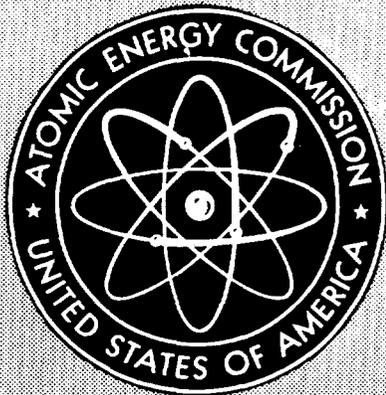


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RADIONUCLIDE CONTENT OF OCEANIC FISH, PLANKTON,
AND WATER IN THE VICINITY OF CHRISTMAS
ISLAND, MARCH THROUGH AUGUST, 1962

By
Arthur D. Welander
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September 4, 1963

Laboratory of Radiation Biology
University of Washington
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RADIONUCLIDE CONTENT OF OCEANIC FISH, PLANKTON,
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MARCH THROUGH AUGUST, 1962

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Seattle, Washington

Lauren R. Donaldson
Director

September 4, 1963

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United States Atomic Energy Commission

fall by Japanese long-line vessels. It is suspected that tuna migrate through the Christmas Island area enroute to other fishing grounds, thus the fish caught in these waters may enter the world tuna market (Shomura, 1962).

Acknowledgements

We gratefully acknowledge the assistance of many people and are especially indebted to Mr. Jack Marr and Mr. Robert T. B. Iverson, U. S. Fish and Wildlife Service, Honolulu, for making the necessary arrangements for use of the ship; to the Units of Joint Task Force Eight, including the U. S. Navy for advice in establishing the cruise plans and Holmes and Narver, Incorporated, for providing a communications officer during one of the surveys; to Captain Harold W. Casey, Veterinary Corps, U. S. Air Force for valuable assistance in the laboratory; to Dr. Ole A. Mathisen of the Fisheries Research Institute, Seattle, and to Dr. Roy E. Nakatani of the Hanford Atomic Products Operation Radiobiological Laboratories, for valuable assistance in the collection of samples while aboard the Charles H. Gilbert and in the field laboratory; and to all the members of the Laboratory of Radiation Biology for their invaluable assistance in the preparation and counting of the samples.

MATERIALS AND METHODS

The time and extent of the collections were determined by the availability of the vessel. The areas sampled were based upon fallout patterns and the restrictions on navigation imposed by Joint Task Force Eight. The locations of the stations occupied during the four cruises are shown in Figure 1 and the details of the sampling schedule are given in Table 1.

The Charles H. Gilbert, under the command of Captain William Tanaka and Field Party Chief Robert T. B. Iverson, collected fish and plankton at two stations (Cruise 55) before the start of Operation Dominic. Two members of the Laboratory of Radiation Biology participated in later cruises, two during the testing period (Cruises 56 and 57) and one after the test series had been completed (Cruise 59). Cruises 56 and 57 were made to the north and to the southeast of Christmas Island along the path of the prevailing upper winds; Cruise 59 was made to the west in the direction of flow of the surface water currents.

The Charles H. Gilbert, a 120-foot vessel, is equipped for oceanographic investigations as well as long-line fishing, for live-bait fishing, and for underwater observations from a bow and stern chamber. Tuna and other climax predators were caught mostly by Japanese long-line fishing methods which have been described in detail by Mann (1955).

