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BIKINI RADIOBIOLOGICAL RESURVEY OF 1948

Applied Fisheries Laboratory
University of Washington
Seattle, Washington

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BIKINI RADIOBIOLOGICAL RESURVEY OF 1948

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Introduction

At the request of the Atomic Energy Commission, with the active participation of the U.S. Navy, a radiobiological resurvey of Bikini Atoll was conducted during the summer of 1948. The University of Washington, Applied Fisheries Laboratory was designated by Supplements 5 and 6 to the Contract No. W-28-094-eng-33 to carry out the field problem and to report the findings.

A preliminary outline of the program of studies for the second radiobiological resurvey of Bikini for the summer of 1948 (Report UWFL-10) was prepared and forwarded to the commission for approval. This report, in part, outlined the objectives as follows:

> "A resurvey of the Bikini Atoll during the summer of 1948 should be undertaken to further our knowledge of the over-all biological problems of the effect of the release of energy from atomic bombs above or under water.
>
> Biological studies are of necessity long time, complex projects. The Bikini biological studies are so very complicated that only through continuous long-time effort can we hope to understand the basic principles involved.
>
> The fundamental data that need to be gathered at regular time intervals for re-evaluation of the problems involved are grouped as follows: (1) the

presence or absence of radiation in the various types of marine organisms; (2) the distribution of radioactive substances in the marine plants and animals from different geographical locations within the atoll; and (3) the amounts of radioactive substances in certain tissues and organs."

Organization

The radiobiological resurvey of Bikini during the summer of 1948 was a fine example of teamwork in research. The Atomic Energy Commission, the U.S. Navy and the University of Washington each contributed personnel, equipment and facilities to make the project possible.

The Atomic Energy Commission provided the administration and financial support. The Washington office of the commission, especially the Division of Biology and Medicine, under the direction of Dr. Shields Warren, and Dr. James H. Jensen, Chief of the Biology Branch, were very helpful in expediting the research. The Hanford Operations Office of the Atomic Energy Commission, especially Mr. W.K. Crane, handled local arrangements for the commission in a most understanding manner.

The U.S. Navy provided transportation to and from the area. Ships, equipment, shore facilities, communications and many other services that made living and working in the area possible, were furnished.

Captain J.S. Russell, U.S.N. aided in many ways in the planning, organizing and expediting of the expedition.

The Island Commander stationed at Kwajalein atoll, Captain J.J. Vest, U.S.N. and his very efficient staff of officers and enlisted personnel were most helpful and considerate. Especially noteworthy was the personal interest of this fine naval group in the success and welfare of the expedition.

The Navy assigned Lt. J.J. Schmidt, U.S.N. as naval liaison officer. Lt. Schmidt accompanied the expedition from the mainland to the Pacific areas and return. His services were especially appreciated, for he handled with tact and skill the many problems of civilians working with a military organization.

The University of Washington, as contractor, provided technical personnel, facilities and equipment for carrying out the research. The administration of the program by Dr. Raymond B. Allen, President, and Nelson Wahlstrom, Comptroller, was understanding and efficient.

Technical personnel

A total of twelve technical staff members was used to carry out the field problem. The nucleus of the field party personnel was drawn from the staff of the Applied Fisheries Laboratory where experienced personnel was available. To

increase the specialty skills available for evaluation of the radiation problems at Bikini, specialists were borrowed from other universities for the field trip.

Since training of technicians in radiation biology is a definite part of the over-all program of which this work forms a part, promising students were included in the field party. A balance in the program was maintained by assigning a junior member of the staff to work with each senior member in carrying out the various phases of the work.

Members of the Bikini Radiobiology Resurvey 1948

Name	Assignment	Permanent address and occupation
Lauren R. Donaldson, Ph.D.[1,2,3]	Group leader and biologist	Prof. of Fisheries; Director, Applied Fisheries Laboratory; U. of W., Seattle, Wash., 98105
Allyn H. Seymour[2]	Executive officer, biostatistician and plankton	Research Associate, Applied Fisheries Laboratory, U. of W.
Arthur D. Welander, Ph.D.[1,2]	Radiobiologist and ichthyologist	Asst. Prof. of Fisheries and Research Associate, Applied Fisheries Lab., U. of W.
Asher A. White, M.D.[1]	Medical Consultant	Lecturer, Univ. of Minn. College of Medicine and Nicollet Clinic, Minneapolis, Minnesota

[1]Operations Crossroads, radiobiology, 1946.
[2]Bikini Scientific Resurvey, radiobiology, 1947.
[3]Operations Sandstone, radiobiology, 1948.

Name	Assignment	Permanent address and occupation
George Hollenberg, Ph.D.	Marine algae	Prof. of Botany, Univ. of Redlands, Redlands, Calif.
Theodore Bullock, Ph.D.	Marine invertebrates	Assoc. Prof. of Zoology, Univ. of Calif., Los Angeles, Los Angeles, Calif.
Spencer W. Tinker	Marine biology	Director, Waikiki Aquarium, Univ. of Hawaii, Honolulu, T.H.
Edward E. Held	Marine invertebrates	Graduate Research, Dept. of Zoology, U.C.L.A., Los Angeles, Calif.
Frank G. Lowman	Biologist, electronics	Research Associate, Applied Fisheries Lab., U. of W., Seattle, Wash.
John J. Koch	Tissue processing, radiation detection	Graduate Research, Applied Fisheries Lab., U. of W., Seattle, Wash.
Richard H. Osborn	Biologist, photographer	Student, Medical School, U. of W., Seattle, Wash.
John R. Donaldson	Fisheries biology and plankton	Student, School of Fisheries, U. of W., Seattle, Wash.

With the completion of the field project the "borrowed" personnel were returned to their various permanent stations. The work of organizing the data and writing the reports has been the work of the regular staff members of the Applied Fisheries Laboratory.

Naval equipment provided for the resurvey

In addition to the transportation and facilities provided by the Navy to move the personnel and equipment from the mainland to the Pacific area and return, two small ships were provided for transportation and to provide living accomodations and laboratory facilities.

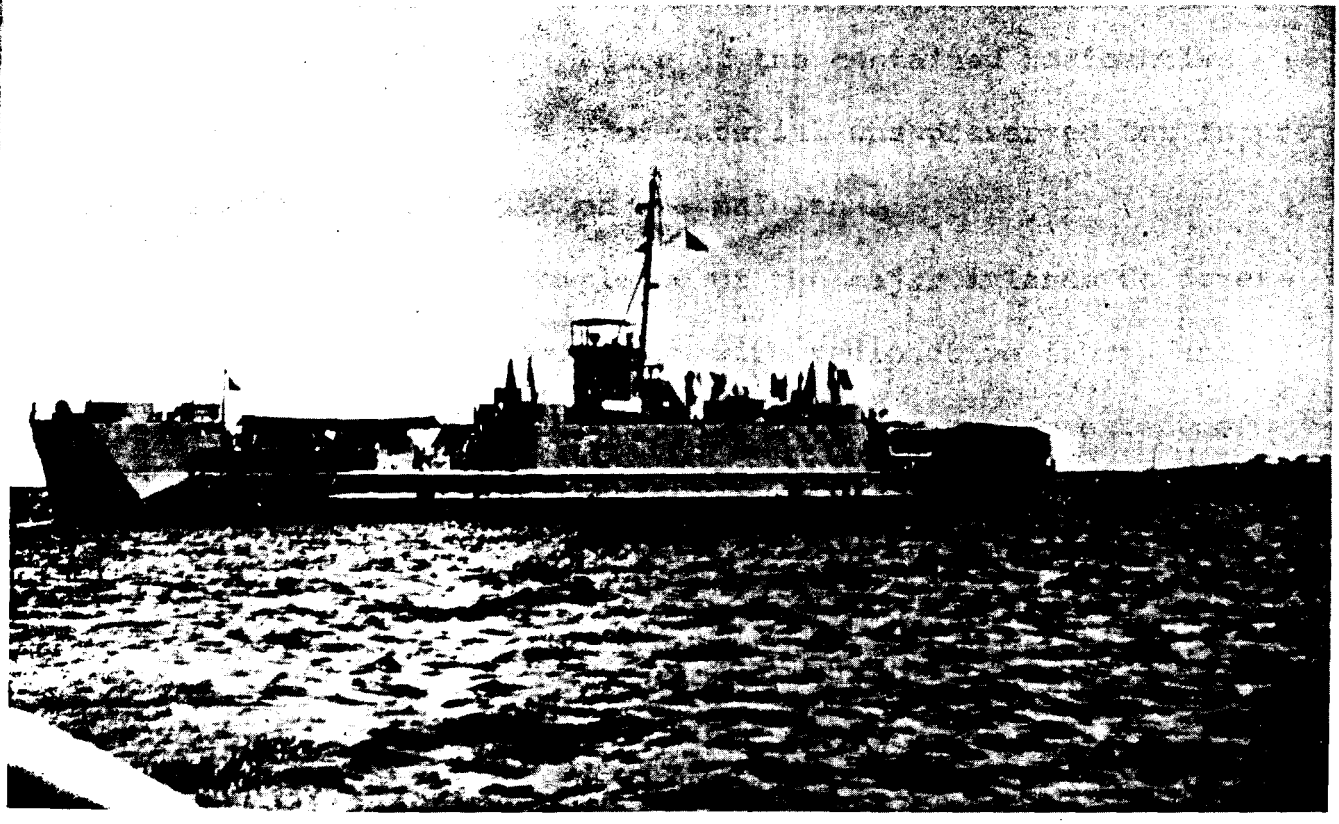
The LCI (L) 1054, with Lt. (j.g.) Sam Mansfield as commanding officer, was assigned to the expedition for an operations base. The LCI with a few alterations to provide deck laboratory space proved to be a very acceptable ship for field operations. In addition to the LCI-1054 a support ship, the AG-140, accompanied the expedition from Kwajalein to Bikini to transport the three (3) small landing craft needed for work boats within the lagoon.

Mail, supplies and personnel were transported between Kwajalein and Bikini by P.B.Y. operating out of Kwajalein.

Time schedule and work programs

The research expedition left San Francisco, California, on Sunday, June 27, 1948, via Naval Air Transport and after a stopover at Honolulu arrived at Kwajalein, M.I. on June 30.

