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DISTRIBUTION OF RADIOACTIVITY IN SEA WATER AND MARINE ORGANISMS FOLLOWING AN UNDERWATER NUCLEAR DETONATION AT THE ENIWETOK TEST SITE IN 1958

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ABSTRACT

An investigation of the radioactive contamination of the water and marine organisms in and near the Eniwetok Test Site was conducted during May 1958, shortly before and immediately following an underwater nuclear detonation. At the end of three and one-half days the boundaries of the radioactive water mass extended beyond the survey area, 50 miles to the west of Eniwetok Atoll, and to a depth of at least 300 meters. The plankton contained high levels of Np^{239}, Mo^{99}-Tc^{99m}, Te^{132}-I^{132}, and U^{237}. Also present in lower amounts were Ce^{141}-Pr^{141}, Ru^{103}-Rh^{103}, Ba^{140}-La^{140}, Zr^{95}-Nb^{95}, and Ce^{144}-Pr^{144}. Ru^{106}-Rh^{106} and Ru^{105}-Rh^{105} were detected once in each of two samples.

Whole fish samples contained essentially the same radioisotopes as the plankton. Shrimp and squid contained high levels of Np^{239} and Te^{132}-I^{132} but no detectable Mo^{99}-Tc^{99m}.

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INTRODUCTION

Studies were made by the United States in 1955 [3] and 1956 [2, 14] and by Japan in 1954 [10] and 1956 [17] to determine the extent of the residual radioactive contamination in the western Pacific Ocean resulting from the nuclear tests at the Eniwetok Test Site. These studies were concerned with radioactive fallout material produced by the detonation of nuclear devices on land or in very shallow water.

The present investigation was conducted during the 1958 test series (Hardtack) and was designed primarily to determine the uptake of the short-lived isotopes by marine organisms and to outline the mass of radioactive water immediately following the underwater detonation of a nuclear device (Wahoo)

The survey was divided into two phases; the first, a predetonation survey, was designed to evaluate the radioactivity contributed by the earlier tests of the series; the second, a post detonation survey, covered the four-day period immediately following the Wahoo detonation.

The Hydrographic Office of the U S. Navy assigned the USS Rehoboth (AGS-50) to assist the Office of Naval Research in a research program related to the Wahoo event. The Atomic Energy Commission supplied part of the funds for the operational cost of the Rehoboth and in return the Rehoboth was made available for use by the University of Washington Laboratory of Radiation Biology, an AEC contractor, for the period May 3, 1958 to May 20, 1958, to conduct a radiobiological survey.

Eight U. S. Navy Hydrographic Office personnel, under the direction of Mr. Alfred W. Anderson, made oceanographic surveys during both phases of the investigation and provided the authors with the water samples from four locations for measurement of radioactivity.

A radiation monitoring team from the Radiation Technical Division of the Naval Medical Research Institute, under the direction of Lt. J. W Duckworth, measured the radioactivity of water at the surface, at the intake to the ship's evaporators, and at designated depths from the surface down to 600 feet. The surface measurements were made with a survey meter and the measurements of the inflow water to the evaporators were made with a specially designed ion-chamber that was fitted around the intake line. For measurements at depth a gamma scintillation-type probe with a continuous recording device was used. The probe was a modified "well-logging" type provided by the AEC Health and Safety Laboratory, New York Operations Office. A report of these measurements is being prepared for publication by the Naval Medical Research Institute.

The measurement of radioactivity of the surface water (initial radiation survey) was conducted with the assistance of personnel from the Laboratory of Radiation Biology (University of Washington) and from the Radiation Safety Section of the Los Alamos Scientific Laboratory under the direction of Maj. Gordon Jacks.

The radiobiological survey extended from 10° 56' N to 11° 25' N and from 161° 16' E to 162° 10' E, the area southwest of Eniwetok Atoll (Fig. 1). The survey included thirty-five plankton stations and four water stations. Eight mid-water trawl collections also were made during the period. Details of these collections describing location, depth of sample, temperature, and depth of thermocline are given in Table 1 and Appendix Tables A, B, and C, and the locations of the stations are shown in Figures 1, 2, and 3. Details of the work aboard ship and the methods of collection were similar to those described by Donaldson _et al._[2] and Seymour _et al._[14]

MATERIALS AND METHODS

Plankton

Plankton samples were collected with a 1/2-meter plankton net of No. 6 mesh while the ship was drifting at a rate of approximately 0.5 to 1.8 knots per hour. The net, hauled by a 3/16-inch wire cable on a

Table 1. Gross beta activity and temperature of the water obtained with Nansen casts. Values expressed in d/m/l in the particulate matter and in the water (filterable portion less K^{40} at time of collection.

Station	Sample no.	Depth (meters)	Temp. °C	d/m/l** Particulate matter***	Water	Total
H-7	106	0	27.82	120	7,400	7,520
Collected	107	8	(27.84)*	170	600	770
5/5/58	108	16	27.81	0	9,000	9,000
1408	109	24	27.81	0	0	0
11°21.8' N;	110	39	27.77	0	850	850
162°09.1'E	111	59	27.77	0	0	0
	112	79	26.69	0	0	0
	113	119	24.68	0	0	0
	114	160	17.85	0	0	0
	115	201	13.21	0	0	0
	116	244	11.07	0	0	0
	117	337	(9.70)*	0	0	0
	118	334	10.04	0	0	0
	119	416	(9.51)*	0	0	0
	120	501	8.17	0	0	0
	121	586	7.22	0	0	0
	122	675	6.27	0	0	0
	123	857	5.12	0	0	0
	124	1039	4.15	0	0	0
W-1	513	0	27.66	64,000	160,000	224,000
Collected	514	5	27.69	62,000	120,000	182,000
5/16/58	515	25	27.69	10,000	73,000	83,000
1910	516	50	27.58	22,000	30,000	52,000
11°19.3'N;	517	100	26.76	3,800	22,000	25,800
162°09.4'E	518	200	15.79	1,900	30,000	31,900
	519	300	10.71	3,100	(lost)	

* Doubtful.

** Correction factor for self absorption based on K^{40}.

*** $> 0.45\mu$.

Table 1. - continued

Station	Sample no.	Depth (meters)	Temp. °C	Particulate matter***	d/m/l** Water	Total
W-2	520	0	27.63	30,000	165,000	195,000
Collected	521	29	27.58	24,000	152,000	176,000
5/17/58	522	48	27.60	19,000	141,000	160,000
1653	523	72	27.56	9,900	60,000	69,900
11°20.5'N	524	96	27.78	7,600	24,000	31,600
162°06.9'E	525	145	22.31	740	26,000	26,740
	526	293	10.08	2,500	32,000	34,500
W-3	527	0	27.60	3,500	12,000	15,500
Collected	528	30	27.55	2,300	14,000	16,300
5/18/58	529	50	27.56	3,000	11,000	14,000
1348	530	75	27.49	3,400	11,000	14,400
11°20.9'N	531	100	27.34	65,000	74,000	139,000
162°10.6'E	532	150	21.98	5,300	13,000	18,300
	533	300	09.88	29,000	49,000	78,000

* Doubtful.
** Correction factor for self absorption based on K^{40}.
*** $>0.45\mu$.

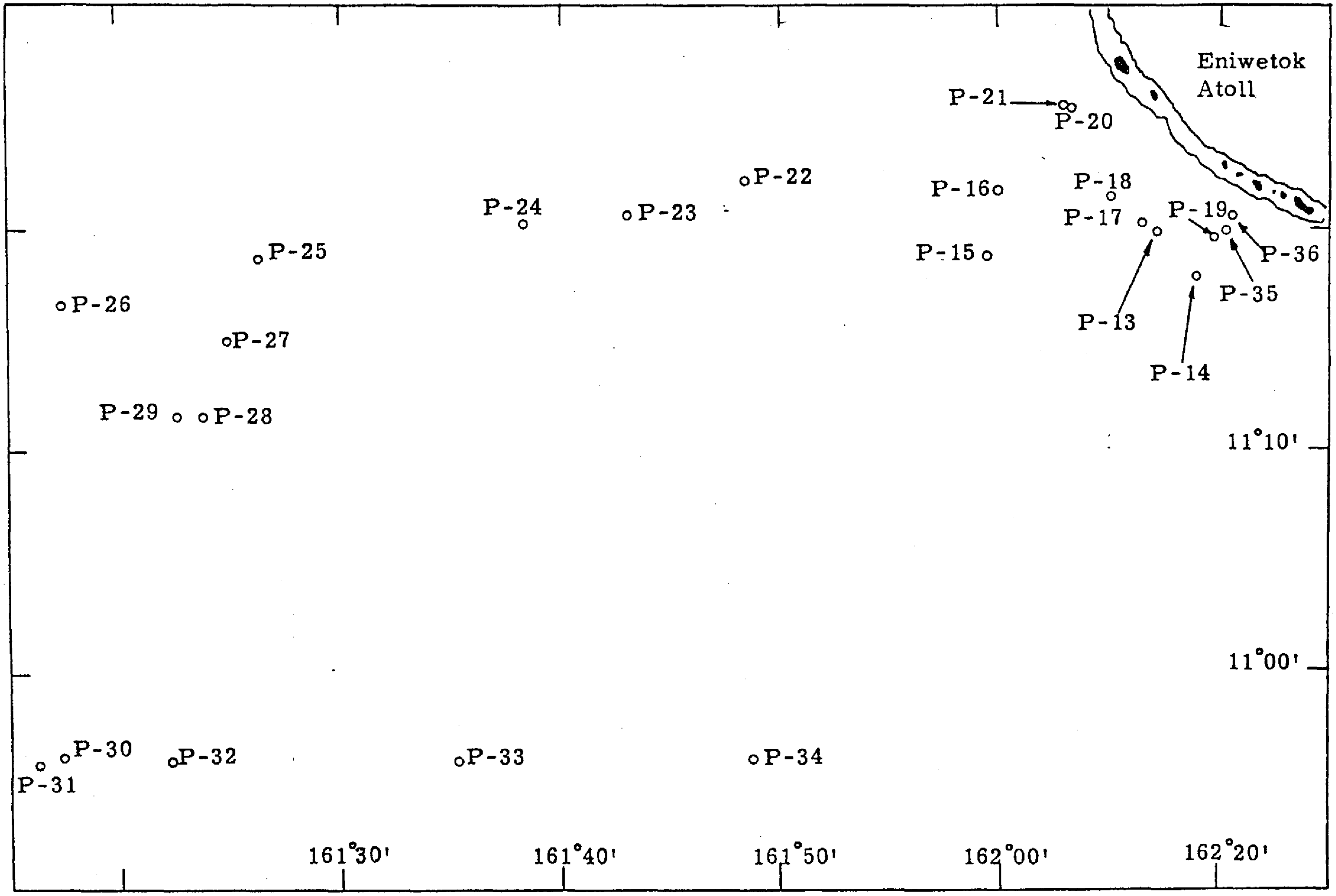


Figure 1. Area of the survey and location of the post-Wahoo plankton stations.

