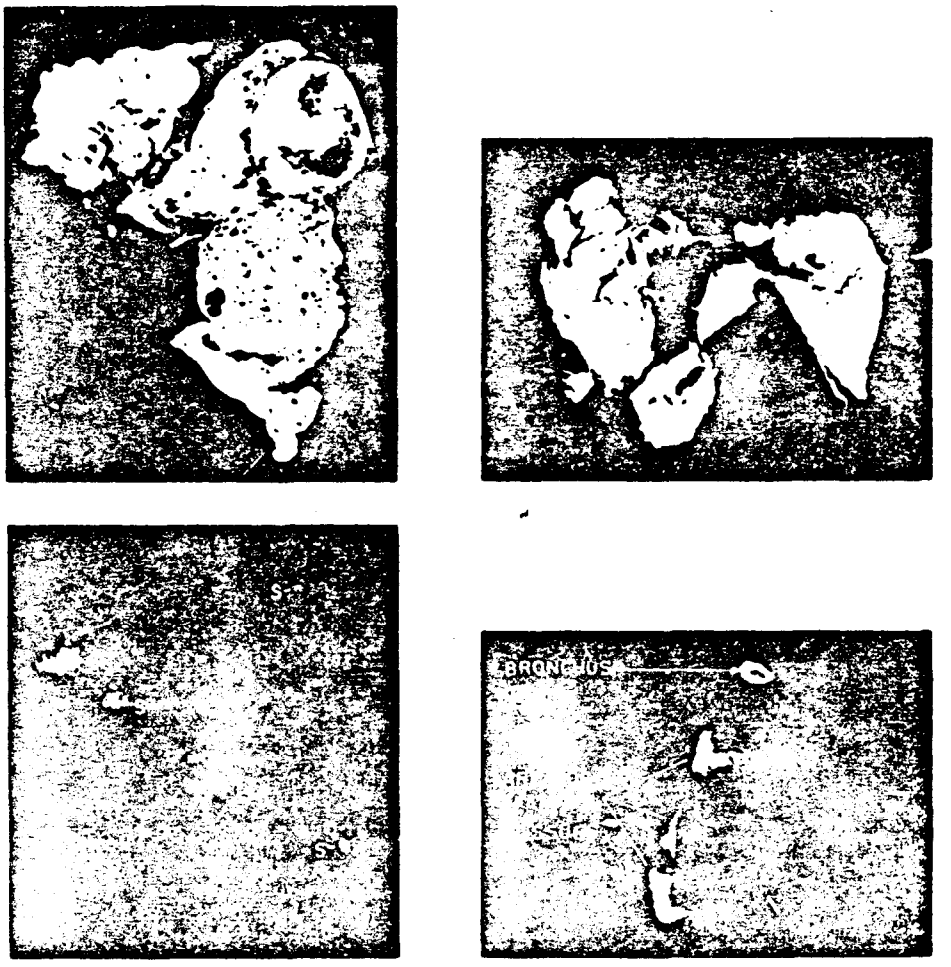

(a) (b)

Fig. 4.9—Photographs and autoradiographs of 100-μ sections of lungs from rats collected at Bijiri nine days after Mike detonation. (a) Blue Brand x-ray film exposed 39 days; exposure started Nov. 29, 1952. Activity within the lung is diffuse in distribution except for spots from limited speck contamination. Magnification $3\frac{1}{2}$x. (b) Super XX film exposed 45 days; exposure started Nov. 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. Magnification, $3\frac{1}{2}$x.

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The least variability in organs and tissues of the postshot 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 postshot rats are compared, muscle is the lowest, and bone is the highest in activity of the samples taken. Lung tissue

the muscle. In the same birds the highest levels of activity were in the gut, or digestive tract, with the exception of Rigili, where 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. 4.10). Inflections in the curve indicate that the beta particles having maximum energies of approximately 0.2, 0.8, and 1.3 Mev are present.

A mass-absorption curve of a noddy tern bone specimen (Fig. 4.10) 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 0.4, 0.95, and 1.3 Mev are suggested.

4.7.7 Conclusions

Feeding habits, as well as the range of activity of 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 whose feeding is confined to the shore or a relatively restricted area, the variability is less than in those whose 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 are 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 posttest 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 posttest 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,

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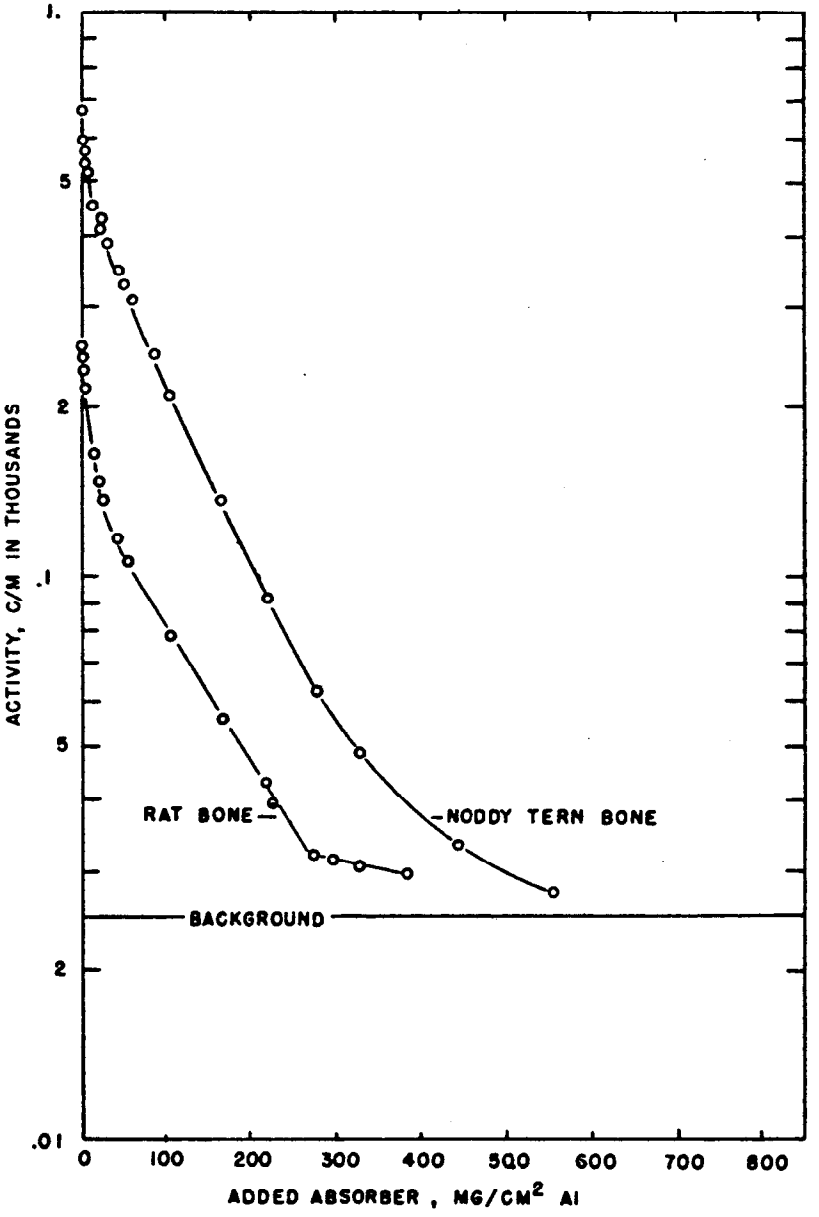

Fig. 4.10—Mass-absorption curves from bones of rat and tern samples, postshot.

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except for concentration of zirconium in an octopus gill and of rare earths by plankton and by a surgeonfish and a butterfly fish. Results of these analyses are shown in Table 4.21.

In the method used, 20- to 50-g portions of sand or soil samples were ashed at 700°C to destroy organic matter, and the ash was 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 per cent 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 were separated from zirconium by precipitation as fluorides. Cerium was separated from trivalent rare earths by precipitation as ceric iodate. In the analysis of Rojoa dredged sand, an attempt was made to separate trivalent rare earths from yttrium by precipitating them on lanthanum carbonate, but an 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 fluoride supernatant by precipitation first as barium fluozirconate and then as zirconium mandelate, which was ignited and weighed as zirconium oxide. The supernatant 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. Ruthenium 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 4.21 as percentage of total recovered activity. Total activity recovered varied from 60 to 100 per cent of total activity in the aliquot of the sample solution used, as determined by plating and counting triplicate 1-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 Ca^{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 Figs. 4.11 and 4.12.

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 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

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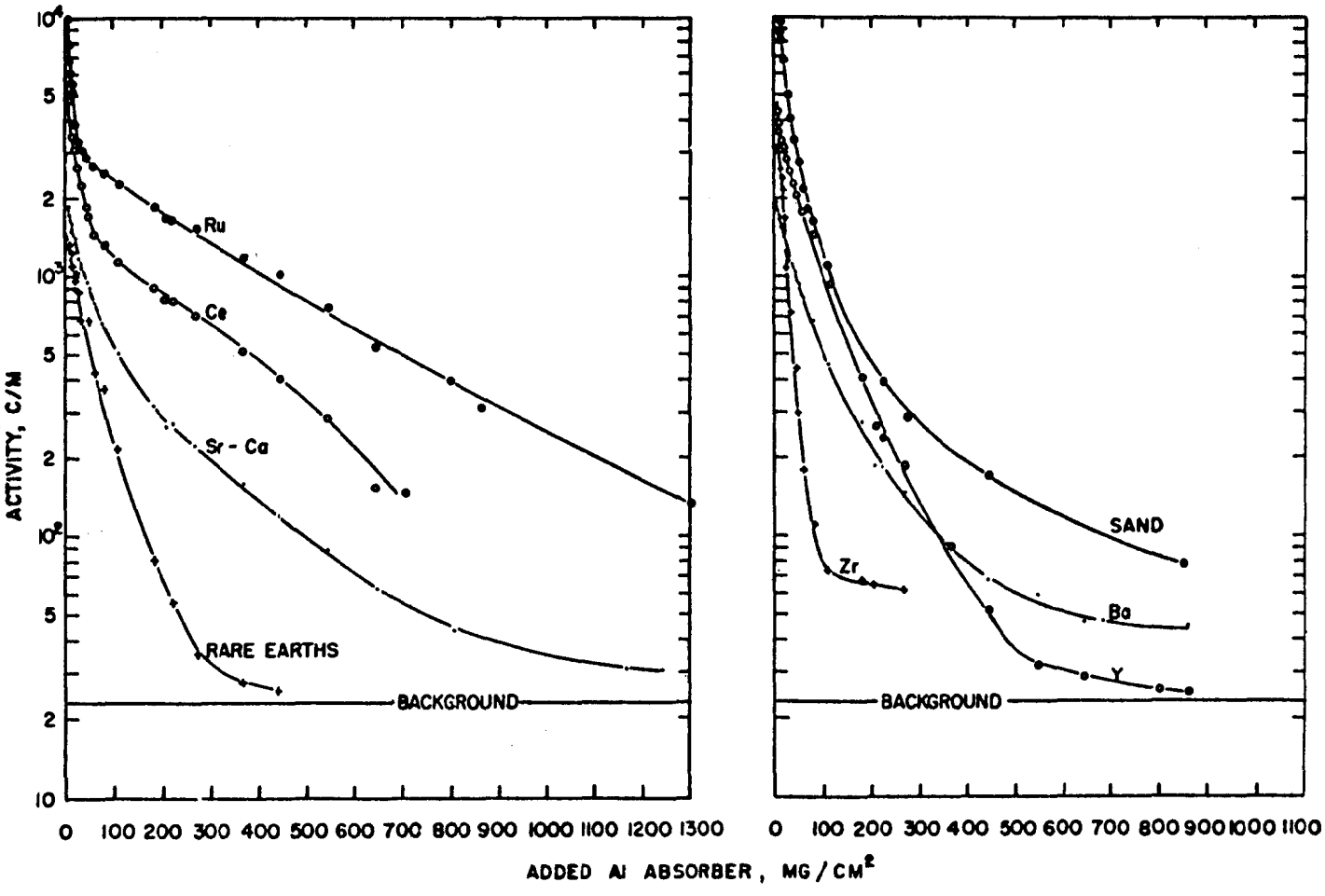

Fig. 4.11—Mass-absorption curves of radiochemically separated fractions of Rojoa dredged sand.