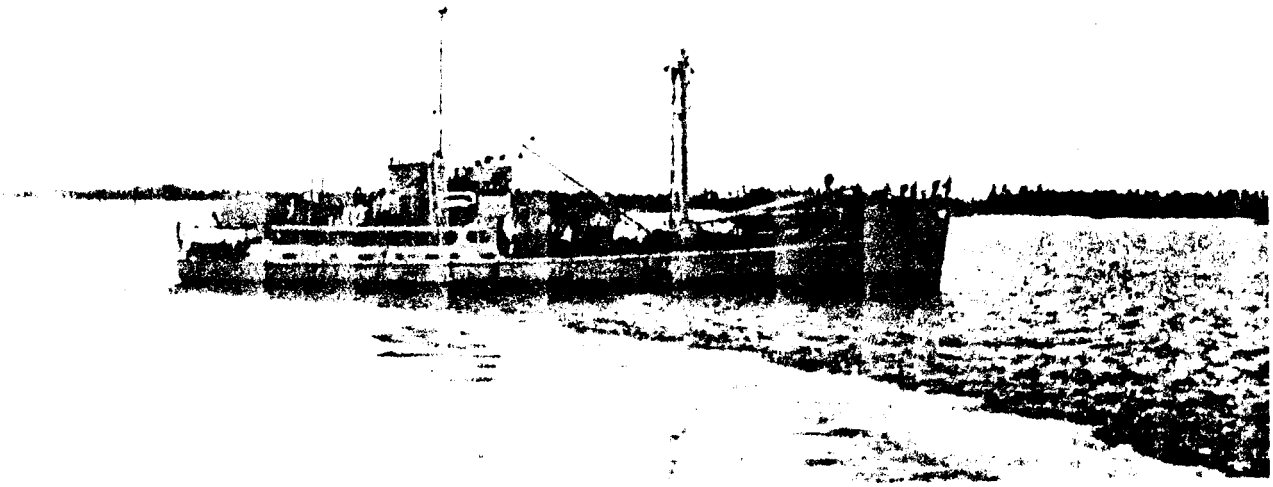
From Kwajalein to Bikini transportation was by ship. The LCI-1054 arrived at Bikini on July 3, 1948, and remained until July 20, 1948, when the ships and personnel were moved to Eniwetok.



The LCI(L)-1054 was assigned to the expedition as an operations base. The forward deck was covered with a tarp to provide deck living space. The after deck was used as a laboratory for processing materials.

During the eighteen (18) days at Bikini collections of material for the study of radiation were made at eleven (11) major stations. This material contained representative samples of the faunal and floral systems from the lagoon, the inner and outer reefs, and from the islands. A total of 1,918 ashed samples was prepared for determination of the contained radioactive materials. A vast quantity of material was preserved for future study in the laboratories on the mainland.

A survey was completed of the major islands to determine the amount of contamination with radioactive debris and drift material. Field counts were also made of the extent of contamination of the land masses, land plants and animals, etc. from the contamination of fission products found in the lagoon.



The AG-140 accompanied the expedition from Kwajalein to Bikini to transport the three (3) small landing craft used for work within the lagoon.

Part 2. Evaluation of radioactive materials in fish collected at Bikini during the summer of 1948.

Collecting methods

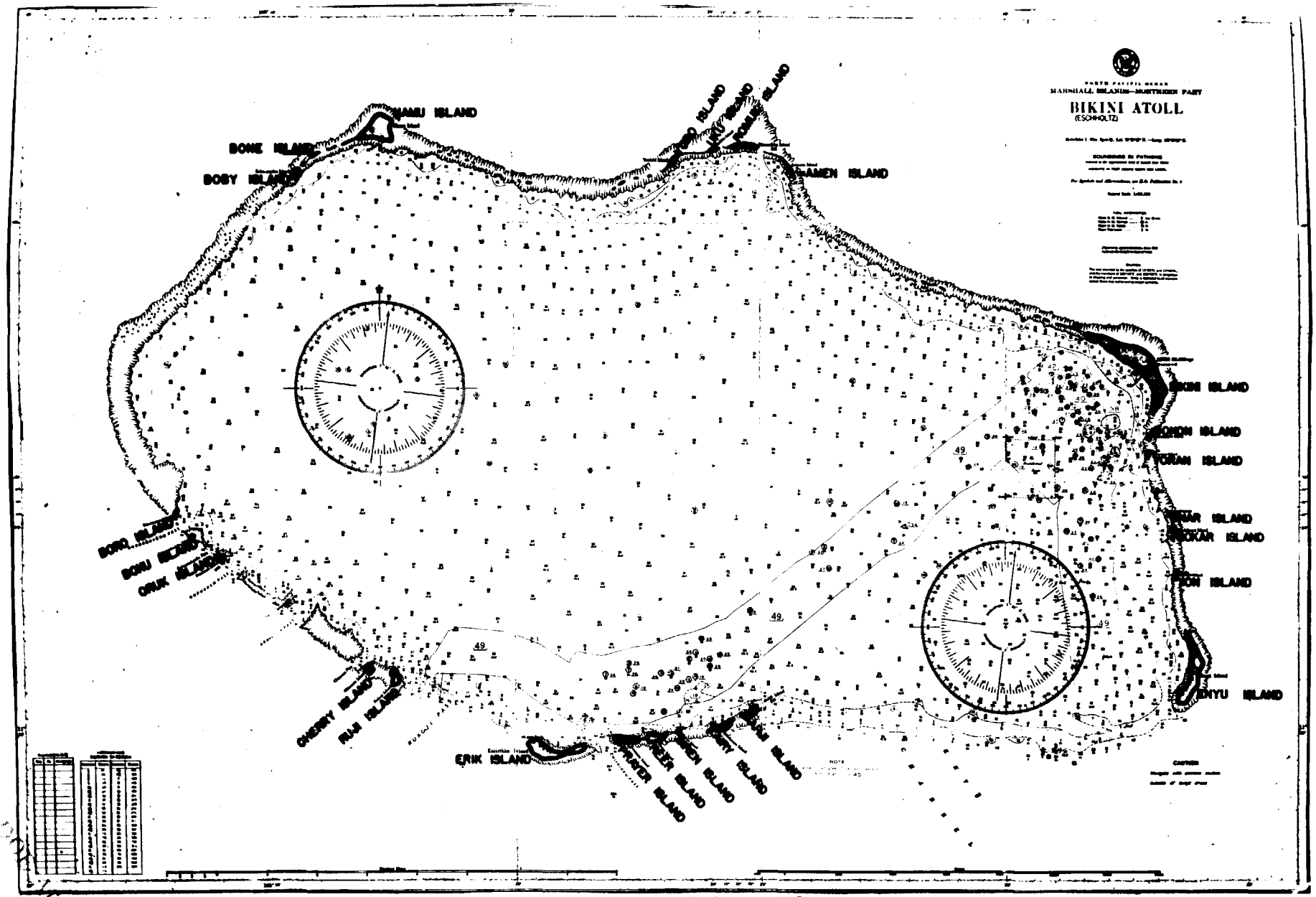
Methods of collecting fish were similar to those used at Bikini in 1946 and 1947 (Report No. UWFL-7). The collections were principally of reef fish killed by rotenone, supplemented by some fish caught by hook and line.

Collecting areas

Eleven areas geographically distributed throughout the atoll, which had been sampled in previous years, were selected as collecting areas. These areas from west to east in a clockwise direction were Boro, Namu, Uku, Amen, Amen-Bikini, Bikini, boat anchorage, Rokar, Enyu, Arji and Erik. Samples were collected on the lagoon side of the islands, supplemented whenever possible with similar collections from the ocean side of the island or reef. The attached map has the major collecting areas marked with an X.

Groups sampled

The fish selected from the collections for determination of contained activity were in one of the following twelve groups: Blenny, cardinal, damsel, eel, goat fish, grouper, lizard, parrot, siganid, squirrel, surgeon and wrasse. These groups, based on the 1946 and 1947 collections, were selected as being commonly available and representative of the reef fish taken by our means



Map of Bikini Atoll.

of collection. An effort was made to collect one or more specimens of each of these groups at each collecting station. Some fish other than those in the groups mentioned above were sampled, especially if all twelve groups were not available.

Number of samples

A total of 1,152 samples was prepared from tissues taken from 187 specimens.

Tissues sampled

Selection of tissues sampled was also standardized with six tissues--skin, muscle, bone, liver, gut and gills--usually taken. The spleen, kidney or gonad was also sampled when fish of sufficient size were available to yield an adequate sample of these tissues.

Sample preparation

The samples were prepared for counting by placing approximetely one gram of tissue--if that much tissue was available--on a one-inch stainless steel plate stamped from .005-inch stock. The samples were heated to about 120°C on a hot plate to initiate the reduction to an ash. After the tissues charred, a drop of olive oil was added to reduce sputtering. The trays with the tissue residue were then placed in a muffle furnace and the temperature gradually raised to 370°C. After two hours of heating the temperature was raised to 500°C and maintained until a white ash was obtained. A drop or more

of nitric acid was then added and the samples removed to cool. If the sample became hydroscopic it was reheated to 500°C and a drop of sulfuric acid added. In spite of such treatment samples with a high calcium content remained hydroscopic. Finally, after completing ashing and upon cooling, the plates were mounted on cards, covered with cellophane and sealed with Scotch tape. All of the fish samples were prepared in the field but were not counted until two months later.

Counting procedure

The samples were counted for beta-gamma activity only. The counting was done at the Applied Fisheries Laboratory, University of Washington, between September 15-28, 1948. With only one scaler in operation and with a large number of fish and other samples to be counted it was decided beforehand to make five-minute counts. (See discussion below under "Error"). Five-minute recounts were made of samples whose net original counts were 0 to 4 per minute. The counter was set in a circular lead shield with a sliding plate holder and connected with a scale of 64 scaler. Both products were made by Victoreen, the scaler being Model X-327.

Corrections in counts

The sample counts were corrected for background, for weight of sample and for geometry. For the entire counting

period, the average background count was 17.0 per minute. Using a U.S. Bureau of Standard Ra D+E standard of approximately 108 disintegrations per second the geometry was calculated as being 18.0 per cent. No correction was made for scattering, for self absorption, for absorption by air and by counter window or for the probability of ionization.

Calculations

Counts were eventually converted to millimicrocuries per kilogram of sample by the following formula:

$$\text{m/uc/kg} = \frac{\text{net count per minute}}{(\text{sample wt.})(\text{geometry})(2.2)}$$

If the number of disintegrations per second for one curie is 3.7×10^{10} and this value is corrected for conversion to minutes and then the equation above is converted to millimicrocuries, the resulting value is 2.2 as appears in the denominator.

The total activity of an individual fish was calculated as the sum of the activity of all of its tissues. This value was obtained in the following manner: (millimicrocuries per kilogram of skin) x (ration of total tissue weight to total body weight) + (m/uc/kg of muscle) x (body ratio) + ditto for bone + for liver, etc. = millimicrocuries per kilogram of fish. The body ratios, Table I, were obtained by weighing the tissues of one fish from eight selected types. Fish, other than those listed, were placed under one of the eight types as follows:

blenny, column 1; cardinal, goat fish, grouper, lizard, variola, snapper, pig fish, remora and half beak, column 2; damsel, column 3; wrasse, column 4; puffer, column 6; and jack, tuna and rainbow runner, column 7.

