UWFL-47

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SURVEY OF RADIOACTIVITY IN THE SEA AND IN PELAGIC MARINE LIFE WEST OF THE MARSHALL ISLANDS, SEPTEMBER 1–20, 1956

By
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March 15, 1957

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Technical Information Service Extension, Oak Ridge, Tenn.

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ABSTRACT

A survey of the radioactivity in the sea in the region of the North Equatorial Current from the Marshall Islands to the Marianas Islands was made in September 1956. The expedition was sponsored by the United States Atomic Energy Commission, Division of Biology and Medicine, and carried out by the Applied Fisheries Laboratory, University of Washington, with the support and cooperation of the United States Navy.

Plankton samples were taken by oblique tows from 200 meters and water samples were taken from the surface, 25, 50, 100, and 150 meters at 74 stations. The general pattern of distribution of radioactivity shows a sharp decrease east of Bikini and a gradual but irregular decrease west of Eniwetok. A slight degree of contamination is indicated as far to the west as Guam, the western extremity of the survey. Non-fission products account for a large proportion of the radioactivity in plankton and fish samples.

CONTENTS

SURVEY OF RADIOACTIVITY IN THE SEA AND IN PELAGIC MARINE LIFE WEST OF THE MARSHALL ISLANDS SEPTEMBER 1-20, 1956

INTRODUCTION

The amount of radioactivity in the sea and in pelagic marine life during and following weapons tests at the Pacific Proving Ground has been the subject of reports by United States and Japanese laboratories.

Following the 1954 test series, the Japanese survey ship, Shunkotsu-Maru, made a general survey of the amount and distribution of radioactivity in sea water and in some of the marine life in the region west of the Marshall Islands. The report of the Japanese survey[1] indicated that measurable amounts of radioactivity were to be found in the sea even as late as the spring of 1955.

Operation Troll[2] was conducted during the spring of 1955 to measure the level of radioactivity in the sea and the movement of the water mass containing the radioactivity. This was a joint operation of the New York Operations Office, U. S. Atomic Energy Commission, Scripps Institute of Oceanography, University of California, and the Applied Fisheries Laboratory, University of Washington.

The findings of Operation Troll, the 17,419 mile cruise of the Taney from February 25 to May 3, 1955, were summarized as follows:

> 1. Sea water and plankton samples show the existence of widespread low-level activity in the Pacific Ocean. Water activity ranged from 0-570 d/min/liter and plankton from 3-140 d/min/g wet weight.
>
> 2. There is some concentration of the activity in the main current streams, such as the North Equatorial Current. The highest activity was off the coast of Luzon, averaging 190 d/min/liter down to 600 m (April 1, 1955).
>
> 3. Analyses of fish indicate no activity approaching the maximum permissible level for foods. The highest activity in tuna fish was 3.5 d/min/g ash, less than 1 percent of the permissible level.
>
> 4. Measurements of plankton activity offer a sensitive indication of activity in the ocean.
>
> 5. Similar operations would be valuable in assessing the activity from future tests and in gathering valuable data for oceanographic studies.

The Division of Biology and Medicine of the U. S. Atomic Energy Commission requested the Applied Fisheries Laboratory of the University of Washington to conduct surveys of the open sea during 1956 to determine "(a) the levels of introduced radioactivity resulting from the tests in the water, plankton, and fish, and (b) how far the activity extends westward in the North Equatorial current."

The first of the two surveys was operating at sea, June 11-21, 1956, during the weapons testing program. The results of this survey are summarized in UWFL-46[3]. The summary of this report states:

> A survey to determine the amount of radioactivity in the waters about Bikini and Enivetok Atolls was made during the period June 11 to 21, 1956.
>
> A grid of stations about 45 miles apart covering 78,000 square miles of ocean between 10° 15' N to 14° N and 159° to 166° E was covered by the survey. The distance traveled was 3,300 miles.
>
> Radioactive materials were found in the plankton samples from every station. The highest plankton counts, 1,100,000 d/m/g (wet weight) were obtained near Bikini Atoll, and the lowest, 1,300 d/m/g, in the northwestern part of the survey area.
>
> The average value for plankton was 71,000 d/m/g which was 7,100 times the average surface water value.
>
> Water samples were collected at surface and at depths of 25, 50, 75 and 100 meters.
>
> The average radioactivity of water was 10,000 d/m/l at the surface and 3,900 d/m/l at 100 meters.

The second survey of the 1956 series was conducted during September, about six weeks after the termination of the weapons testing program, during which time decay and dispersion of the radioactivity had taken place. As in the first survey, the U. S. Navy assigned a naval vessel, in this case the USS <u>Marsh</u> (Destroyer Escort 699), to be used as the survey ship. This survey operated from the Marshall Islands westward to Guam between 9° N and 15° N.

The findings of this second survey are reported on the following pages.

Acknowledgements

The success of the oceanographic surveys is attributable to the support and cooperation of many organizations and individuals. This cooperation was especially evident in both the Walton and Marsh surveys during and following Operation Redwing.

The Division of Biology and Medicine, of the U. S. Atomic Energy Commission, particularly Dr. W. R. Boss, helped greatly in the planning and coordination of the program.

Units of Joint Task Force Seven, especially Task Group 7.3 (Navy), were particularly helpful.

The Atomic Energy Commission Resident Engineer, Mr. Thomas Hardison, and members of his staff provided invaluable support during and following the surveys.

The Navy can well be proud of the work of Commander Wilfred G. Chartier, Captain of the USS Marsh, and of the officers and crew who made possible the radiobiological-oceanographical survey from a ship not designed for such work.

PLANS, EQUIPMENT AND OPERATIONS AT SEA

The amount of radioactivity in the sea water and in marine life in the region near Bikini and Eniwetok Atolls during and following the 1956 atomic testing program, as well as the movement and dispersal of the radioactivity after completion of the test program, was evaluated by two radiobiological-oceanographic surveys. The first survey, made from the Walton in June 1956, covered fifty-three stations in an area between 11° N and 14° N, 180 miles west of Eniwetok and 30 miles east of Bikini (UWFL-46)[3].

The second survey, made from the Marsh, covered 74 stations in an area bounded by 9° N and 15° N and approximately 145° E and 166° E (Fig. 1). This area is within the North Equatorial Current, which flows westward. In planning the track for this survey it was necessary to consider the areas of fallout, the direction and rate of drift of the North Equatorial Current (taken as ten miles per twenty-four hours for planning purposes), the fuel requirements of the ship and refueling facilities, which were available only at Kwajalein and Guam.

Installation of equipment aboard the Marsh was started at Eniwetok August 28 and the survey started September 1. The first leg, from Eniwetok to Guam, was completed on September 7. Marine organisms were collected from the reef on the eastern side of Guam to supplement the oceanic collections. The second leg, from Guam to Kwajalein, covered the period from September 9 to September 17. This period was interrupted for twenty-four hours begin-

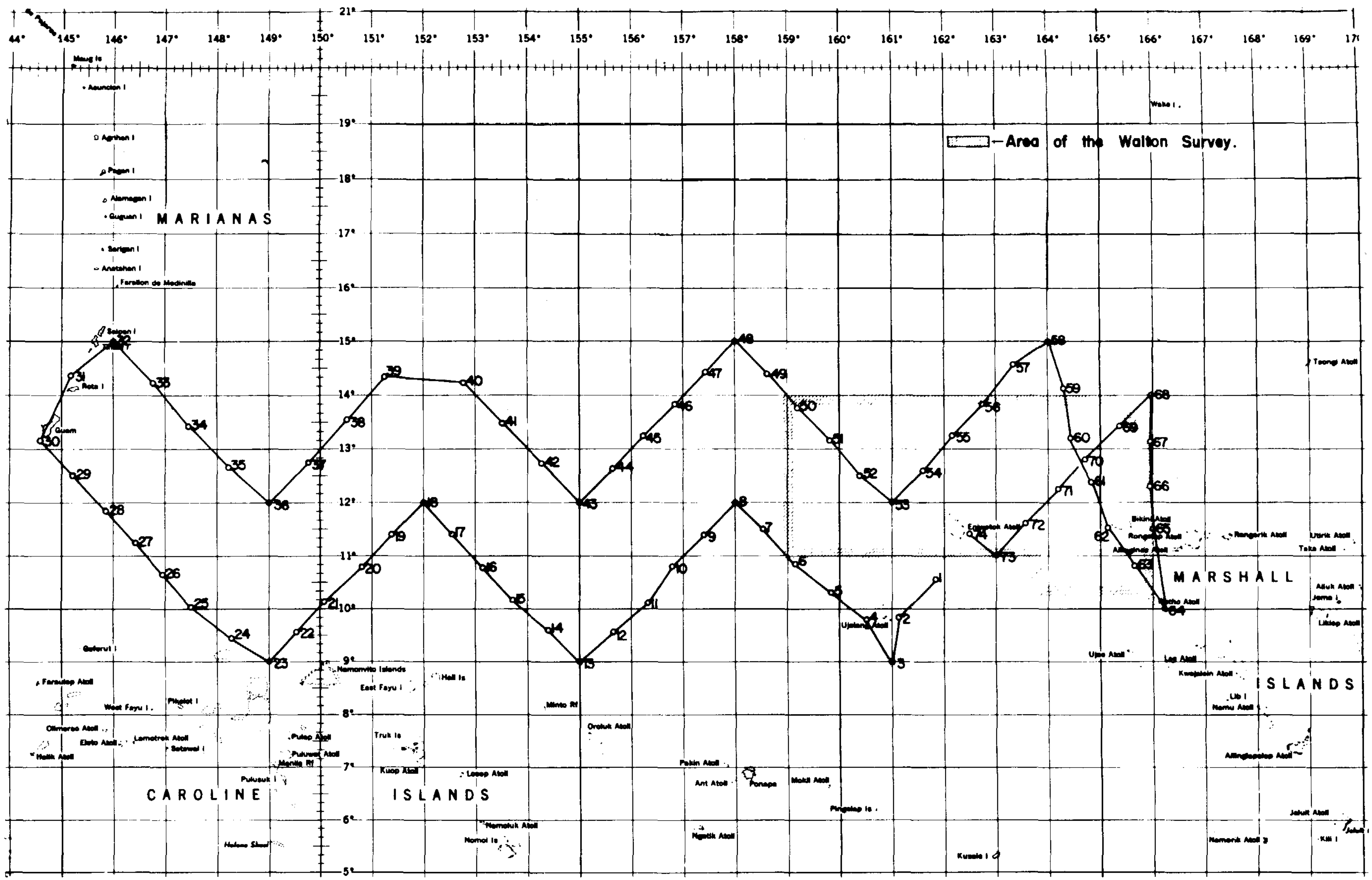

Fig. I. Track of the __Marsh__ and area of the __Walton__ survey.

ning September 10 while the Marsh was engaged in a sea-air rescue mission. The third leg, from Kwajalein to Eniwetok, was started September 17 and completed September 20.

Equipment

The collecting equipment used on the Marsh was the same as that used on the Walton. Installation was approximately the same. Photographs of the major items of equipment installed aboard the Walton appear in UWFL-46.

Space below decks for quarters and equipment consisted of the after compartments for officers' quarters, chief petty officers' quarters and crew's berthing.

The major items of equipment were

1. A continuous surface water monitoring probe with tank and water connections, a unit designed and constructed by the Health and Safety Laboratory of the New York Operations Office.
2. A power winch feeding a 3/16-inch steel cable over an A-frame and davit for use with plankton nets and water sampling bottles.
3. A steel platform extending two feet over the portside of the ship under the davit to provide space for work with nets and water sampling bottles.
4. A temporary chemistry laboratory.
5. Three nuclear radiation detection instruments.
6. A bathythermograph which was part of the ship's equipment.

Operation of the Ship

"One boiler operation was maintained during the survey, to ensure maximum fuel-economy, except while entering and leaving port. Speeds between stations . . . were as follows: first leg twelve knots, . . .; second leg fifteen knots, . . .; third leg eleven knots, ..."* The ship's speed was gradually reduced when coming on station during which time the bathythermograph drop was made. When the speed was one to two knots and the ship was headed with the wind off the port bow the portscrew was stopped and the plankton net was dropped. A speed of about one knot was maintained during the plankton haul. The vessel came to a dead stop while the water bottle casts were made. Cruising speed was gradually resumed following completion of the collections.

COLLECTION AND PREPARATION OF SAMPLES

Plankton, water and fish samples and continuous measurements of the activity in the surface water were taken. These samples and their preparation were the same as for the Walton survey with the following exceptions.