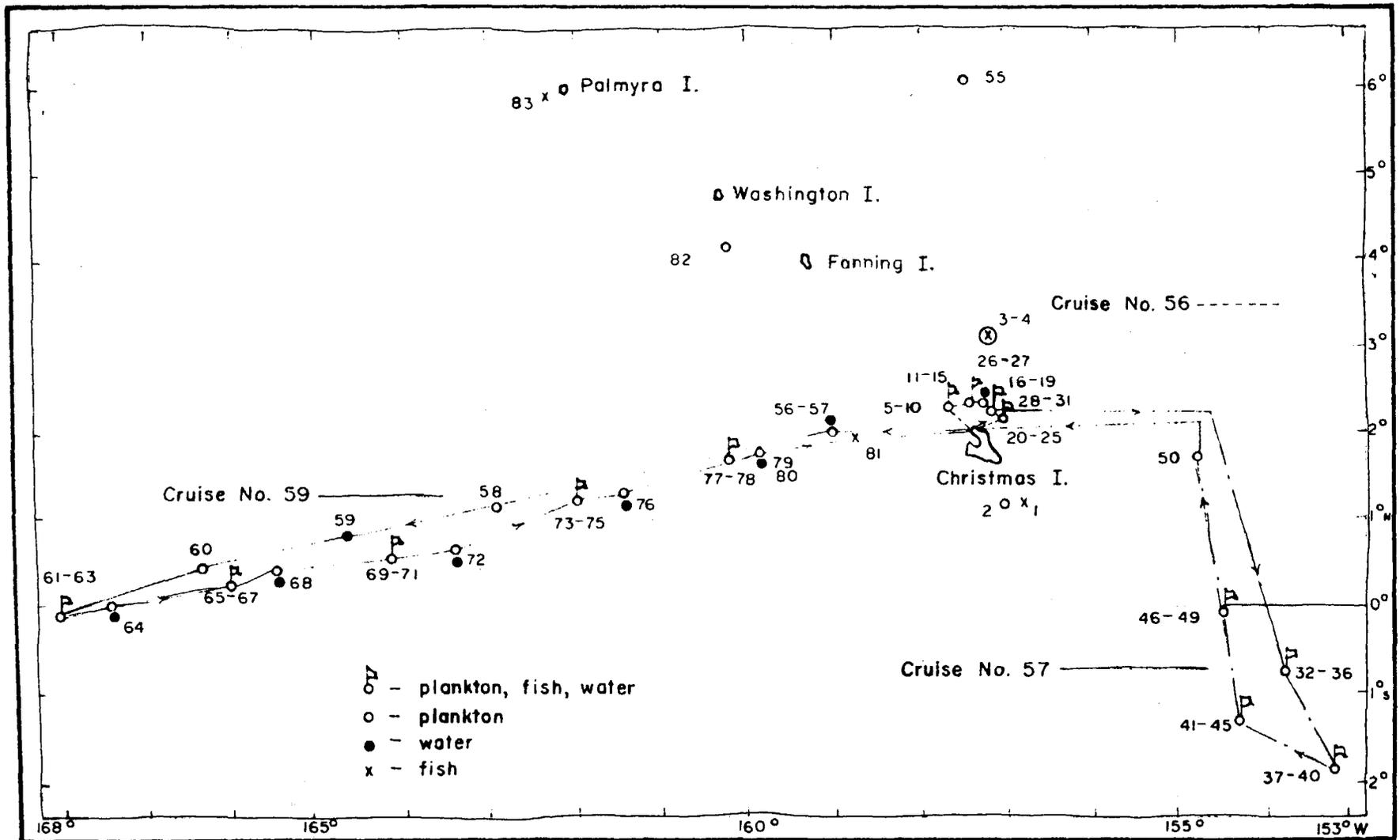


Fig. 1. Tracks of the cruises of the Charles H. Gilbert (USFWS 1003) during Operation Dominic: Cruise 55, Stations 1-4, March 1962; Cruise 56, Stations 5-27, May 1962; Cruise 57, Stations 28-50, June 1962; and Cruise 59, Stations 51-87, August 1962.

Table 1. Details of the stations occupied by the Charles H. Gilbert (USFWS-1003),
March through August, 1962.