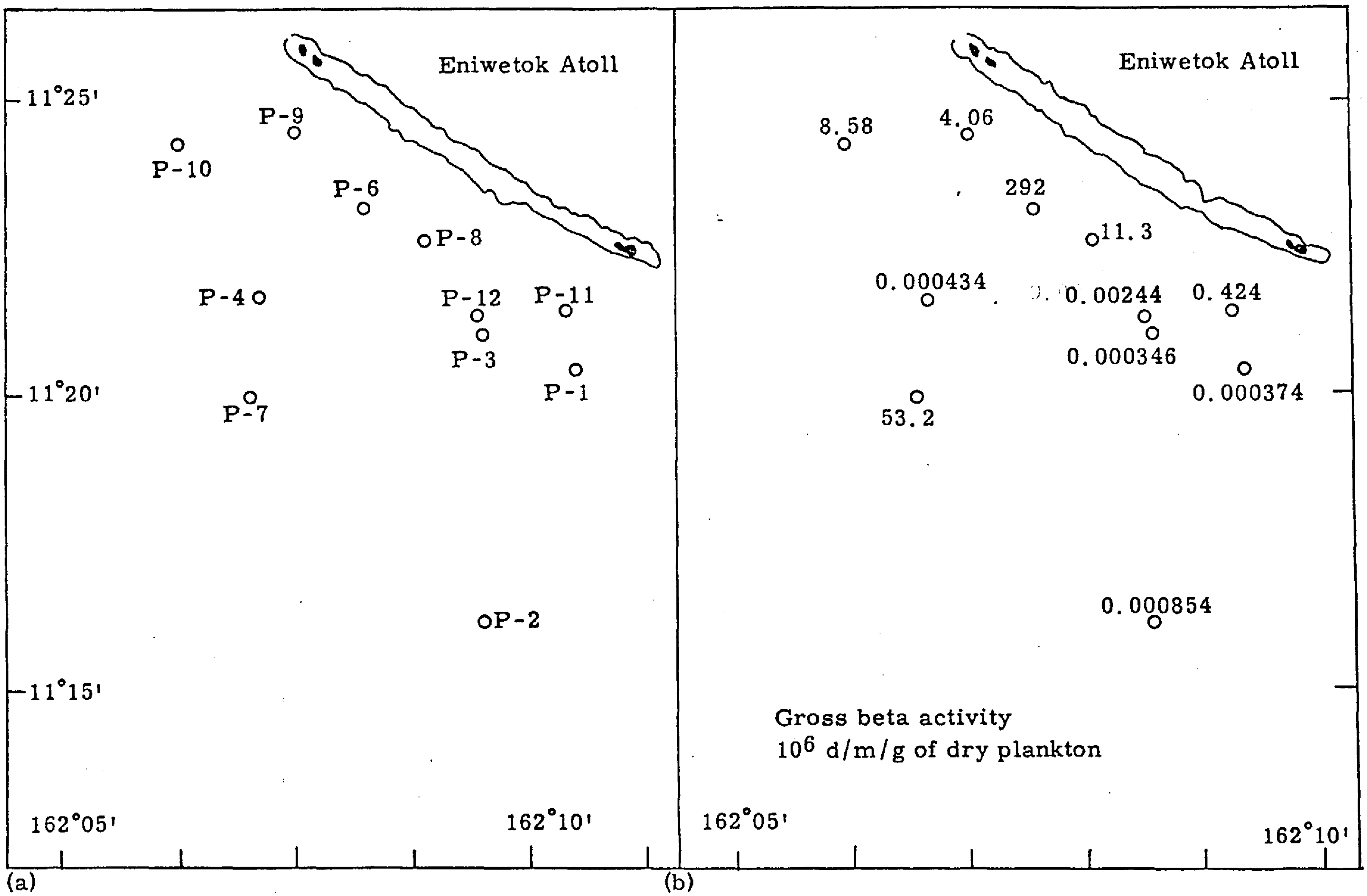


Figure 2. Pre-Wahoo plankton. (a) Location of plankton stations; (b) gross beta activity of plankton samples.

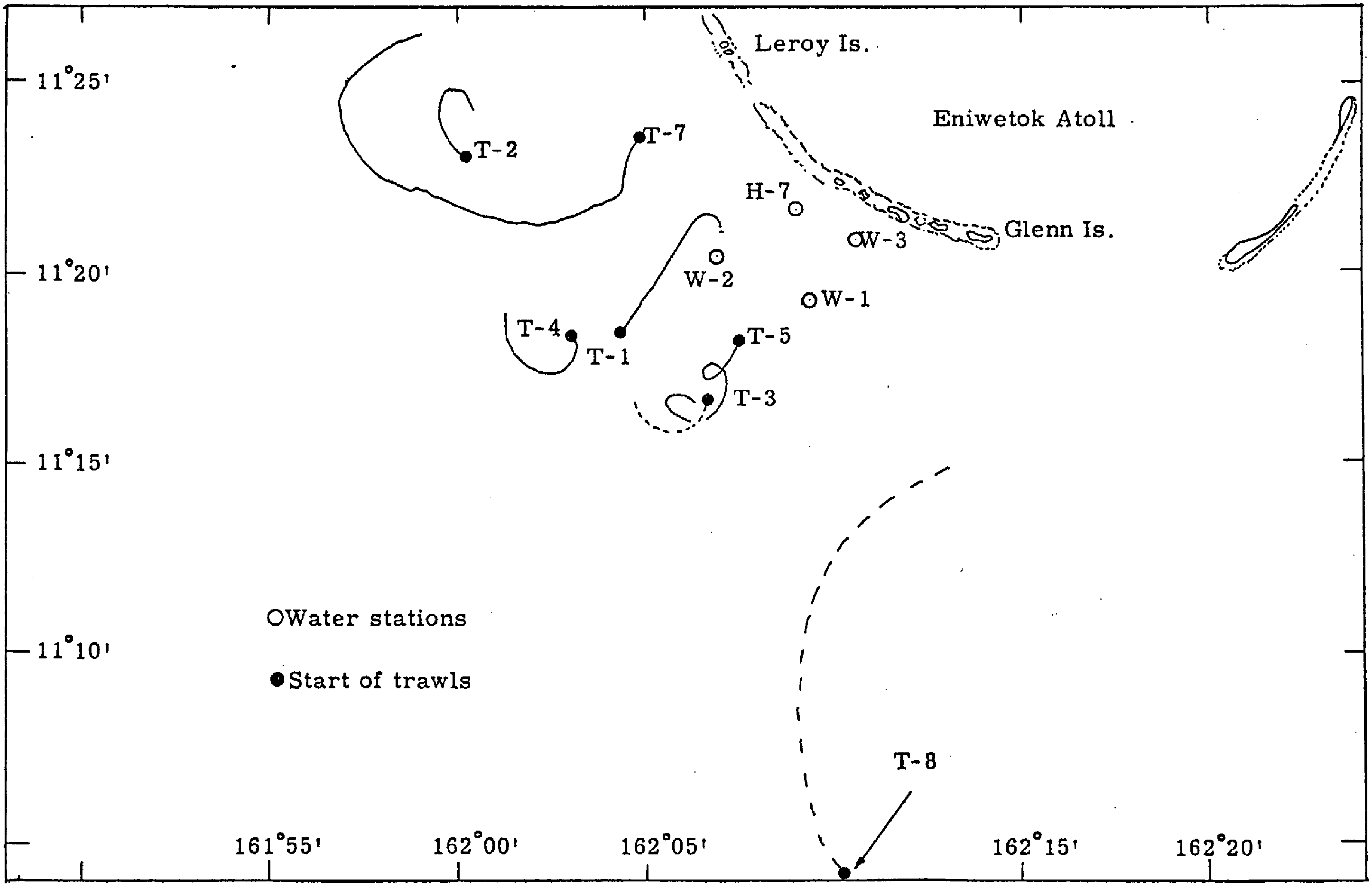


Figure 3. Location of the water stations and of the mid-water trawl hauls. The course plotted for T-8 is approximate.

bathythermograph (BT) winch, was lowered rapidly to the desired depth, towed at this depth for designated periods varying from 15 to 125 minutes, and then raised rapidly to deck level. Haul depths from the surface to 457 meters were determined by the use of a BT. The volume of the sample was determined volumetrically by allowing the sample to settle for five minutes in a graduate cylinder. Details of the plankton hauls are given in Appendix Table A.