Table I. Ratio of Tissue Weight to Total Body Weight for Eight Selected Types of Bikini Fish

	Fish	1. eel	2. brown spot. grouper	3. convict surgeon	4. parrot	5. siganid	6. squir-rel	7. 2 line macke-ral	8. shark (esti-mated)
Ratio tissue weight to total body weight	Tissue								
	skin	.108	.064	.065	.114	.026	.173	.034	.100
	muscle	.686	.662	.567	.591	.616	.450	.788	.500
	bone	.099	.224	.175	.220	.170	.288	.118	.150
	liver	.013	.003	.020	.005	.009	.007	.005	.100
	gut	.084	.025	.151	.055	.164	.063	.030	.100
	gills	.009	.021	.022	.015	.013	.019	.025	.050
	spleen					.002			
	Total	.999	.999	1.000	1.000	1.000	1.000	1.000	1.000

Error in net count at the 95 per cent confidence level was calculated from the formula:

per cent error = $(K/\sqrt{C})(100)$ where K is a constant equal to 1.96 for the 95 per cent confidence level, C is the total count and 100 the correction for per cent.

Analysis of data:

The data was analyzed with the purpose of estimating activity by areas, by species and by tissue. Analysis by area was based on the average activity of all fish sampled from one collecting area. Explanation of the calculation of activity by species is given above and is an average for all areas. Tissue activity was calculated as the average activity per kilogram of tissue for all fish from all areas.

Results:

The results are shown in tabular form in Table II and in graphical form in Figures 1, 2, 3, 4 and 5. In general the counts were low, usually not exceeding twice background (see Figure 1). By areas the activity in the western half of the atoll (Erik, Boro, Namu) was slightly lower but otherwise no pattern was apparent as is shown in Figure 2. Average activity by species ranged from 9.60 to 0 millimicrocuries per kilogram of fish. The activity by species listed in the following descending order of magnitude is as follows: lizard, wrasse, half-beak, siganid, barracuda, damsel, parrot, cardinal, blenny, surgeon, snapper, goat fish, grouper, jack, eel, variola, remora, tuna, squirrel, mackeral, pig fish, rainbow runner, puffer, mullet and shark. See Figure 3. Activity in tissue ranged from 22.7 to 3.0 millimicrocuries per kilogram of tissue. In Figure 4 the tissues are arranged as to activity in the following descending order: spleen, liver, kidney, gut, skin, bone, gills, muscle and ovary.

Error

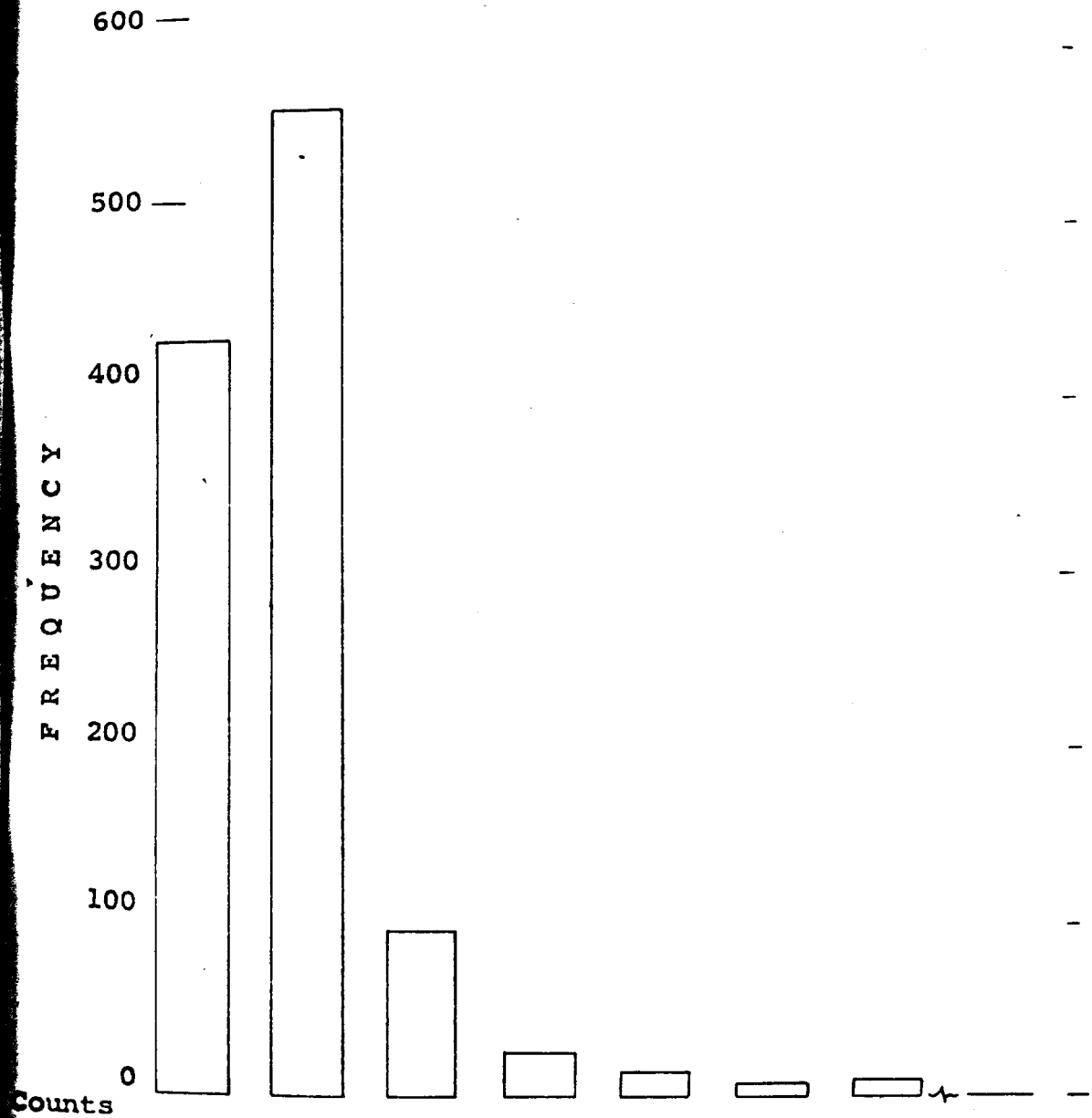
The per cent error in counting and hence in estimating activity is relatively great due both to the low activity of the samples and to the short counting period. For these reasons values of about 4 or 5 to 0 millimicrocuries per kilogram are are in general of questionable significance.

Expressed as Millimicrocuries per Kilogram of Fish

Area	blenny	cardinal	damsel	eel	goatfish	grouper	lizard	parrot	algaeid	squirrel	surgeon	wrasse	wrasse	wrasse	snapper	pigfish	barracuda	halfbeak	mullet	remora	puffer	jack	mackerel	tuna	rainbow runner	shark	Total n		Ave. all species
Boro 8799	3	1	4		2	0		5		0	4	0				2											21	10	2.10
Namu 9514	0	9	3 5	2		0 1 3				1	2 1	1			0 15		6					1 1 1	1 0	1		0	34	22	2.45
Uku 0914	24	7	1	0	7	8		3		4	3	2															39	10	5.90
Amen 1219		1 6	11 18	9 5	2 4	12 10	20		12	1	14 1	35 5															166	17	9.76
Bikini-Amen 1609-1708	2 1		4	8	12 5	2	9	5		6 8	5	13	4		6 3								1	1		0	95	19	5.00
Bikini 2307-2604	7 16	5 8	8 6 5	1 5 3	1 6	3 6 5		1 12	3 7 10	2 6 3	10 14	10 5						9									0	179	29	6.17
Anchorage 2103-2504	4														6 4	4				6 1	1	15 3 2 7 9 3 2	1 8		3	0	79	18	4.39
Rokar 2798		10	9	8	13	8		6 6	8 5	3	8	5															89	12	7.42
Enyu 2894		0	6	1	7	1	9		7		6	6							1								44	10	4.40
Arji 1092	2	3	3	10	1	4	10	11	7	0	5	22			3		4					10 0	2	6			105	18	5.72
Erik 0290, 0190 Ruji Pass	0	18	4	0	0	3 6	0	10 3		1	3	6			4	2	9						4	8 5 3	0	0	89	22	4.04
Total	50	68	87	52	60	74	48	62	59	35	76	110	4		41	8	19	9	1	7	1	54	17	24	3	0	978		
n	10	11	14	12	12	16	5	10	8	12	13	12	1		8	3	3	1	1	2	1	12	6	7	2	5		187	
Ave. all areas	5.00	6.18	6.21	4.33	5.00	4.62	9.60	6.20	7.38	2.92	5.85	9.17	4.00		5.12	2.67	6.33	9.00	1.00	3.50	1.00	4.50	2.83	3.43	1.50	0			5.23

Figure 1

Grouped Frequencies of Fish Samples
by Net Counts



Counts per Minute	0 or less	0.1-5.0	5.1-10.0	10.1-15.0	15.1-20.0	20.1-30.0	30.1-40.1	70.7
n	435	567	95	25	14	7	8	1
Per Cent	37.8	49.2	9.2	2.2	1.2	0.6	0.7	0.1

Figure 2

Average Beta-Gamma Counts of Fish by Areas Expressed as Millimicrocuries Per Kilogram of Wet Tissue.