Cruise, Station no.	Location		Date 1962	Sample collected	Depth (m) or gear
	Latitude	Longitude			
<u>Cruise No. 55</u>					
1	1° 07'N	156° 45'W	March 28	Fish	LL*
2	1° 06'N	157° 04'W	March 28	Plankton	0,50**
3	3° 02'N	157° 12'W	March 29	Fish	LL
4	3° 06'N	157° 13'W	March 29	Plankton	0,50
<u>Cruise No. 56</u>					
5	2° 10'N	157° 41'W	May 2	Plankton	0,50
6	2° 13'N	157° 38'W	May 2	Water	0-300***
7	2° 14'N	157° 39'W	May 2	Fish	MW
8	2° 10'N	157° 39'W	May 3	Fish	LL
9	2° 9'N	157° 43'W	May 3	Plankton	50
10	2° 10'N	157° 41'W	May 3	Water	0-300
11	2° 18'N	157° 25'W	May 4	Fish	LL
12	2° 18'N	157° 28'W	May 4	Plankton	50
13	2° 19'N	157° 26'W	May 4	Water	0-300
14	2° 19'N	157° 25'W	May 4	Plankton	0,50
15	2° 19'N	157° 21'W	May 4	Fish	MW
16	2° 10'N	157° 08'W	May 5	Fish	LL
17	2° 8'N	157° 14'W	May 5	Water	0-300
18	2° 10'N	157° 15'W	May 5	Plankton	50
19	2° 9'N	157° 10'W	May 5	Plankton	0,50
20	2° 10'N	156° 57'W	May 6	Fish	LL
21	2° 9'N	157° 08'W	May 6	Water	0-300
22	2° 9'N	157° 08'W	May 6	Plankton	50
23	2° 8'N	157° 02'W	May 6	Plankton	50
24	2° 8'N	157° 02'W	May 6	Fish	MW
25	2° 9'N	157° 00'W	May 7	Fish	LL
26	2° 14'N	157° 16'W	May 7	Water	0-300
27	2° 14'N	157° 16'W	May 7	Plankton	50
<u>Cruise No. 57</u>					
28	2° 16'N	157° 07'W	June 12	Fish	LL
29	2° 10'N	157° 14'W	June 12	Water	0-300
30	2° 11'N	157° 16'W	June 12	Plankton	50
31	2° 14'N	157° 03'W	June 12	Plankton	50
32	0° 46'S	153° 44'W	June 14	Fish	LL
33	0° 48'S	153° 50'W	June 14	Plankton	50
34	0° 46'S	153° 49'W	June 14	Water	0-300
35	0° 39'S	153° 31'W	June 14	Fish	MW
36	0° 38'S	153° 28'W	June 14	Plankton	0,50
37	1° 59'S	153° 12'W	June 15	Fish	LL
38	1° 58'S	153° 20'W	June 15	Water	0-300
39	1° 58'S	153° 20'W	June 15	Plankton	50
40	1° 54'S	153° 13'W	June 15	Plankton	0,50
41	1° 22'S	154° 14'W	June 16	Fish	LL
42	1° 22'S	154° 22'W	June 16	Water	0-300
43	1° 22'S	154° 22'W	June 16	Plankton	50
44	1° 20'S	154° 19'W	June 16	Plankton	0,50
45	1° 20'S	154° 17'W	June 16	Fish	MW
46	0° 5'S	154° 32'W	June 17	Fish	LL
47	0° 5'S	154° 39'W	June 17	Water	0-300
48	0° 5'S	154° 38'W	June 17	Plankton	50
49	0° 2'S	154° 17'W	June 17	Plankton	0,50
50	1° 43'N	154° 50'W	June 18	Plankton	0

*LL - Longline
 **30 minutes haul at depth designated
 ***0-300, surface, 25, 50, 100, and 300 meters.