In order to direct the movement of the ship while attempting to delineate the mass of radioactive water produced by the Wahoo detonation, a 5-cc portion of plankton samples P-22 to P-35 was filtered through a Millipore filter disc 47 mm in diameter (pore size 0.45μ), and the total gamma activity of the plankton was determined immediately on the wet sample. Later, at the Eniwetok Marine Biological Laboratory on Parry Island, the gross beta activity of the sample was determined on the dried material.

In some samples the plankton were separated into "large" and "small" plankton. The sample was first filtered through a bronze screen 2-3/4 inches in diameter with a mesh of 99 to the inch (large plankton), and then through a Millipore filter disc with a pore size of 0.45μ (small plankton).

For the determination of gross beta activity, a portion of each sample was placed on a 1-1/2-inch stainless steel planchet, dried under infrared lamps, and counted aboard ship. The beta-counting equipment consisted of an end-window counter with a 2-inch Anton tube in a 3-inch Anton shield and a Nuclear-Chicago Model 181 scaler. The correction factors for geometry, self-absorption, backscatter, and decay used to convert c/m to d/m/g of wet tissue at time of collection are included in Appendix Tables D to H.

The samples for total gamma counting were placed in pliofilm bags and counted in a single-channel, 50-position, automatic-advance spectrometer with a 2-inch well-type sodium iodide crystal. Samples containing significant amounts of gamma activity were analyzed to determine the energies of the radionuclides present. Samples containing detectable amounts of beta activity were recounted at frequent intervals to determine radioactive decay.

Because of the difficulties of weighing samples aboard ship, the weights were determined at the Eniwetok Marine Biological Laboratory.

The radiochemical composition of nine samples was determined by ion-exchange techniques.

Fish

A mid-water trawl of the Isaacs-Kidd type with a spread of six feet[1] was used to collect fish and macroplankton from depths of 14 to 365 meters. Trawl hauls were made at speeds of 4 to 5 knots and for periods of 35 to 147 minutes. A deep-sea, steam-powered anchor-winch was used for streaming the trawl with a 1/2-inch wire cable. The maximum tension obtained during the deepest trawl was approximately 6, 000 pounds as measured by a dynamometer. The average tension while trawling was approximately 3, 500 pounds. Details of each trawl haul are given in Appendix Table B.

After the small fish, shrimp, and miscellaneous plankton were separated, portions of each of these were placed on planchets for beta counting and in pliofilm bags for gamma counting. Radiochemical analyses were made of six samples by ion-exchange techniques.

Water

Four series of water samples, one before and three following the Wahoo detonation, were obtained from casts with Nansen bottles made by personnel of the U. S. Navy Hydrographic Office. The last three series consisted of seven samples obtained from depths of 0 to 300 meters, whereas the first series consisted of nineteen samples from depths of 0 to 1, 039 meters. Details of each sample are given in Table 1.

Five hundred ml of water were passed through a Millipore filter 47 mm in diameter and with a pore size of 0. 45μ to collect the particulate matter present in the water. The filter paper was placed on a 1-1/2-inch stainless steel planchet, dried, and dissolved with acetone, then counted for total beta activity. Four ml of saturated sodium carbonate were added to 80 ml of the filtrate, and the carbonate precipitate was collected on a second Millipore filter paper and counted for beta activity. Naturally occurring K^{40}, normally present in sea water to the extent of about 660 d/m/l (beta), remains in the filtrate by this method. Radiocesium also remains in the filtrate; however, it accounts for less than one per cent of the total disintegration rate at the time of collection [3].

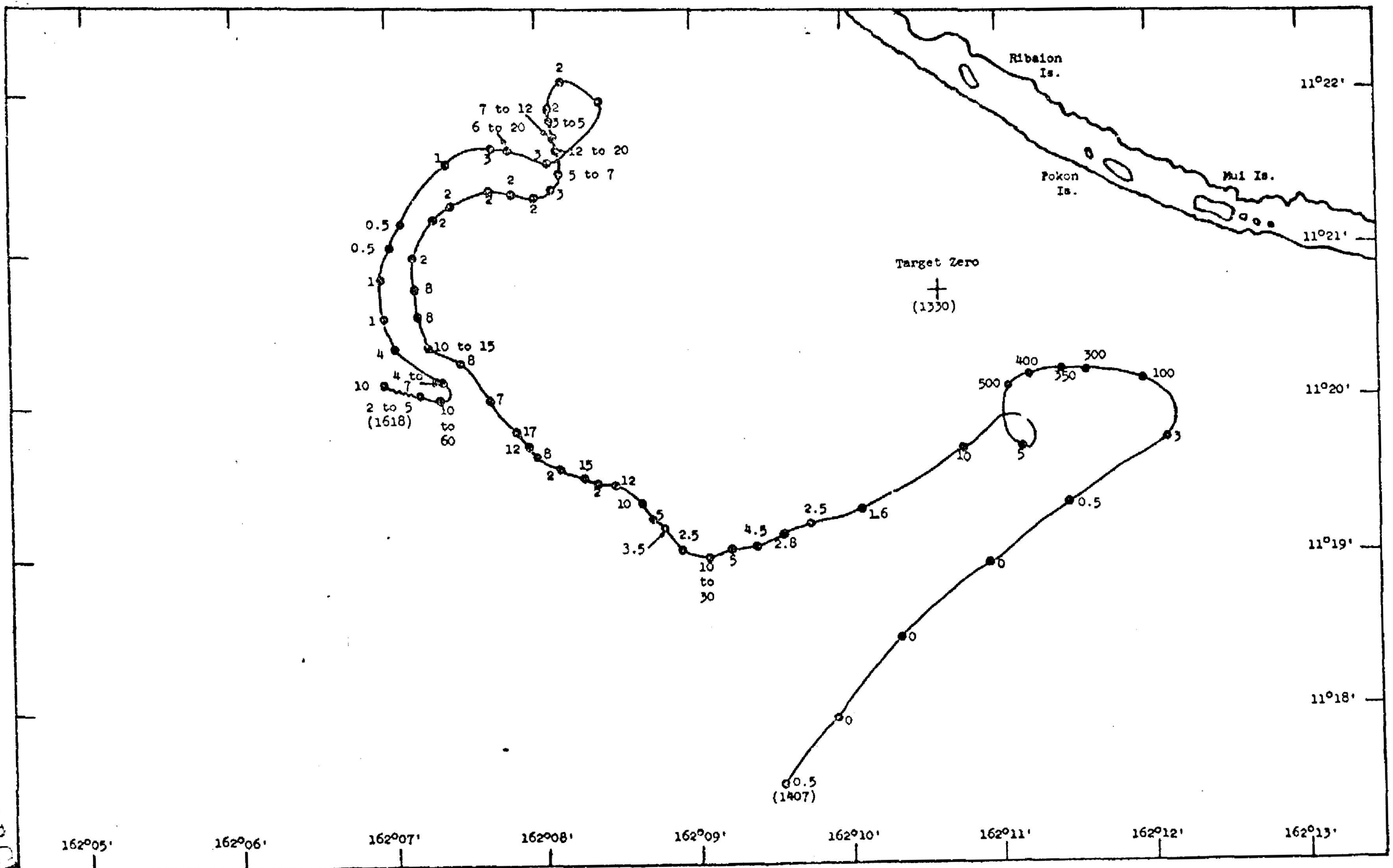
Gamma radiation survey of surface water

The gamma radiation measurements of the surface water immediately following the Wahoo test were obtained with U. S. Navy survey meters (AN/PDR-27C and AN/PDR-43(XN-2)) by three-man teams stationed on the bow of the ship. The readings were relayed to the bridge by telephone at frequent intervals and plotted with the positions of the ship during the survey. The ship was maneuvered to follow a 10 mr/hr surface radiation field (Fig. 4).

Radiochemical analyses of the samples

Radiochemical analyses by ion-exchange techniques were made of sixteen samples including plankton, fish, shrimp, and squid. The samples were wet-ashed with concentrated HNO_3 and superoxol and dissolved in 0.2N HCL. The samples were then passed through 0.28 cm^2 x 10-cm columns containing Dowex-50* (100 -200 mesh), and the radioisotopes were eluted with 50 ml of the following reagents: 0.5 per cent oxalic acid and 5 per cent ammonium citrate at pH 3, pH 4, and pH 6.5 [9]. Aliquots of the collected fractions were counted for total gamma activity, and the fractions with significant amounts of gamma radioactivity were

*Available from Dow Chemical Co., Midland, Michigan.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analyzed in the gamma spectrometer described above. The specific radioisotopes could be identified in a sample when the radioactivity of the isotope was one per cent or more of the total radioactivity of the sample. The fractions which contained more than one radioisotope were further separated by other ion-exchange methods.

Anion fractions

The anion fractions of plankton samples P-6, P-13 and P-15 + P-17 were dried, redissolved in 0.1 M oxalic acid, and passed through 0.13 cm^2 x 26-cm columns containing Dowex-1* (200-400 mesh) for the separation of the anions of Sb, Sn, Te, and Ru. The separation was done by the modified procedure of Smith and Reynolds as described by Palumbo and Lowman.(13)

The anion fractions of samples P-25 + P-26, P-24 + P-35, and P-13 + P-15, and the fractions from the secondary separation of P-15 + P-17, were dried and redissolved in concentrated HCl to separate the complex radionuclide mixtures, as described by Wish.(16) In these experiments the samples were passed through 0.03 cm^2 x 15 cm-columns containing Dowex-1 (200-400 mesh) and the radionuclides were sequentially removed by using mixtures of hydrofluoric and hydrochloric acids. Because of the corrosive nature of the HF acid, column plugs made of lucite shavings were used and the fractions were collected in

*Available from Dow Chemical Co., Midland, Michigan.

lusteroid test tubes.