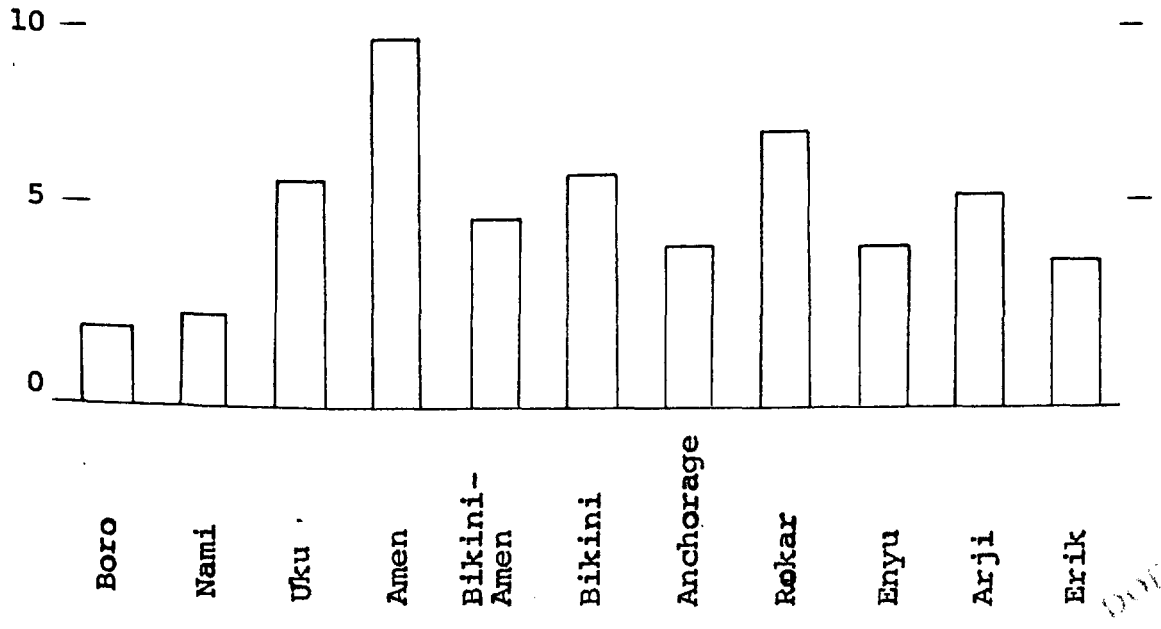


Figure 3
Average Beta-Gamma Counts of Fish by Species Expressed in Millimicrocuries per Kilogram of Fish

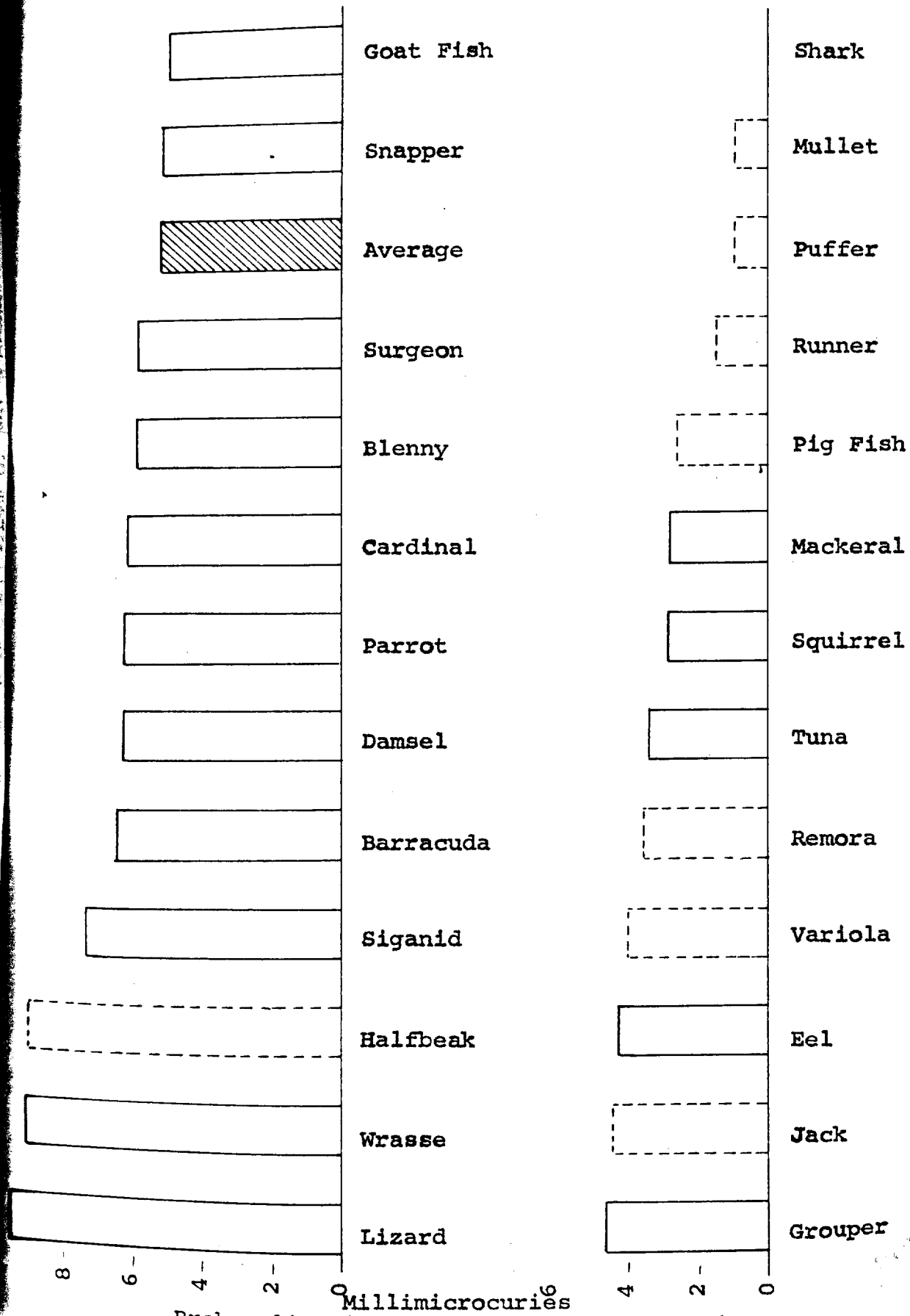


Figure 4

Average Beta-Gamma Counts of Fish Tissues
Expressed as Millimicrocuries
of Wet Tissue

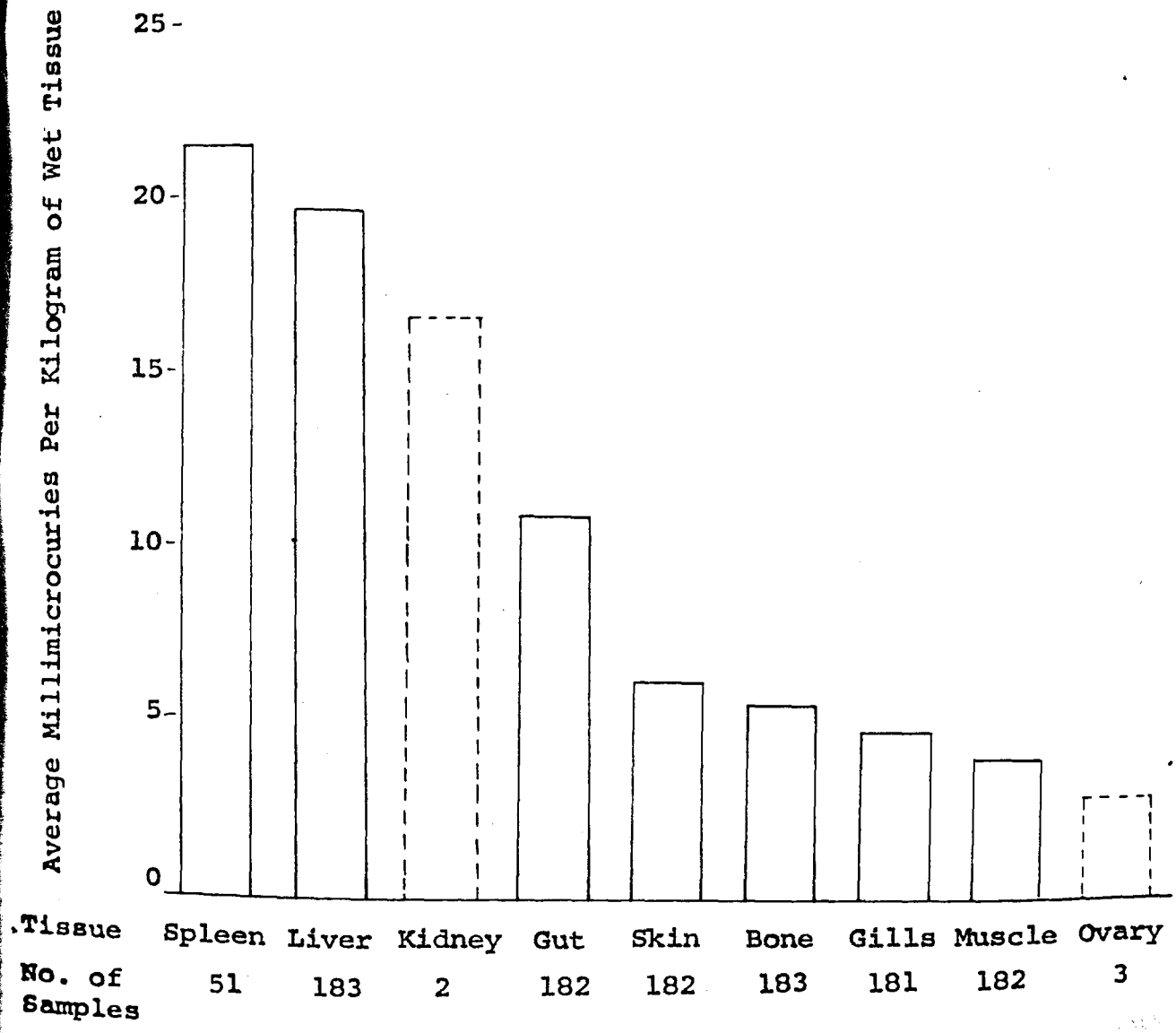
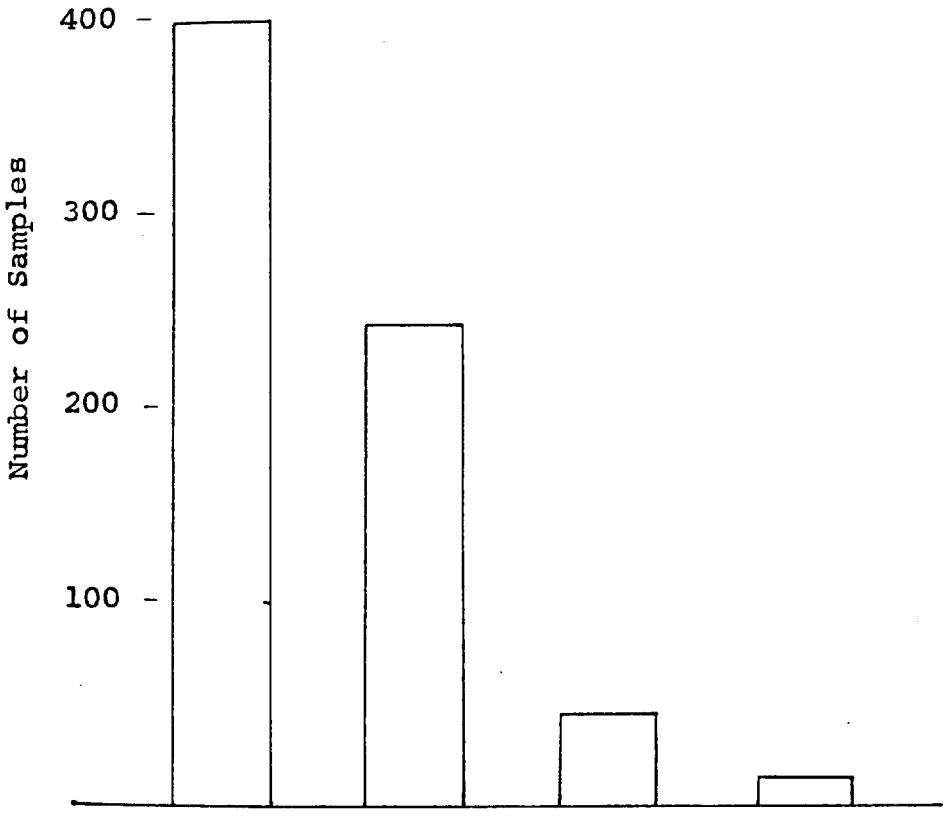


Figure 5

Grouped Frequencies by Per Cent Error in Net Count of Fish Samples



Per Cent Error in Net Count	Over 100	50.1-100	25.0-50	Less than 25	
n	409	248	47	14	Total 718*
Per Cent of Total	57.0	34.5	6.5	2.0	100

*The 434 samples not entered in this total were zero count or less.