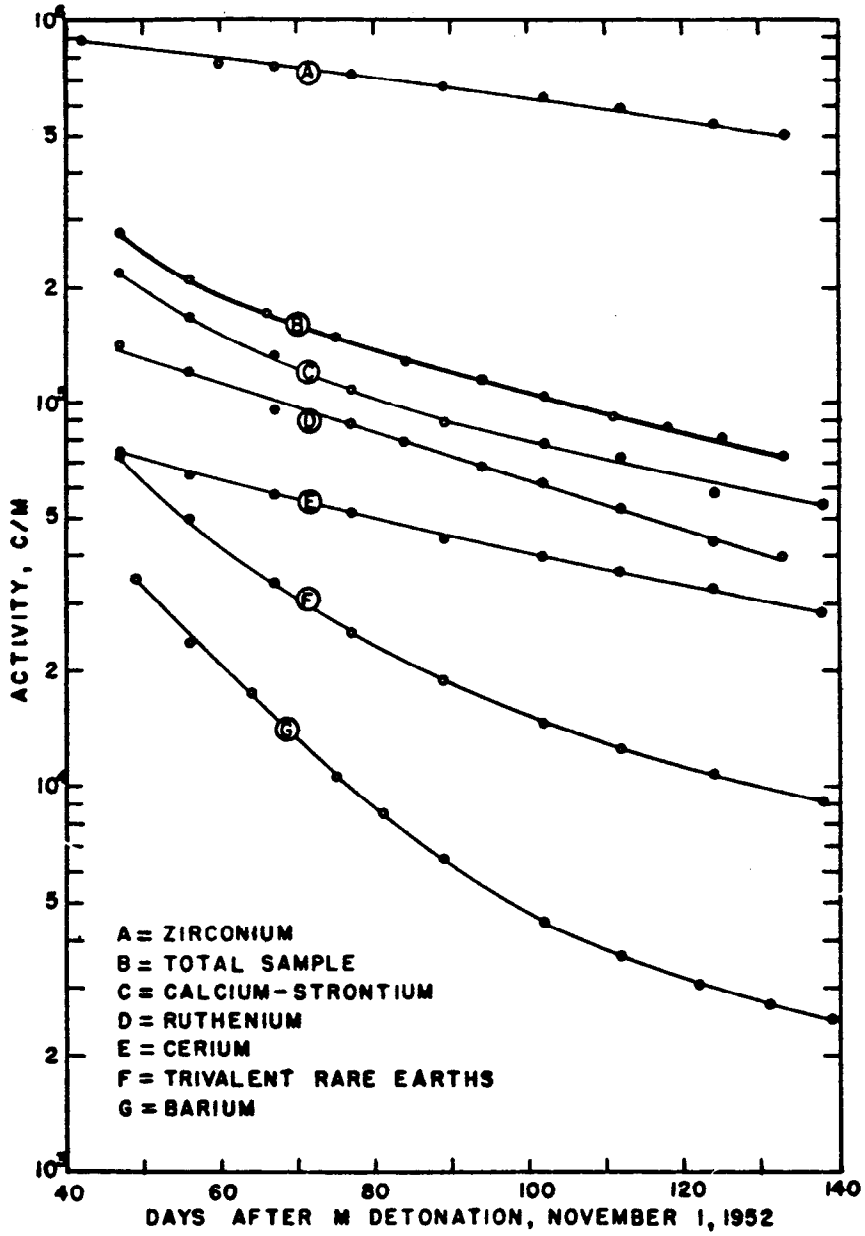

Fig. 4.12—Decay curves of radiochemically separated fractions of Rojos dredged sand.

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Table 4.21 — RADIOCHEMICAL ANALYSES OF SAND, SOIL, AND BIOLOGICAL SAMPLES, POSTTEST*

Sample	Area	Date counted	Analysis						
			Cerium	Trivalent rare earths	Zirconium	Ruthenium	Barium	Strontium and calcium	Cesium (?)†
Sand, dredged	Rojoa	12-12-52	30	22	14	19	6	8	0
Sand, beach	Engebi	4-14-53	31	13.5	20	31.5		3	
Soil	Rigili	1-13-53	32	19	21	21	4	3	0
Soil	Rojoa	1-13-53	25	21	24.5	19	6.5	4	0
Soil	Runit	1-13-53	24.5	16	25.5	19	4	11	0
Plankton	Bogallua	4-14-53	51.5	20	9.5	15		4	
Algae:									
Udotea	Bogallua	2-1-53	29.5	27	19	20	3.5	1	0
Lyngbya	Bogallua	2-1-53	35	14	26	24	1	1	0
Halimeda	Bogallua	2-1-53	19	32	14	21	8	6	0
Rhizoclonium and *Enteromorpha*	Lake George area (pretest)	4-14-53	73.5	14	1	5		6.5	
Octopus:									
Gill	Bogallua	4-14-53	18	3	44	2		34	
Digestive gland	Bogallua	4-14-53	43	16	19	8		14	
Fish:									
Butterfly gut	Bogallua	5-5-53	49	17	5	23		2	3.5
Grouper gut	Bogallua	5-5-53	29	15	15	33		4.5	3
Surgeon gut	Bogallua	5-5-53	46	16	14.5	17.5		3	2
Surgeon muscle	Bogallua	5-5-53	34	16	11	5.5		3	30
Surgeon skin	Bogallua	5-5-53	20	12.5	32	17		7	11

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Table 4.21 — (Continued)

Sample	Area	Date counted	Analysis						
			Cerium	Trivalent rare earths	Zirconium	Ruthenium	Barium	Strontium and calcium	Cesium (?)†
Land plants:									
Sedge stems and leaves	Engebi	2-1-53	26	24	13	22	4	11	0
Triumfetta stem	Engebi	2-1-53	24.5	24.5	14	16.5	4.5	16	0

• Values represent percentage of total recovered activity.

† 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.

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 fall-out 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 fall-out 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 in the following paragraphs.

(a) 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 the film was developed, 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 Figs. 4.13a to d, sand samples and active and nonactive particles which have been separated from the samples are shown. Counting rates for the particles are given in the legends.

In Bijiri dredged sand, radioactive particles were different in appearance from inactive particles. Active particles 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, is shown in Fig. 4.14.

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 Bijiri sand samples (see Fig. 4.15). 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. 4.16) show that the ash is evenly distributed and that the unexposed portions of the autoradiographs are not due to the absence of ash.

(b) 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 foraminifers, gastropods, mysids, and other crustaceans, there could be found some radioactive and some nonradioactive 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 dissolved 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.

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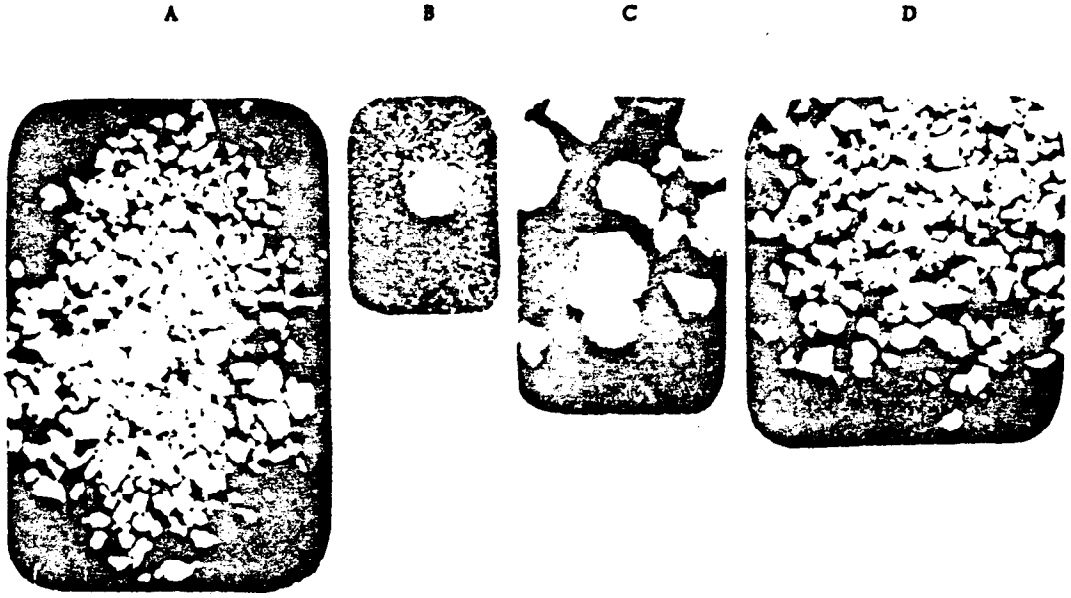

Fig. 4.13a—Photomicrographs of Engebi beach sand on ashing plates counted May 1953. (A) 1970 c/m. Entire sample weighed 6.2 mg, which is typical of plates 1 to 100. Magnification, 8x. (B) 1680 c/m. White sphere from upper-right portion of (A). Magnification, 23x. (C) 930 c/m. Another white sphere fused to a larger irregular particle. Magnification, 23 x. (D) 1130 c/m. Most of sample showing sphere of (C) near bottom. Magnification, 8x.