Oxalate fractions

The oxalate fraction of the primary ion-exchange separation of sample P-6 was dried and redissolved in concentrated HCl for the separation of the transition elements, as described by Kraus and Moore.[6] The sample was passed through a 0.28 cm^2 x 26-cm column containing Dowex-1-(200-400 mesh).

Determination of strontium-90

Samples of plankton and a sample of shrimp were analyzed for Sr^{90} by the ion-exchange method of Kawabata and Held.[5] The ashed sample was first treated with 80 per cent HNO_3 to remove strontium from the bulk of the sample and from most of the other radioisotopes present. The solution containing the strontium nitrate precipitate was filtered through a glass filter and was then dissolved in hot 0.2N HCl. After cooling, it was passed through a cationic resin column and possible contaminants were eluted from the column with 0.5 per cent oxalic acid and 5 per cent ammonium citrate at pH 3.5. The column was then stored for 14 days to allow the Y^{90} daughter to build up. The Y^{90} was reeluted from the column with ammonium citrate at pH 3.5 and the amount of Sr^{90} present was calculated from the amount of Y^{90} recovered. The identity of Y^{90} was confirmed by determining the decay rate of the sample eluted.

RESULTS

Initial radiation survey

The Wahoo device was detonated at 1330 on May 16, 1958, and at 1407 hours, the radiation survey to determine the 10 mr/hr limits of the radioactive water mass was started. A summary of the ship's track and the radiation readings in mr/hr recorded during the survey are presented in Figure 4. Immediately before the Wahoo test while the ship was 7,000 yards south of target zero, the background radiation aboard ship was 2.0 mr/hr. The average background radiation in the target area was 1.5 mr/hr. In the following discussion the average background value has been subtracted from the values presented.

Following the detonation, as the ship proceeded in a northeasterly direction, it entered a 3 mr/hr field, at which time (1435) it was turned to the west, During the turn, the radiation level increased rapidly to 500 mr/hr (1451) and then dropped rapidly to 5 mr/hr as the ship's course was changed sharply southward and away from target zero. This point, approximately one mile southeast from target zero, probably represents the limit of the main body of radioactive water at this time (1455). The survey was continued in a southwesterly direction and at 1510, when readings of 10 to 30 mr/hr were obtained, the course was changed to a northwesterly one. At 1530, readings of 2 to 8 mr/hr were obtained when the ship was three and one-quarter miles due west of target zero. As the ship continued northward and then circled back (1542) to parallel the course taken earlier, radiation readings of 2 to 20 mr/hr were observed. At the northernmost point of the survey the readings were 2 mr/hr, and at the westernmost point they were 1 mr/hr. This line represents the approximate detectable downwind limits of contamination at this time. At 1618 the initial survey was completed when the ship was approximately 6, 500 yards downwind (WSW) from target zero.

The level of radioactivity in the target area during the next forty-eight-hour period decreased to the pre-Wahoo level.

Water

The gross beta radioactivity in the pre and post test samples is given in Table 1. The radioactivity in the samples collected prior to the Wahoo detonation was limited to the top 39 meters and for the most part was in a soluble form. Five and one-half hours after detonation, radioactivity was present at all depths sampled and the amounts of radioactivity were much higher than those found one and three-quarter miles southwest of target zero. The particulate matter suspended in the water accounted for 6 to 40 per cent of the gross beta activity. Twenty-seven hours after detonation, four miles due west of target zero, the measured amounts of beta radioactivity in the water were approximately the same. At W + 48, at target zero, the greatest amount of radioactivity was found in the samples taken below the thermocline.

Plankton

The radioactivity measurements of the plankton samples are given in Table 2. A small amount of beta activity found in the first four samples can be attributed to residual contamination from previous tests. Because of the thousand-fold increase in radioactivity of plankton sample P-6 collected on May 6, 1958, as compared to those collected previous to this date, it is assumed that this increase in radioactivity was due to the fallout of the Cactus device detonated on the same day. Samples P-7 to P-12, collected before the Wahoo test, contained radioactivity in lower amounts (Fig. 2). These samples were examined by gamma spectrometry immediately after collection and the following short-lived isotopes were present in the decreasing order of their contribution to the total activity:[15] Np^{239} (2.3 days), Mo^{99}-Tc^{99m} (66 hours),* Ce^{141}-Pr^{141} (33.1 days),* Ru^{103}-Rh^{103} (39.8 days),* Ba^{140}-La^{140} (12.8 days),* Te^{132}-I^{132} (77.7 hours),* Zr^{95}-Nb^{95} (65 days),* Ce^{144}-Pr^{144} (285 days),* and Ru^{106}-Rh^{106} (1 year),* in both the large and small plankton. A summary of the results of separations of the radionuclides in sample P-6 by ion-exchange methods is given in Table 3. Gamma spectrum analyses indicated that plankton samples P-7 to P-12 contained these radionuclides in the same relative proportions.

*Effective half life.

Table 2. Radioactivity of the plankton. Values expressed as d/m/g of gross beta activity and c/m/cc of total gamma activity at time of collection.

Sample no.	Collected Date	Collected Hour	Radioactivity: Gross beta activity 10^6 d/m/g of dry plankton*	Radioactivity: Gamma activity 10^6 c/m/cc of wet plankton
P-1	5/4/58	1540	0.000374	
P-2	"	1945	0.000854	
P-3	5/5	1423	0.000346	
P-4	"	1950	0.000434	
P-6	5/6	1615	292.0	
P-7	"	1953	53.2	
P-8	5/7	1427	11.3	
P-9	"	1637	4.06	
P-10	5/8	1845	8.58	
P-11	5/9	1225	0.424	
P-12	5/10	1300	0.00244	
P-13	5/16	1609	32.2	
P-14	"	1907	257	
P-15	5/17	1015	4.76	
P-16	"	1405	10.3	
P-17	"	1705	96.2	
P-18	"	2140	17.4	
P-19	5/18	1040	25.2	
P-20	"	1830	15.5	
P-21	"	2304	33.7	
P-22	5/19	0858	18.6	0.200
P-23	"	1000	46.6	0.166
P-24	"	1100	3.60	0.182
P-25	"	1230		0.286
P-26	"	1352		0.220
P-27	"	1814	7.66	0.100
P-28	"	1935	12.1	0.125
P-29	"	2004	27.4	0.080
P-30	5/20	0101	7.52	0.0182
P-31	"	0145	6.93	0.0129
P-32	"	0400		0.0222
P-33	"	0617	3.18	0.0432
P-34	"	0855		0.0344
P-35	"	1510		0.0480
P-36	5/26	0945	2.30	

*Correction factor for self-absorption based on K^{40}.

Table 3. Gamma emitting radioisotopes in samples of plankton. Values expressed as per cent of the total radioactivity contributed by each radioisotope at the time of collection.

Radioisotope	Sample: Percent of total activity					
	P-6	P-13	P-13* P-15*	P-15 P-17	P-25 P-26	P-34 P-35
Np^{239}	56	73	67	62	81	74
Mo^{99}-Tc^{99m}	31	2.2	17	13	3.6	5.3
Ce^{141}-Pr^{141}	3.6	2.7	0.6	0.9	2.0	1.9
Ru^{103}-Rh^{103}	3.0	1.5	0.8	0.3	1.1	1.0
Ba^{140}-La^{140}	2.9	2.4	0.7	2.2	4.4	2.3
Te^{132}-I^{132}	1.4	7.3	13	12	5.4	9.9
Zr^{95}-Nb^{95}	1.1	nd	0.3	0.5	0.7	1.7
Ce^{144}-Pr^{144}	0.6	nd	nd	0.1	nd	nd
Ru^{106}-Rh^{106}	0.3	nd	nd	nd	nd	nd
U^{237}	nd**	11	0.3	1.2	2.0	3.3
Ru^{105}-Rh^{105}	nd	nd	nd	7.0	nd	nd
Total d/m/g x 10^6	100	360	140	150	15.0	8.6

* Small plankton.
** Not detected

On may 14, 1958, a second fallout was detected in the area in which the ship was operating. This contamination may have resulted from the Butternut, Fir, or Koa devices which were detonated one to to two days earlier. General contamination of the ship at a level of 5 to 10 mr/hr raised the background in the counting room to a very high level (445,000 c/m total gamma, 0.02-2 MEV). This level decreased to 60,000 c/m just prior to the Wahoo detonation on May 16, 1958.

The first post-Wahoo plankton sample, P-13, was taken at the end of the initial radiation survey (1609 hours) at a depth of 9 to 15 meters in an area with a gamma radiation level of 10 mr/hr, four miles west of target zero. The amount of radioactivity was high (32,000,000 d/m/g dry) but not as high as that found in sample P-14 taken that evening (1907 hours) at a position less than three miles to the southeast. These differences in amounts of radioactivity may reflect the variation in the radioactivity of samples taken in the target area or may indicate that maximum uptake of radioactivity by the plankton did not occur until this time. The location of the plankton sampling stations and the radioactivity of the samples collected after Wahoo are shown in Figures 1, 5, and 6.