Water samples were taken from the surface, 25, 50, 100 and 150 meters to make certain that at least the deepest bottle would be below the thermocline. The plankton volumes were determined

* Quoted from letter from Commanding Officer, USS Marsh (DE 699) to CTG 7.3, 23 September 1956.

by using a 100/110-ml cassia volumetric flask instead of a graduated cylinder. All samples except fish were processed aboard ship immediately after being collected. Fish were frozen aboard ship, dissected and dried at the Eniwetok Marine Biological Laboratory, and ashed and counted at the University of Washington.

The water supply for the probe tank for continuous monitoring, instead of being taken from the fire mains as on the <u>Walton</u>, was supplied by a Marlow Centrifugal Pump, Model No. 12, HEL-9, operated at its full capacity of 50 gallons per minute. Chemical pumps of lesser capacity which had been furnished with the tank were tried but were inadequate. One and one-half-inch pipe was used for intake and discharge. The pipe was welded to the deck and hull of the ship and the free end of the intake pipe was held against the force of the water by a chain leading to a stanchion on deck. Even with these precautions and generally good sailing conditions, the pipe broke on the last day of the cruise.

METHODS OF ANALYSIS

All counting, with the exception of fish samples, was done aboard ship within a few hours after the time of collection.

<u>Counting Equipment</u>. Samples were prepared on 1½-inch stainless steel plates and counted with 2-inch Anton tubes in a 3-inch lead Anton pig with Nuclear-Chicago Model 181 scalers. Background varied from 17.3 to 37.1 c/min.

<u>Correction Factors</u>. The same correction factors were used as for the <u>Walton</u> data, the details of which are given in UWFL-46.

The total correction factors to convert counts per minute to disintegrations per minute were 3.5 for plankton, 4.0 for water, and 3.3 for filter papers. Negative values are given wherever the count was less than background. No correction was made for decay since the counting was done essentially immediately after collection and the values given are as of the time of collection. Decay curves are shown in Figure 2.

Gamma Ray Spectra. Gamma ray spectra were run at the University of Washington laboratories in Seattle on a single channel, automatic advance, gamma spectrometer. The spectrometer consists of a Nuclear-Chicago Model 1810 radiation analyzer, a Nuclear-Chicago Model DS-3 scintillation well counter, a Tracerlab Superscaler, a Nuclear-Chicago Model C-111 printing timer, and an automatic baseline advance device built at Seattle.

Spectrum ranges of 0.5, 2.0, and 4.0 MEV were used.

RESULTS OF SURVEY

Plankton

The highest value of radioactivity in plankton, 21,000 d/m/g wet, was found at station 55 about 80 miles north of Eniwetok and the lowest value, 27 d/m/g, was found immediately south of Guam. This lowest value was slightly lower than the value obtained near the same station during Operation Troll (39-61 d/m/g), indicating that Guam was near the westernmost extremity of the radioactive contamination which resulted from Operation Redwing. A slight degree of contamination is indicated by comparison with plankton samples from Puget Sound and off the Queen Charlotte

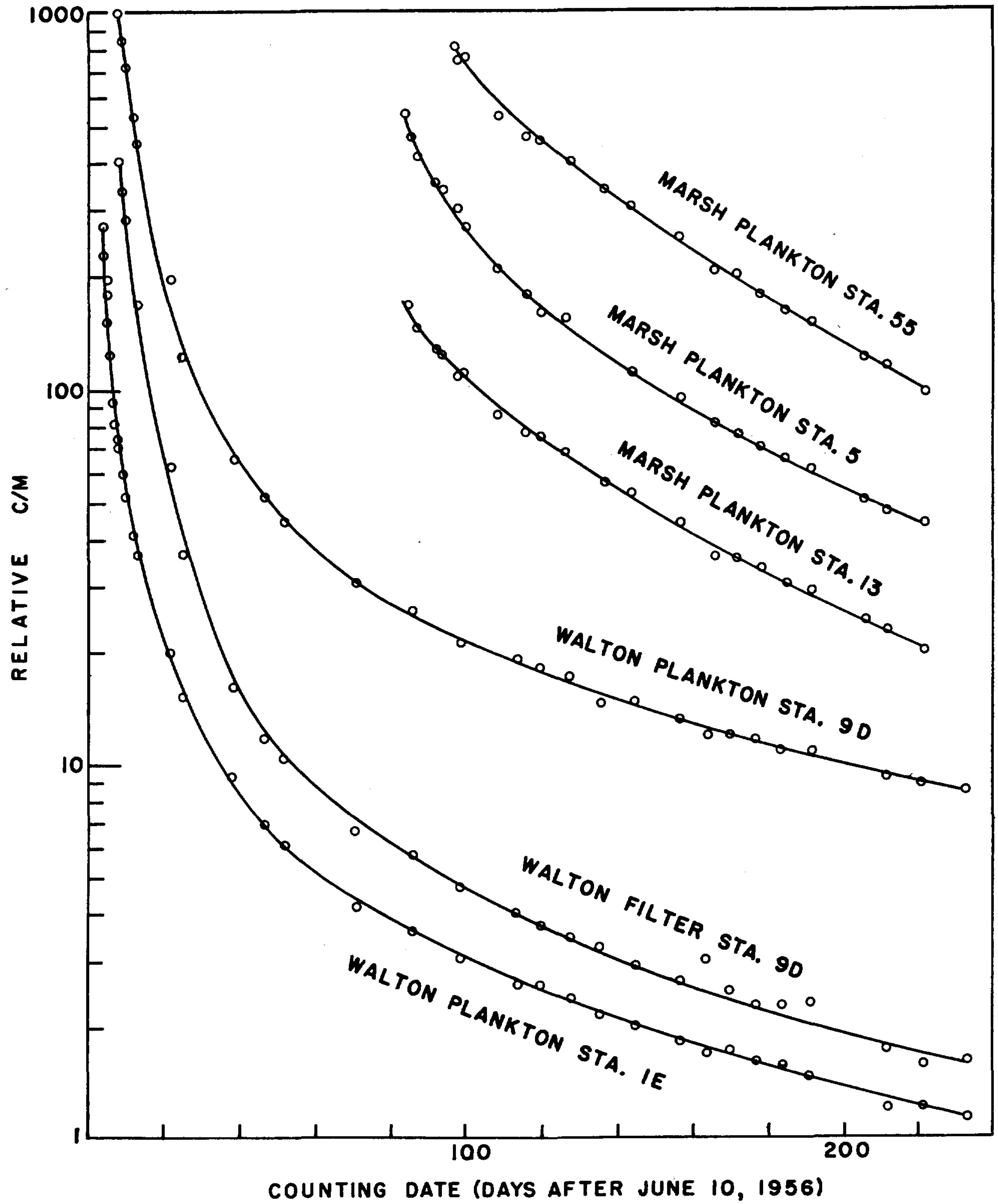

Fig. 2. Decay of Marsh and Walton samples.

Islands, which ranged from 0-16 d/m/g. Activity in the water, however, immediately south of Guam was about three times higher at the time of the Marsh survey than during Operation Troll.

The distribution of plankton activity is shown in Figure 3 and Table 1. Figure 4 is a graphic presentation of the data from Table 1. There is a sharp decrease in activity east of Bikini and a gradual but irregular decrease west of Eniwetok. Activity levels in plankton samples from immediately east of Bikini are about the same as those in the vicinity of Guam.

The plankton tows were made to a depth of about 200 meters, which assured complete sampling of the stirred layer. It is generally accepted that the stirred layer exists only above the thermocline, a region in which temperature decreases rapidly with increase in depth. Bathythermograph casts were made at each station to determine temperature changes with depth. Unfortunately the only bathythermograph which was operable at stations 1 - 30 was only able to measure temperatures to a depth of 200 feet. This situation was remedied at Guam and from that point on temperature measurements were available to 400 feet. From the later data and the results of the Walton and Troll surveys it is evident that in general the upper level of the thermocline was just below 100 meters.

The average of the ratios of plankton activity to water activity was 2500; possible reasons for variations in this value are discussed on pages 27-33.

Water

The activity of the water from all depths is presented in

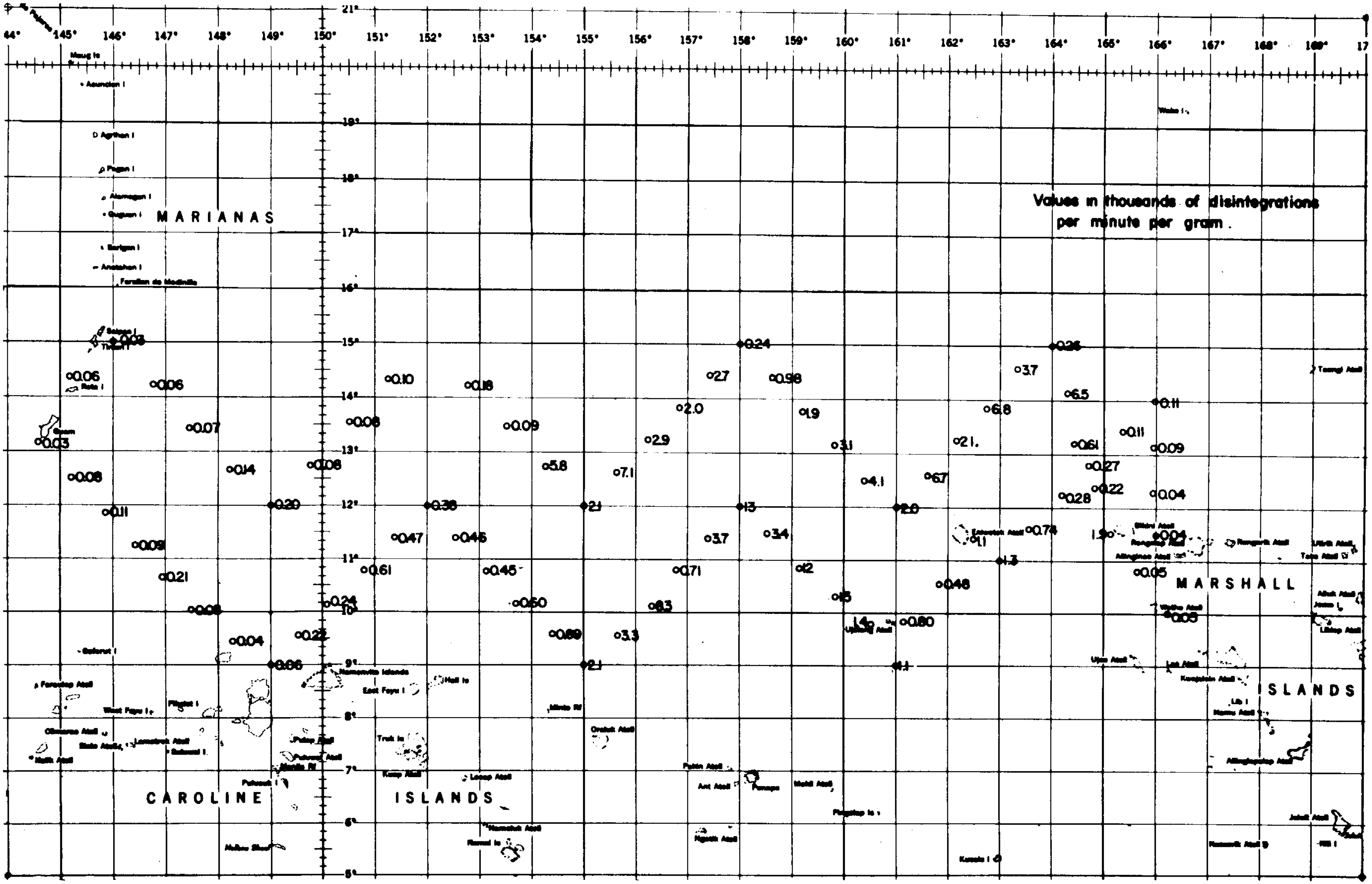

Fig. 3. Distribution of plankton activity.