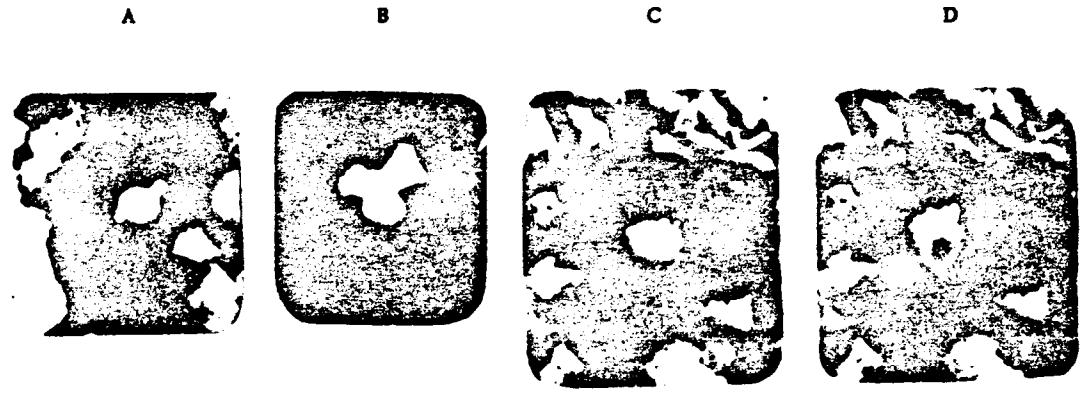

Fig. 4.13b—Photomicrographs of Engebi beach sand on ashing plates counted May 1953. (A) 3300 c/m. Central white sphere bearing two protrusions. Total plate, 3800 c/m. Magnification, 23x. (B) 1160 c/m. White sphere fused to irregular particles. Total plate, 2900 c/m. Magnification, 23x. (C) 2900 c/m. Spheroid with equatorial protrusions. Total plate, 3200 c/m. Magnification, 23x. (D) 2900 c/m. Other side of particle shown in (C) showing a dark inclusion. Magnification, 23x.

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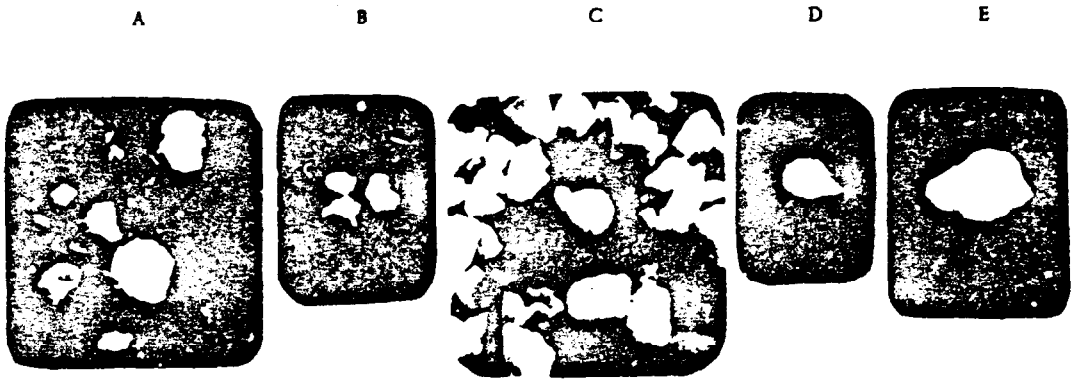

Fig. 4.13c—Photomicrographs of Engebi beach sand on ashing plates counted May 1953. (A) 4000 to 5000 c/m. Estimated using end-window survey meter. Fragments of a white hollow sphere broken in handling. Total plate, 5500 c/m. Magnification, 23x. (B) 1400 c/m. Three irregular particles. Total plate, 2100 c/m. Magnification, 23x. (C) 1900 c/m. Central white sphere with protrusions. Total plate, 2200 c/m. Magnification, 23x. (D) 8000 c/m. Hottest particle encountered; sphere with protrusion. Total plate, 8600 c/m. Magnification, 23x. (E) 2000 c/m. Irregular particle with heat-smoothed appearance. Magnification, 23x.

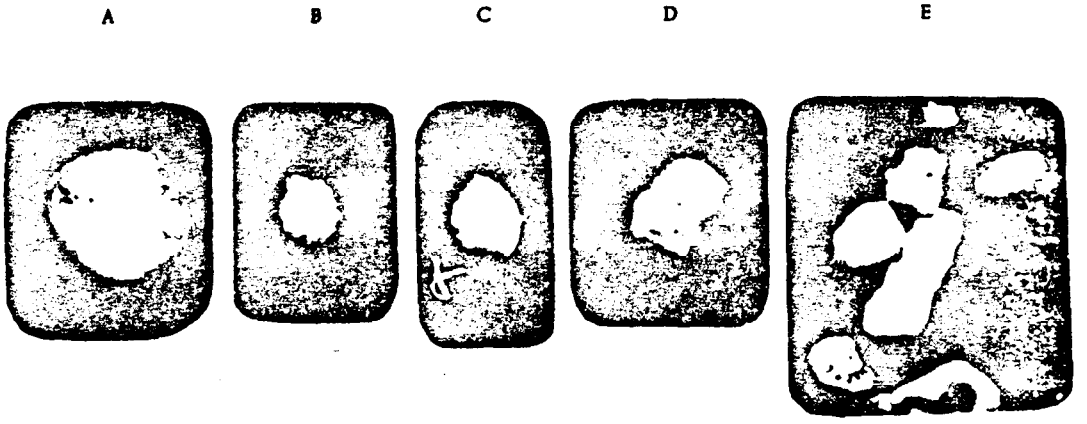

Fig. 4.13d—Photomicrographs of Engebi beach sand on ashing plates counted May 1953. (A) 7800 c/m. End view of mottled gray cylinder 1 mm long. Magnification, 23x. (B) 450 c/m. Unsmoothed chalky fragment. Magnification, 23x. (C) 6000 c/m. Particle with heat-smoothed appearance of upper surface. Magnification, 23x. (D) 1300 c/m. Mottled irregular particle. Magnification, 23x. (E) 300 c/m. Eight particles, some of which, from their appearance, were suspected of being radioactive but gave no reading on end-window survey meter. Magnification, 23x.

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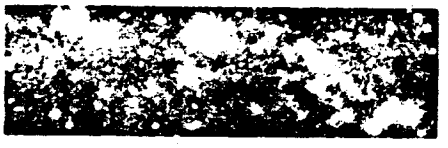

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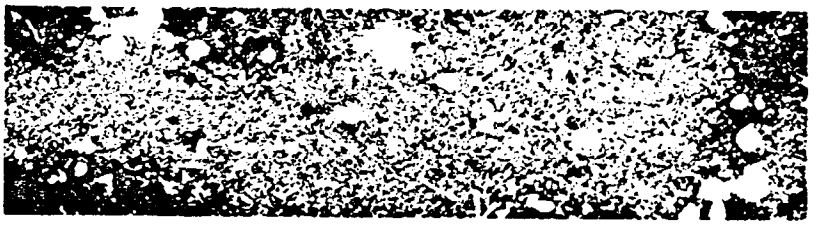

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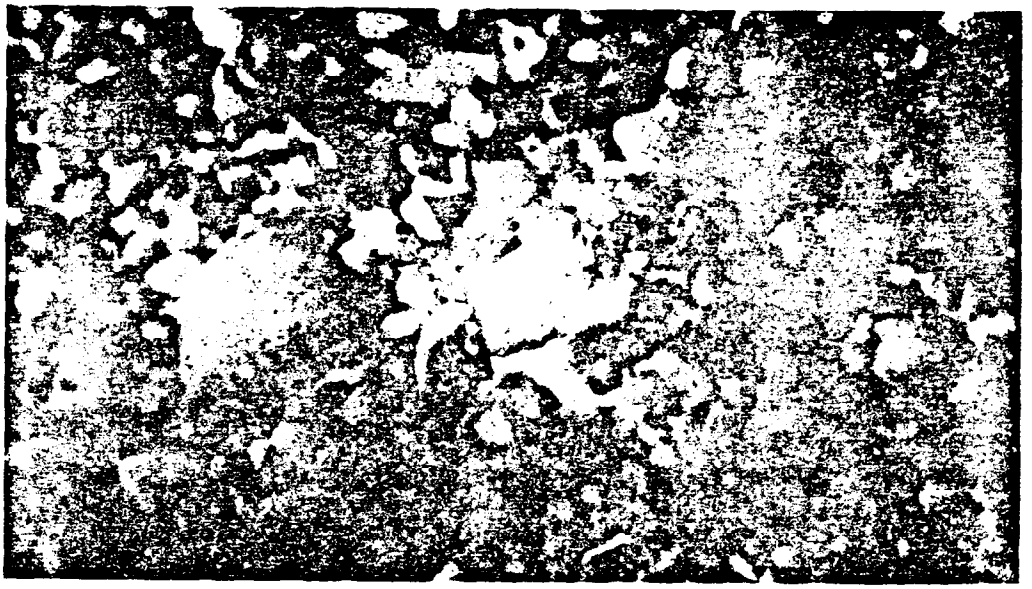

(c)

Fig. 4.14—Autoradiograph, photograph, and photomicrograph of Bijiri dredged sand. (a) Actual size autoradiograph of Biijiri and Rojoa dredged sand on $^3/_4$-in. scotch tape. (b) Photograph of same sand preparation partially illuminated from below through a positive transparency of its own autoradiograph. Magnification, 1.8 x. (c) Photomicrograph of the large radioactive particle near top center of (b). This irregular chalky particle weighed 0.6 mg when removed to a plate on May 18, 1953, and counted 5300 c/m in the Nucleometer. Magnification, 20 x.