The results of ion-exchange separations of the radionuclides of some of the plankton samples and analysis of the fractions by gamma spectrometry are given in Table 3. The percentages of total activity

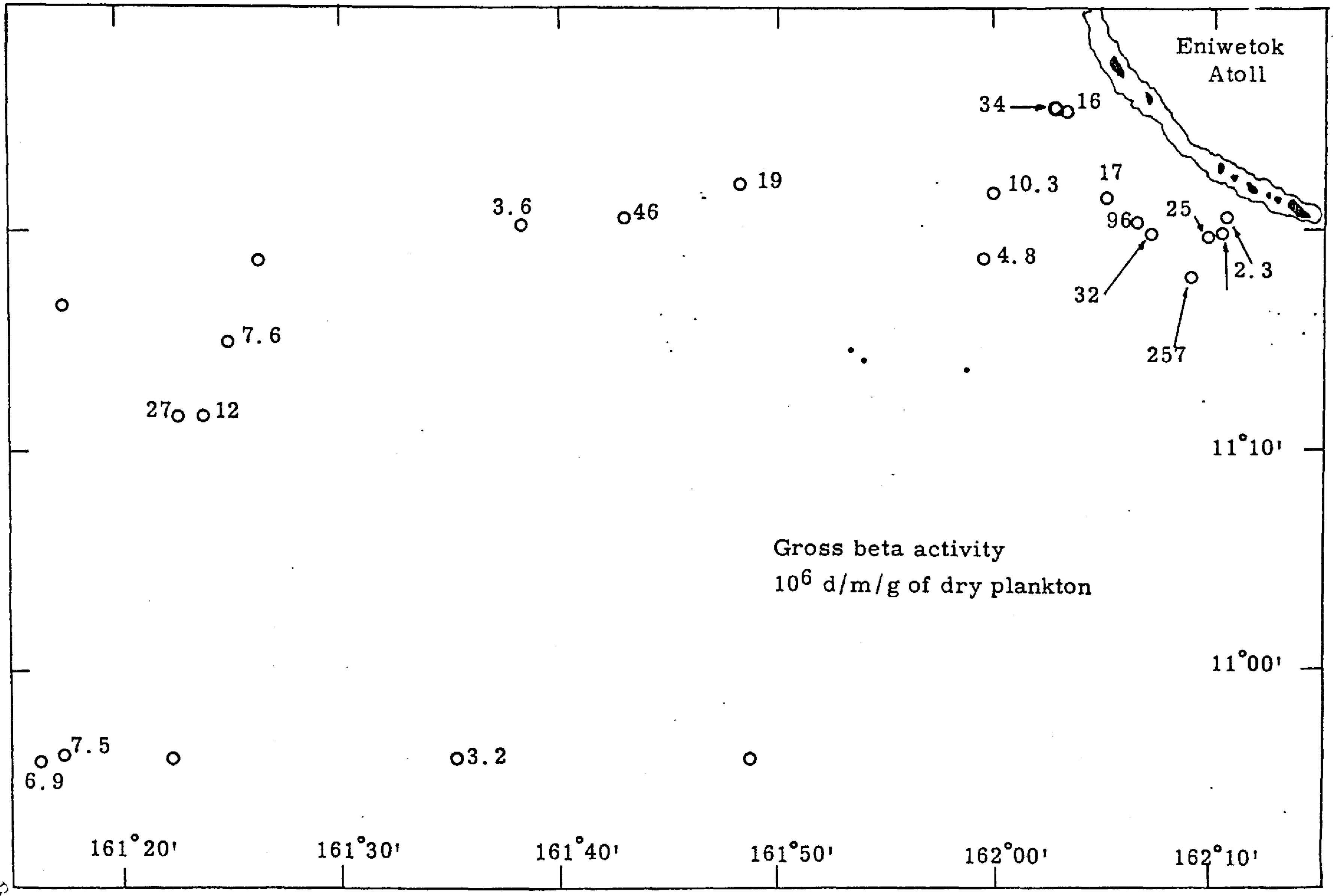

Figure 5. Gross beta activity of the post-Wahoo plankton samples.

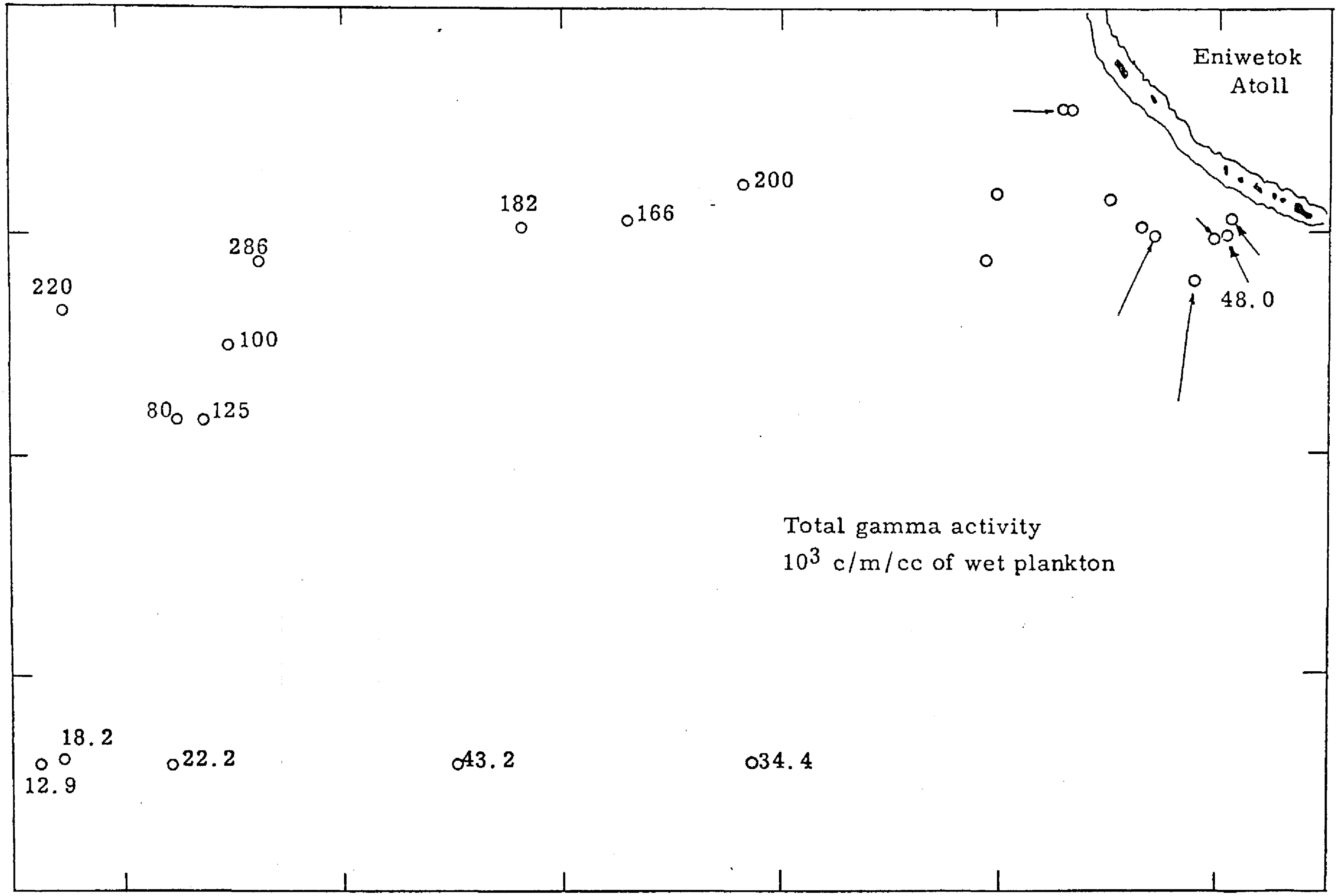

Figure 6. Total gamma activity of the post-Wahoo plankton samples.

given in Table 3 are based upon the calculated activity of the samples at the time of collection.

Levels of strontium-90

The results of the Sr^{90} determinations of plankton and a shrimp sample are given in Table 4. The only pre-Wahoo plankton samples that contained detectable amounts of Sr^{90} were samples P-6 and P-7, collected on the same day the Cactus device was detonated. Samples P-8 and P-12, collected 19 to 80 hours later, contained no Sr^{90}.

The plankton samples collected after Wahoo, however, contained levels of Sr^{90} that comprised from 0.0001 per cent to 0.04 per cent of the total beta radioactivity. Apparently the Wahoo detonation made a new source of Sr^{90} available to the plankton.

Fish and other organisms

Eight mid-water trawls were made during the survey, one of which was lost during the recovery operation. The following organisms were collected most frequently: euphausids, lantern fish, crab larvae, and miscellaneous macroplankton species. Eel larvae and small squid were obtained in two hauls. Silversides (fish of the family Atherinidae) and hatchet fish (Sternoptychidae) were obtained only once.

The gross beta radioactivity of the organisms collected in the mid-water trawl is given in Table 5. There was no detectable radioactivity in the samples collected before Wahoo (T-1 to T-4). Post-Wahoo

Table 4. Sr^{90} in samples collected aboard the USS Rehoboth May 6 to May 20, 1958. Analyses made January 21, 1959. Values expressed as d/m/g of dry weight at time of collection.

Sample		Date of collection	Gross beta activity 10^6 d/m/g	Sr^{90} d/m/g	Sr^{90} per cent of gross beta activity
P-6	Large plankton	5-6-58	290	2050	0.00070
P-7	" "	"	55	12	0.00002
P-8	" "	5-7	11	0	0
P-9	" "	"	4.0	0	0
P-10	" "	5-8	8.6	0	0
P-12	" "	5-10	0.0024	0	0
P-13	" "	5-16	32	6.0	
P-13)	Small plankton	"			
P-15)	" "	5-17	44.0	415	0.00090
P-15	Large plankton	5-17	4.8	1710	0.04000
P-16	" "	"	10	441	0.00400
P-17	" "	"	96	226	0.00020
P-18	" "	"	17	3280	0.02000
P-25)	" "	5-19	54	705	0.00010
P-26)	" "	"			
P-34)	" "	5-20	8.9	1030	0.01000
P-35)	" "	"			
T-7	Shrimp	5-18	3.2	0	0

Table 5. Gross beta radioactivity of the organisms collected in the mid-water trawls. Values expressed as d/m/g of dry weight at time of collection.