Table 1. (continued)

Cruise, Station no.	Location		Date 1962	Sample collected	Depth (m) or gear
	Latitude	Longitude			
<u>Cruise No. 59</u>					
51	19° 42'N	157° 23'W	July 23	Plankton	0
52	16° 14'N	157° 49'W	July 24	Plankton	0
53	12° 49'N	157° 57'W	July 25	Plankton	0
54	9° 23'N	158° 14'W	July 26	Plankton	0
55	6° 3'N	157° 36'W	July 27	Plankton	0
56	1° 56'N	159° 3'W	July 29	Plankton	0,50
57	1° 57'N	159° 3'W	July 29	Water	0
58	1° 6'N	162° 52'W	July 30	Plankton	0,50
59	0° 46'N	164° 40'W	July 31	Water	0
60	0° 24'N	166° 23'W	July 31	Plankton	0,50
61	0° 6'S	168° 2'W	August 1	Fish	LL
62	0° 10'S	168° 7'W	August 1	Water	0,100
63	0° 10'S	168° 7'W	August 1	Plankton	50
64	0° 0'N	167° 29'W	August 1	Plankton, water	0
65	0° 20'N	165° 58'W	August 2	Fish	LL
66	0° 20'N	166° 4'W	August 2	Water	50,100
67	0° 20'N	166° 4'W	August 2	Plankton	50
68	0° 26'N	166° 4'W	August 2	Plankton, water	0
69	0° 34'N	164° 00'W	August 3	Fish	LL
70	0° 31'N	164° 6'W	August 3	Plankton, water	50,100
71	0° 31'N	164° 6'W	August 3	Plankton, water	0
72	0° 39'N	163° 27'W	August 3	Plankton, water	0
73	1° 14'N	161° 56'W	August 4	Fish	LL
74	1° 13'N	162° 2'W	August 4	Plankton, water	50,100
75	1° 13'N	162° 2'W	August 4	Plankton, water	0
76	1° 19'N	161° 30'W	August 4	Plankton, water	0
77	1° 40'N	160° 16'W	August 5	Fish	LL
78	1° 39'N	160° 20'W	August 5	Plankton, water	50,100
79	1° 48'N	159° 54'W	August 5	Plankton, Water	0
80	1° 48'N	159° 54'W	August 5	Plankton, water	0
81	1° 59'N	158° 44'W	August 6	Fish	Live bait
82	4° 8'N	160° 18'W	August 9	Plankton	0
83	5° 54'N	162° 17'W	August 10	Fish	Live bait
84	7° 4'N	161° 40'W	August 11	Plankton	0
85	11° 8'N	160° 24'W	August 12	Plankton	0
86	14° 31'N	159° 31'W	August 13	Plankton	0

Long-line gear was fished at 17 stations during the four cruises. Sixty "baskets" of 6-hook, 180 to 210-fathom mainline gear with 16-fathom droppers were fished at each station. The catch rate ranged from 0.6 to 21.9 tuna per 100 hooks per set. Details of the catch are given in Table 2. Some of the skipjack tuna used for samples were taken by live-bait fishing, whereas the flying fish samples were obtained from specimens that flew onto the ship's deck at night.

Samples of muscle and liver were dissected from the fresh fish, labelled, placed in a plastic bag, and frozen aboard ship for transport to Christmas Island. Here some samples were weighed, dried in an oven at 95° C for 24 hours, reweighed, ground and placed in a standard size plastic container for counting; other samples were frozen or dried and shipped to the Laboratory in Seattle for further processing and analysis. In most of the tuna-like fishes samples of light and dark muscle and liver were analyzed separately.

Plankton and nekton samples were collected with one-meter diameter plankton nets and a six-foot diameter Isaacs-Kidd mid-water trawl. Sixteen 30-minute surface plankton tows, thirty-four 30-minute, 50-meter plankton tows and one 30-minute, 100-meter plankton tow were made with the one-meter open net. Settling volumes, after the large organisms (jellyfish, lantern fish, etc.) were removed, ranged from 73 to 1,150 ml per tow.

Table 2. Fish samples collected during cruises of the Charles H. Gilbert, March through August, 1962.