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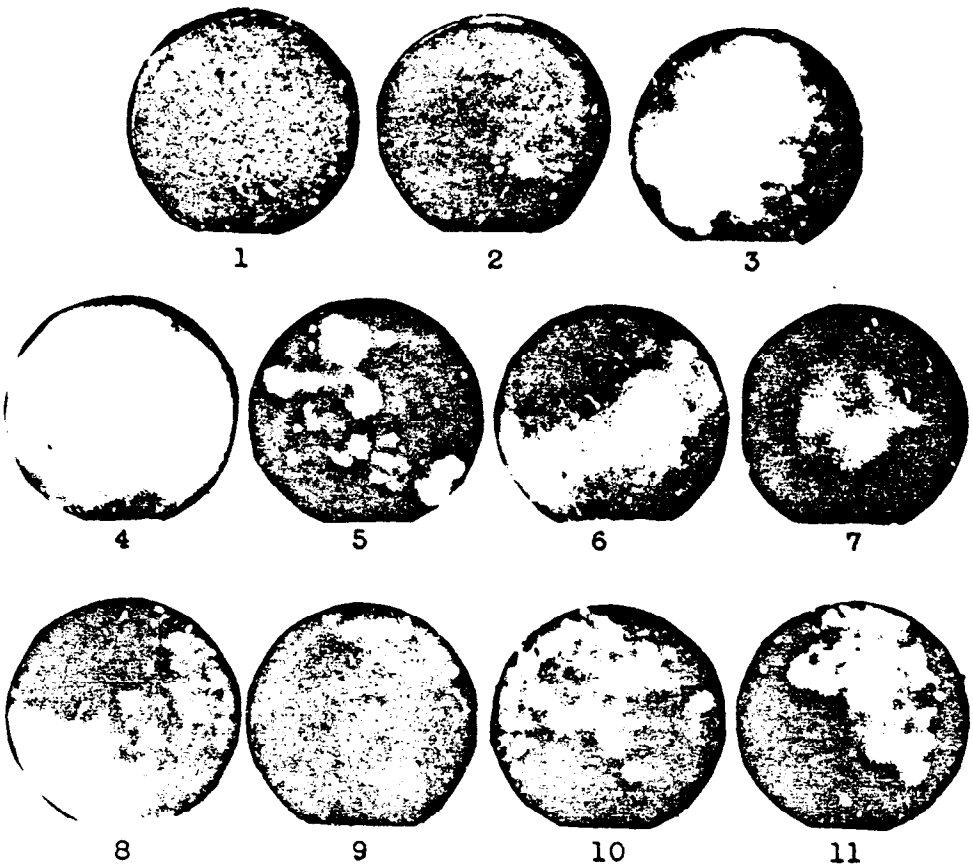

Fig. 4.15—Actual-size autoradiographs of eleven of the more radioactive posttest ashed samples. Pictures should not be compared because of different photographic treatment. (1) Plate 423, Bogallua, damselfish muscle. (2) Plate 407, Bogallua, *Tridacna* (clam) muscle. (3) Plate 403, Bogallua, octopus digestive gland. (4) Plate 427, Bogallua, damselfish viscera. (5) Plate 353, Bogallua, plankton. (6) Plate 354, Bogallua, plankton. (7) Plate 483, Engebi, hermit-crab viscera. (8) Plate 500, Engebi, *H. atra* (sea-cucumber) gut and contents. (9) Plate 676, Aaraanbiru, tattler (bird) gizzard. (10) Plate 816, Aaraanbiru, *Lyngbya* (alga), entire. (11) Plate 819, Aaraanbiru, *Jania*-like alga, entire.

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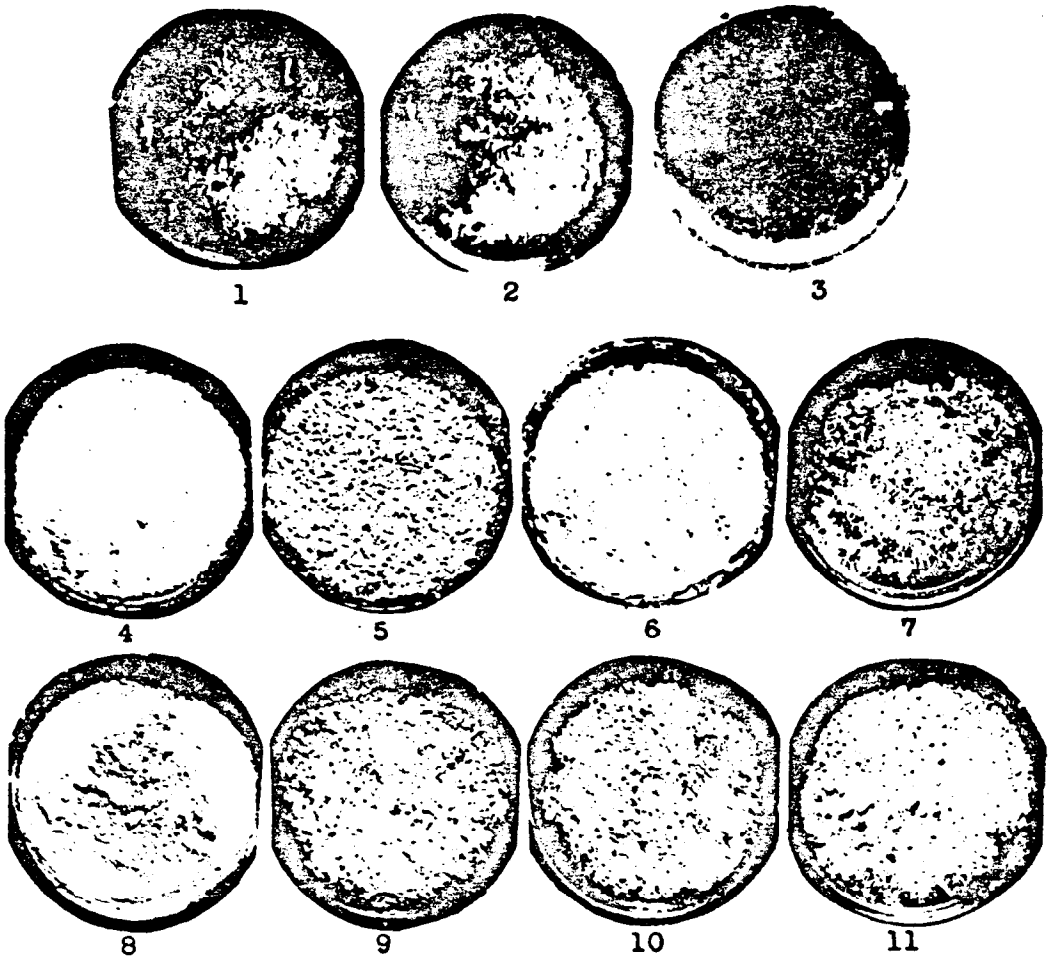

Fig. 4.16—Approximately actual-size photographs of eleven of the more radioactive posttest ashed samples. The autoradiographs of these samples are shown in Fig. 4.15. Orientations do not necessarily correspond in the two figures.

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(c) 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 Fig. 4.17. 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 *Lyngbya* and in the ramuli of *Bryopsis*, shown in Fig. 4.17, indicate that speck contamination is of minor importance in these specimens. In one alga of the preshot collection (Fig. 4.17), 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.

(d) 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 Nov. 8, 1952, of three highly radioactive nodules firmly attached 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 1-mg hollow sphere yielded 100,000 d/m. It is possible either that these bodies were cysts produced by the coral itself 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 (Fig. 4.18).

Photographs and autoradiographs of *Heliopora* and of the above samples of *Acropora* collected at Bogallua are shown in Fig. 4.18. 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 1 mm 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, 160,000, 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.

(e) 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 and 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 (Figs. 4.19 and 4.20) or in the teeth (surgeonfish, Figs. 4.21 and 4.22). Carnivores and omnivores showed striking differences in the amount within the body cavity (Figs. 4.21 and 4.22).

(f) Land plants. Washing with running tap water removed 10 to 20 per cent 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. 4.23). 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, in the skin and gut of the sea cucumber, and on the outer surfaces of algae and land plants.

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(a) (b)

(c) (d) (e)

Fig. 4.17—Autoradiographs of algae exposed to Super XX pan film. (a) *Udotea*, before washing, $2\frac{1}{2}$-hr exposure. (b) *Udotea*, same plant after washing with detergent, 60-hr exposure. (c) *Lyngbya*, 52-day exposure. (d) *Bryopsis*, 52-day exposure. (e) *Enteromorpha* and *Rhizoclonium*, 60-day exposure. (a) to (d) postshot; (e) preshot.

(a) (b)

(c)

Fig. 4.18—Corals found on Bogallua Nov. 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. Magnification, 13x.

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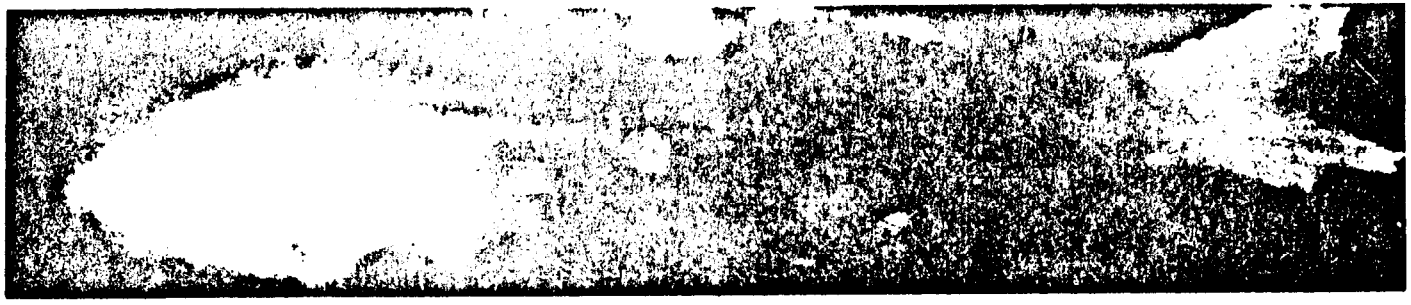

Fig. 4.19—Autoradiograph of goatfish, *M. auriflamma*, showing radioactivity in the gills. Blue Brand, Dec. 3, 1952, to Jan. 5, 1953.

Fig. 4.20—Photograph of fish used in autoradiograph of Fig. 4.19. Section of vertebrae removed for counting. Counts in tissues were: muscle, 1,660; skin, 17,500; bone, 16,000; liver, 29,900; and gut, 75,600.

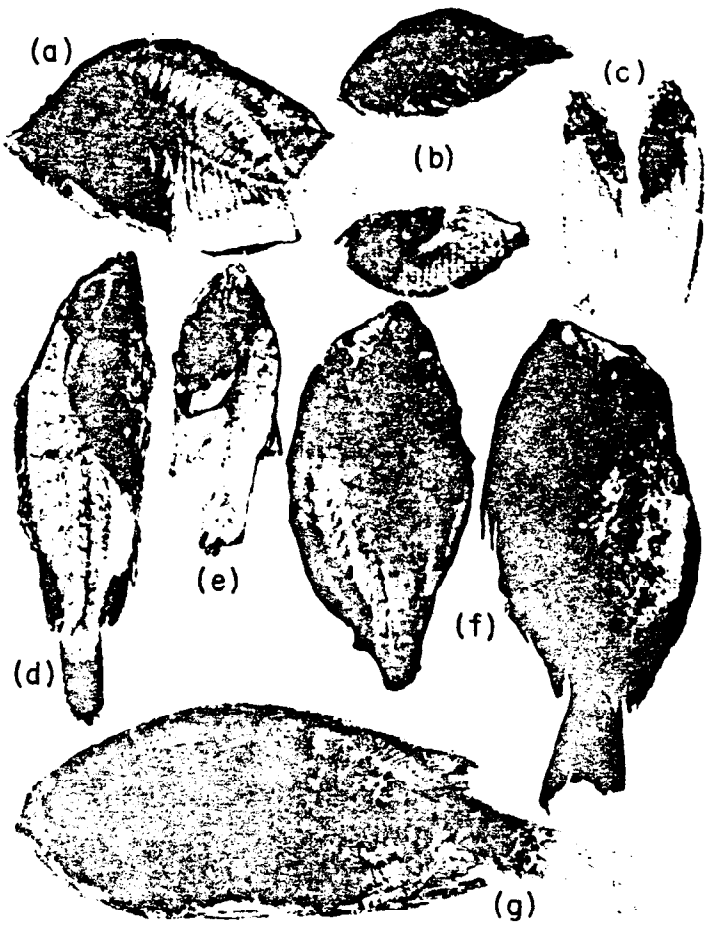

Fig. 4.21—Photographs of fish collected at Bogallua Nov. 8, 1952. (a) The right half of a butterfly fish, *C. citrinellus* (omnivore, upper left). (b) Both halves of a damselfish, *A. glaucus* (omnivore, top center). (c) Both halves of a wrasse, *H. margaritaceus* (carnivore, upper right). (d) Left half of a grouper, *E. merra* (carnivore, extreme left). (e) Right half of a cardinal, *A. bandanensis* (carnivore, left center). (f) Left and right halves of a surgeonfish, *A. elongatus* (omnivore, right center and extreme right). (g) Squirrelfish, *M. pralinius* (carnivore, bottom).