Sample no.	Maximum depth (meters)	Type of organism	d/m/g
T-1	180	Shrimp	Background**
		Plankton	Background**
T-2	180	Miscellaneous*	Background**
T-3	175	Miscellaneous*	Background**
T-4	6	Miscellaneous*	Background**
T-5	25	Fish	259, 000
		Shrimp	2, 680, 000
		Squid	3, 060, 000
T-7	365	Fish	1, 730, 000
		Shrimp	3, 240, 000
		Squid	900, 000
		Plankton (large)	114, 000
T-8	365	Fish	756, 000
		Shrimp	1, 050, 000
		Plankton (large)	106, 000

*Mixture of small fish, shrimp and plankton.
**Background, 16 c/m.

organisms, however, contained high amounts, and the radioactivity of the whole shrimp samples was approximately two to ten times as high as that of the whole fish.

Fish also were collected with three of the plankton samples, and two dolphins (Coryphaena hippurus) were caught by hook and line. The gross beta activity of these fish, of a squid, and of a portion of an alga (Turbinaria ornata*) collected during this period are given in Table 6.

Results of the radiochemical separations and gamma spectrum analyses of some samples in Table 6, as well as others, are given in Table 7.

Table 6. Gross beta radioactivity of the miscellaneous samples. Values expressed as d/m/g of dry weight at time of collection.

Sample No.	Organism	d/m/g x 10^3
P-7	Lantern fish (whole)	4,940
P-17	Jack "	82.9
P-35	Blenny "	69.0
F-1	Dolphin	
	muscle	12.0
	liver	7.1
F-2	Squid	
	muscle	62.6
	stomach	156
A-1	Alga(Turbinaria ornata)	5,840

*This alga is not pelagic and normally grows on the reef.

Table 7. Relative amounts of the radioisotopes present in fish, crustacea, squid, and in an alga collected May 6, 1958 to May 18, 1958.

	Relative amount of radioisotope								
Organism	Np^{239}	Te^{132} I^{132}	Mo^{99} Tc^{99m}	Ru^{103} Rh^{103}	Ba^{140} La^{140}	Zr^{95} Nb^{95}	Ru^{106} Rh^{106}	U^{237}	Ce^{141} Pr^{141}
Fish*	++++	+++	+	++	+	+		+	
Shrimp*	++++	++		+++	+		+	++	
Squid*	++++	+++		+				+	
Fish**	++++	++	+	+	+			+	
Shrimp**	++++	+++							
Lantern fish**	++++	+++	+						
Jack	++++	+++	++					+	
Dolphin (liver)	++++	++		++					
Alga(*Turbinaria ornata*)					++				+++

+ = low amount, 5 per cent of total activity; ++ = 6-20 per cent of total activity; +++ = 21-49 per cent of total activity; ++++ = 50 per cent of total activity.
*Collected in mid-water trawl T-5; **collected in mid-water trawl T-7.

DISCUSSION

The extent of contamination of the water immediately following the Wahoo detonation was determined by means of gamma survey meters. This initial survey showed that at W + 1-1/2 (one and one-half hours after Wahoo) the area of contamination extended one and one-half miles southeast of the target, and at W + 2-1/2, it extended about four miles west of target zero. The radioactivity of water samples taken at W + 5, about two miles southwest of target zero, was found mostly above the thermocline, although some radioactivity was found in the deeper samples.

At W + 27, survey meter measurements taken four miles west of target zero were not significantly greater than the pre-Wahoo levels. However, gross beta activity determinations of water from the same area contained high levels of radioactivity in the uppermost 50 meters and lesser amounts in the deeper water. At W + 48, in water samples taken at target zero, the greatest amount of radioactivity was in the samples taken below the thermocline. These data show that the deeper water was moving horizontally at a slower rate than the water above the thermocline.

The radioactivity measurements of the plankton showed that in three days the contamination had extended at least 50 miles to the west of target zero. Samples taken 20 miles to the south, about 10 hours later, contained the lowest levels of gamma radioactivity. The low levels in the plankton from this location indicated that the southwestern perimeter of the contaminated water mass at this time was only a few miles away. The low level of radioactivity also suggests that the radioactive water had travelled primarily in a westward rather than a southwestward direction.

The radioisotopic composition of the plankton samples collected before and after the Wahoo detonation is given in Table 3. Np^{239} was the major contributor in all of the samples, but the relative amounts of Mo^{99}-Tc^{99m}, Te^{132}-I^{132}, and U^{237} differed, Mo^{99}-Tc^{99m} was much higher and Te^{132}-I^{132} was much lower in the pre-Wahoo sample. Ru^{105}-Rh^{105} was detected in one post-Wahoo sample and Ru^{106}-Rh^{106} was detected in one pre-Wahoo sample.

These differences in radioisotopic content may be used to establish the origin of the radioactive material in the samples collected during the survey. As seen in Table 3, the radioisotopes in samples P-25 and P-26, collected at the western periphery, were similar to the radioisotopes in earlier samples; therefore, it was assumed that the origin of the radioactive material was the same for all samples collected after the Wahoo detonation.

Results of radiochemical separations and gamma spectrum analyses revealed that the percentages of Ba^{140}-La^{140} and U^{237} were higher in large plankton and Mo^{99}-Tc^{99m} were higher in small plankton; otherwise the radioisotopic compositions were similar.

Analysis of sea water collected shortly after another underwater detonation (Umbrella), in the lagoon at Eniwetok, showed that Np^{239}, Te^{132}-I^{132}, Ce^{143}-Pr^{143}, and Mo^{99}-Tc^{99m} were the predominant radioisotopes in the particulate matter ($>0.45\mu$) present in the surface water near target zero (Table 8).

Table 8. Percentage of gamma emitting radioisotopes in the particulate ($>0.45\mu$) and soluble ($<0.45\mu$) form in sea water collected 75 minutes after the Umbrella event.[8]

Radioisotope	Particulate 10^6 d/m/l	Per cent of particulate activity	Soluble 10^6 d/m/l	Per cent of soluble activity
Np^{239}	5.2	62.5	30.0	75.6
U^{237}	0.02	0.2	4.0	10.1
Te^{132}-I^{132}	1.9	22.3	1.9	4.7
Mo^{99}-Tc^{99m}	0.48	5.8	3.1	7.8
Ce^{141}-Pr^{141}	0.028	0.3		0
Ce^{143}-Pr^{143}	0.66	7.9		0
Ce^{144}-Pr^{144}	0.0028	<0.1		0
Ba^{140}-La^{140}	0.076	0.9	0.7	1.8

Some of these isotopes also were present in high amounts in the $<0.45\mu$ fraction (Table 8), which could include materials in the colloidal form. These radioisotopes, with the exception of Ce^{143}-Pr^{143}, were also the predominant ones in the plankton collected after Wahoo, a weapons testing device identical to Umbrella.[12] These data suggest that in the first few days after detonation of a nuclear device these radioisotopes are mostly insoluble and that in this form they are removed from the water by the plankton.

In considering the distribution of radioactivity in the sea following a nuclear detonation, the role of the plankton should be considered. To estimate the relative amounts of radioactivity in water and plankton samples, the amount of water strained by the plankton net was calculated in the following manner.

The total volume of water filtered was calculated to be the product of the distance the net was towed, the filtering efficiency of the net (50 per cent), and its cross-sectional area. When the radioactivity of the total volume of water that passed through the net was calculated and compared with the radioactivity of the plankton in the same volume of water, the value for the water was found to be several thousand times greater (Table 9). This comparison indicates that the removal of radioactivity from the water by the plankton was apparently a minor factor, at least in the first 48 hours after detonation.

The amount of Sr^{90} in the samples varied from 0 to 0.04 per cent of the gross beta activity. These values agree well with those obtained

Table 9. Comparison of the gross beta activity of the total plankton and total water strained for three samples collected after the Wahoo detonation.

Sample	Date	Hour	Total volume Water M^3	Total volume Plankton cc	d/m/total volume Water	d/m/total volume Plankton	d/m/total volume water / plankton
P-14	5/16/58	1907		8		1.7×10^6	4,400
W-1	5/16/58	1910	90		7.5×10^9		
P-17	5/17/58	1705		14		5.2×10^6	11,000
W-2	5/17/58	1653	180		5.7×10^{10}		
P-19	5/18/58	1040		10		1.1×10^6	3,000
W-3	5/18/58	1348	180		3.3×10^9		

in other investigations of the levels of Sr^{90} in marine organisms in the open sea [3, 4, 7, 11].

The low levels of Sr^{90} in the plankton may be due to the low amounts present at the time of collection and to the unavailability of Sr^{90}, which may be explained on the basis of solubility, coprecipitation with calcium carbonate, competition with calcium, and isotopic dilution by stable strontium [7].

The small fish collected after Wahoo had essentially the same radioisotopic composition as the plankton samples. A sample of dolphin liver obtained before Wahoo contained Np^{239}, Ru^{103}-Rh^{103}, and Te^{132}-I^{132} but no detectable amounts of the other radioisotopes which were found in the smaller fish and in the plankton.

Samples of whole shrimp and squid had high levels of Np^{239} and relatively higher levels of Te^{132}-I^{132} than the plankton. However, they contained no detectable amounts of Mo^{99}-Tc^{99m}.

Because these data indicate that some discrimination occurs in the uptake of radioisotopes by marine organisms, it would be of interest to determine which isotopes are incorporated or metabolized by these organisms. Some of the radioisotopes were concentrated rapidly by samples of mixed plankton species; knowledge of their concentration and fate in single species of plankton would be of interest.

SUMMARY

1. A survey of the radioactivity of sea water and marine organisms was conducted at the Eniwetok Test Site from May 3, 1958 to May 20, 1958, immediately before and after an underwater nuclear detonation.

2. Seventy-two hours after the underwater nuclear detonation, Wahoo, the radioactive water mass thus produced extended more than 50 miles westward from site zero, both above and below the thermocline.