The per cent error could have been greatly reduced by making longer counts. This error was reduced in 603 samples by making five-minute recounts. These samples had original net counts between 0 and 4 per minute. Activity was then computed from the average of the two counts, which is equivalent to an average based on a 10-minute counting period, thus reducing the per cent error. The recounts were made a month and a half after the original counts, but since it was twenty-seven months after the blast no correction was made for decay betweem time of original count and recount. When the 1,152 samples were grouped as to per cent error of the net count, 14 samples were in the class of 0-25, 47 samples in the class 25.1-50, 248 samples in the class 50.1 to 100 and 409 in the class of over 100 per cent error. The count of the other 434 samples was background or less. The histogram of Figure 5 is a chart of these data.

In estimating the activity by areas there may be a slight error due to the fact that exactly the same species were not collected at any two areas. Since there was a deliberate effort to collect in each area the species noted at the beginning of this report, the error would be insignificant and well within the range of other errors.

The calculation of total body activity assumes that the body ratios of Table I would hold for all fish of similar

shape or relationship, and that all tissues of the body could be grouped as shown in the same table. These assumptions are not altogether correct but the error involved is relatively insignificant.

In the figures and tables relating to activity by species and by tissue it is well to note the number of samples which usually fall into one of the two categories "adequate" or "very small" and to discount conclusions based upon the latter.

Some samples other than fish were brought back to the University of Washington and prepared in the lab. It was found that when samples of calcium carbonate were treated in the manner outlined above the resulting sample was heavier and thicker than the original sample. An alternate method was developed whereby the material was ground with a pestle in a mortar, a thin layer of the pulverized material spread over a 1-1/2" plate and then the material covered with a thin plastic film (0.5 per cent Formvar E in ethylene dichloride) so that it would adhere to the plate. Then, when similar samples prepared by the two methods were counted, the samples prepared by the second method gave counts that were consistently higher, averaging 30-40 per cent greater for the few samples tested. For the fish, this would indicate that some of the activity of the bone and possibly other tissues was lost during the heating and treatment and thus the estimates of activity here recorded would be minimum values.

Summary

Collections of fish were made at eleven stations distributed throughout the atoll. The collections were principally of reef fishes but were supplemented by some hook and line-caught fishes. One hundred eighty-seven fish were used to provide tissue samples from which 1,152 preparations and counts were made. Activity by areas (Figure 2) was slightly less for the most western part of the atoll but no pattern was evident otherwise. By species the activity expressed as millimicrocuries per kilogram of fish ranged from 9.6 to 0 (average, 5.2) in the following order: lizard, wrasse, half-beak, siganid, barracuda, damsel, parrot, cardinal, blenny, surgeon, snapper, goat fish, grouper, jack, eel, variola, remora, tuna, squirrel, mackeral, pig fish, rainbow runner, puffer, mullet and shark (Figure 3). For those underlined there were five to 16 samples. The average value for the activity of tissues from all species from all areas expressed as millimicrocuries per kilogram of wet tissue (Figure 4) ranged from 22.7 to 3.0 in the following order: spleen, liver, kidney, gut, skin, bone, gills, muscle and ovary.

Part 3. Radioactive materials accumulated by the algae of the lagoon and the inner and outer reef areas.

In the foregoing discussion dealing with the activity in fish, the sections pertaining to collecting areas, sample preparation, counting procedure, correction in counts, calculations and error are also relative to the data on algae discussed in Part 3.

Collecting areas

Samples were collected from the shallow water areas on both the lagoon and ocean side of the atoll, in the same general areas as the fish collections but over a greater range. In deeper water, collections were obtained by dredging and from growths of algae on floats of one kind or another. These samples were gathered in two general locations, near the reef, in which case they were assigned to the nearest reef station, or in the target area.

Groups and number sampled

An effort was made to collect the same genus in all areas for comparative purposes. However, only three genera were collected at every one of the ten reef collecting stations. Twenty-four genera plus three more general groups were collected in all and from these representative groups 206 samples were ashed and radiation activity counted. The samples were weighed wet, that is, the sample was removed from a bucket of

salt water, drained but not dried, then weighed. The samples were counted the last week in September, 1948. As with the fish samples, recounts were made of those samples with net counts of zero to four and the data of the two counts averaged.

Analysis of data

The activity was calculated as millimicrocuries per kilogram of wet tissue. After determining activity, the data were analyzed both as to activity by area and by generic group.

Results

Activity by groups is tabulated in Table III and by areas in Figure 6. Since the activity of target area samples was significantly greater than that from the reef, the tabulation by groups is separated into those two categories. By groups the average activity from all stations exclusive of the target area was 17.3 millimicrocuries per kilogram of wet tissue and ranged from 0 to 102. For the target area the average of all groups was 193 and the range 27 to 618. For the reef stations the average value for all groups combined ranged from 6.7 to 24.2 with the areas in the western part of the atoll yielding the lowest values. The highest single value for the reef stations was 182 and for the target area 1,009 millimicrocuries per kilogram of wet tissue.

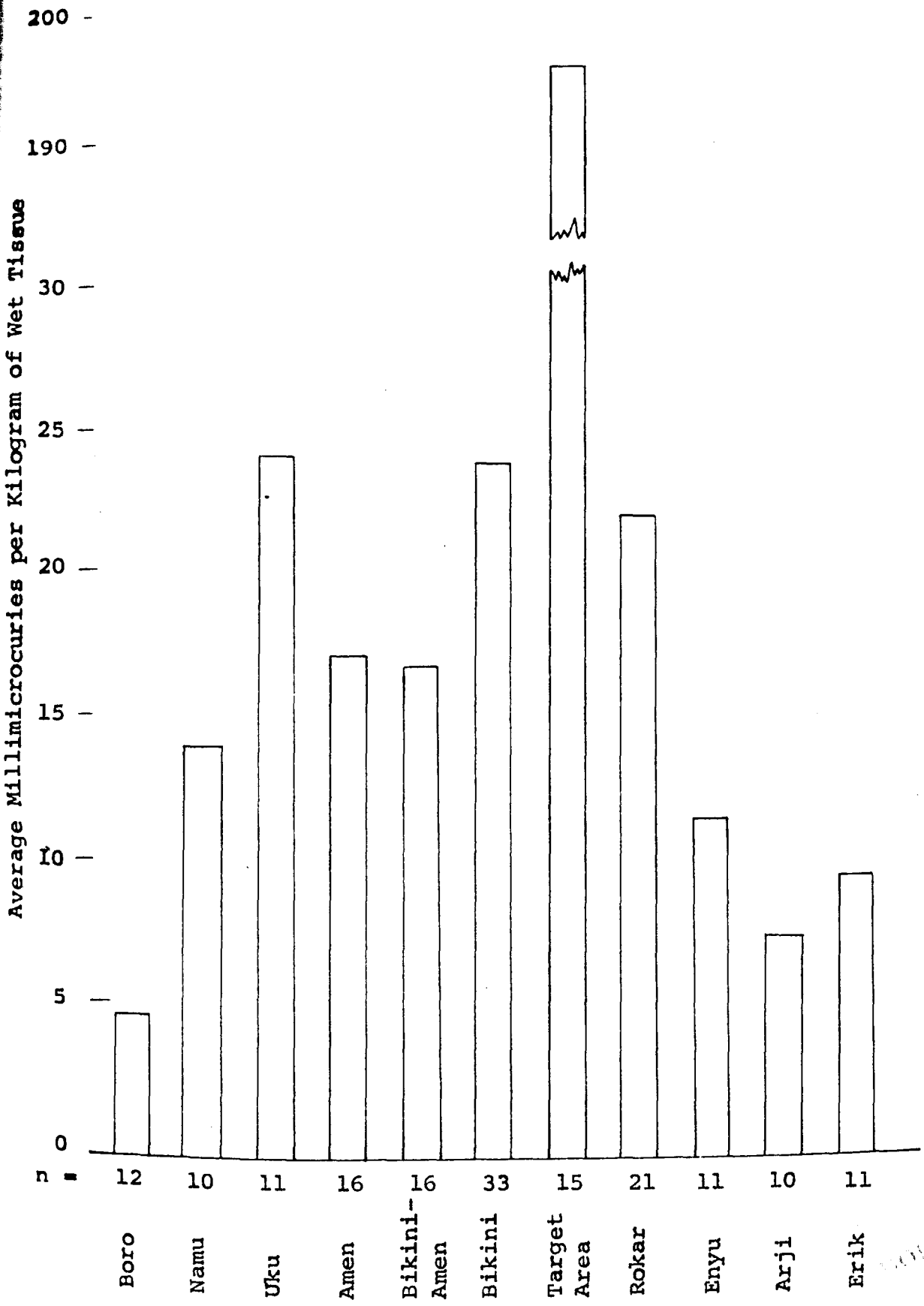
Table III

Average Beta-Gamma Counts of Algae by Areas Expressed as Millimicrocuries per Kilogram of Wet Tissue

	Reef Stations		Target Area	
Group	No. of Samples	Ave.	No. of Samples	Ave.
Enteromorpha	1	102		
green algae	1	63		
Dictyurus	1	50		
Jania	2	50		
Griffithsia	1	50		
Microdictyon okamurai Setchell	3	32		
Blue green algae	9	32	4	103
Lynbya	1	30		
Rhipilia	8	28		
Calothrix	1	26		
Liagora	4	26		
Pocockiella	10	23		
Ectocarpus	8	20	3	100
Laurencia	5	19		
Dictyosphaeria cavernosa (Forsak.) Borgesen	12	18		
Spyridia filamentosa (Wulfen) Harvey	4	17	2	24
Udotea	18	16		
Caulerpa urvilliana (Mont.) Weber van Basse	15	10		
Halimeda	22	7	2	400
encrusting coralline	6	7		
Turbinaria ornata J. Ag.	4	6		
Dictyota	2	6	1	27
Sphacelaria	1	5		
Porolithon	1	5		
Caulerpa racemosa (Forsak.) J. Ag.	8	4		
Lithophyllum	3	1		
red algae	1	0		
Padina commersoni Bory	0		1	75
"Halimeda sand"	0		2	618
Total, all species	152	17	15	193

Figure 6

Average Beta-Gamma Counts of Algae by Areas Expressed as Millimicrocuries per Kilogram of Wet Tissue



Part 4. Radioactive materials contained in selected samples of invertebrate organisms.