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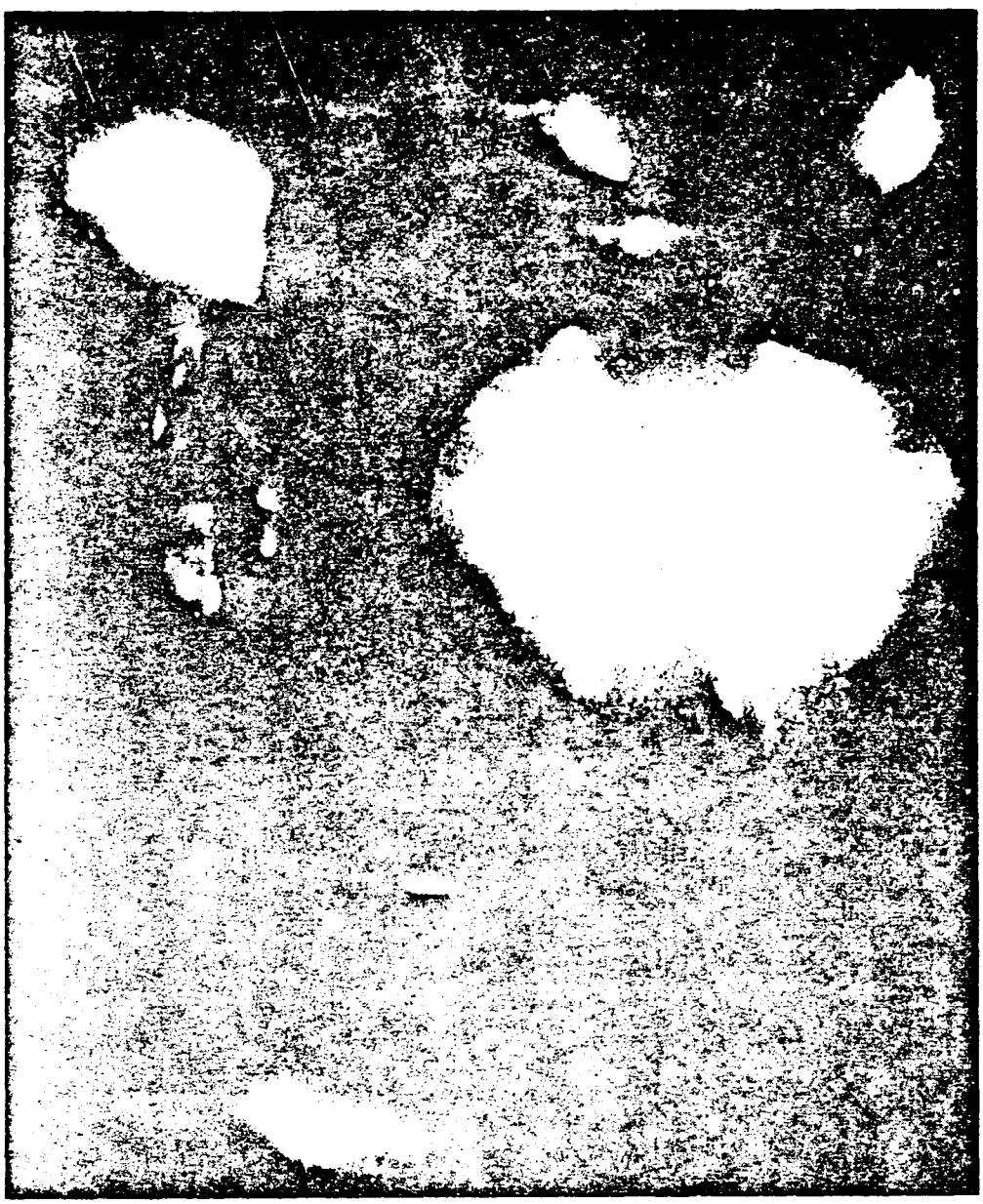

Fig. 4.22 — Autoradiograph of fish shown in Fig. 4.21. Activity is greatest in the surgeonfish, moderate in the butterfly, wrasse, and damselfish, and slight in the grouper and squirrelfish. Counts in disintegrations per minute per gram of the tissues of the surgeonfish were: muscle, 26,000; skin, 150,000; bone, 120,000; liver, 400,000; and gut, 6,800,000. Counts in the squirrelfish were: muscle, 10,000; skin, 31,000; bone, 16,000; liver, 30,000; and gut, 21,000. Autoradiograph was produced by an eight-day exposure, Jan. 6 to 14, 1953.

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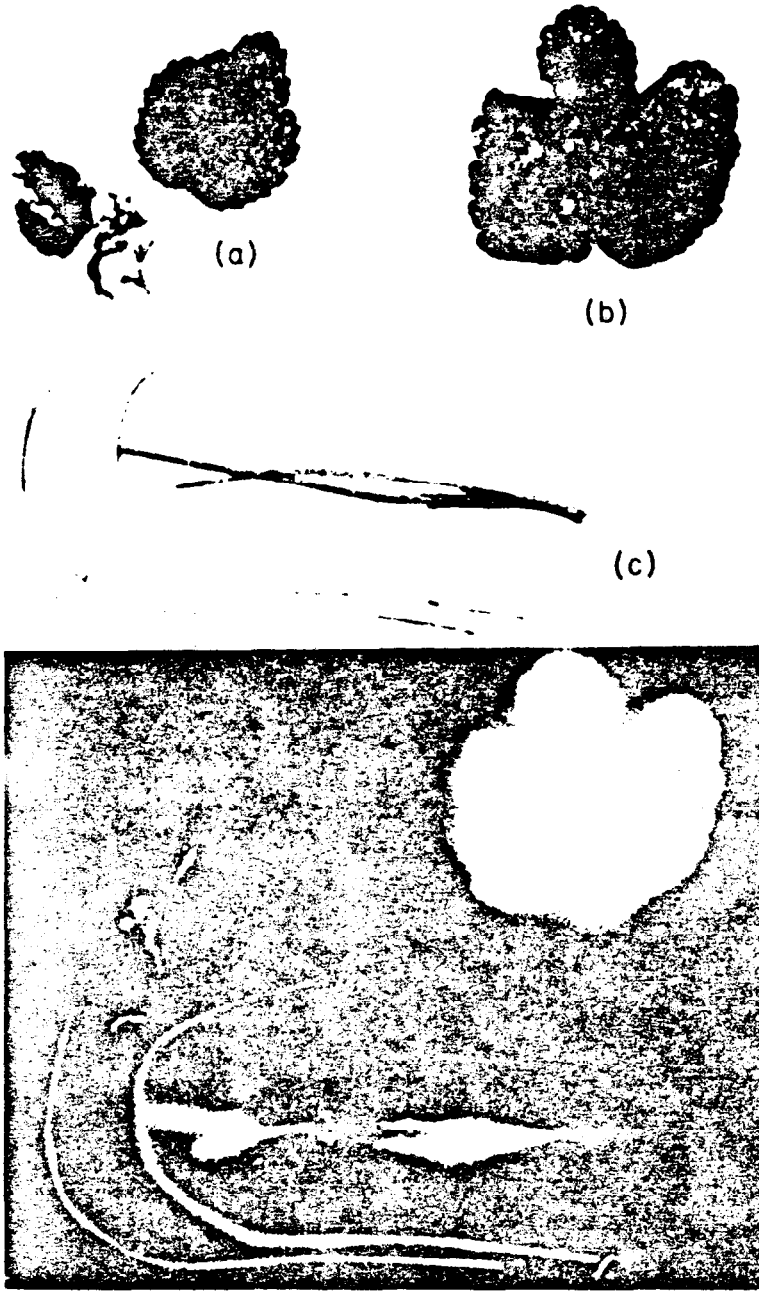

Fig. 4.23—Land plants from Engebi, postshot. (a) and (b) Portions of *T. procumbens*. (c) *F. cymosa*, upper portion, not washed; lower portion washed with running tap water. (d) Autoradiographs of (a), (b), and (c). Autoradiograph (d) was produced by a seven-day exposure to Super XX pan film.

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Usually the crab carapace was prepared for ashing without any attempt to scrub or scrape the surface. In one instance, however, one-half the carapace was prepared as usual, whereas 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 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 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 4.22). A total of nine specimens was collected in 4 to 7 ft of water within an area of less than 1000 sq ft. The two species live side by side and are both detritus feeders. *H. atra*, however, have a habit of coating themselves with sand, whereas *Stichopus* do not. Even though the former were washed and scrubbed with the hand at the time of collection, it is clear that the specific activity of their body wall, which includes the skin, is higher. That this is due to surface contamination is further substantiated by the greater individual differences in the specific activity of the body wall of *H. atra*.

Table 4.22 — COMPARISON OF RADIOACTIVITY OF TWO SPECIES OF SEA CUCUMBERS COLLECTED AT AARAANBIRU, POSTSHOT*

H. atra		*Stichopus sp.*	
Body wall	Gut and contents	Body wall	Gut and contents
140	4600	8.5	2600
230	1100	5.4	5800
17	5800	7.2	4400
64	6800	6.1	4200
		5.4	3600
Av. 110	4600	6.5	5200

* Measured in disintegrations per minute per gram (× 1000), wet sample.

The degree to which the food habit affects the specific activity of the digestive tract and its contents is found in a comparison of the viscera of a pistol shrimp, *Crangon sp.*, and a blue-green alga, *Lyngbya sp.*, which are intimately related ecologically. Two specimens of shrimp were found, one at Rigili and one at Runit, living in a completely closed cylinder of the living algae. The cylinders had to be torn open in order to remove the shrimp. A similar, if not the same, association was reported by Taylor[6] with specimens from Rongerik and Bikini Atolls in the Marshall Islands. This shrimp feeds, at least in part, upon the algae in which it lives. It may, however, 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 in Table 4.23, indicates the effect of food habit upon the radioactivity of the digestive tract.