Table 1. Radioactivity of Marsh Samples

Plankton values in disintegrations per minute per gram of wet sample
Water " " " " " " liter
Filter paper " " " " " for the residue from 1 liter of water

Stn.	Surface w.	Surface fp.	25m w.	25m fp.	50m w.	50m fp.	100m w.	100m fp.	150m w.	150m fp.	400m w.	400m fp.	Plankton
1	14356	2459	1766	277	302	98	1306	35	692	27	252*	44*	483
2	10838	8022	404	59	226	35	166	29	136	1			796
3	5140	3117	286	54	168	21	58	4	12	74			1065
4	6706	1510	294	12	126	9	--	--	-56	-6			1448
5	6552	588	2080	124	5310	370	1228	306	298	46			14788
6	8064	453	3738	281	4346	261	472	48	178	96			11683
7	634	1581	1112	88	666	46	140	27	156	40			3426
8	5460	1343	3020	218	5172	276	552	128	308	30			12604
9	1786	2096	1184	158	1252	93	388	41	174	50			3692
10	3072	1323	664	36	284	18	186	10	122	18			713
11	1834	548	164	27	188	10	106	20	88	10			8348
12	2926	329	598	42	648	22	106	31	72	18			3313
13	3286	779	672	47	670	46	104	34	90	20			2065
14	1650	2353	468	47	214	22	100	16	110	22			886
15	1886	256	528	59	434	31	234	15	84	27			596
16	1824	502	250	24	248	15	194	1	122	3			450
17	1450	214	190	16	200	18	112	14	36	7			459
18	1606	380	250	22	160	18	56	14	16	8			382
19	1354	108	238	17	294	18	68	6	-8	2			466
20	1378	5428	222	38	302	62	82	11	66	4			612

* Sample from 500m

Table 1. (continued)

Stn.	Surface w.	Surface fp.	25m w.	25m fp.	50m w.	50m fp.	100m w.	100m fp.	150m w.	150m fp.	400m w.	400m fp.	Plankton
21	1304	1924	250	37	270	20	34	8	56	8			236
22	1932	352	216	58	164	19	64	4	94	3			215
23	734	562	118	14	84	11	112	9	40	13			60
24	814	321	70	3	114	0	62	-2	68	2			43
25	406	341	-4	-3	66	4	4	10	36	10			78
26	2504	359	140	12	92	0	22	-1	16	7			208
27	1238	342	58	15	48	0	60	3	48	--			93
28	1642	398	128	22	110	7	20	7	60	3			108
29	310	410	138	18	38	12	-2	3	90	7			82
30	672	499	110	13	62	11	40	7	58	8			27
31	546	90	226	11	58	6	126	4	106	6			63
32	116	128	84	17	152	7	24	11	112	6			30
33	176	38	128	6	96	6	72	3	112	7			60
34	170	25	134	11	80	6	24	6	58	-7			68
35	214	16	62	2	--	--	-16	0	-26	3			140
36	122	42	--	--	--	--	--	--	--	--			197
37	132	23	104	11	78	5	-26	3	4	5			77
38	34	56	118	26	94	40	82	1	34	0			78
39	74	48	108	13	130	14	150	1	94	3			104
40	226	62	66	82	60	11	-8	6	10	-1			176
41	154	12	90	7	54	5	30	0	80	4			85
42	4860	320	4590	312	4608	264	426	22	214	36			5816
43	178	100	188	9	190	16	78	9	94	6			2100
44	2638	542	1848	132	1786	131	208	16	98	10	890*	479*	7060
45	1684	256	1378	73	1202	56	106	13	130	59			2891

* Sample from 450m, top of this bottle did not close

* Sample from 450m, top of this bottle did not close

Table 1. (continued)

Stn.	Surface w.	Surface fp.	25m w.	25m fp.	50m w.	50m fp.	100m w.	100m fp.	150m w.	150m fp.	400m w.	400m fp.	Plankton
46	2490	163	1672	116	1956	98	98	-4	92	7			2012
47	276	24	136	18	238	7	-10	-5	-40	4			2656
48	274	30	250	12	228	7	-22	-1	48	-4			240
49	742	110	564	32	50	23	-34	8	36	10			984
50	1654	78	1266	62	1144	61	78	10	104	34	84	7	1925
51	944	76	772	44	1426	61	70	0	118	3	44	7	3112
52	278	62	514	21	1176	64	98	12	224	25	92	63	4112
53	936	46	784	42	632	38	254	15	202	10	72	14	2006
54	2708	160	2494	106	2562	108	540	54	440	290	208	34	6674
55	1466	83	1310	64	3208	148	780	58	296	22	126	7	20926
56	2854	152	2586	160	2680	120	202	14	540	22	202	129	6839
57	420	16	444	14	512	11	82	9	132	2	122	9	3734
58	244	24	226	20	272	11	88	0	92	10			260
59	4408	216	3896	156	3864	145	654	69	168	12			6503
60	50	16	142	8	160	4	126	1	74	3			612
61	126	5	162	9	152	5	62	13	-4	1			224
62	1256	70	134	4	134	9	758	47	106	7	288	43	1925
63	112	13	100	3	144	5	84	1	92	4			53
64	--	--	--	--	--	--	--	--	--	--			50
65	190	9	22	9	132	12	146	12	74	8			39
66	104	10	32	3	108	11	96	10	86	0			35
67	42	6	16	6	76	9	-42	6	34	3			94
68	134	21	130	13	770	42	58	0	20	4			150
69	68	4	68	-1	116	-4	80	1	88	-2			107
70	84	19	54	5	96	-1	50	10	118	8			272
71	520	21	580	23	268	9	18	-1	52	11			280
72	188	14	284	7	952	37	176	16	118	-6			743
73	74	10	110	8	142	4	1340	63	96	4			1253
74	62	18	116	14	242	8	756	27	232	11			1145

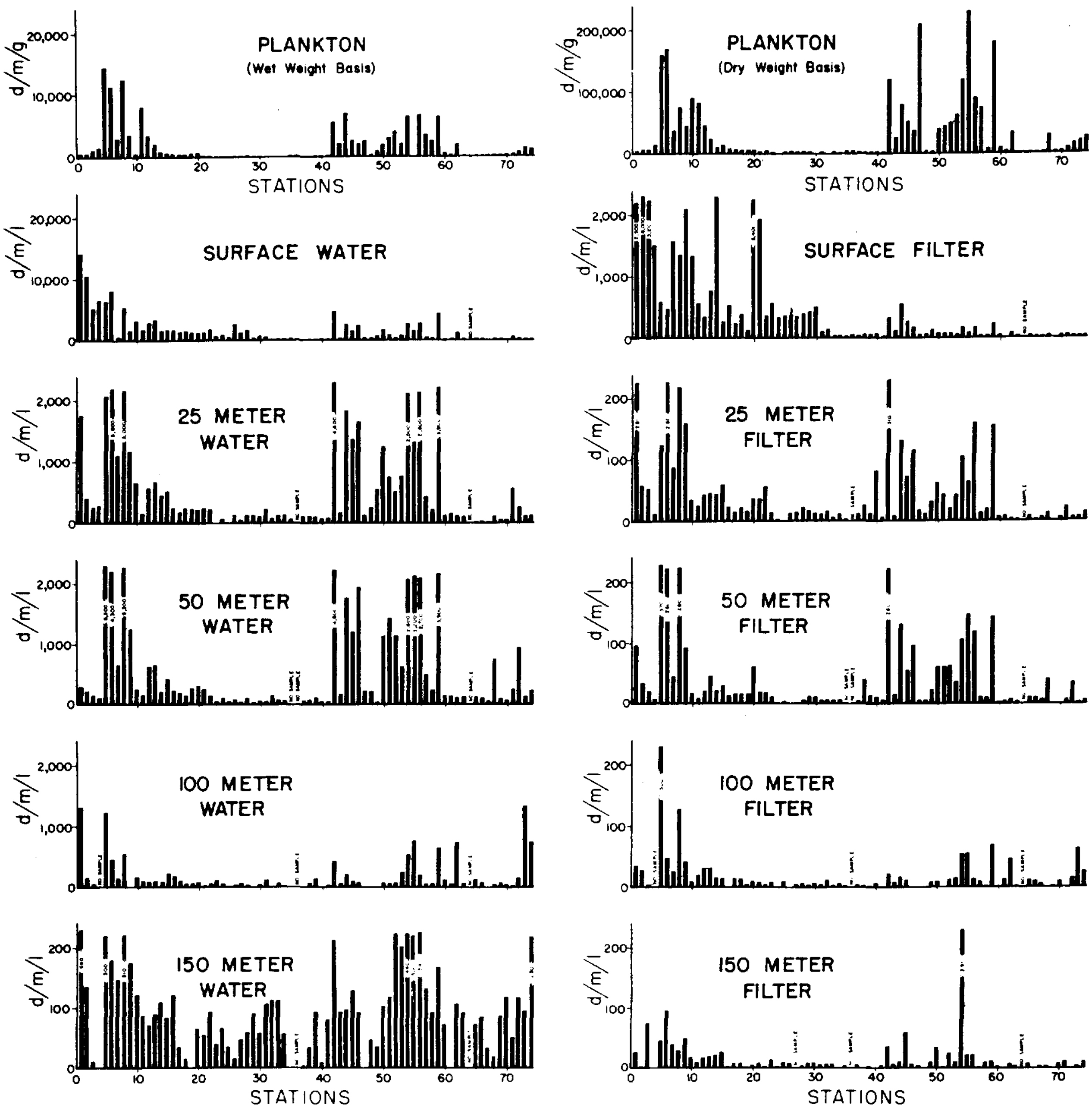

Fig. 4. Graphic presentation of the data.

Table 1. The sums of the values of activity of the residue from one liter of sea water and of the filtered water, less K^{40}, for each station and depth are given in Table 2. Figure 4 is a graphic presentation of the data from Table 1 along with the plankton values. It is evident from this figure that although the absolute values for the various depths or kinds of samples are different, the general pattern of horizontal distribution of activity is approximately the same. The distribution of activity in the surface water samples is plotted in Figure 5.

The highest levels of total activity in the surface water (residue on filter paper plus filterable portion, less K^{40}) were found between Eniwetok and Ujelang, and the lowest value northeast of Bikini. These values were 19,000 d/m/l and 48 d/m/l. Values in the vicinity of Guam are 4 to 20 times the lower value, indicating that some contamination from Operation Redwing had reached this far. Possible interpretations of the relationship between water and plankton activity are discussed on pages 27 - 33.

At every depth sampled the particulate matter retained on the filter had lower levels of activity than did the filterable fraction; this was true also for the Walton samples with the exception of the surface water, in which the particulate matter contained 58 percent of the activity. The average values of radioactivity in the two fractions and the percentages from both the Marsh and Walton data are presented for comparison in Table 3. In both sets of data the particulate matter contributes about three times as much of the total activity in the surface

Table 2. Radioactivity of Water (filter + water, less K^{40})

(Values in disintegrations per minute per liter)

Station	Surface	25m	50m	100m	150m	400m
1	16815	2043	400	1341	719	296 (from 500m)
2	18860	463	261	195	137	
3	8257	340	189	62	86	
4	8216	306	135	--	-62	
5	7140	2204	5680	1534	344	
6	8517	4019	4607	520	274	
7	2215	1200	712	167	196	
8	6803	3238	5448	680	338	
9	3882	1342	1345	429	224	
10	4395	700	302	196	140	
11	2382	191	198	126	98	
12	3255	640	670	137	90	
13	4065	719	716	138	110	
14	4003	515	236	116	132	
15	2142	587	465	249	111	
16	2326	274	263	195	125	
17	1664	206	218	126	43	
18	1986	272	178	70	24	
19	1462	255	312	74	-6	
20	6806	260	364	93	70	
21	3228	287	290	42	64	
22	2284	274	183	68	97	
23	1296	132	95	121	53	
24	1135	73	114	60	70	
25	747	-7	70	14	46	
26	2863	152	92	21	23	
27	1580	73	48	63	48	
28	2040	150	117	27	63	
29	720	156	50	1	97	
30	1171	123	73	47	66	
31	636	237	64	130	112	
32	244	101	159	35	118	
33	214	134	102	75	119	
34	195	145	86	30	51	
35	230	64	--	-16	-23	
36	164	--	--	--	--	
37	155	115	83	-23	9	
38	90	144	134	83	34	
39	122	121	144	151	97	
40	288	148	71	-2	9	

Table 2. (continued)

Station	Surface	25m	50m	100m	150m	400m
41	166	97	59	30	84	
42	5180	4902	4872	448	250	
43	278	197	206	87	100	
44	3180	1980	1917	224	108	*1369 (from 450m)
45	1940	1451	1258	119	189	
46	2653	1788	2054	94	99	
47	300	154	245	-15	-36	
48	304	262	235	-23	44	
49	852	596	73	-26	46	
50	1732	1328	1205	88	138	91
51	1020	816	1487	70	121	51
52	340	535	1240	110	249	155
53	982	826	670	269	212	86
54	2868	2600	2670	594	730	242
55	1549	1374	3356	838	318	133
56	3006	2746	2800	216	562	331
57	436	458	523	91	134	131
58	268	246	283	88	102	
59	4624	4052	4009	723	180	
60	66	150	164	127	77	
61	131	171	157	75	-3	
62	1326	138	143	805	113	331
63	125	103	149	85	96	
64	--	--	--	--	--	
65	199	31	144	158	82	
66	114	35	119	106	86	
67	48	22	85	-36	37	
68	155	143	812	58	24	
69	72	67	112	81	86	
70	103	59	95	60	126	
71	541	603	277	17	63	
72	202	291	989	192	112	
73	84	118	146	1403	100	
74	80	130	250	783	243	

* Bottle did not close.