Cruise no.	Station no.	Date	Yellowfin	Bigeye	Skipjack	Shark	Black marlin	Flying fish	Other fish
55	1	Mar. 28	1			1			
	3	" 29		2					
56	7	May 2							
	8	" 3	3	1		2		1	
	11	" 4	6	5					
	16	" 5	21						
	20	" 6	20			1			Sailfish (1), Wahoo (1)
	25	" 7	2				1		
57	--	June 10			2				
	28	" 12	7						
	32	" 14	7	1	4		1		
	37	" 15	10	2					Wahoo (1)
	41	" 16	2	2					
	46	" 17	1		6	1			
59	58	July 30						1	
	61	Aug. 1	2			2	1	3	Wahoo (1)
	65	" 2	2	3			1	1	Sailfish (1)
	69	" 3	1	1			1		
	73	" 4	9	2	2	1		1	
	77	" 5	9	3	2	1	1	1	Albacore (1)
	81	" 6						2	
	82	" 9	1						
	83	" 10	3						

A portion of each tow was preserved in formalin for purposes of identification; the remainder was drained, placed in plastic bags and frozen for shipment to Christmas Island.

Five 30-minute hauls were made with the Isaacs-Kidd mid-water trawl to depths of approximately 70 meters. In most cases surface tows made at night with the one-meter plankton net provided greater catches of small fish than did the trawl.

Nansen bottle casts were made at each long-line station. During Cruises 56 and 57 one-liter sea water samples were obtained at 25, 50, 100, and 300-meter depths. During Cruise 59 Nansen bottle casts were made to obtain water samples for radiological analyses. Samples were obtained from about 50 meters in the area above the thermocline, and a second sample from the region of the thermocline, between 90 and 130 meters, as determined by the bathythermograph casts. Four Nansen bottles were placed close together on the cable above the thermocline, four close together in the thermocline, and the samples from each group of four bottles were pooled. In addition, a five-gallon, surface water sample was obtained at each water station and at other locations as shown in Figure 1 and Table 1. All water samples were stored in polyethylene containers and shipped to Seattle for analysis.

The water samples were filtered through a Millipore filter 47 mm in diameter with a pore size of 0.45μ to collect the

particulate matter suspended in the water. The filtrate was then carried through a standard sulfide precipitate procedure for the separation of strontium-90 and cesium-137 from other radionuclides present in the sample. Strontium-90 was separated from cesium-137 by the standard oxalate procedure. Five samples of surface water were analyzed for strontium-90 and cesium-137 and the remainder of the samples were analyzed only for those radionuclides precipitated by the sulfide procedure. The results of these analyses are expressed in picocuries per liter of water at time of collection.

The arrangement for the gamma spectrum analyses of the fish, plankton and water samples included a three-inch by three-inch sodium iodide detector and a multichannel analyzer (Nuclear Data 512). The time of counting varied from 40 to 800 minutes depending upon the size of the sample and upon the expected level of radioactivity in the sample. Part of the samples were processed at Christmas Island but the bulk of the collections were frozen or dried and shipped to Seattle for analyses.

The analyzer output data were processed by an IBM computer (Model 709). The computer program was designed to analyze the counting data for five comparatively long-lived radionuclides, potassium-40, cobalt-60, zinc-65, cesium-137, cobalt-57, and cerium-141,144, as well as for four comparatively short-lived radionuclides, barium-lanthanum-140, zirconium-niobium-95, ruthenium-103, and iodine-131. Except for potassium-40, a

naturally occurring radionuclide, these are the fallout radionuclides which are most likely to be present in biological samples.

With fish samples there was a question about the presence of cobalt-57 and cerium-144, or both, since the gamma photopeaks for these two radionuclides are similar. Previous radiochemical analyses have shown that cobalt-57 is found in the internal organs of marine fish and invertebrates and that radiocerium is not (Lowman et al., 1957 and 1960), thus it was assumed that only cobalt-57 was present.