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Table 4.23 — COMPARISON OF SPECIFIC ACTIVITY FOUND IN SHRIMP AND ALGAE*

Sample	Rigili	Runit
Shrimp:		
Muscle	15,000	7,000
Viscera	110,000	31,000
Algae	210,000	36,000

*Measured in disintegrations per minute per gram, wet sample.

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CHAPTER 5

CONCLUSIONS

The radioactivity of the six groups of organisms by islands is summarized in Table 5.1.

The individual counts for preshot 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 posttest 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 posttest counts was also skewed to the left.

The average values (Table 5.1) 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 postshot collections (1) by the station with the greatest activity, (2) 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 postshot land plants, which ranked third.

The pattern of distribution of activity of the preshot collections clearly indicates the areas of former test sites, Engebi, Aomon-Bilijiri, and Runit. Pretest 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 posttest 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 postshot to preshot activity as determined by the averages for each group of organisms was approximately 300 for the aquatic organisms and 1000 for the land plants and vertebrates.

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Table 5.1 — RADIOACTIVITY OF SAMPLES SUMMARIZED BY GROUPS AND BY ISLANDS*†

Island	Water n	Water Av.	Plankton n	Plankton Av.	Algae n	Algae Max.	Algae Min.	Algae Av.	Invertebrates n	Invertebrates Max.	Invertebrates Min.	Invertebrates Av.
Pretest·												
Japtan					6	0.099	0.041	0.066	49	0.47	0	0.024
Igurin	2	0.000005	2	0.94	8	0.51	0.067	0.18	23	0.46	0	0.041
Rigili	2	0.000055	1	1.3	8	0.97	0.14	0.40	33	2.8	0	0.24
Bogombogo	2	0.00073	2	2.6	9	4.3	0.24	1.4	55	16	0	0.99
Engebi	2	0.000030	2	0.30	10	21	0.18	8.3	72	48	0	3.2
Aomon-Rojoa	2	0.000015	2	0.22	12	54	1.7	7.7	45	8.5	0	1.12
Runit	2	0.00019	2	0.12	18	51	0.087	7.6	52	80	0	3.9
Av.		0.00014		0.92				3.7				1.4
Posttest:												
Japtan	2	0.00013			6	0.70	0.22	0.30	49	0.47	0	0.083
Igurin	2	0.00052	2	88	10	40	4.1	15	68	75	0	4.0
Rigili	2	0.0020	2	45	6	2,100	28	550	92	400	0.35	44
Bogallua	2	0.094	2	850	8	14,000	1,200	5,200	23	7,700	25	1,180
Engebi	2	0.021			3	6,800	2,500	4,000	21	15,000	10	1,670
Aaraanbiru	2	0.0060	2	64	9	6,200	56	2,400	38	6,800	2.1	1,090
Aomon-Biijiri												
Runit	2	0.00044	2	58	13	250	13	103	50	160	0.63	26
Av.		0.018		180				1,800				570

Island	Fish n	Fish Max.	Fish Min.	Fish Av.	Land plants n	Land plants Max.	Land plants Min.	Land plants Av.	Land vertebrates n	Land vertebrates Max.	Land vertebrates Min.	Land vertebrates Av.
Pretest:												
Japtan	45	0.074	0	0.022	14	0.074	0	0.014				
Igurin	50	0.105	0	0.021	22	3.7	0	0.28	16‡	0.047	0	0.013
Rigili	50	0.73	0	0.092	17	8.6	0	0.56	24‡	0.038	0	0.010
Bogombogo	50	2.5	0	0.19	22	1.6	0	0.12	2‡	0	0	0
Engebi	50	72.0	0	2.0	24	3.4	0.092	0.83	8§	0.018	0	0.006
Aomon-Rojoa	50	4.2	0	0.34	30	1.3	0	0.28	32§	0.026	0	0.008
Runit	50	45	0	2.6								
Av.				0.76				0.35				0.007
Posttest:												
Japtan	50	0.86	0	0.22	6	0.33	0.13	0.24	28‡	0.54	0.070	0.23
Igurin	50	4.1	0	0.50	11	39	0.83	16	21‡	1.7	0.044	0.48
Rigili	54	380	0.10	21	20	820	1.0	100	19‡	53	0.019	8.6
Bogallua	79	6,800	0.46	310								
Engebi	66	7,500	0.37	590	6	4,000	280	1,900				
Aaraanbiru	70	6,800	0.22	160					21‡	280	0.28	23
Aomon-Biijiri					12	370	4.9	89	48§	46	0.48	6.2
Runit	68	72	0.10	8.3	2	60	20	40	21‡	23	0.17	2.5
Av.				160				360				6.9

*Measured in disintegrations per minute per gram (× 1000), wet sample.
†n refers to plates counted, not to specimens.
‡Birds.
§Rats.

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CHAPTER 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 ensure proper 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.

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APPENDIX B

ALGAE COLLECTED AT ENIWETOK, 1952

Group*†	Name	Family	Japtan	Igurin	Rigtli	Bogombogo	Bogallua	Engebi	Aomon	Aaraanbiru	Runit	USS Oakhill
1	*Entophysalis crustacea* (J. Ag.) Dr. & Daily	Chroococcaceae									x	
2	*Lyngbya sordida* Gom.	Oscillatoriaceae		x	x	x	x				x	
3	*Lyngbya* sp.	Oscillatoriaceae			x		x		x	x		
4	*Symploca hydnoides* Gom.	Oscillatoriaceae									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.	Ulotrichaceae										x
9	*Enteromorpha* sp.	Ulotrichaceae							x			
10	*Rhizoclonium riparum* Harv.	Cladophoraceae							x			
11	*Caulerpa racemosa* var. *clavifera* (Turn.) W.-v.Bosse	Caulerpaceae	x	x			x			x	x	
	uvifera (Turn.) W.-v.Bosse	Caulerpaceae	x	x			x			x	x	
12	*Caulerpa serrulata* var. *typica* Tseng	Caulerpaceae		x		x	x	x	x		x	
13	*Caulerpa* sp.	Caulerpaceae	x									
14	*Vaucheria* sp.	Vaucheriaceae									x	
15	*Avrainvillea lacerata* (Harve.) J. Ag.	Codiaceae									x	
16	*Codium* sp.	Codiaceae							x			
17	*Halimeda monile* (Ellis & Sol.) Lamx.	Codiaceae		x	x		x		x		x	
18	*Halimeda stuposa* W. R. Taylor	Codiaceae	x	x	x	x	x		x	x		
19	*Halimeda* sp.	Codiaceae	x	x	x	x	x	x	x	x	x	
20	*Udotea* sp.	Codiaceae		x			x				x	

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Group*†	Name	Family	Japtan	Igurin	Rigili	Bogombogo	Bogallua	Engebi	Aomon	Aaraanbiru	Runit	USS Oakhill
21	*Bryopsis pennata* Lamx.	Bryopsidaceae	x					x		x	x	
22	*Bryopsis* sp.	Bryopsidaceae	x						x			
23	*Dictyosphaeria cavernosa* (Forrsk.) Borgs.	Valoniaceae									x	
24	*Microdictyon* sp.	Valoniaceae				x					x	
25	*Valonia* sp.	Valoniaceae	x		x				x	x		
26	*Dictyota pinnatifida* Kutz.	Dictyotaceae		x	x	x		x	x	x	x	
27	*Dictyota* sp.	Dictyotaceae									x	
28	*Padina Commersonnii* Bory	Dictyotaceae						x				
29	*Pocockiella Papenfussii* W. R. Taylor	Dictyotaceae					x					
30	*Asparagopsis Sanfordiana* Harv.	Bonnemaisoniaceae	x									
31	*Jania rubens* (L) Lamx.	Corallinaceae							x			
32	*Jania* sp.	Corallinaceae							x		x	
33	*Ceramium* sp.	Ceramiaceae	x		x		x					
34	*Centroceras clavulatum* (C. Ag.) Montagne	Ceramiaceae			x							
35	*Centroceras* sp.	Ceramiaceae									x	
36	*Laurencia* sp.	Rhodomelaceae					x					
37	*Polysiphonia* sp.	Rhodomelaceae						x			x	
38	*Roschera calodictyon* (Harv.) W.-v.Bosse	Rhodomelaceae		x							x	

*Arranged in phylogenetic sequence.
†Groups 1 to 6, blue-green; 7 to 25, green; 26 to 29, brown; 30 to 38, red.

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APPENDIX C

INVERTEBRATE-SAMPLE DATA

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Table C.1 — INDIVIDUAL VALUES OF INVERTEBRATE SAMPLES, PRETEST*†