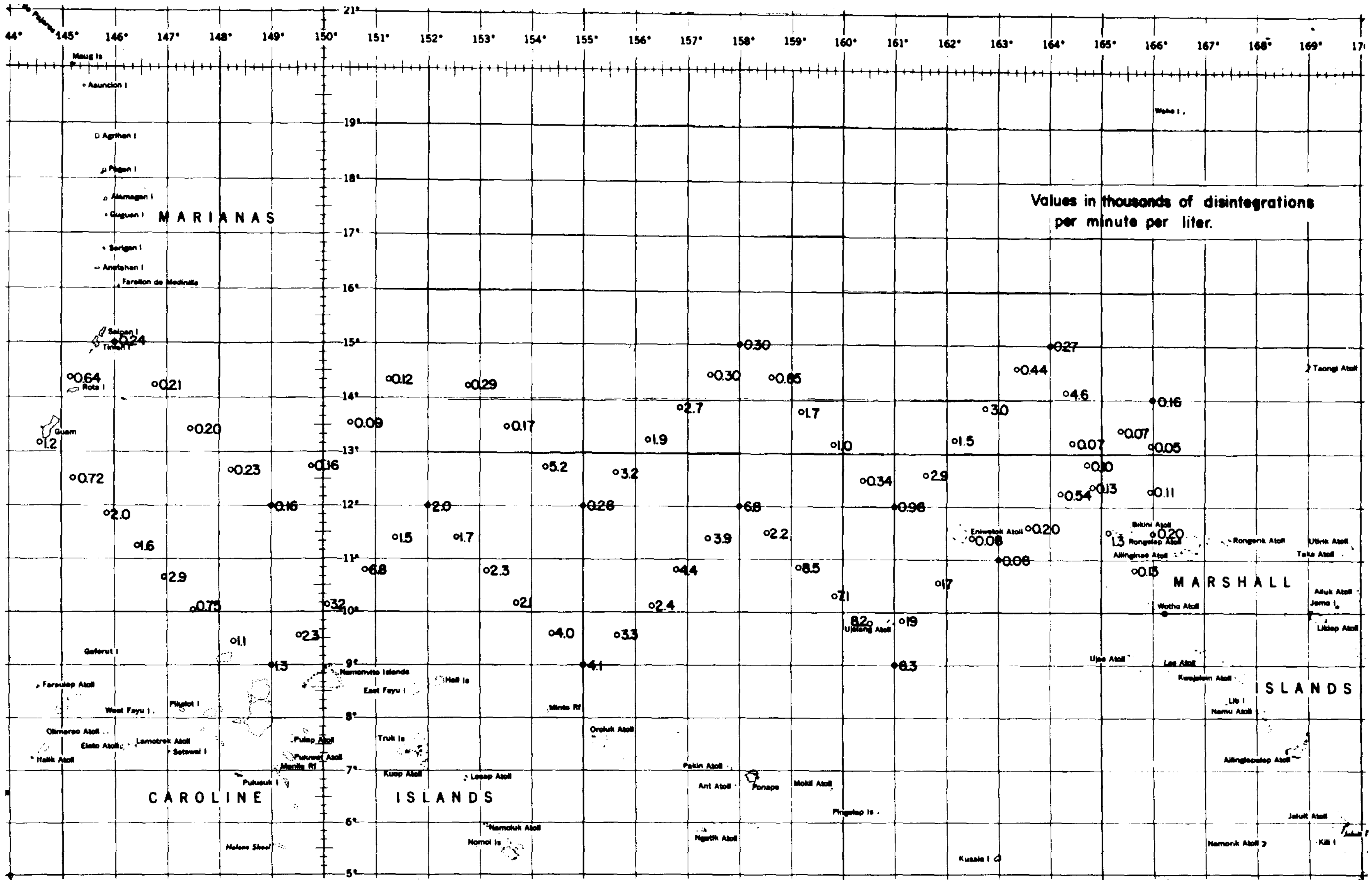

Fig. 5. Radioactivity of surface water.

Table 3. Average Value for All Stations for Plankton Residue from Water, and Filtered Water (less K^{40}) as of Date of Collection

(Marsh Samples September 1-20, 1956; Walton Samples June 12-21, 1956)

Marsh

Depth in Meters	Plankton d/m/g (wet)
0-200	2126

	Residue from Water		Filtered Water		Total
	d/m/l	per cent of total	d/m/l	per cent of total	d/m/l
0	838	32	1745	68	2583
25	49	7	658	93	707
50	45	6	765	94	810
100	19	9	196	91	215
150	17	13	111	87	128
400*	36	19	149	81	185

Walton

Depth in Meters	Plankton d/m/g (wet)
0-200	71,000

	Residue from Water		Filtered Water		Total
	d/m/l	per cent of total	d/m/l	per cent of total	d/m/l
0	5900	58	4200	42	10000
25	280	4	6500	96	6800
50	1800	19	7800	81	9600
75	1300	19	5500	81	6800
100	1000	26	2900	74	3900

* Ten stations only.

Fig. 5. Radioactivity of surface water.

water as it does at greater depths. This greater concentration in the surface layer, where phytoplankton is most abundant[4], coupled with the facts that plankton has a higher specific activity than water and that a few samples of microplankton taken during Operation Troll showed an even higher specific activity than the macroplankton suggests that the microplankton may be the principal source of the radioactive particulate matter.

The activity in the particulate matter was measured from surface samples taken every half-hour (approximately every 8 miles) while approaching and leaving station 62 off the western end of Bikini. Water for these samples was taken from the outlet of the tank for continuous monitoring. The results (Fig. 6) indicate that some radioactive materials are being eluted from Bikini Atoll to the northwest. However, these materials probably add only an insignificant amount to the total activity in the area between Bikini and Eniwetok. The discrepancy between the activity in the sample taken from the tank and that taken from the water bottle at the station off Bikini is probably largely due to a lag in passage of water through the tank.

Continuous Monitoring

The scintillation probe used is successful for the determination of levels of activity in contaminated sea water during the first few weeks following the detonation of a nuclear device; however, on the basis of our limited experience, the probe is not of sufficient sensitivity for the measurement of low levels of γ activity in sea water as late as two months following

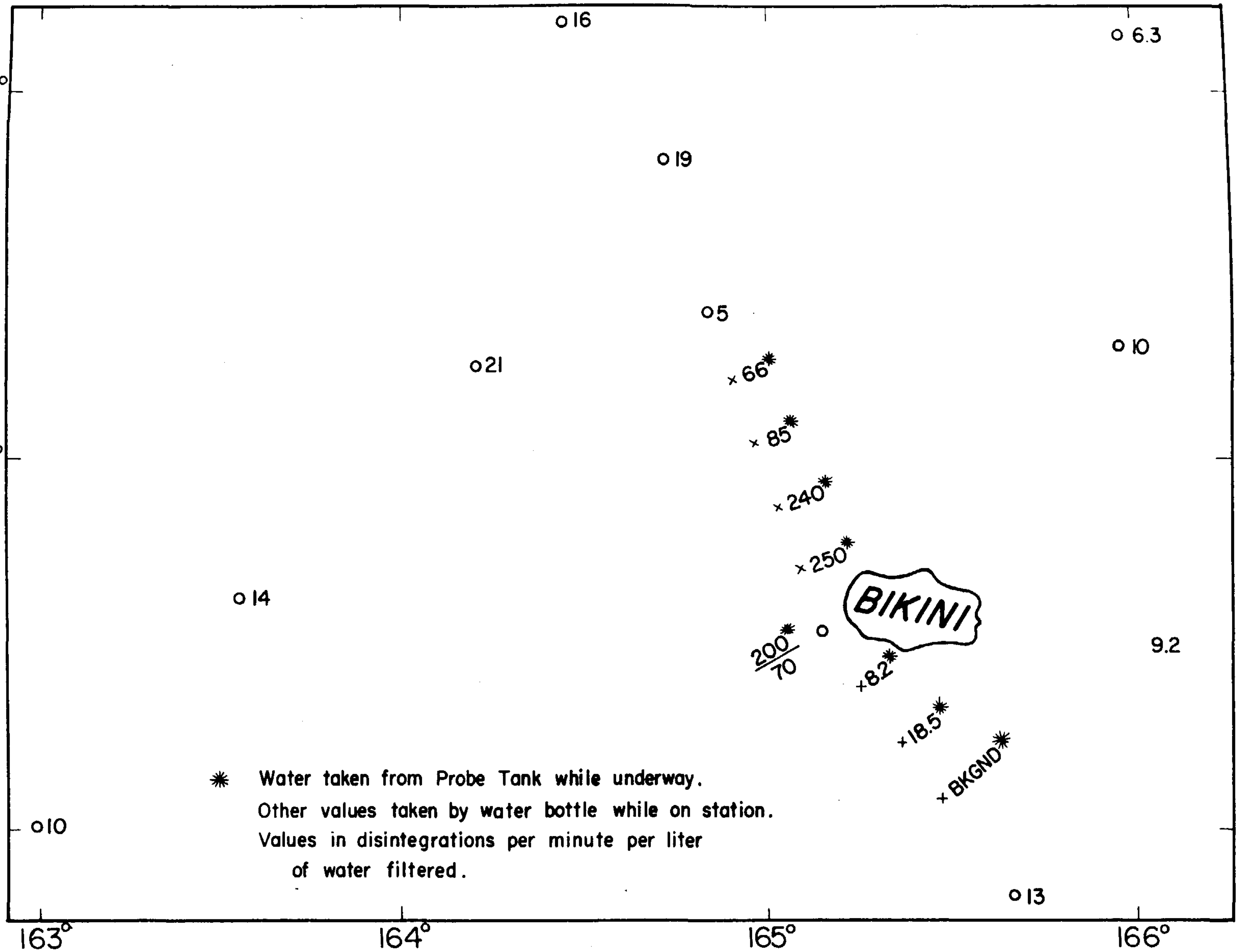

Fig. 6. Radioactivity of filters in the vicinity of Bikini Atoll.

detonation.

Little, if any, correlation exists between the probe values and the actual levels of radioactivity present in sea water as determined from samples taken during the Marsh expedition (Fig. 7). The lack of sensitivity might possibly have been due to faulty "A" and "B" batteries in the probe assembly although this is not likely. The instrument was sensitive to a γ source inserted into the calibration port several times throughout the duration of the trip.

Although the instrument, in its present form, cannot be used for detecting low levels of contamination the following modifications might be made to increase its sensitivity and usefulness.

1. Incorporate suitable voltage stabilization circuits in the filament, B+, and high voltage supplies (the ship-line supply fluctuates from 80 v to 135 v).
2. Replace the present crystal and photomultiplier with a 7-inch diameter unit.
3. Rebuild the water tank to minimize vibration effects on the scintillation probe and increase the volume of water around the probe.
4. Incorporate intermediate ranges into the control box with the following ranges: 5, 30, 50, 300, 500 and 3000 microroentgens.