The levels of strontium-90 in a few samples of water and fish were determined by a radiochemical method which combines standard wet chemical techniques and the technique of ion-exchange chemistry (Kawabata and Held, 1958).

Since the time elapsed between collection and counting may be as great as six months, errors in estimating activity in short-lived radionuclides, such as iodine-131, are large.

RESULTS

Fish

In Table 3 the data on the radionuclide content of three tissues of yellowfin tuna, based on the date of collection, are summarized. A total of 107 yellowfin were caught, most of them during Cruises 56, 57, and 59. This species accounted for 63 per cent of the total number of specimens collected and analyzed.

Table 3. Radioactivity of nine gamma-emitting radionuclides in light and dark muscle and liver of yellowfin tuna collected in the vicinity of Christmas Island, March through August, 1962. Values expressed in picocuries per gram of wet tissue at time of collection.

Radionuclides	Light muscle				Dark Muscle				Liver			
	March 28	May 3-7	June 12-17	August 1-10	May 3-7	June 12-17	August 1-10	March 28	May 3-7	June 12-17	August 1-10	
Ba-140	Mean	---	0.57	1.4	0.91	4.1	1.1	3.0	---	0.88	2.0	2.0
	Range	---	0.29-1.0	0.89-2.1	---	0.77-11.0	0.35-1.8	1.0-5.1	---	0.43-2.1	0.31-3.1	0.79-4.8
	N. **	---	50/4	27/3	26/1	50/4	25/4	26/7	---	51/11	27/3	22/11
K ⁴⁰	Mean	4.0	4.1	3.7	4.0	3.6	3.1	3.2	3.2	2.7	2.9	2.9
	Range	---	3.1-5.9	1.8-4.6	2.7-5.2	1.1-4.6	2.3-4.0	2.0-4.5	---	1.3-5.0	1.0-5.3	1.7-4.8
	No.	1/1	50/48	27/25	26/26	50/49	25/25	26/26	1/1	51/51	27/24	22/22
Co ⁶⁰	Mean	---	0.08	0.088	0.20	0.14	0.086	0.076	0.26	0.38	0.20	0.29
	Range	---	0.033-0.050	0.066-0.13	0.19-0.23	0.058-0.30	0.042-0.18	0.041-0.15	---	0.056-1.2	0.055-0.34	0.087-0.62
	No.	---	50/9	27/3	26/6	50/22	25/15	26/15	1/1	51/50	27/25	22/22
Zn ⁶⁵	Mean	---	0.14	0.17	0.13	0.68	0.28	0.29	2.2	1.2	0.90	1.3
	Range	---	0.088-0.19	0.13-0.22	---	0.29-0.91	0.15-0.70	0.14-0.46	---	0.68-2.4	0.29-3.6	0.23-3.8
	No.	---	50/3	27/4	26/1	50/8	25/9	26/16	1/1	51/51	27/24	22/22
Zr-Nb ⁹⁵	Mean	---	0.26	---	0.25	2.4	0.10	0.14	---	0.15	0.093	0.24
	Range	---	---	---	0.043-0.34	0.19-14.0	0.094-0.11	---	---	0.043-0.39	0.062-0.39	0.095-0.65
	No.	---	50/1	---	26/7	50/7	25/2	26/1	---	51/25	27/3	22/7
Cs ¹³⁷	Mean	---	0.031	0.040	0.054	0.089	0.066	0.095	---	0.12	0.084	0.12
	Range	---	---	0.024-0.057	0.049-0.059	0.031-0.18	0.040-0.12	0.059-0.12	---	0.038-0.24	0.075-0.093	0.052-0.48
	No.	---	50/1	27/2	26/7	50/5	25/5	26/7	---	51/28	27/3	22/10
Ru ¹⁰³	Mean	---	0.99	---	1.3	2.4	---	---	---	0.22	0.099	---
	Range	---	0.93-1.0	---	1.2-1.6	0.15-4.2	---	---	---	0.12-0.35	0.063-0.14	---
	No.	---	50/2	---	26/6	50/5	---	---	---	51/3	27/2	---
I ¹³¹	Mean	---	---	---	16.0	16.0	8.8	6.7	---	0.81	0.27	8.5
	Range	---	---	---	10.0-24.0	0.44-32.0	---	---	---	0.34-3.1	0.23-0.30	---
	No.	---	---	---	26/6	50/2	25/1	26/1	---	51/8	27/2	22/1
Co ⁵⁷	Mean	---	0.091	---	0.029	0.066	0.026	0.030	0.14	0.14	0.11	0.094
	Range	---	---	---	0.022-0.041	0.023-0.16	0.020-0.035	0.019-0.042	---	0.033-0.31	0.040-0.43	0.027-0.21
	No.	---	50/1	---	26/6	50/17	25/6	26/10	1/1	51/50	27/20	22/19