3. The radioisotopic composition of the plankton and other marine organisms was determined by means of ion-exchange separations and gamma spectrum analyses.

4. Np^{239} was the major radioisotope present in all of the samples, contributing more than 50 per cent of the total radioactivity.

5. Other radioisotopes present in the plankton in the order of contribution were: Te^{132}-I^{132}, Mo^{99}-Tc^{99m}, Ba^{140}-La^{140}, U^{237}, Ce^{141}-Pr^{141}, Ru^{103}-Rh^{103}, Zr^{95}-Nb^{95} and Ce^{144}-Pr^{144}. Ru^{105}-Rh^{105} and Ru^{106}-Rh^{106} were detected only once.

6. Small whole fish contained essentially the same radioisotopes as the plankton. A liver sample from a large dolphin (fish) contained only Np^{239}, Ru^{103}-Rh^{103}, and Te^{132}-I^{132}.

7. Shrimp and squid samples concentrated Np^{239} and Te^{132}-I^{132} but contained no Mo^{99}-Tc^{99m}.

LITERATURE CITED

1. Aron, W. 1958. Preliminary report of midwater trawling studies in the North Pacific Ocean. Tech. Report No. 58. Univ. of Washington (Oceanography).

2. Donaldson, L. R. et al. 1956. Survey of radioactivity in the sea near Bikini and Eniwetok Atolls, June 11-21, 1956. U. S. AEC Report UWFL-46. Off. Tech. Services, U. S. Dept. of Commerce.

3. Harley, J. H. (Ed.). 1956. Operation Troll. U. S. AEC Report NYO-4656. Off. Tech. Services, U. S. Dept. of Commerce.

4. Hiyama, Y. and R. Ichikawa. 1957. Uptake of strontium by marine fish from the environment. Records of Oceanographic Works in Japan (Tokyo), 3:78-84.

5. Kawabata, T. and E. E. Held. A method for determining strontium-90 in biological samples. Lab. of Radiation Biology, Univ. of Washington. Unpublished.

6. Kraus, K. A. and G. E. Moore. 1953. Anion exchange studies. VI. The divalent transition elements manganese to zinc in hydrochloric acid. Anal. Chem. 75:1460-1462.

7. Lowman, F. G. 1958. Radionuclides in plankton near the Marshall Islands, 1956. U. S. AEC Report UWFL-54. Off. Tech. Services, U. S. Dept. of Commerce.

8. Lowman, F. G. 1959. ms.

9. Lowman, F. G., R. F. Palumbo, and D. J. South. 1957. The occurrence and distribution of radioactive non-fission products in plants and animals of the Pacific Proving Ground. U. S. AEC Report UWFL-51. Off. Tech. Services, U. S. Dept. of Commerce.

10. Miyake, Y., Y. Sugiura, and K. Kameda. 1956. On the distribution of the radioactivity in the sea around Bikini Atoll in June, 1954. In Research in the Effects and Influences of the Nuclear Bomb Test Explosions, II. Japan Society for Promotion of Science (Tokyo), pp. 953-964.

11. Mori, T., M. Saiki, K. Shirai, and S. Ohno. 1956. Studies on the radioelements in the contaminating radioactive skipjacks caught at the Pacific Ocean in 1956. Report of the investigation of the influence of the atom explosion (Examination on the land). Ministry of Health and Welfare, Bur. of Pub. Sanitation (Tokyo).

12. Operation Hardtack, Task Group 7.1 Operation Plan No. 1-58. 1958. Report No. J-3-H-600. Joint Task Force Seven, Los Alamos, N. Mex.

13. Palumbo, R. F. and F. G. Lowman. 1958. The occurrence of antimony-125, europium-155, iron-55, and other radionuclides in Rongelap Atoll soil. U. S. AEC Report UWFL-56, Off. Tech. Services, U. S. Dept. of Commerce.

14. Seymour, A. H. et al. 1957. Survey of radioactivity in the sea and in pelagic marine life west of the Marshall Islands, September 1-20, 1956. U. S. AEC Report UWFL-47, Off. Tech. Services, U. S. Dept. of Commerce.

15. Strominger, D., J. M. Hollander and G. T. Seaborg. 1958. Table of Isotopes. Revs. Modern Physics, Vol. 30, No. 2.

16. Wish, L. 1957. Quantitative ion-exchange separations for sequential radiochemical analysis. U. S. Naval Radiological Defense Lab. Report USNRDL-TR-185.

17. Yagi, M. 1956. Radiological survey of western area of the dangerous zone around the Bikini-Eniwetok Atolls, investigated by the "Shunkotsu Maru" in 1956. Pt. I (Ch. V). Research Division, Fisheries Agency, Japan.

A P P E N D I X

Appendix Table A. Log of the plankton samples collected aboard the USS Rehoboth during May 1958.

Sample no.	Collected		Position		Time (min)	cc	Depth of plankton tow (m)	Temp. °F		Depth of thermocline (m)
	Date	Hour	°N. Lat.	°E. Long.				Haul depth	surface	
	May									
P-1	4	1540	11 20.4'	162 09.2'	35	18	274	51	84	100
P-2	4	1945	11 16.1	162 08.6	95	50	207	58	81.8	110
P-3	5	1423	11 21.0	162 08.6	55	23	197	59.4	82.3	90
P-4	5	1950	11 21.6	162 06.7	45	10	189			
P-6	6	1615	11 23.1	162 07.6	18	10	183	63	82.2	85
P-7	6	1953	11 19.9	162 06.6	43	30	201	58	81.3	80
P-8	7	1427	11 22.6	162 08.1	36	18	183	59.2	82	110
P-9	7	1637	11 24.4	162 07.0	38	25	189	62	82.4	100
P-10	8	1845	11 24.2	162 06.0	67	34	183	56	81.7	105
P-11	9	1225	11 21.4	162 09.3	48	10	186	63	81.6	125
P-12	10	1300	11 21.3	162 08.6	125	37	192	63	81.6	105
P-13	16	1609	11 20.0	162 07.4	37	22	12 & 8		81.9	
P-14	16	1907	11 19.3	162 09.4	23	8	25			
P-15	17	1015	11 18.7	161 59.5	30	20	60			*
P-16	17	1405	11 21.4	161 59.8	63	15	102		81.7	85*
P-17	17	1705	11 20.5	162 06.7	55	14	98	79		
P-18	17	2140	11 21.4	162 04.5	15	7	183			*
P-19	18	1040	11 20.0	162 09.7	35	10	183	68	85	105
P-20	18	1830	11 25.8	162 03.2	60	27	186	61.5	81.5	80
P-21	18	2304	11 25.6	162 03.2	36	15	45 & 12			*
P-22	19	0858	11 22.0	161 47.7	16	12	30	86*		

*Faulty BT (bathythermograph), trace not clear

Appendix Table A. (continued)

Sample no.	Collected Date	Collected Hour	Position °N. Lat.	Position °E. Long.	Time (min)	cc	Depth of plankton tow (m)	Temp. °F Haul at depth	Temp. °F surface	Depth of thermocline (m)
P-23	19	1000	11 20.9	161 43.1	15	10	30			
P-24	19	1100	11 20.2	161 38.3	15	15	30	87*		
P-25	19	1230	11 18.4	161 28.2	15	5	30			
P-26	19	1352	11 16.6	161 17.6	15	8	46	85*		
P-27	19	1814	11 14.8	161 25.0	15	12	49	86*		
P-28	19	1935	11 11.3	161 23.5	15	10	49	86*		
P-29	19	2004	11 11.3	161 22.8	18	10	30	85.5*		
P-30	20	0101	10 56.0	161 17.4	15	18	3 & 6			
P-31	20	0145	10 56.0	161 16.4	15	15	46			
P-32	20	0400	10 56.0	161 22.0	17	12	46			
P-33	20	0617	10 56.0	161 35.2	18	4	50	84*		
P-34	20	0855	10 56.0	161 49.0	18	25	49	85.5*		
P-35	20	1510	11 20.0	162 10.0	20	9	52	82.1		
P-36	26	0945	11 20.7	162 10.7	36		253	53.4	81.7	80

*Faulty BT (bathythermograph), trace not clear.

Appendix Table B. Log of the mid-water trawl samples.

Sample no.	Collected Date	Collected Hour	°N. Lat.	°E. Long.	Time (min)	Maximum depth (m)	Cable length (m)	Temp. °F Haul depth	Temp. °F Surface	Depth of thermocline (m)
T-1	5/4/58	1114	11 18.4	162 04.3	62	177	640	60	82	120
T-2	5/4/58	1252	11 23.0	162 00.2	98	177	640	59	82	90
T-3	5/4/58	2205	11 16.7	162 06.6	75	175	640	62	81.6	90
T-4	5/7/58	2240	11 18.3	162 03.1	35	6	99			
T-5	5/16/58	2215	11 18.2	162 07.5	65	24	146			
T-6	Lost									
T-7	5/18/58	1518	11 23.5	162 04.8	207	366	1830			
T-8	5/20/58	1306	11 04.2	162 10.2	118	366	1830			

Appendix Table C. Log of the miscellaneous samples.

Sample no.	Organism	Collected Date	Collected Hour	Position °N. Lat.	Position °E. Long.	Depth (m)
P-7	Lantern fish	5/6/58	1953	11 19.9	162 06.9	201
P-17	Jack	5/17/58	1705	11 20.5	162 06.7	98
P-35	Blenny	5/20/58	1510	11 20	162 10	52
F-1	Dolphin	5/19/58	1640	11 11	162 37.6	surface
F-2	Squid	5/19/58	0500	11 20	162 10	surface
A-1	Alga (<u>Turbinaria ornata</u>)	5/18/58	1800	11 26.7	162 00.3	surface

Appendix Table D. Radioactivity of the plankton. Correction factors used to convert counts per minute at time of initial count to d/m/g dry weight at time of collection.