Fish

Levels of radioactivity in fish tissues are given in Table 4. They are remarkably uniform in the three skipjack taken near station 23; the liver has the highest level of activity, 186 d/m/g

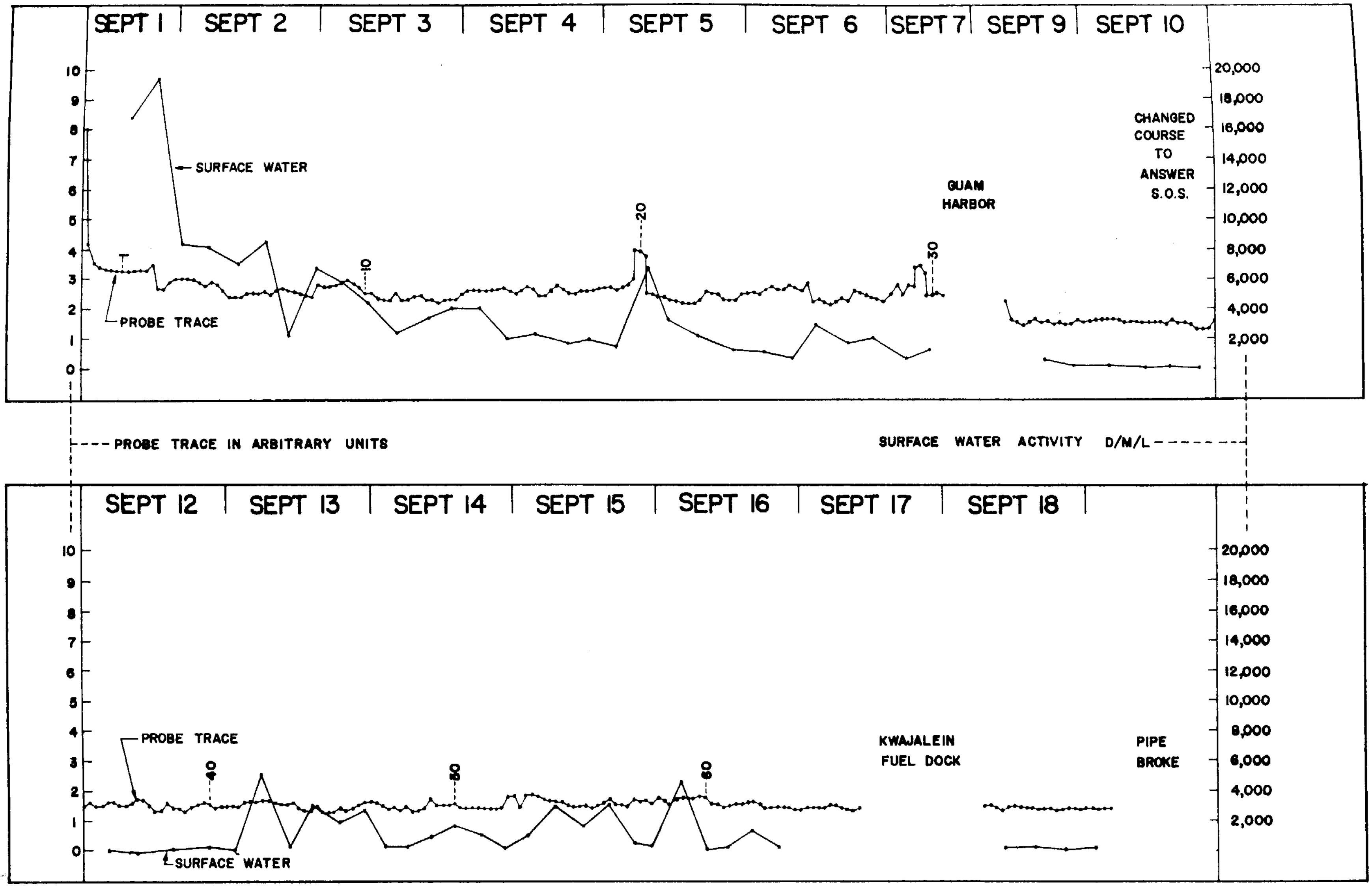

Fig. 7. Probe trace and surface water values.

Table 4. Radioactivity of Fish Caught on the *Marsh* Survey
d/m/g (wet)

Skipjack Taken Near Station 23:

	Light Muscle	Dark Muscle	Liver
Specimen "A"	93	139	188
" "B"	74	109	170
" "C"	80	137	200
Average	82	128	186

Flying Fish Taken from Stomach of Skipjack (Specimen "A" above):

Muscle	Liver
119	--

Flying Fish Taken Near Station 54:

Muscle	Liver
360	7460

Homogenate of Tissues from Fifty Reef Fish Taken at Guam:

	Muscle	Liver
Aliquot 1	70	167
" 2	105	
" 3	156	
Average	110	167

(wet), which is higher than dark muscle by a factor of about 1.5 and than light muscle by a factor of about 2. A flying fish taken from the stomach of one of the skipjack had about the same level of activity in muscle tissue as did the skipjack. Reef fish taken from the eastern shore of Guam had about the same levels of activity as did the skipjack taken approximately 350 miles to the southeast. A single flying fish taken approximately 60 miles northwest of Eniwetok had about 40 times as much activity in the liver, as did the skipjack and Guam reef fish, and about 3 times as much activity in the muscle.

The activity in fish tissues from Guam was greater than that found in fish from the same area in 1955[2] by a factor of 1.3 for liver and 6.9 for muscle, an indication there had been some additional radioactive contamination since the time of Operation Troll. The levels are low even though they are several times those found in fish from Puget Sound in 1955[2].

No radiochemical analyses were made because the activity levels were too low for accurate determinations. It is clear from previous analyses of fish from contaminated areas in the Pacific that it is not likely strontium-90 would contribute any of the activity, and at most two percent of the total β-activity.[5,2]

A diagram of the γ spectrum of the flying fish liver is shown in Figure 11, page 40; the presence of Ce^{144}-Pr^{144}, Zr^{95}-Nb^{95}, Co^{58}, Co^{60} and Zn^{65}, is indicated.

DISCUSSION OF SURVEY DATA

The ratio of the radioactivity in plankton to that in water on a basis of equal weights is highly variable from station to station and from collection date to collection date.

Some of the variability is probably due to inaccuracies in water sample values. A single value for water is probably less reliable than a single value for plankton because of the method of sampling and the lower level of activity in the water; when the water value is based on the average of several observations the comparison is fairly reliable, but a comparison based on a single water value is less reliable. The average of ratios for all stations of the Marsh survey was 2500 (minimum 29, maximum 18,000). The average ratios for the Walton and Troll surveys were 7,000 and 300 respectively.

Several factors may enter into the reduction of the plankton-water ratio with time. One factor may be that selective uptake by the plankton is less evident from relatively fresh fallout material, where a wide spectrum of radioisotopes is available. A decreasing ratio with time after fallout, evident from comparing the Walton, Marsh and Troll data, supports this possibility. Furthermore, the western stations (14 - 42) of the Marsh survey, which would tend to have older fallout material than the eastern stations, have a lower ratio of plankton activity to water activity than do the eastern stations. The values and their standard errors are 475 ± 98 and 3716 ± 754 respectively.

There is, however, another factor which appears to be of considerable importance. This is the effect of distribution of activity in the water with depth on the activity in the plankton sample. The plankton sample is taken from a water layer at a depth of 200 meters to the surface. The water samples are taken at discrete depths down to 150 meters. The following uncertainties are therefore inherent in the sampling method. First, there is not a uniform decrease of activity with depth (Figs. 8 and 9). There are, indeed, changes with depth which range from a sharp decrease from the surface to 25 meters to the other extreme where there are sharp increases at a depth of 100 meters. Secondly, since the water samples are taken at discrete intervals of 25 to 50 meters, the present data do not permit ruling out the possibility that extremes of activity in narrow regions distort the total picture at a given station either by being missed completely or being overemphasized. And thirdly, there is no guarantee that the plankton is uniformly distributed throughout the depth which is sampled by the plankton net. There is, for example, some evidence that a change in the vertical distribution of the plankton population occurs from hours of daylight to hours of darkness. The diurnal-nocturnal difference in ratio of activity in surface plankton (material on filter papers) to that in the surface water is significant at stations 1-30, which for the most part show a sharp decrease in activity in the water from the surface to 25 meters, and no subsequent increase. No such significant difference was found at the remaining stations,

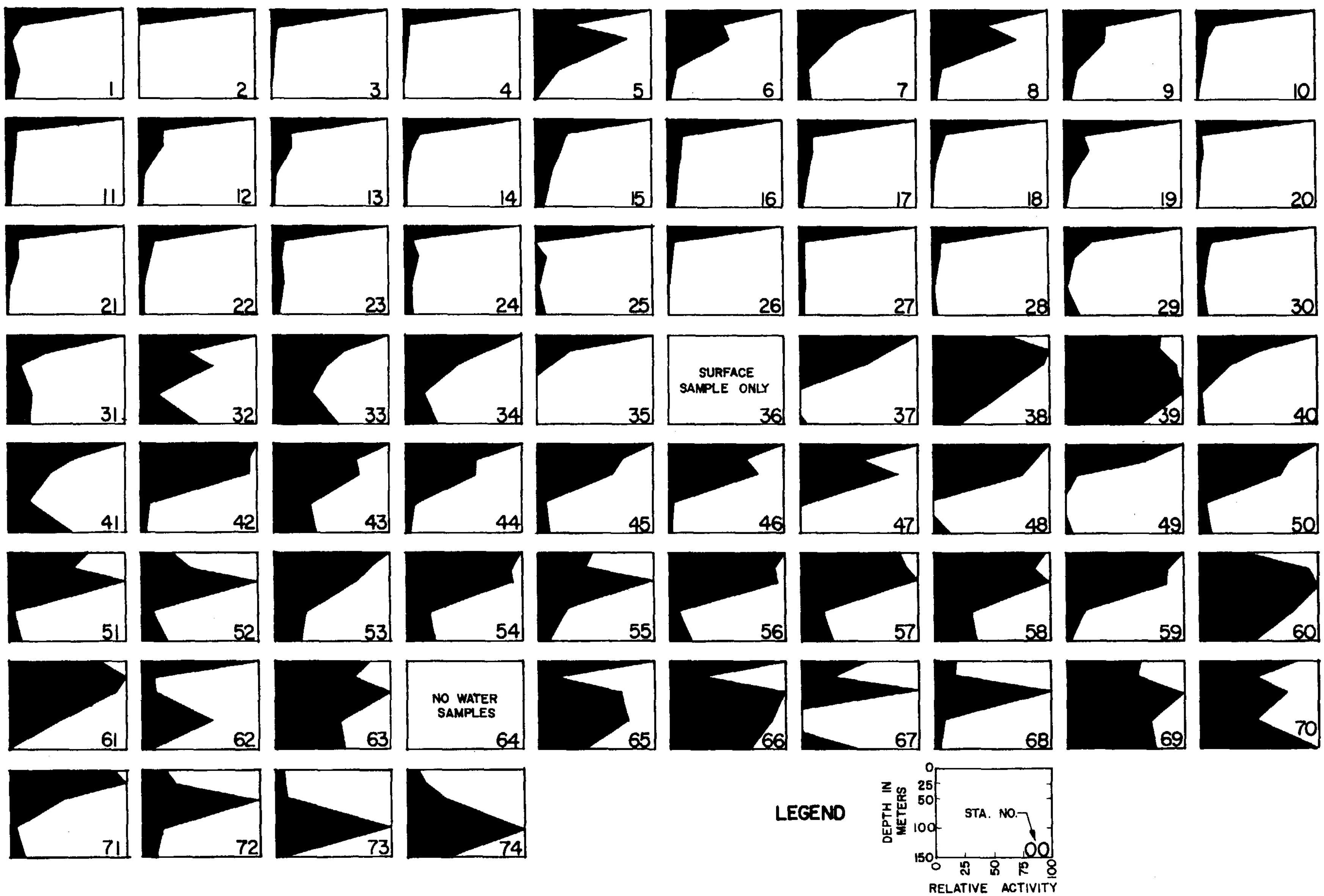

Fig. 9 Relative radioactivity of water (filter and filterable fraction less K^{40}) at each depth sampled