Sample	Jupiter	Iguana	Rigil	Bogomboge	Bogomboge dredge	Engebi (inner)	Engebi (outer)	Engebi dredge	Aomon	Aomon dredge	Pilirani	Runit	Runit dredge
Sponge	0.14; 0.23	0.15	2.8	3.3; 16	0.42		48		3.0			0.06; 0.06; 1.1	
Worms	0			0.30			0.02					17	3.2
Hydroid									0.06; 3.6			7.3	
Coral, hard	0(5)		0(3)	0(4); 0.26	0(3); 0.07			0.26(2)	0	0(3); 0.32			
Starfish	0(2)		0.43	3.9			0.76	0.52		2.5			
Brittle stars			0.57									0.30	1.6
Urchins:													
Entire	0(5)												3.3(2)
Test			0				0.35; 0.43; 0.66		0.81		0		
Gut			0.57				0.6; 7.1; 18		2.5		0.05		
Other tissue			0; 0.13				0.14; 0.20; 0.90; 0.5		0.40		0.03		
Heart urchin:													
Entire					2.5			3.9					
Test										0.51			0.13
Gut													0.02
Other tissue										0			2.3
Sand dollar:													
Test													1.0
Soft parts													7.3
Cucumber:													
Entire		0											
Integument	0	0.03	0.10; 0.26	0.05; 0.06			0.11	0.09; 0.58	0.88	0.30		0.30; 0.55	
Gut	0	0†	0.051; 0.36	3.6; 3.9					0.53†; 3.2	0.092		0.44; 0.76	
Other tissue		0.05	0.03; 0.04				0.06	0.38	0.76	0.81		0.29	
Barnacle								3.4					
Shrimp:													
Entire	0											0.09	0.09
Soft parts							0.02						
Exoskeleton							0.35						
Hermit crab:													
Entire			0						0.16				3.4
Digestive system	0(2)	0.08											
Muscle	0(2)	0		0.08									
Exoskeleton	0(2)	0.46		0.68									
Cephalothorax	0			1.7		0.23	1.8	0.73			0	0.69	
Abdomen	0	0.03		0.15		0.10	0.55	0.80				1.3	
Crab, misc.:													
Entire	0(3)	0(2)		0.19; 0.20(2); 0.64; 0.68		0	2.0; 6.5					4.5	3.5
Exoskeleton				0					0.44	0.70; 1.1			
Gills										0.78			
Digestive system				1.5					1.4				
Muscle				0									
Octopus:													
Digestive system		0.08				0						0.81	
Gills		0				0							
Muscle		0				0						0.06	
Exoskeleton		0				0						1.6	
Grapsus:													
Digestive system	0	0(2)				0.06; 0.13						0.68	
Gills	0	0				0.23						1.3	
Muscle	0.08	0				0						0.16	
Exoskeleton	0	0				0						0.13	
Eupleura:													
Digestive system	0		0.05			0.11					0		
Gills			0.08			0.13					0.06		
Muscle	0		0.02			0					0		
Exoskeleton	0		0			0.22					0		
Eggs											0.03		
Snail:													
Egg collar													17
Soft parts	0(4)	0.08	0; 0.03; 0.13, 0.51	0.16; 0.19; 0.50; 0.93; 3.9			2.1, 3.6; 4.2; 15; 16	0.14; 3.3	0.52; 0.53; 1.6; 8.3			0.33; 1.7; 80	3.3
Foot	0						2.2						
Liver	0		0.57				2.0						
Shell	0(3); 0.27, 0.47		0.2); 0.55	0(4); 1.1			0, 0.63; 0.94; 1.1; 2.4; 3.3	0; 0.52	0(3); 0.78			0(3); 0.63	1.7
Sea-hare gut							33						
Clams:													
Entire													0.76; 1.6
Soft parts			0.07		0.21		0.2		0.28	1.1		0.73; 4.3	
Foot											0.2)		
Visceral mass				0.32, 1.0; 1.4							0.06; 0.07		
Siphons											0.03		
Mantle				0.25, 0.30							0(2)		
Muscle				0.10; 0.14							0		
Shell			0	0.24	0		14		0.28	0	0	0.74; 1.4	
Isognomon:													
Entire		0											
Soft parts	0		0.37	0.40		0.66	2.0		1.2			2.6	
Shell	0		0.27	1.7		0.53	6.4		2.5			5.0	
Cephalopod:													
Entire									0.26			0	
Lymph heart									0.58				
Gill									0.10				
Mantle									0.02				
Tentacle									0				
Tunicate					0.39; 0.66			5.8					
Number	49	23	33	45	10	188	39	15	31	14	18	35	17
Mean	0.024	0.041	0.239	1.117	0.398	0.1281	5.405	1.303	1.148	1.064	0.018	3.071	3.663
Standard deviation	0.084	0.099	0.503	2.53	0.706	0.1746	8.94	1.74	1.67	2.18	0.026	13.6	4.11

*Measured in disintegrations per minute per gram (× 1000), wet sample.

†When the same value occurs more than once in a cell, the number of occurrences is enclosed in parentheses.

Gut includes contents, except where otherwise noted.

†Without gut contents.

§Combined Engebi, inner and outer: number, 57, mean, 3.738, standard deviation, 7.77.

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Table C.2—RADIOACTIVITY OF INVERTEBRATE ORGANS AND TISSUES BY FOOD HABITS, POSTSHOT*

Island and tissue or organ	Plankton				Grazer				Scavenger				Detritus			
	n	Av.	Max.	Min.	n	Av.	Max.	Min.	n	Av.	Max.	Min.	n	Av.	Max.	Min.
Japtan																
Digestive tract†	1	0.076							4	0.17	0.39	0.081	1	0.14		
Skeletal‡	1	0			1	0			7	0.16	0.26	0.061	1	0		
Muscle	1	0.055							2	0.049	0.068	0.029				
Digestive gland	1	0.33							4	0.050	0.062	0.039				
Gill	1	0.12							4	0.015	0.058	0	1	0.063		
Igurin																
Digestive tract†	1	3.7							7	5.4	9.7	0.93	2	64	75	53
Skeletal‡	1	2.2			4	0.60	1.2	0.21	6	1.2	1.5	0.84				
Muscle	1	0.15			1	0.25			3	0.10	0.12	0.069				
Digestive gland	1	1.1							5	0.61	0.99	0.40				
Gill	1	0.22			1	2.5			5	0.64	1.0	0.19	1	0.48		
Rigili																
Digestive tract†	3	74	110	0.75	6	153	400	1.2					2	200	260	130
Skeletal‡	2	9.1	17	1.1	6	8.0	23	0.56	7	23	43	4.9				
Muscle	1	0.76			4	3.4	7.7	0.35	5	1.8	3.3	0.90				
Digestive gland	1	3.9			1	220			5	29	62	12				
Gill									5	49	74	5.5	2	3.6	4.2	2.9
Bogallua																
Digestive tract†	2	530	700	350									1	5,900		
Skeletal‡	2	123	170	75												
Muscle	2	54	56	52												
Digestive gland	2	120	130	110												
Gill	3	190	330	110												
Engebi																
Digestive tract†	1	460							1	7,600			1	15,000		
Skeletal‡	1	45							1	750						
Muscle	1	10							1	410						
Digestive gland	1	24														
Gill	1	51											1	100		
Aaraanbiru																
Digestive tract†	3	220	620	2.3									9	4,300	6,800	1,100
Skeletal‡	1	18			1	20										
Muscle	2	2.3	2.5	2.1					1	3.1						
Digestive gland	2	8.8	11	6.5												
Gill	1	9.8														
Runit																
Digestive tract†	1	31											3	110	130	85
Skeletal‡	1	3.9			3	3.1	5.2	1.2	5	17	32	3.9	2	4.5	5.5	3.4
Muscle	2	2.0	3.1	0.94	2	4.3	5.1	3.4	3	1.3	1.8	0.76				
Gill													1	12		

*Measured in disintegrations per minute per gram (× 1000), wet sample.
†Digestive tract with contents.
‡Including shell.

Table C.3 — LIST OF SPECIFIC ACTIVITY OF INVERTEBRATE SAMPLES, POSTSHOT

Japtan	
Soft coral	Background
Corals:	
Montipora	Background
Porites	Background
Pocillopora	Background
Heliopora	Background
Anemone	Background
Starfish:	
Asterid	0.16
Asterid	0.47
Sea cucumber:	
H. atra	
Body wall	0.057
Gut	0.14
Respiratory tree	0.063
Hermit crabs:	
Cenobita	
Carapace	0.17
Gills	Background
Gastric mill and gut	0.081
Liver	0.044
Muscle	0.088
Cenobita	
Carapace	0.20
Gills	Background
Gastric mill and gut	0.39
Liver	0.062
Muscle	0.051
Calcinus	
Cephalothorax	0.11
Appendages	0.26
Viscera	0.062
Integument	0.082
Pagurus	
Carapace and integument	0.061
Gill	Background
Gastric mill	0.12
Liver	0.055
Muscle	0.029
Xanthid	
Carapace and muscle	0.14
Viscera and gills	0.050
Xanthid	
Carapace	0.20
Gill	0.058
Gastric mill	0.098
Liver	0.039
Muscle	0.068
True crabs:	
Grapsid	
Carapace and muscle	0.10
Viscera	0.13
Snails:	
Vasum	
Shell	Background
Soft parts	0.059
Clams:	
Tridacna	
Shell	Background
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
Sea cucumbers:	
H. atra	
Body wall	0.087
Gut	53
Respiratory 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

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Table C.3 — (Continued)

Igurin (continued)	
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	Background
Grapsus	
Carapace	1.5
Gills	1.0
Gastric mill	9.7
Liver	0.81
Muscle	0.12
Green gland	0.52
Eggs	0.17
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

Igurin (continued)	
Muscle	0.15
Liver	1.1
Visceral mass	3.7
Gill	0.22
Algae, sponge and sand scraped from shell	6.8
Oysters:	
Isognomon	
Shell	2.2
Soft parts	14
Rigili	
Sponge:	
Red	41
White	69
Black	15
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
Respiratory tree	2.9
H. fuscorubra	
Body wall	22
Gut	260
Respiratory tree	4.2
Shrimp:	
Crangon	
Muscle	15
Viscera	110
Hermit crabs:	
Dardanus	
Carapace	4.9
Gill	5.5
Gastric mill and gut	16
Muscle	2.0
Liver	13
Integument	7.4
Eggs	2.3
Pagurus	
Thorax	82
Viscera	140
Integument	140

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Table C.3 — (Continued)

Rigili (continued)	
Legs	43
Eggs	49
True Crabs:	
Grapsus	
Carapace	13
Gills	42
Gastric mill	6.4
Gut	3.2
Liver	34
Muscle	1.7
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 and gill	41
Gut	55
Liver	220
Foot	3.5
Abalone	
Mantle	7.7
Viscera*	140
Viscera*	160
Foot	2.1
Drupa	
Shell	10
Foot and 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

Rigili (continued)	
Soft parts	3.3
C. moneta	
Shell	3.8
Foot and 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	3,100
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

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Table C.3 — (Continued)

Bogallua (continued)	
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
Respiratory tree	100
Shrimp:	
Crangon	330
Hermit crabs:	
Dardanus	
Gastric mill and gut	7,600
Muscle	410
Leg	750
True crabs:	
Xanthid	1,800
Grapsid	450
Snails:	
Morula	
Shell	190
Soft parts	100
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
Aaraanbiru (continued)	
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:	

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Table C.3—(Continued)

Runit (continued)	
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
Gut	130
Respiratory tree	12
Shrimp:	
Crangon	
Muscle	7.0
Viscera	31
Carapace	32
Gill	30
Eggs and 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

Runit (continued)	
Snails:	
Turbo	
Shell	2.9
Foot and mantle	5.1
Viscera	42
Nerita	
Shell	5.2
Mantle	3.0
Viscera	45
Foot	3.4
C. moneta	
Shell	1.2
Foot and mantle	6.6
Viscera	43
Clams:	
Tridacna	
Mantle	5.6
Muscle	3.1
Viscera and gill	18
Hippopus	
Shell	3.9
Mantle	0.63
Muscle	0.94
Viscera and gill	31
ADDENDA	
Japtan	
Sea urchin:	
Echinodermata	
Test	Background
Viscera	Background
Rigili	
True crabs:	
Grapsus	
Carapace	14
Gills	62
Gastric mill	280
Gut	240
Liver	62
Muscle	0.90
Swimmerettes	110

*Two samples from the same animal.