*No activity significantly above background.

**Total number of samples/number of samples significantly above background.

In general, the levels of radioactivity were low, usually averaging less than the potassium-40 levels. Those radionuclides which were found in amounts greater than four picocuries per gram of wet tissue were present in comparatively few specimens. For example, iodine-131 was detected in only 21 of 219 specimens and for some of the 21 the error was so great that the value was of questionable significance. Also, the wide range of values for a single type of sample indicates the great amount of variation in the samples.

Differences in levels of radioactivity in the different tissues were slight and variable, partly because of the low, often barely detectable, levels. However, in the greatest number of samples the liver contained detectable amounts of radioactivity. On the other hand, the levels of potassium-40 in liver samples appear to be slightly lower than those of muscle.

Significant changes in radioactivity in the fish during the testing period were not observed because of the inconsistency and variability of the data. There does not appear to be any marked increase either in the levels of radioactivity or in the number of fish samples containing detectable amounts of the specific radionuclides, with the possible exception of barium-lanthanum-140 and iodine-131 in liver tissue and iodine-131 in light muscle tissue.

The levels of specific radionuclides in the species other than yellowfin tuna were similar to the levels of radioactivity in the yellowfin tuna (Tables 4, 5, and 6). Levels of radioactivity for most radionuclides usually were lower in all species and tissues than the potassium-40 levels. As in the yellowfin, the exceptions occurred in some tissues containing radioiodine. The samples with detectable amounts of radioiodine constitute about seven per cent of the total number of samples. Differences in levels of radioactivity in the tissues of different species were slight and variable. However, the number of samples with detectable levels of specific radionuclides was greatest in the liver tissue and least in the light muscle tissue.

The strontium-90 levels in eight fish tissue samples analyzed were also very low, ranging from no significant data (nsd) to 0.053 picocuries per gram wet weight. The data are summarized in Table 7. The strontium values appear to be slightly higher than those reported by R. Fukai, H. Suzuki, and K. Watanabe (1962).

Plankton

Samples of plankton were taken at 86 stations. The samples containing large organisms were subdivided into fish, crustacea, jellyfish, salps, Pyrosoma and smaller plankton which have been called "remainders." If no large organisms were found, the plankton organisms were not separated and the sample was labelled

Table 4. Radioactivity of nine gamma-emitting radionuclides in dark muscle of fish collected in the vicinity of Christmas Island, March through August, 1962. Values expressed in picocuries per gram of wet tissue at time of collection.