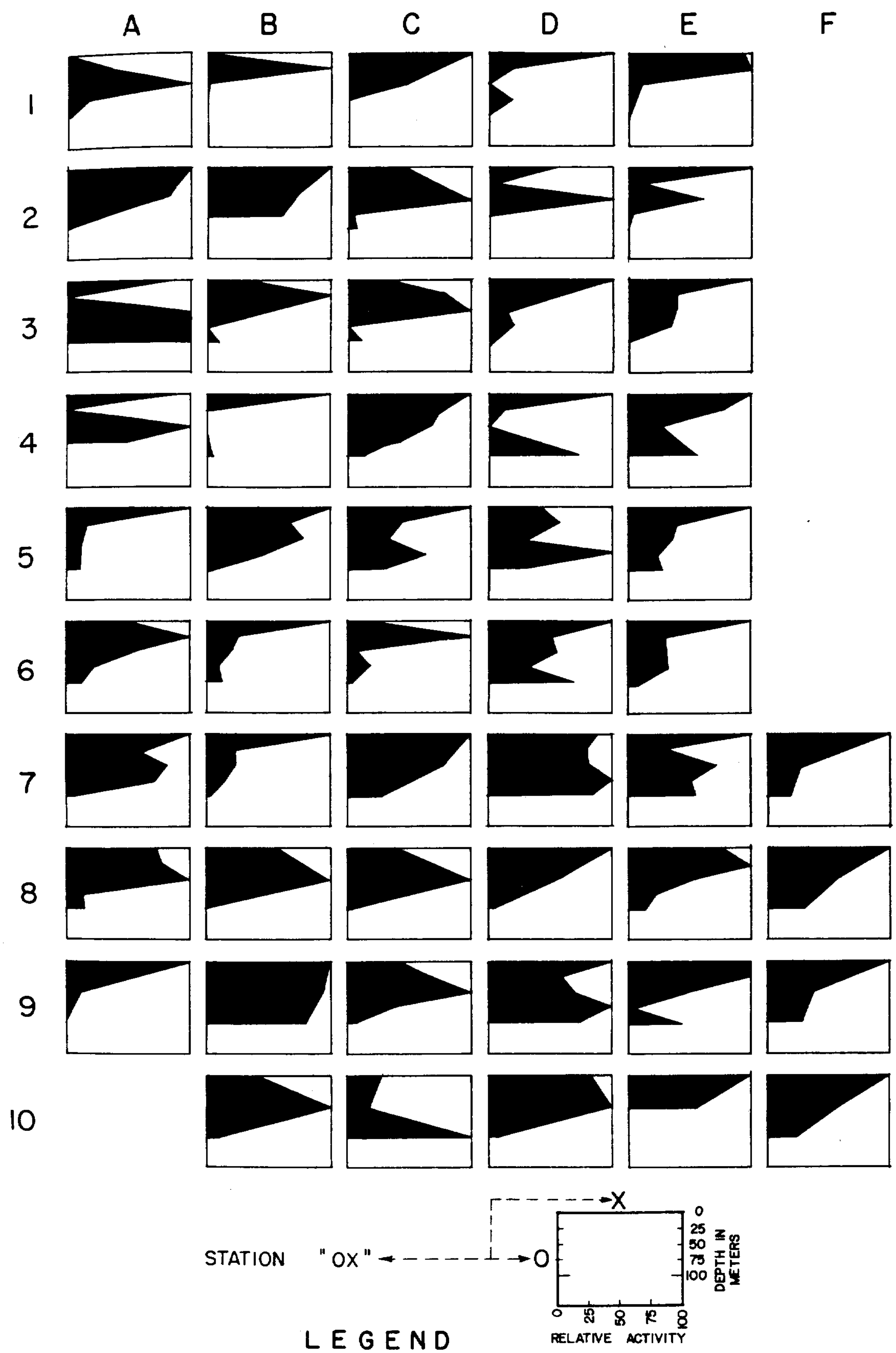

Fig. 9. Relative radioactivity of water (filter and filterable fraction, less K^{40}) at each depth sampled. Maximum value at each station taken as 100. Walton samples.

Fig. 8. Relative radioactivity of water (filter and filterable fraction less K^{40}) at each depth sampled. Maximum value at each station taken as 100. Marsh samples.

where variable levels of activity with depth would mask any diurnal-nocturnal variation that might exist.

The change of relative radioactivity of the water with depth is variable but appears to fall into regional patterns. It is likely that at the time of the Marsh survey those regions containing the highest relative activity levels in the deeper layers were regions primarily affected by fallout, while those regions having the bulk of the radioactive materials in the surface layer were regions to which the radioactive materials in solution had been carried by surface currents. It would follow that by the time of the survey vertical mixing had not taken an important part in redistribution of the radioactive materials; possible exceptions may occur in the immediate vicinity of the Marshall and Marianas Islands.

This interpretation which is based on the assumption that most of the radioactive material went into either a true solution or a suspension of very small colloidal particles soon after fallout is supported by the fact that most of the activity passes through a Millipore filter (Table 3). However, differences in specific gravity of the particles would result in the same type of distribution. It is possible that relatively higher values near the surface for stations to the westward are accounted for, in part, by fallout of lower specific gravity than that of fallout nearer the test site. The particles of lower specific gravity would be assumed to have gone into complete solution while still near the surface.

Figure 8 represents the activity at each of the five depths sampled relative to the highest activity at each station of the Marsh survey, and Figure 9 represents the same thing for the Walton survey.

In general, the presence of relatively higher levels of activity at greater depths at the Walton stations corresponds to the situation at the Marsh stations except in the area south and west of 12° N and 157° E, where the Marsh stations had a marked preponderance of activity in the surface water. The Walton survey was made during the test series when radioactive materials in the water had had only a few days or at most, a few weeks, to be moved by ocean currents from the area of fallout. In addition, the bulk of the activity was found to the north and northwest of the test site. Barnes[6] reports that the surface layers in this region move about three times faster than the layers at 300 meters, and Yoshida[7] shows the westward velocity of the surface water as about 1½ times the velocity at 40 meters at 17° N. It seems possible, therefore, that the Marsh stations south of 12° N and west of the test site represent, for the most part, a region which received its radioactivity via the ocean currents. Stations 4 to 9 are exceptional in this region but they are also stations with high levels of activity (Figs. 3 and 5, and Table 1), probably due to fallout from tests made after the completion of the Walton survey.

There are unusually high levels of radioactivity at depths of 50 m to 100 m at the three stations immediately east of Eniwetok and at station 68 which is about 2° N of Bikini. The unusual condition at these stations may be due to sampling. If the condition is real, some of the factors which may be involved include differences in rate and set of currents adjacent to the atolls, turbulence, and eddies north of Bikini.[6,8]

Careful analysis of the bathythermograph records would be required before any possible relationship between the distribution of activity and the thermocline could be determined. It appears, however, that 100-m samples were taken below the thermocline at most, if not all, stations. Samples were taken at 400 m or 500 m at ten stations east of 159° E and had levels of activity comparable to those at 100 m and 150 m at the same stations (Table 1).

RESULTS AND DISCUSSION OF RADIONUCLIDE ANALYSIS

Fission product separations (see UWFL-33 for techniques)[9] and gamma spectrometric determinations were made on plankton samples collected during the Walton and the Marsh surveys. Plankton samples collected from the Walton in June 1956 were analyzed chemically June 30 and August 29 of the same year. Similar samples collected from the Marsh in 1956 were analyzed both for fission products and certain radioactive non-fission product isotopes during the last week of December 1956 and the first week of January 1957.

In addition to the chemical analyses, gamma spectrum curves were made on two Walton plankton samples, one of which was collected just north of Bikini Atoll (station 9D), and the other in the open sea (8C) about 65 miles northwest of Bikini Atoll.

In general, the observed percentages of total beta activity contributed by the various fission products, corresponded approximately to those expected on the basis of the Hunter and Ballou curves.[10]

Of the Walton samples, chemical analyses were made on plankton from nine stations: 1E, 3A, 4D, 7D, 8A, 9A, 9C, 9D and 10B (Table 5). Variation in isotope percentages is great between samples and no definite pattern of variation is evident between the different collecting areas. If the averages of all samples are compared with the expected percentages (based on an average 30-day interval following detonation), the results are as follows:

Table 5. Percent Contribution of Fission Products to Total β-Activity in Plankton Collected June 1956 on the <u>Walton</u> and Analyzed July 30 and August 29, 1956 (Values as of date of analysis)

Sample number	Zr^{95}	Ru^{103} Ru^{106} + Rh^{106}	Ba^{140}	Ce^{141} Ce^{144} + Pr^{144}	Trivalent rare earths	Total	Insoluble in HNO_3 (5)	Soluble residue (6)(7)	Total	d/m/g of wet plankton
1E (1)	12	15	4.8	27	20	79	11 (3)	-	-	1,800
4D (1)	0	33	4.5	23	22	82	13 (3)	5.1	100	12,200
8A (1)	5.5	17	2.2	20	25	70	15 (3)	4.3	89	11,700
9D (1)	10	21	1.1	20	17	69	12 (3)	2.1	83	158,000
3A (2)	8.9	12	<8	28	25	82	8.4 (4)	15	105	882
7D (2)	12	19	2.5	34	17	84	6.2 (4)	10	100	6,740
9A (2)	11	18	2.4	32	15	78	11 (4)	12	101	3,680
9C (2)	8.9	12	0.6	25	9.5	56	5.7 (4)	14	76	56,400
10B (2)	11	16	1.7	29	12	70	8.4 (4)	21	99	12,100

No measurable radiostrontium or radiocesium were found.
(1) Analyses of July 30, 1956.
(2) Analyses of August 29, 1956.
(3) Residue insoluble in HNO_3 after dry ashing at 600°C.
(4) Residue after wet ashing with HNO_3 and H_2O_2.
(5) Gamma ray spectrograph indicates this was a mixture of Ce^{144}-Pr^{144}, Zr^{95}, $Ru^{103,106}$-Rh^{106}.
(6) Residual solution after completion of analyses.
(7) Gamma ray spectrograph indicates this solution was a mixture of Ce^{144}-Pr^{144}, Zr^{95}, $Ru^{103,106}$, Rh^{106}, Zn^{65}.

Isotope	Observed percent	Expected percent	Ratio $\frac{\text{observed percent}}{\text{expected percent}}$
Zr^{95}	8.8	8.2	1/1
Triv. R.E.	18.0	19.5	1/1
$Ru^{103,106}$, Rh^{106}	18.0	5.7	3/1
$Ce^{141,144}$, Pr^{144}	26.0	13.2	2/1
Ba^{140}	3.1	10.8	1/4

In addition to the great individual variation, differences were also observed in the total amount of activity accounted for. At stations 9C and 9D, both of which are within 45 miles of Bikini Atoll, only about 80 percent of the total beta activity was accounted for as fission products. On the basis of a gamma spectrum run on sample 9D about 5 percent of the total gamma activity was Zn^{65}. No evidence of cobalt isotopes was found. On the other hand, in the gamma spectrum curve of plankton from station 8C. 65 miles northwest of Bikini, the non-fission product isotopes $Co^{58,60}$, Zn^{65} and possibly Co^{57}*, accounted for more than 50 percent of the total gamma activity on November 26, 1956**. (Fig. 10).

Of the Marsh samples, chemical separations for fission products and zinc and cobalt were made on plankton from stations 5, 42 and 55 (Table 6).

* The chemical and resin column data indicate the possible presence of Co^{57}. The gamma spectra made on the separations, however, indicate that the isotope is V^{49} rather than Co^{57}.

** The techniques employed for identifying the different cobalt isotopes involve the use of chemistry, ion exchange resin columns, beta energy determinations, and gamma spectrometry. The techniques and results obtained for various biological samples will be published in a later paper.

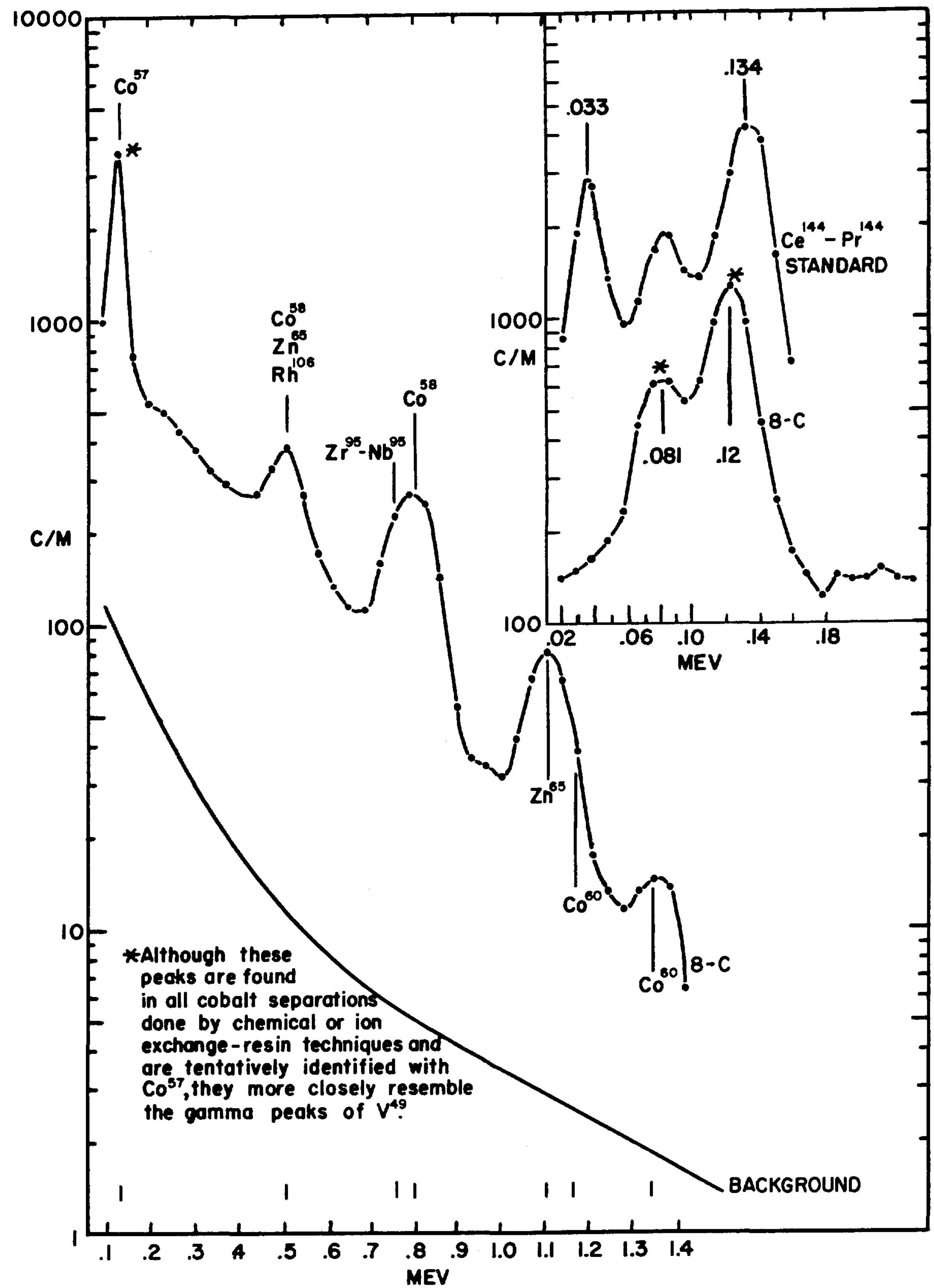

Fig. 10. Gamma spectrum of Walton plankton sample 8-C.