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APPENDIX D

COMMON NAMES, GENERA, AND SPECIES OF FISH USED FOR COUNTING AND NUMBER OF SPECIMENS

Common name	Genus	Species	No. of specimens
		Carnivores	
Grouper	*Epinephelus*	*merra*	11
	Epinephelus	*elongatus*	3
	Epinephelus	*macrospilos*	1
Wrasse	*Halichoeres*	*trimaculatus*	17
	Halichoeres	*margaritaceus*	4
	Halichoeres	*kallochroma*	1
	Halichoeres	*notopsis*	1
	Thalassoma	*quinquevittata*	5
	Stethojulis	*axillaris*	9
	Gomphosus	*varius*	1
	Cheilinus	*sp.*	1
	Pseudocheilinus	*hexatania*	1
Squirrel	*Holocentrus*	*microstomus*	6
	Holocentrus	*lacteo-guttatus*	5
	Holocentrus	*diadema*	4
	Myripristus	*argyromus*	2
	Myripristus	*pralinius*	1
Goatfish	*Mulloidichthys*	*samoensis*	6
	Mulloidichthys	*auriflamma*	3
	Parupeneus	*barberinus*	1
Cardinal	*Apogon*	*snyderi*	5
	Apogon	*novemfasciata*	6
	Apogon	*doryssa*	1
Eel	*Gymnothorax*	*buroensis*	4
	Gymnothorax	*picta*	1
	Gymnothorax	*undulata*	2
Goby	*Valenciennea*	*strigata*	3
	Valenciennea	*sexguttata*	3
	Gobiodon	[illegible]	5

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[redacted]

Common name	Genus	Species	No. of specimens
	Carnivores (continued)		
Snapper	*Lethrinus*	*microdon*	2
	Lutianus	*janthinuropterus*	2
	Lutianus	*monostigma*	1
Jack	*Caranx*	*sexfasciata*	3
Smelt	*Pcrapercis*	*montillae*	1
Halfbeak	*Hyporhamphus*	*dussumieri*	2
Reeffish	*Pseudochromis*	*nigricans*	5
Flatfish	*Bothus*	*mancus*	1
	Omnivores		
Damsel	*Abudefduf*	*biocellatus*	30
	Abudefduf	*lacrymatus*	4
	Abudefduf	*sordidus*	3
	Abudefduf	*vaiuli*	1
	Pomacentrus	*jenkensi*	4
Surgeon	*Acanthurus*	*triostegus*	12
	Acanthurus	*elongatus*	3
	Naso	*litturatus*	1
Butterfly	*Chaetcdon*	*citrinellus*	3
	Chaetodon	*lunula*	3
	Chaetodon	*auriga*	5
	Chaetodon	*ephippium*	1
Parrot	*Scarus*	*erythrodon*	10
	Scarus	*sordidus*	5
Blenny	*Istiblennius*	*edentulus*	6
	Istiblennius	*paulus*	3
	Istiblennius	*coronotus*	1
Mullet	*Neomyxis*	*chaptalli*	5
Puffer	*Canthigaster*	*solandri*	4
Brotulid	*Dinemathichthys*	*iluocoeteoides*	1
Filefish	*Oxymonacanthus*	*longirostris*	1

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APPENDIX E

LAND PLANTS COLLECTED AT ENIWETOK, 1952

Group*†	Name	Family	Japtan	Igurin	Rigili	Bogombogo	Engebi	Aomon	Rojoa	Runit
1	*Calocera* sp.	Dacromycetaceae		x						
2	*Marasmius* sp.	Agariceae							x	
3	*Mycena* sp.	Agariceae		x	x					
4	*Xylaria* sp.	Agariceae							x	
5	*Physcia picta* (Swartz) Nylander	Physiciaceae				x				
6	*Pandanus* sp.	Pandanaceae	x							
7	*Tacca leontopetaloides* (L.) Merrill	Taccaceae	x							
8	*Lepturus repens* (Forster) R. Brown	Poaceae		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.	Portulacaceae	x							
16	*Portulaca quadrifica* L.	Portulacaceae								
17	*Portulaca* sp.	Portulacaceae				x	x			
18	*Boerhaavia tetranda* Forster	Nyctaginaceae	x							
19	*Boerhaavia* sp.	Nyctaginaceae	x							
20	*Ipomoea alba* L.	Convolvulaceae	x	x			x		x	
21	*Cordia subcordata* Lamarck	Boraginaceae	x		x					
22	*Tournefortia argentea* L.	Boraginaceae	x	x	x	x	x	x	x	
23	*Canavalia microcarpa* (DeCandolle) Piper	Leguminosae		x						
24	*Guettarda speciosa* L.	Rubiaceae				x				
25	*Morinda citrifolia* L.	Rubiaceae	x	x						
26	*Scaevola frutescens* (Mill.) Krause	Goodeniaceae	x	x	x	x	x		x	

*Groups 1 to 4, fungi; group 5, lichens; groups 6 to 26, flowering plants.
†Arranged in phylogenetic sequence.

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APPENDIX F

RADIOACTIVITY OF BIRDS, POSTSHOT*

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	0.32	0.064	0.18	0.16	0.22	
	N. T.	0.94	0.087	1.0	0.14	0.10	0.30	0.24	
Av.		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	
Av.		14	0.72	23	3.6	2.1	4.7	13	1.9
Engebi‡	N. T.	17,000							
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
Av.		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	
	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	
Av.		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	
Av.		0.75	0.54	0.74	1.08	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	
Av.		0.37	0.21	0.37	0.13	0.14	0.20	0.18	
Eniwetok (USS Oakhill anchorage)	S. T.	0.85	0.16	0.55	0.12	0.40	0.21	0.12	

*Measured in disintegrations per minute per gram (× 1000), 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; and S. T., sooty tern.

‡Bird had been killed by blast.

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APPENDIX G

SURVEY-METER READINGS, POSTSHOT

Island	Date	Distance to ground, in.	Radiation,* mr/hr			Remarks
			γ	γ and hard β	γ, soft and hard β	
Rigili	11-5-52	12	8	9	11	Lagoon side 10 ft out into the water
		2	120	370	700	Inshore 15 yd at edge of vegetation
		36	80	120	140	Inshore 15 yd
Runit	11-6-52	24	11			Water-washed rocks
		2		25	28	on lagoon beach
		36	16			Sandy beach 10 yd
		2	16	16	16	inshore from edge of water
		36	55			Sandy beach inshore
		2	75	75	75	30 yd from edge of water
		36	60			North end
		2	90	380	1,200	of island
Rojoa	11-7-52	36	500			On beach at edge
		2	750	1,250	2,250	of water and on shore
Aaraanbiru	11-7-52	36	420			On beach at edge of
		2	620	1,050	2,050	water and on shore
Engebi	11-8-52	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/sq cm polyethylene bag.

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APPENDIX H

PROCEDURES FOR PRECIPITATION OF FISSION PRODUCTS AND CALCIUM AND STRONTIUM

1. The sea water was acidified and stirred to remove bicarbonates.
2. Ferric chloride was added and precipitated by the 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 was allowed to stand several hours.
4. The combined precipitates were filtered, and the filter paper with precipitate was 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 the 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 ml, and duplicate 20-ml aliquots were taken.
9. The aliquots were diluted to 100 ml, and calcium and strontium were reprecipitated by the addition of saturated ammonium oxalate solution. The precipitate was plated and counted.

The 0.5-liter postshot 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 the 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 the 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.

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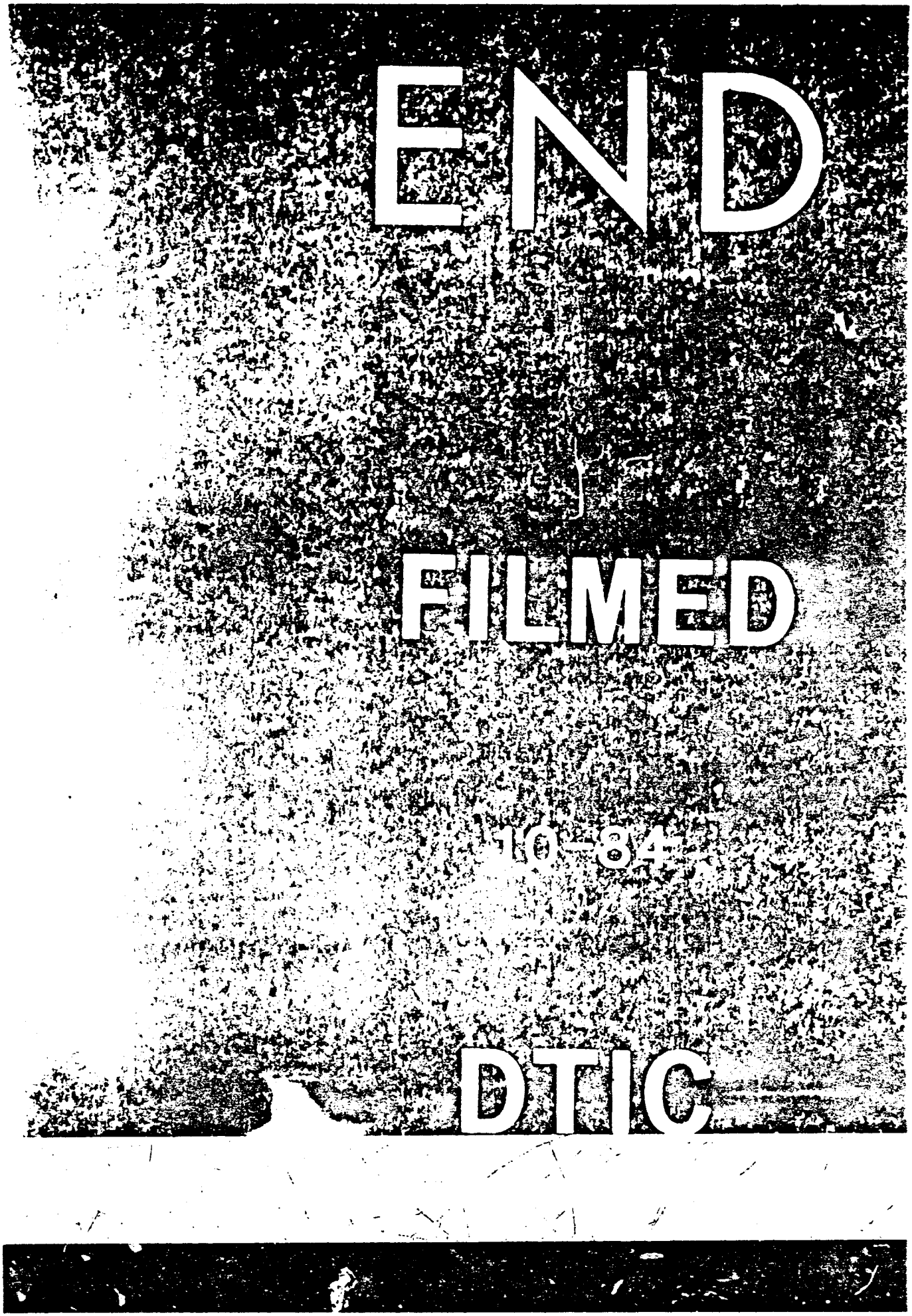
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