Collecting methods and areas

The bulk of the invertebrate collections was gathered in the shallow water near the reef in the vicinity of the fish-collecting stations. Off the reef collections of invertebrates were of those found growing on the buoys in the target area and on the floats that were made and anchored in the lagoon during July, 1948.

Many groups of invertebrates were sampled with some of the smaller groups being combined into the more general groups shown in Table IV. A total of 389 samples was prepared and the radiation counted September 29 to October 5, 1948. If there was more than one tissue from a single specimen, the average of all tissues, without weighing, was the value used to calculate average count by group or by area.

Sample preparation, counting procedure, correction in counts and calculations were the same as similar procedures discussed in Part 2.

Results

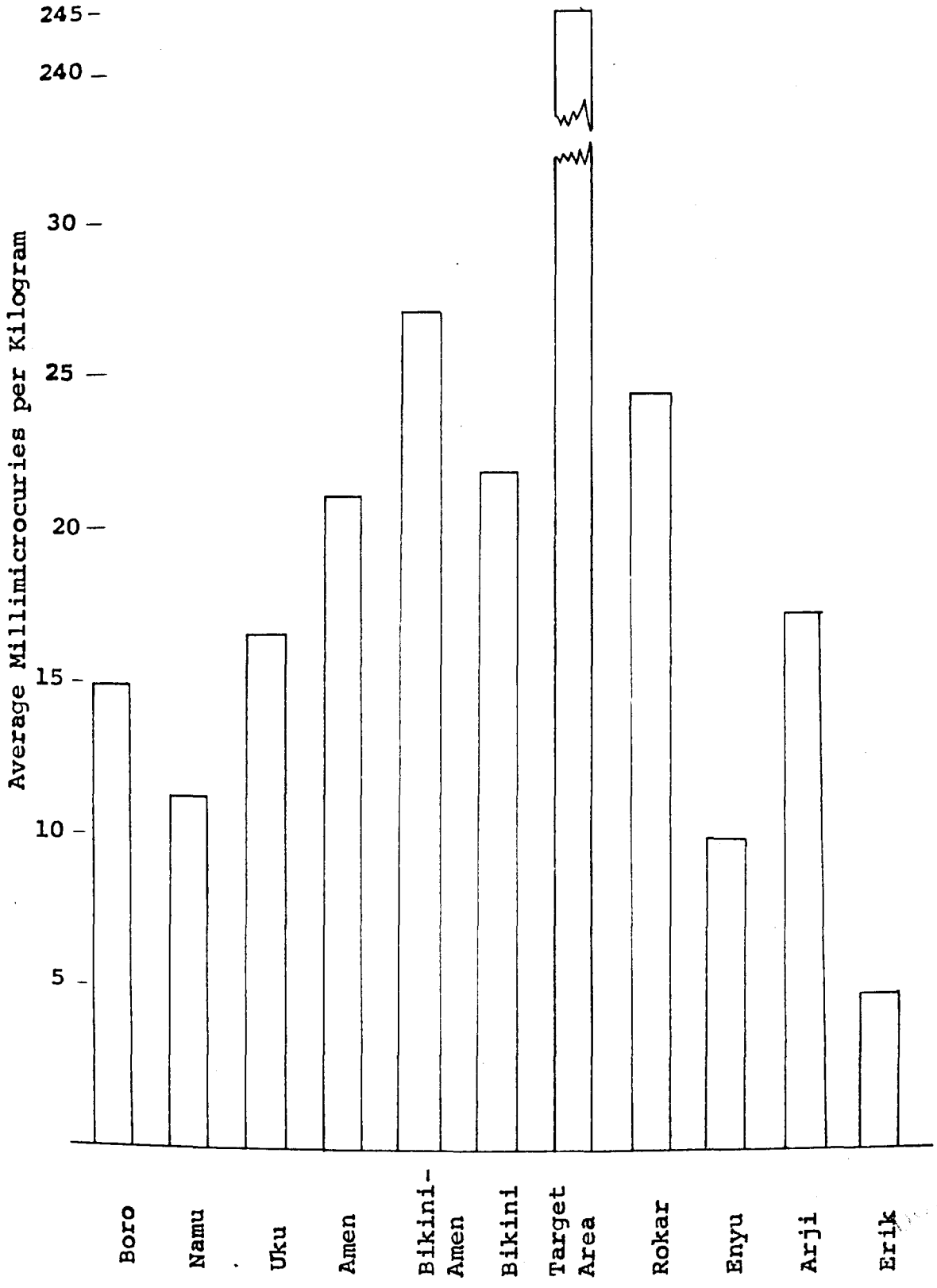
The average count by areas of all groups combined is shown as the histogram of Figure 7. Again the target area collections were higher, being estimated at 245 millimicrocuries per kilogram of organism as compared to the range of average

Table IV. Average Beta-Gamma Counts of Invertebrates by Groups Expressed as Millimicrocuries per Kilogram of Sample.

	Average--all areas less target	Average--target
anenome	0	-
barnacle	9	5
brittle star	8	18
clams	15	-
cone shell	3	-
coral	8	85
crustacea	10	28
hydroids	33	74
octopus	67	-
oyster	18	66
miscellaneous worms	5	105
sand dollar	31	-
scallops	9	-
sea cucumber	8	110
sea slug	22	-
shrimp	29	8
snail	19	-
sponge	57	741
tunicates	21	24
urchins	9	1950

Figure 7

Average Beta-Gamma Counts of Invertebrates by Areas
Expressed as Millimicrocuries Per Kilogram of Sample



values of 5 to 28 m/uc/kg for the reef stations about the periphery of the atoll. The average count by groups is divided into the collections from the target area and those from the reef. For the reef these values range from 0 to 67 and average 19.0 m/uc/kg. For the target area the range was 0 to 1,950.

Of special interest are the counts of specimens taken from floats that had been in the lagoon for only 14 days. On July 5 twelve home-made floats of approximately 8 square feet and made of scrap lumber, mostly 2 x 4 and 1 x 4, were anchored in the lagoon in and near the target area. This collection was designed to follow up a similar collection of last year (see Report No. UWFL-11*).

On July 19 the floats were lifted and samples removed. Because of the short period growth was not great but some hydroids and barnacles were present. The hydroid samples also included algae, which was difficult to separate from the hydroids. The counts are tabulated in Table V and it is interesting to note that two years after the blast the hydroid samples (including both hydroids and algae) were able to obtain, in two weeks or less, measurable amounts of radioactive materials. The average value of the hydroid samples from the floats was 62 millimicrocuries per kilogram of wet tissue.

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*Donaldson, Lauren R., Allyn H. Seymour, Arthur D. Welander and Kelshaw Bonham. "Concentration of Active Materials by Hydroids in the Bikini Lagoon during the Summer of 1947." Applied Fisheries Laboratory, University of Washington, Seattle.

Table V. Beta-Gamma Activity Expressed as Millimicrocuries per Kilogram of Organisms that grew on Floats in Bikini Lagoon from July 5 - 19, 1948

Area		Hydroid	Barnacle	Tunicate
2605		5, 24	31	
2604	Bikini, S. end	101, 23, 34	31	
2603	Bikini-Bokon	57, 62	0	
2602	Bokon-Yoran	42	11	
2698	Rokar	73	0	
2300	Near target area	189	0	0
2203	Target area	74	10, 6	
2102	Target area		7	
2103	Target area	70	0	
2005	Near target area		6	
	Total	754	102	0
	n	12	11	1
	Average	62.8	9.3	0

Part 5. Bikini plankton and the part it plays in the distribution of radiation around the lagoon.

Plankton tows, as time permitted, were made in the lagoon. Two types of nets were used, a standard one-meter Michael Sar net constructed of no. 14 and no. 24 xxx silk grit gauze and a smaller 12-inch marine-type towing net constructed of silk of either 38 or 125 meshes per inch. Location of hauls was either Bikini Island anchorage or the target area. From 30 tows 31 samples were prepared in the field and were counted at the laboratory on August 5 and 6, 1948.

The beta-gamma counts for all samples expressed as millimicrocuries per kilogram of wet sample are presented in Table VI. The higher values for the target area were due in part to the algae taken in the overnight sets. For these sets two small nets were used with a glass ball tied to the net ring and the towing rope then tied to a buoy. Chafing of the rope scraped some of the algae off the buoy and the algae drifted into the net.

The average value of all hauls for both areas was 44 m/uc/kg. The limited data does not warrant further analysis but it is significant to note that the counts of samples from the tows of the fine meshed net are generally higher, thus suggesting that the microplankton may be more radioactive than the macroplankton.

Table VI. Average Beta-Gamma Counts of Plankton Expressed as Millimicrocuries per Kilogram of Wet Tissue from 1948 Bikini Collection

Area	Anchorage			Target Area			
Type of Net	1 m. net	small net coarse	small net fine	1 m. net	small net coarse	small net fine	
Date							
7/5	48		49				
7/6	6, 12	13	15				
3 PM 7/16	1	25	3				
10 PM 7/16	16	24	68				
3 PM 7/17				8	90	39	
10 PM 7/17	2		6				
7/17-7/18[a]						116, 99	
9 AM 7/18				18		112	
10 PM 7/18	4		21				
7/18-7/19[a]						174, 453	
3 PM 7/19				29, 59		88	
10 PM 7/19	1		14				
Total	81	62	176	70	90	661	1140
Average	12	21	25	23	90	132	44

a. net buoyed out overnight and tied to float; considerable algae from float.

Part 6. Bikini atoll land survey with counts of the activity found on the land areas.

The collection of marine plants and animals, including plankton, was supplemented by occasional collections of terrestrial plants and animals and by regular surveys of the activity of the beach, land and vegetation. The usual procedure was to take one or two survey meters on each trip into the field and to make a survey of the land area within the vicinity of the station selected to collect marine plants and animals.