Sample no.	Initial count Date	Hour	c/m	Decay factor	At time of collection c/m	Dry weight	c/m/g	d/m/g*** dry weight
P-1	5/4		5	*	5	.205	107	374
P-2	"		10	"	10	.123	244	854
P-3	5/5		14	"	14	.141	99	346
P-4	"		16	"	16	.129	124	434
P-6	5/11	0845	111,416	**	1,500,000	.018	83,300,000	292,000,000
P-7	5/9	1355	56,681	"	350,000	.023	15,000,000	53,200,000
P-8	5/7	1605	89,398	"	94,000	.029	3,240,000	11,300,000
P-9	"	1950	29,922	"	33,500	.029	1,160,000	4,060,000
P-10	5/9	1350	52,526	"	71,000	.029	2,450,000	8,580,000
P-11	5/9	1720	4,799	"	5,200	.043	121,000	424,000
P-12	5/10	2155	26	"	37	.053	698	2,440
P-13	5/16	1715	84,602	"	92,000	.010	9,200,000	32,200,000
P-14	"	2012	18,749	"	22,000	.0003	73,300,000	257,000,000
P-15	5/17	1115	6,692	"	6,800	.005	1,360,000	4,760,000
P-16	5/17	1620	14,508	"	14,700	.005	2,940,000	10,300,000
P-17	"	1845	101,598	"	110,000	.004	27,500,000	96,200,000
P-18	"	2320	23,324	"	24,900	.005	4,980,000	17,400,000
P-19	"	1940	99,054	"	115,000	.016	7,190,000	25,200,000
P-20	"	2047	57,980	"	62,000	.014	4,430,000	15,500,000

*No decay factor used because of low counts and long half lives.
**Decay extrapolated from decay curves.
***Includes correction factor for self-absorption, geometry, and back scatter (3.5).

Appendix Table D. - continued

Sample no.	Initial count Date	Hour	c/m	Decay factor	At time of collection c/m	Dry weight	c/m/g	d/m/g*** dry weight
P-21	5/19	0733	64,795	**	77,000	.008	9,620,000	33,700,000
P-22	6/6	0750	8,341	"	90,083	.017	5,300,000	18,600,000
P-23	"	0755	14,756	"	159,365	.012	13,300,000	46,600,000
P-24	"	0800	30,578	"	330,242	.032	1,030,000	3,600,000
P-27	"	0830	7,084	"	76,507	.035	2,190,000	7,660,000
P-28	"	0840	10,879	"	117,493	.034	3,460,000	12,100,000
P-29	"	0900	10,860	"	117,288	.015	7,820,000	27,400,000
P-30	"	0910	1,592	"	17,194	.008	2,150,000	7,520,000
P-31	"	0930	3,116	"	33,653	.017	1,980,000	6,930,000
P-33	"	1100	2,690	"	29,052	.032	908,000	3,180,000
P-36	5/30	1030	3,888	"	29,549	.045	657,000	2,300,000

** Decay extrapolated from decay curves.
*** Includes correction factor for self-absorption, geometry, and back scatter (3.5).

Appendix Table E. Radioactivity of the mid-water trawl organisms. Correction factors used to convert counts per minute at time of initial count to d/m/g dry weight at time of collection.

Sample no.	Organism	Initial count			Decay factor	At time of collection			
		Date	Hour	c/m		c/m	dry wt.	c/m/g	d/m/g***
T-5	Fish	5/17	0015	15,678	1.28*	20,000	.270	74,100	259,000
	Shrimp	"	"	65,823	1.18*	66,000	.086	767,000	2,680,000
	Squid	"	0913	91,271	1.005*	91,700	.105	873,000	3,060,000
T-7	Fish	5/18	2215	46,802	1.11*	52,000	.105	495,000	1,730,000
	Shrimp	"	2223	85,536	1.15*	98,000	.106	925,000	3,240,000
	Squid	"	2220	25,377	1.06*	27,000	.105	257,000	900,000
	Macroplankton	6/5	1030	4,166	1.15	4,790	.147	32,600	114,000
T-8	Fish	5/30	1638	1,673	7.5**	12,550	.058	216,000	756,000
	Shrimp	"	"	12,038	7.1**	85,500	.285	300,000	1,050,000
	Macroplankton	"	1635	949	7.1**	6,740	.223	30,200	106,000

*Calculated from decay curves
** " " " " (T-7 samples)
***Includes correction factor for self-absorption, geometry and back scatter (3.5).

Appendix Table F. Radioactivity of the miscellaneous organisms. Correction factors used to convert counts per minute at time of initial count to d/m/g dry weight at time of collection.

Sample no.	Organism	Initial count Date	Hour	c/m	Decay factor*	At time of collection c/m	dry wt.	c/m/g	d/m/g**
P-7	Lantern fish	5/30/58	1645	1,112	62.0	69,000	.049	1,410,000	4,940,000
P-17	Jack	5/17/58	1908	2,277	1.03	2,320	.098	23,700	82,900
P-35	Blenny	5/30	1641	743	3.97	2,950	.150	19,700	69,000
F-1	Dolphin								
	Muscle	5/30	1643	145	4.55	660	.192	3,440	12,000
	Liver	5/27	1300	331	2.96	980	.482	2,030	7,100
F-2	Squid								
	Muscle	5/19	0933	3,155	1.01	3,200	.179	17,900	62,600
	Stomach	"	1046	12,263	1.06	13,000	.291	44,700	156,000
A-1	Alga (*Turbinaria ornata*)	5/18	1852	44,708	1.00	45,000	.027	1,670,000	5,840,000

* Calculated from decay curves.

** Includes correction factor for self-absorption, geometry and backscatter (3.5).

Appendix Table G. Radioactivity of the water (particulate matter). Correction factors used to convert counts per minute at time of initial count to d/m/l at time of collection.

Sample no.	Depth (m)	Initial count Date	Hour	c/m	Decay factor*	At time of collection c/m	d/m**	Volume (l)	d/m/l
W-1-513	0	5/16	2317	3,636	1.86	6,760	22,300	.350	63,700
" 514	5	"	"	5,502	1.71	9,410	31,000	.500	62,000
" 515	25	"	2310	736	2.11	1,550	5,120	"	10,200
" 516	50	"	"	2,030	1.64	3,330	11,000	"	22,000
" 517	100	5/17	0005	431	1.34	580	1,910	"	3,820
" 518	200	"	"	147	1.90	280	924	.490	1,890
" 519	300	"	0200	274	1.71	469	1,550	.500	3,100
W-2-520	0	5/17	1635	4,499	1.02	4,600	15,200	.500	30,400
" 521	29	"	1630	3,698	1.01	3,700	12,210	"	24,400
" 522	48	"	1757	2,743	1.06	2,900	9,570	"	19,100
" 523	72	"	1820	1,449	1.04	1,500	4,950	"	9,900
" 524	96	"	1815	1,092	1.05	1,150	3,800	"	7,600
" 525	145	5/24	1800	108	1.04	112	370	"	740
" 526	293	5/17	1808	361	1.05	380	1,250	"	2,500
W-3-527	0	5/18	1600	525	1.00	525	1,730	.500	3,460
" 528	30	"	1520	354	1.00	354	1,170	"	2,340
" 529	50	"	"	437	1.05	460	1,520	"	3,040
" 530	75	"	1540	497	1.05	520	1,720	"	3,440
" 531	100	"	1600	9,498	1.03	9,800	32,300	"	64,600
" 532	150	"	1500	791	1.01	800	2,640	"	5,280
" 533	300	"	"	4,320	1.01	4,400	14,500	"	29,000

*Calculated from decay curves

**Includes correction factor for self-absorption, geometry and backscatter (3.3).

Appendix Table H. Radioactivity of the water (filterable portion less K^{40}). Correction factors used to convert counts per minute at time of initial count to d/m/l at time of collection.

Sample no.	Depth (m)	Initial count			Decay factor*	At time of collection			
		Date	Hour	c/m		c/m	d/m**	Volume (l)	d/m/l
W-1-513	0	5/16	2332	2,757	1.42	3,900	15,600	.100	156,000
" 514	5	"	"	1,438	2.02	2,900	11,600	.100	116,000
" 515	25	5/17	0025	1,065	1.72	1,830	7,320	"	73,200
" 516	50	"	"	435	1.72	748	2,990	"	29,900
" 517	100	"	0200	327	1.72	562	2,250	"	22,500
" 518	200	"	0210	443	1.72	762	3,050	"	30,500
" 519	300	"	0200		1.72				
W-2-520	0	5/17	1828	3,135	1.05	3,300	13,200	.080	165,000
" 521	29	"	1824	2,578	1.18	3,040	12,200	"	152,000
" 522	48	"	1919	2,402	1.18	2,830	11,300	"	141,000
" 523	72	"	1850	1,180	1.02	1,200	4,800	"	60,000
" 524	96	"	1915	404	1.18	477	1,910	"	23,900
" 525	145	"	1922	337	1.54	520	2,080	"	26,000
" 526	293	"	1913	588	1.09	640	2,560	"	32,000
W-3-527	0	"	1630	180	1.31	236	944	.080	11,800
" 528	30	"	1650	273	1.03	282	1,130	"	11,100
" 529	50	"	1705	200	1.10	220	880	"	11,000
" 530	75	"	1650	198	1.10	218	872	"	10,900
" 531	100	"	1645	1,438	1.02	1,470	5,880	"	73,500
" 532	150	"	1630	235	1.10	258	1,030	"	12,900
" 533	300	"	1645	892	1.10	981	3,920	"	49,000

*Calculated from decay curves.

**Includes correction factor for self-absorption, geometry and backscatter (4.0).