Table 6. Radiochemical Analysis Made December 1956-January 1957 on Selected Marsh Plankton Samples

Sample number	d/m in each aliquot used	$Sr^{89,90}$	Cs^{137}	Ba^{140}	$Ce^{144}-Pr^{144}$	Triv. R. E.	Ru^{106}	Zr^{95}	Co	Zn^{65}**	Nb^{95}*	Insol.	Total
5	1,722	0	<1	<1	8	4	3	25	3	0**	47	1	93**
42	3,289	1.5 or <1.5	0	<1	20	5.1	3	21	31	6	40	8	136
55	2,245	0	0	<1	8.4	5	3.5	31	3	2**	59	1	113**
Expected		6.4	<1	<1	16	15	4	12	-	-	23		77.4

* Based on zirconium count.

** The zinc separations were not satisfactory. On the basis of gamma spectrometry, (see Figs. 11 and 12), a large part of the total gamma activity was contributed by zinc.

Station 5 is located 160 miles southwest of Eniwetok and station 55, 90 miles due north of Eniwetok (Fig. 1). Plankton from stations 5 and 55 yielded similar radiochemical analytical results and in addition have almost identical gamma spectra, which are essentially the same as that of the plankton samples from one of the neighboring stations, 54 (Fig. 11).

Station 42 was taken 470 miles west of Eniwetok. The isotopic content of plankton from this station was clearly different from that of stations 5, 54 and 55 on the bases of both chemical and gamma spectrum analysis.

Comparisons of the relative activity of the different isotopes from plankton at stations 5, 55 and 42 as determined by chemical analysis with the expected activity based on the Hunter and Ballou[10] curves are as follows:

Isotope	Expected percent *	Observed percent at stations 5 and 55	42
$Sr^{89,90}$	7.5	0	1.5
Cs^{137}	$<$ 1.	0	0
$Ba^{137,140}$	$<$ 1.	$<$ 1.	$<$1.
$Ce^{144}-Pr^{144}$	16.	8.2	20.
Triv. R.E.	15.	4.5	5.1
Ru^{103}, $Ru^{106}-Rh^{106}$	5.0	3.0	3.0
Zr^{95}	12.5	28.	21.
$Co^{57,58,60}$	0	3.0	31.
Zn^{65}	0	$\sim$ 1.**	6.0

* Based on an average 8-month interval following detonation.

** According to the gamma spectrum, Zn^{65} accounts for approximately 50 percent of the total activity at stations 5 and 55.

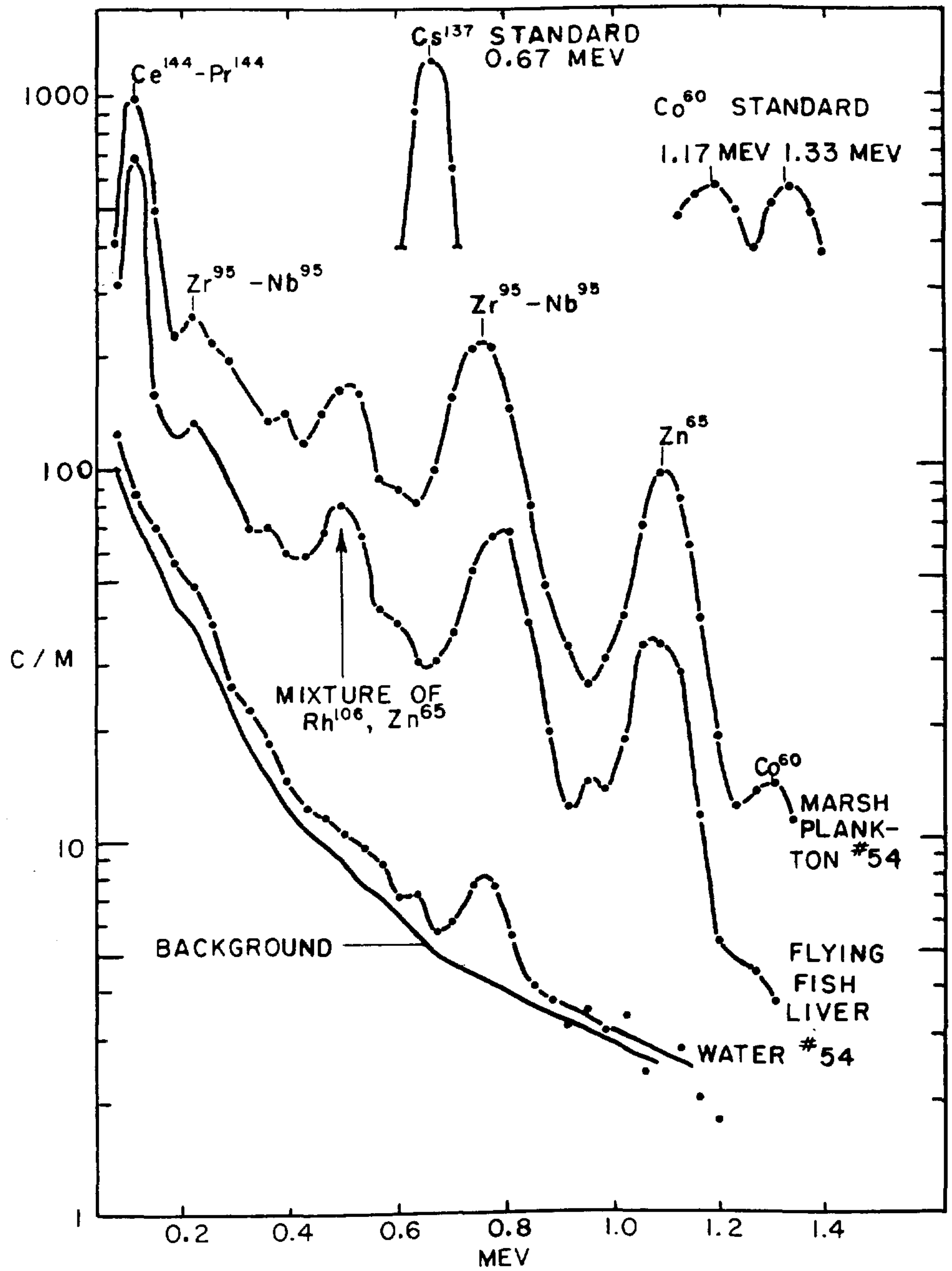

Fig. 11. Gamma spectra of samples of sea water, plankton, and flying fish liver from Marsh station 54.

The results of the analysis of the radionuclides in samples from station 42 differ from those at stations 5 and 55 in that the levels of Ce^{144}-Pr^{144} and $Co^{57,58,60}$ are respectively 2.5 and 10 times higher at 42; $Sr^{89,90}$ is absent at 5 and 55, but present at 42 at a level of about 20 percent that expected from the Hunter and Ballou[10] curves. On the basis of the gamma spectrum curves, however, the apparent radiochemical determination of Ce^{144}-Pr^{144} in sample 42 is too high.

In plankton from all three stations the trivalent rare earths are present at about 30 percent and Ru^{103}, Ru^{106}-Rh^{106} at about 50 percent of the expected levels. Zr^{95}, on the other hand, is present at a level about twice that expected.

The total recovered activity in the chemical separations is greater than that usually found. This may be due to error in counting the original sample introduced by the presence of appreciable amounts of Co^{57}, Co^{58}, Co^{60} and Zn^{65}, all of which emit relatively low energy beta particles in comparison to those from mixed fission products.

The gamma spectra of plankton from Marsh stations 5, 54 and 55 indicate a low percentage of cobalt isotopes, but a high level of Zn^{65} (approximately 50 percent of the total gamma emission) along with Ce^{144}-Pr^{144}, Zr^{95}-Nb^{95} and Ru^{106}-Rh^{106} (Fig. 11)

At station 54, gamma spectra were obtained for sea water after filtration through a Millipore filter, for plankton, and a flying fish liver (Fig. 11). The curves for the plankton and fish liver are similar. All of the detectable gamma activity in the water, however, was contributed by Zr^{95}-Nb^{95}.

Gamma spectra were determined on plankton from station 42 and on portions of this sample including the formalin preservative filtrate, the Fe $(OH)_3$ scavenge from the ashed plankton sample, and the cobalt separation on the same specimen (Fig. 12). The total plankton sample has a lower Zn^{65} component than that found in sample 54. In addition Ce^{144}-Pr^{144}, Ru^{106}-Rh^{106} and Zr^{95}-Nb^{95} contributes little of the total gamma radiation (Fig. 12). The major part of the gamma activity is contributed by Co^{57}, Co^{58} and Co^{60}; also a limited amount of Fe^{59} is present.

The cobalt in plankton sample 42 is partly soluble in neutral formalin and is found in high amount in the filtrate. Although some evidence of the Ce^{144}-Pr^{144} peaks are present in the plankton curve on the low MEV range, the curve on the filtrate gives only the Co^{57} peak (Fig 12, inset). This peak is also shown by the cobalt separation from plankton sample 42 in the same figure.

In summary, the gamma-spectra findings on non-fission products in both the Walton and Marsh plankton samples are as follows:

Station		Levels of non-fission product isotopes		
		Zn^{65}	Cobalt isotopes	Fe^{59}
Walton	8-C	+ +	+ +	n.d.
	9-D	low	n.d.	n.d.
Marsh	5	+ +	low	n.d.
	54	+ +	low	n.d.
	55	+ +	low	n.d.
	42	+	+ +	+

+ + very high
+ high
n.d. not detected

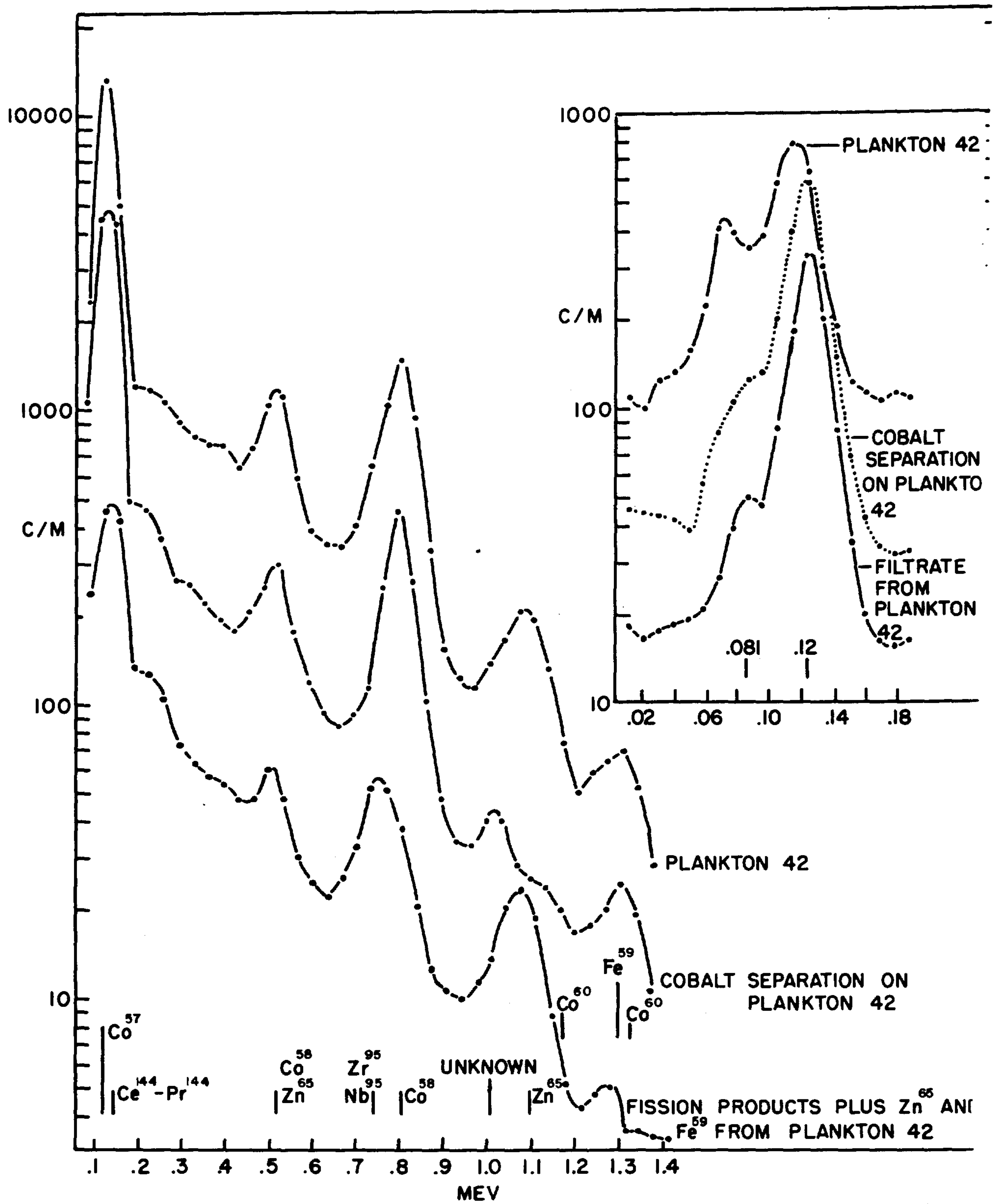

FIG. 12. Gamma spectra of Marsh plankton sample 42 and its chemically separated fractior