The instruments used were the Victoreen, Model 263 A, beta-gamma survey meters. Readings were made both with and without the shield and unless indicated, the readings given below are those without the shield. The meter readings translated to counts per minute as determined by a radium standard, ranged from 20 for a "one" reading on the low scale to 124,000 for a "twenty" reading on the high scale for one instrument and 35 and 89,000 respectively for the other. The instruments were calibrated at Hanford previous to departure from Seattle and were again calibrated in the field. Since the tube was somewhat light-sensitive the low meter readings, i.e., up to perhaps 3 or 4 on the low scale (approximately 100 c/m) are especially unreliable.

Lieutenants Schmidt and Bishop and Seaman Smith of the U.S. Navy also materially assisted in these surveys.

Bikini Island

July 4, Area 2307, N.W. tip of island: The beach had low activity generally but the coral ranged from 0-12,000 c/m, the high counts being from coral coated with an oil scum. An iron float counted 2,500 per minute.

July 10, from N.W. tip of Bikini Island, southeastward on the lagoon side for about 2-1/2 miles to the 1946 C.P.O. landing was explored. This area was carefully surveyed by two teams, one working along the beach and the second on the island proper from high tide line inland for about 50 yards. The Bikini Island survey was the most exhaustive of the land surveys.

The highest reading found by the beach crew was equivalent to about 3,000 c/m shield open and 185 c/m shield closed, suggesting that a considerable part of the radiation registered by the instrument was beta. One object investigated in this area was a life raft that had drifted onto the beach, undoubtedly from a target ship. Objects that had floated onto the beach had higher counts than the beach, i.e., higher than the coral sand and coral rock. Such things as a navigation marker, a raft, pontoons, boxes, tar on rock, boats, canvas, boards, sponge, cloth, rope, and rust were surveyed and gave 23 readings equivalent to an average of about 300 c/m shield open and 50 c/m shield closed. Eleven counts of sand and rock averaged 100 per minute shield open and 25 per minute (same as background) shield closed. In

general the counts at the N.W. tip of the island were slightly higher than elsewhere on the island.

Survey of the island proper yielded characteristic results. Soil readings were approximately the same as background and those of the dead vegetation were somewhat greater than background and those of the dead vegetation were still slightly higher. Figure 8 shows a view of vegetation on Bikini Island. Twenty-three counts were made of green vegetation and included such items as grass; miscellaneous foliage; palm trunk, fronds and roots; pandanus leaves and trunk; and papaya tree, fruit and foliage. The average for these counts was about 80 per minute or approximately twice background and ranged from background up to about 200 c/m. Dead vegetation surveyed included grass, miscellaneous leaves, palm stump, palm fronds, coconut and pandanus stump. Fifteen counts of these items averaged about 150 per minute, about twice the green vegetation count and four times background, and ranged from 75 to 200 per minute. Miscellaneous objects such as a box, canvas cot, paper carton, rope, boards, battery case, cloth, gas cans, tent, chair, table, building, concrete water basin, cork, truck, tire and a derrick were surveyed and of 36 counts the average value was about 125 c/m with a range from background to 275. There was no noticeable change in radiation from the starting point to the end of the survey.

Figure 8. Bikini Island. Live vegetation such as pandanus, right, and coconuts, left, averaged twice the background count, while dead leaves and grasses averaged about four times background. The coral sand, center foreground, gave background counts only.

Rokar Island

July 6--Background count only along the water's edge. Readings increased up to 2-1/2 times background from water's edge up to the vegetation line. Figure 9 shows a section of the shore line. Some drift objects on beach had more activity than the general area.

Amen Island

July 7--The southeast end of the island was surveyed on the lagoon and ocean side by two parties. Readings translated to counts per minute are as follows:

lagoon side--beach (coral, sand and rock) at low tide line was background but driftwood on the high tide line counted as high as 20,000 shield open and 1,000 shield closed. Iron objects and canvas up to 350.

ocean side--coral, sand and rock was background but a life raft that had drifted ashore was 46,000 shield open and 2,200 shield closed. Iron objects up to 5,000.

island proper--dead leaves on lagoon side averaged 300 but ranged up to 500; green leaves 100.

Enyu Island

July 8--The island was surveyed for about a mile on the lagoon side and 300 yards on the ocean side of the N.W. end. Readings translated to counts per minute were as follows:

Figure 9. Rokar Island, on the eastern rim of the atoll and upwind from the blasts. The counts of the white coral sand along the beach were at background but increased to two and one-half times background at the vegetation line.

lagoon side--beach, i.e., coral sand and rock, background but drift including canvas, rope, boards, tire, water bag and wooden grill work ranged from 150 to 21,000. One spot of driftwood was 21,000 open and 900 closed, and the wooden grillwork was 6,500 open and 350 closed. A survey was made of the LCT-816, a target ship that was beached in this area. Following are the counts per minute for the LCT-816 (Figure 10), with values for shield open given first, followed by those for shield closed: ramp 3,700, 190; table 425; rope 19,000, 1,100; canvas 4,900, 370; starboard living quarters 1,500; immediately outside 5,600; (Figure 11); rope 23,000; canvas on gun mount 37,000, 1,500; paint on gun tub 5,600; gloves 32,000; following items from pilot house--book 700; canvas 8,800; iron 4,900; background 600; door mat 60,000.

ocean side--beach, background only; life raft 46,000 open, 2,200 closed.

island proper--sand, background; green vegetation 250; dead vegetation, 400.

Uku Island

July 9--two groups, circled island.

lagoon side--beach, slightly above background; drift (metal screen, old boards, sponge, rubber, canvas, Tridacna shell) average 250 c/m with range 0-700; tar on cans 1,500; boat GS53-tank, 125; tar on tank, 125; canvas, background; metal,

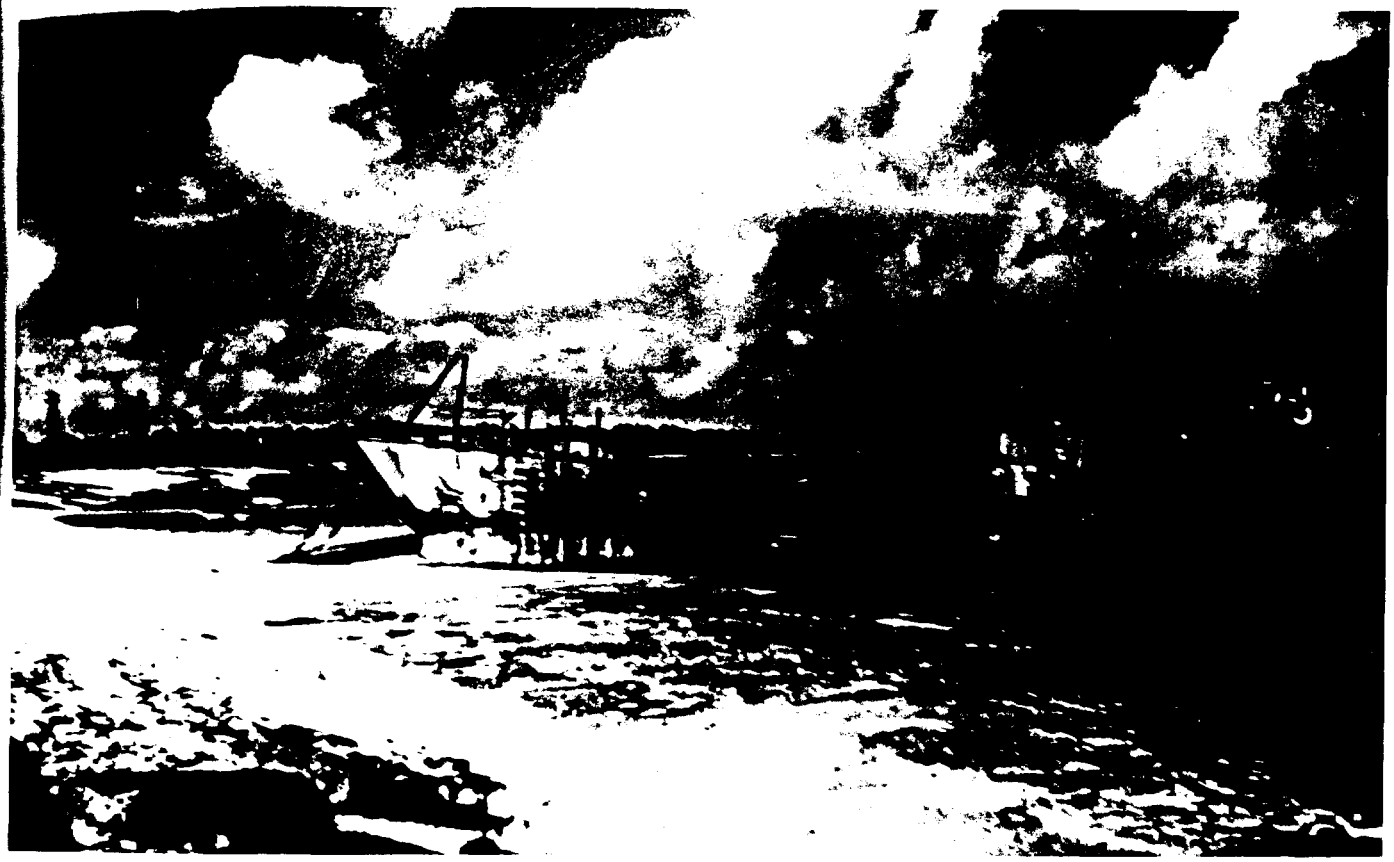


Figure 10. Beached LCT-816 on Enyu Island. The entire ship was contaminated with active materials.

Figure 11. Deck area of the LCT-816 with survey crew making readings. The starboard living quarters, left, produced activity counts of 1,500 per minute; canvas on gun mount, center, 37,000; paint on gun tub 5,600; mat at door to pilot house, 60,000; etc.

background; landing craft west of Uku--paint, engine, battery table, canvas, cable, rope and tire fender--background to 100 c/m.

ocean side--beach, approximately background; four blackened boxes ranged from 370-7,900 c/m; same boxes shield closed, up to 7,100 c/m.

island proper--sand, twice background; green vegetation (12 counts) averaged 100; dead vegetation, 200.

Arji Island

July 12--Surveyed about one-half mile on both lagoon and ocean side at east end of island.

lagoon side--beach, slightly above background; drift (sponge, board, log, float, wood, PA45-6 hull, rope, iron, boar fender, life raft, paravane, cloth, life jacket, buoy, canvas, cask and floats) averaged about 175 c/m open and 40 c/m closed. A floor mat counted 49,000 open and 3,200 closed.

ocean side--beach approximately background; miscellaneous (mattress, box and plywood) average 100 c/m open and approximately background closed.

island proper--green vegetation, 75 open and 40 closed; dead vegetation , 500 open, 100 closed.