In both the Walton and Marsh plankton samples, marked variation in ratios of the different fission and non-fission radioisotopes is evident and cannot be explained on the basis of present evidence. However, at least two factors may be contributing to the variation and each of the two could mask the possible effect of the other. These factors include, (1) heterogeneity in composition of the plankton collected at the various stations, and (2) variation in available isotopes in given areas due to local fallouts from different types of nuclear devices, and from differences in time of firing.

Plankton is composed of many types of organisms including dinoflagellates, diatoms, protozoa, copepods, ostracods, euphausids, amphipods, coelenterates, siphonophores, worms, pteropods, heteropods, primitive chordates, and the eggs and larvae of fish. The fraction of the total mass contributed by any one group can vary widely in different areas. It is known that species differences in uptake of isotopes do occur. Yoshii (1956)[11] observed that radioactive isotopes in copepods and primitive chordates collected in the spring of 1954 in the vicinity of the Marshall Islands, differed both in beta energy and rate of decay, and Kawabata (1956)[12] stated "Although the mechanisms of the accumulation of radioisotopes in planktons and their action in the organisms are still vague, it is, by all means, of importance that certain planktons selectively accumulate specific radioactive elements of minute amount in the sea water in their bodies."

Future plankton work at the Pacific Proving Ground should include studies on the different species comprising the samples, especially with regard to differential uptake of isotopes.

SUMMARY

1. A survey of the radioactivity in the sea water, plankton and fish was made in September 1956 in an area bounded by 9° N and 15° N and approximately 145° E and 166° E.

2. The general pattern of distribution of activity in the sea shows a sharp decrease in activity east of Bikini and a gradual but irregular decrease west of Eniwetok.

3. Plankton appears to be the most sensitive indicator of radioactivity in the sea; the average of ratios of plankton activity to sea water activity was 2,500.

4. The highest value of radioactivity in plankton, 21,000 d/m/g wet, was found about 80 miles north of Eniwetok and the lowest value, 27 d/m/g, near Guam.

5. The highest value for water activity, 19,000 d/m/l, was found between Eniwetok and Ujelang and the lowest value, 48 d/m/l, northeast of Bikini.

6. Sea water filtered through millipore filters had higher levels of activity than the residue on the filter paper.

7. Microplankton is probably the principal source of the radioactive particulate matter.

8. The change of relative radioactivity of the water with depth is variable but appears to fall into regional patterns.

Summary (continued)

9. Some radioactive materials are being eluted from Bikini Atoll but their addition to the total activity in the area between Bikini and Eniwetok is probably insignificant.

10. Reef fish from Guam and skipjack taken approximately 350 miles to the southeast had about the same levels of activity; 136 d/m/g wet (β activity) in skipjack livers was the highest level found in that area.

11. A single flying fish taken approximately 60 miles northwest of Eniwetok had a total β-activity of 7,500 d/m/g wet in the liver and 360 d/m/g wet in the muscle.

12. Plankton was found to contain $Sr^{89,90}$, $Ba^{137,140}$, Ce^{144}-Pr^{144}, Ru^{103}, Ru^{106}-Rh^{106}, Zr^{95}, $Co^{57,58,60}$, Zn^{65}, Fe^{59}, and trivalent rare earths.

13. There is a difference in isotopic content of plankton collected 90 miles north of Eniwetok and plankton collected 470 miles west of Eniwetok.

14. The liver of a flying fish collected about 90 miles north of Eniwetok contained Ce^{144}-Pr^{144}, Zr^{95}-Nb^{95}, Co^{58}, Co^{60}, and Zn^{65}.

15. A scintillation probe for continuous monitoring of levels of γ activity in the sea water was found to have insufficient sensitivity to discriminate between stations in areas of low activity.

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APPENDIX

Appendix Table 1. Marsh Oceanographic Survey Positions
(All positions: "North Latitude"-"East Longitude")

Number	Latitude °	Latitude '	Longitude °	Longitude '	Number	Latitude °	Latitude '	Longitude °	Longitude '
1	10	34	161	50	38	13	33	150	31
2	09	51	161	18	39	14	20	151	15
3	09	00	161	00	40	14	14	152	46
4	09	48	160	31	41	13	29	153	31
5	10	19	159	50	42	12	44	154	16
6	10	51	159	09	43	12	00	155	00
7	11	30	158	32	44	12	38	155	38
8	12	00	158	00	45	13	15	156	14
9	11	24	157	24	46	13	51	156	51
10	10	48	156	47	47	14	26	157	26
11	10	07	156	19	48	15	00	158	00
12	09	34	155	39	49	14	24	158	37
13	09	00	155	00	50	13	46	159	12
14	09	36	154	24	51	13	10	159	49
15	10	10	153	42	52	12	30	160	23
16	10	47	153	08	53	12	00	161	00
17	11	23	152	33	54	12	36	161	36
18	12	00	152	00	55	13	15	162	10
19	11	24	151	23	56	13	50	162	45
20	10	47	150	48	57	14	35	163	21
21	10	08	150	05	58	15	00	164	00
22	09	34	149	32	59	14	08	164	18
23	09	00	149	00	60	13	12	164	26
24	09	27	148	17	61	12	23	164	50
25	10	02	147	30	62	11	32	165	08
26	10	39	146	57	63	10	49	165	39
27	11	15	146	26	64	10	00	166	14
28	11	51	145	52	65	11	30	166	00
29	12	31	145	13	66	12	18	165	57
30	13	10	144	35	67	13	09	165	58
31	14	22	145	10	68	14	00	165	59
32	15	00	146	00	69	13	26	165	22
33	14	14	146	46	70	12	48	164	43
34	13	26	147	27	71	12	15	164	12
35	12	40	148	13	72	11	37	163	34
36	12	00	149	00	73	11	00	163	00
37	12	45	149	46	74	11	25	162	30

Appendix Table 2. Relative Radioactivity with Depth at Each Marsh Station
(Highest value at each depth taken as 100)

Station	Surface	25m	50m	100m	150m
1	100	12	2.4	8.0	4.3
2	100	2.5	1.4	1.0	.73
3	100	4.1	2.3	.75	1.0
4	100	3.7	1.6	--	-.75
5	100	31	80	21	4.8
6	100	47	54	6.1	3.2
7	100	54	32	7.5	8.8
8	100	48	80	10	5.0
9	100	35	35	11	5.8
10	100	16	6.9	4.5	3.2
11	100	8.0	8.3	5.3	4.1
12	100	20	21	4.2	2.8
13	100	18	18	3.4	2.7
14	100	13	5.9	2.9	3.3
15	100	27	22	12	5.2
16	100	12	11	8.4	5.4
17	100	12	13	7.6	2.6
18	100	14	9.0	3.5	1.2
19	100	17	21	5.1	.41
20	100	3.8	5.3	1.4	1.0
21	100	8.9	9.0	1.3	2.0
22	100	12	8.0	3.0	4.2
23	100	10	7.3	9.3	4.1
24	100	6.4	10	5.3	6.2
25	100	-.94	9.4	1.9	6.2
26	100	5.3	3.2	.73	.80
27	100	4.6	3.0	4.0	3.0
28	100	7.4	5.7	1.3	3.1
29	100	22	6.9	.14	13
30	100	11	6.2	4.0	5.6
31	100	37	10	20	18
32	100	41	65	14	48
33	100	63	48	35	56
34	100	74	44	15	26
35	100	28	--	-7.0	-10
36	100	--	--	--	--
37	100	74	54	-15	5.8
38	62	100	93	58	24
39	81	80	95	100	64
40	100	51	25	-.67	3.1
41	100	58	36	18	51
42	100	95	94	8.7	4.8
43	100	71	74	31	36
44	100	62	60	7.0	3.4
45	100	75	65	6.1	9.7

Appendix Table 2. (continued)

Station	Surface	25m	50m	100m	150m
46	100	67	77	3.5	3.7
47	100	51	82	-5.0	-12
48	100	86	77	-7.6	14
49	100	70	8.6	-3.1	5.4
50	100	77	70	5.1	8.0
51	69	55	100	4.7	8.1
52	27	43	100	8.9	20
53	100	84	68	27	22
54	100	91	93	21	25
55	46	41	100	25	9.5
56	100	91	93	7.2	19
57	83	38	100	17	26
58	95	87	100	31	36
59	100	38	87	16	3.9
60	40	91	100	77	47
61	77	100	92	44	-1.8
62	100	10	11	61	8.4
63	84	69	100	57	64
64	--	--	--	--	--
65	100	16	72	79	41
66	96	29	100	89	72
67	56	26	100	-42	44
68	19	18	100	7.1	3.0
69	64	60	100	72	77
70	82	47	75	48	100
71	90	100	46	2.8	10
72	20	29	100	19	11
73	6.0	8.4	10	100	7.1
74	10	17	32	100	31

Appendix Table 3. Relative Radioactivity with Depth at Each Walton Station

(Highest value at each depth taken as 100)

Station		Surface	25m	50m	75m	100m
1	A	3.6	44	100	17	1.4
	B	1.6	100	0	0.86	--
	C	100	74	47	0	0
	D	100	19	0	19	0
	E	94	100	8.1	3.9	0
2	A	100	--	81	--	0
	B	98	100	71	62	--
	C	49	74	100	4.7	5.8
	D	50	3.3	100	3.3	--
	E	100	13	63	5.4	0
3	A	78	0	100	100	100
	B	31	100	--	0	8.6
	C	34	80	100	0	12
	D	100	59	15	18	4.4
	E	100	41	39	34	4.1
4	A	83	0	100	50	--
	B	100	1.0	0	0	3.8
	C	100	73	69	45	12
	D	100	11	0	32	71
	E	100	76	26	39	55
5	A	100	17	13	12	11
	B	100	67	78	47	2.3
	C	100	42	31	61	24
	D	44	56	31	100	12
	E	100	40	35	24	28
6	A	49	100	54	21	12
	B	100	24	18	8.5	12
	C	18	100	7.7	19	4.5
	D	100	52	55	34	66
	E	100	31	32	33	9.0
7	A	100	62	33	73	8.1
	B	100	23	23	15	3.2
	C	100	--	81	--	29
	D	89	77	82	100	85
	E	100	30	71	52	55
	F	100	--	26	--	18
8	A	74	79	100	14	13
	B	57	--	100	--	1.1
	C	42	--	100	--	1.1
	D	100	--	59	--	4.9
	E	79	100	55	24	14
	F	100	--	56	--	29

Appendix Table 3. (continued)

Station	Surface	25m	50m	75m	100m
9 A	100	--	12	--	0
B	100	--	95	--	80
C	43	70	100	39	6.4
D	100	60	70	100	75
E	100	98	48	6.2	43
F	100	--	38	--	28
10 A	--	--	--	--	--
B	41	--	100	--	8.1
C	29	--	19	--	100
D	83	--	100	--	5.4
E	100	--	58	--	--
F	100	--	57	--	24