Erik Island

July 13--area monitored was about one mile on the western end, lagoon side and road, and the western tip both ocean and lagoon sides.

lagoon side--sand and coral 80 open, 45 closed; drift (driftwood, box, canvas, spool, life jacket, floats, sponge, rubber, cork, rope, oar) averaged about 100 c/m open and 40 c/m closed.

ocean side--beach, background only; drift (screen, board, canvas, mess kit) averaged 125 open, 40 closed; one 6 x 6 timber covered with an oil scum or tar was roughly 60,000 open and 700 closed.

island proper--green vegetation approximately 120 open, 50 closed; dead vegetation, 225 open, 65 closed; sand 75, 20.

Boro Island

July 14--a small island, circled while monitoring.

lagoon side--coral rock slightly above background; drift (paddle, sponge, rubber, box, mattress, rope, life jacket, raft--not covered with oil scum) averaged about 135 c/m open and 25 c/m closed. There was considerable drift covered with oil scum that counted about 4,000 c/m open and 200 c/m closed. One plywood trough counted about 23,000 open and 650 closed.

ocean side--sand, background; drift (concrete, bamboo, board, canvas, rubber, sponge) averaged 175 c/m open, 35 c/m closed.

island proper--green vegetation 80 open, 25 closed; dead vegetation, 500 open, 100 closed.

Namu Island

July 15--surveyed western end of island on both lagoon and ocean sides.

lagoon side--sand, background; oil scum on coral rock 500 open, 50 closed; drift coated with oil scum 2,800 (range 600-5,600 open, 150 (range 45-275) closed. Miscellaneous drift without oil scum (sponge, spool, box, float, life jacket, cloth, boiler) averaged 165 open, 50 closed.

ocean side--beach, background; drift yielded approximately the same count for similar items as on lagoon side. An exception was a 4 x 8 timber (no oil) that counted 1,900 open, 200 closed.

island proper--green vegetation, 85 open, 25 closed; dead vegetation, 120 open, 40 closed.

In addition to making on the spot counts with a survey meter, land animals and plants and miscellaneous pieces of drift were collected for ashing and counting in the laboratory. The record of thirty-five such dcounts is presented in Table VII.

Table VII. Beta-Gamma Activity Expressed as Millimicrocuries per Kilogram of Sample of Land Animals, Vegetation and Miscellaneous Drift Items.

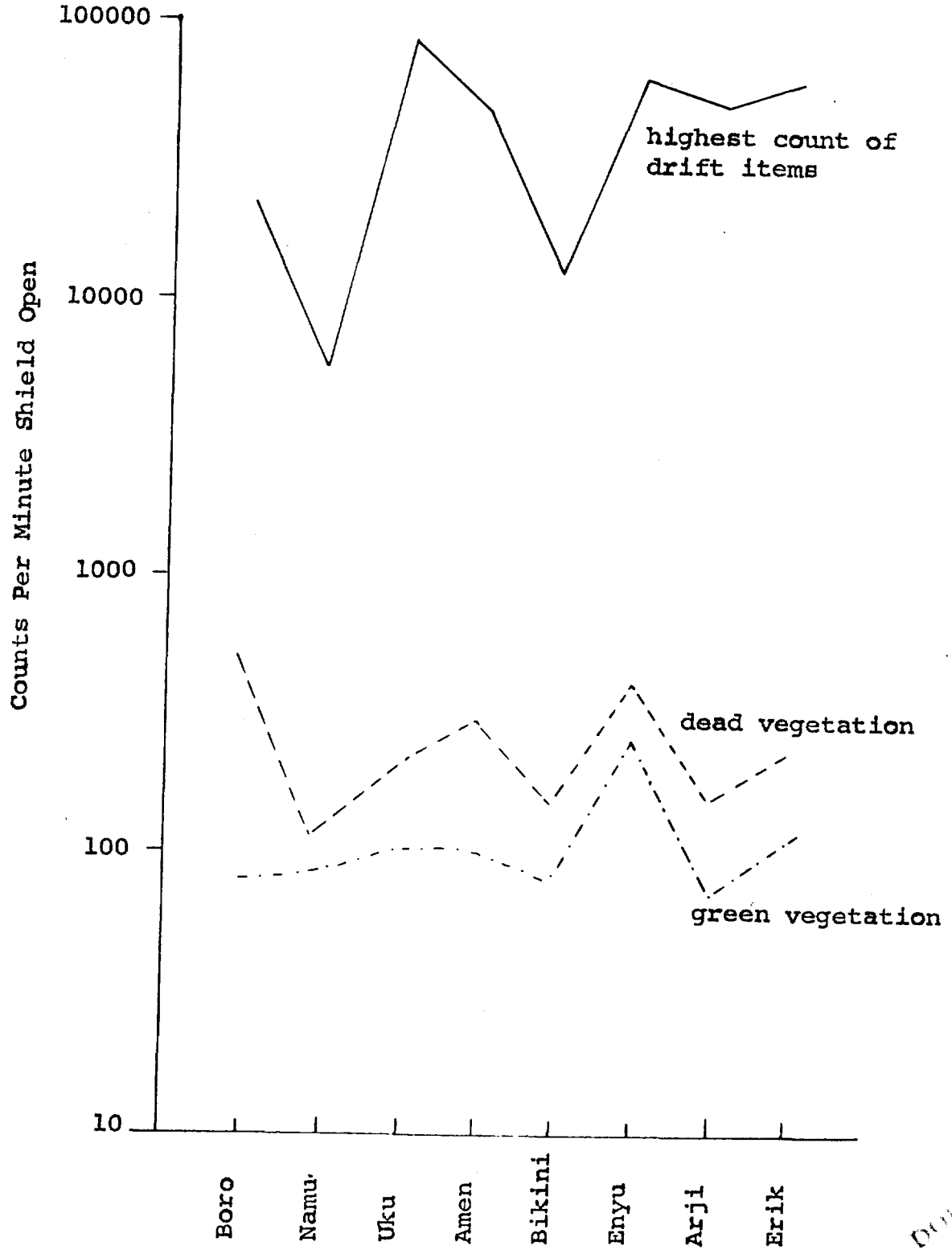
	Bikini	Amen	Rokar	Erik	Average
coconut	3, 3, 2, 0, 7, 3, 5				3
pandanus	2, 2				2
papaya	5				5
misc. fruit	9, 4				6
grass	228	40			134
misc. dried vegetation	151, 95, 235, 68, 43, 64				109
birds	8, 1, 6			4	5
cat	3, 0				2
caterpillars	2				2
gecko	29				29
moth	7				7
bracket fungus	24				24
canvas		174,7644			3909
rope		2066			2066
tarred block			61		61
cockroach	20				20

Summary of beach and land survey

A survey of beach and land activity was made of eight islands in Bikini Atoll with Victoreen, Model 263A, beta-gamma survey meters. The counts of coral sand and coral rock of the beaches and islands proper were approximately background. Drift on the beach on either lagoon or ocean side had varying amounts of activity from background up to 80,000 c/m. The high counts were either of items from target vessels or of items coated with an oil scum also probably of target ship origination. Counts of beached target ships are given. The count of green vetetation was approximately two to three times background and that of the dead vegetation two to three times that of the green vegetation. The approximate average counts by islands of the green vegetation, the dead vegetation and the highest counts of drift objects are shown in Figure 12. Counts of similar items brought back to the laboratory for counting are tabulated in Table VII. An average value of the activity of drift objects is meaningless because of the wide range of counts and the arbitrary manner in which objects were selected for counting. There is no apparent geographical relation with activity. The relation of counts obtained when window was open to when window was closed was of the nature of 20 to 1, suggesting a high proportion of beta radiation.

Figure 12

Counts Per Minute of Green Vegetation, of Dead Vegetation and of Most Active Drift Items by Areas as Translated from Readings of a Beta-Gamma Survey Meter



Part 7. Evaluation of the 1948 field studies, with a statement on information needed for a better understanding of the biological problems of a contaminated area.

The twelve (12) men of the technical staff of the Bikini Radiobiological Resurvey of 1948 were able to gather a vast amount of data during the eighteen (18) days they studied at Bikini. These data have made it possible to evaluate the problem of radiation contamination in the faunal and floral systems of the area. They do not, however, provide the finality to many of the questions that is desired. This may, in part, be due to the sparcity of data, but surely the major problems are those of complexity of the reactions and the necessity for a lapse of time during which the problem may evolve. As the years pass it will be possible to develop better understanding of the problems of contamination. The hazard to personal health will have passed but the basic problems will prevail.

Areas of contamination

The target area continues to be the source of greatest concentration of active materials. Plants and sedentary animals collected in that area contained higher activity counts than more remote regions.

Scattered bits of wreckage and drift materials with contamination are found in all areas within the lagoon.

The north reef, between Bikini Island and Amen Island, has the highest concentration of activity of any of the outer lagoon areas.

There is a continual transfer of active materials from the target area, upwind, to the eastern rim of the lagoon.

Concentration of activity by biotic forms

Algae, in general, tended to have a greater concentration of active materials two years after the blast than do other forms.

Invertebrate forms vary greatly in the amount of activity contained in representative forms collected from the eleven (11) major collecting regions about the atoll. The amount of active materials contained in the invertebrate forms was, in general, less than that contained in algae from the same collecting area.

Fishes from the eleven (11) collecting stations were less contaminated than the algae or invertebrates.

Plankton, especially the microplankton which contained more activity than the macroplankton, appears to be able to concentrate the trace amounts in the sea water into measurable amounts of activity in the organism.

Rapidly growing forms such as hydroids on the floats are able to absorb measurable amounts of activity in very short periods of time.

Spread of activity about the lagoon

All the data assembled indicate that the spread of the activity from the target area to the more remote parts of the lagoon continues. The mechanism by which the transfer takes place is not completely understood. The planktonic forms, especially the microplankton, are assumed to be largely responsible. The efficiency of the retention of the transported activity is apparently extremely high when one considers the rate of decay of the active substances and the dilution of the waters within the lagoon. With a 28-day half for dilution the water has undergone twenty-six (26) half exchanges during the past two years.

"Bikini continues to be one of the most important biological experiments of our time."

Problems for future study

1. Continued periodic checks of the amount, distribution and effect of the active material in Bikini Lagoon should be made.

2. Field studies should continue to explore the basic phenomenon of the mechanisms of translocation of the activity and its concentration in the faunal and floral systems.

3. Laboratory studies should be very carefully integrated with the field studies to provide specific information on parts of the general problem.

4. Future work should include food chain studies to parallel the activity studies.

5. Evaluation of the chemical components of the active materials is needed for an understanding of the selectivity evidenced by the various forms.

6. Tissue selectivity has been explored; emphasis should now be placed on the effect of contained activity upon the various forms.

7. There is need for a training program to expand our efforts to enlist and develop competent, understanding research workers for work in radiation and the problems it presents in biology.

8. Bikini Atoll should be retained and used as a field laboratory for the study of problems of radiation and biology.