Radionuclide		Yellowfin	Bigeye	Skipjack	Marlin	Wahoo	Albacore	Sailfish
Ba-La ¹⁴⁰	Mean*	2.7	1.9	2.0	---***	---	---	---
	Range*	0.35-11.0	---	1.5-3.0	---	---	---	---
	No.**	107/15**	21/1	16/3	---	---	---	---
K ⁴⁰	Mean	3.4	2.8	3.2	2.9	4.7	3.1	4.2
	Range	1.1-4.8	1.8-4.3	2.7-4.6	1.6-5.0	---	---	---
	No.	107/105	21/18	16/16	5/5	2/1	1/1	1/1
Co ⁶⁰	Mean	0.11	0.12	0.10	0.37	---	0.055	0.14
	Range	0.041-0.30	0.047-0.26	0.058-0.15	---	---	---	---
	No.	107/52	21/7	16/13	5/1	---	1/1	0/1
Zn ⁶⁵	Mean	0.38	0.26	0.28	0.29	---	---	---
	Range	0.14-1.9	0.11-0.45	0.21-0.36	0.17-0.48	---	---	---
	No.	107/33	21/5	16/4	5/4	---	---	---
Zr-Nb ⁹⁵	Mean	1.7	0.39	0.23	1.3	---	---	1.1
	Range	0.094-14.0	0.35-0.43	0.20-0.26	0.58-2.1	---	---	---
	No.	107/10	21/2	16/2	5/2	---	---	0/1
Cs ¹³⁷	Mean	0.085	0.065	0.083	0.15	---	---	---
	Range	0.031-0.18	0.056-0.074	0.059-0.12	---	---	---	---
	No.	107/17	21/2	16/3	5/1	---	---	---
Ru ¹⁰³	Mean	2.4	1.6	---	2.0	---	---	7.7
	Range	0.15-4.2	---	---	---	---	---	---
	No.	107/5	21/1	---	5/1	---	---	0/1
I ¹³¹	Mean	12.0	19.0	2.8	23.0	---	0.48	---
	Range	0.44-31.0	---	---	---	---	---	---
	No.	107/4	21/1	16/1	5/1	---	1/1	---
Co ⁵⁷	Mean	0.048	0.039	0.063	0.044	---	---	---
	Range	0.020-0.16	0.016-0.066	0.019-0.049	0.031-0.064	---	---	---
	No.	107/33	21/7	16/7	5/4	---	---	---

*Mean and range of only those samples with values significantly greater than the background count.

**Total number of samples/samples significantly greater than background count.

***No activity significantly greater than background count.

Table 5. Radioactivity of nine gamma-emitting radionuclides in light muscle of fish collected in the vicinity of Christmas Island, March through August, 1962. Values expressed in picocuries per gram of wet tissue at time of collection.

Radionuclide		Yellowfin	Bigeye	Shipjack	Shark	Flying Marlin fish	Wahoo	Albacore	Sailfish
Ba-La ¹⁴⁰	Mean*	0.91	1.2	2.0	---***	1.1	---	---	---
	Range*	.29-2.1*	0.78-1.6	0.41-3.6	---	0.80-1.3	---	---	---
	No.**	109/8**	21/3	18/2	---	6/2	---	---	---
K ⁴⁰	Mean	3.9	3.9	3.5	3.5	3.3	3.6	4.7	3.6
	Range	1.8-5.9	3.1-5.0	2.6-4.4	2.6-4.9	2.7-3.8	1.9-6.3	4.3-5.0	---
	No.	109/105	21/21	18/18	5/5	6/6	5/5	2/2	1/1
Co ⁶⁰	Mean	0.12	0.13	0.10	0.19	0.038	---	---	---
	Range	.033-.41	.035-.23	.053-.14	---	---	---	---	---
	No.	109/18	21/4	18/3	5/1	6/1	---	---	---
Zn ⁶⁵	Mean	0.15	0.21	0.24	---	---	0.87	---	---
	Range	.088-.23	---	0.21-.28	---	---	---	---	---
	No.	109/8	21/1	18/3	---	---	5/1	---	---
Zr-Nb ⁹⁵	Mean	0.25	0.35	0.051	0.28	---	---	---	---
	Range	.043-.94	.34-.37	---	---	---	---	---	---
	No.	109/8	21/2	18/1	5/1	---	---	---	---
Cs ¹³⁷	Mean	0.049	0.054	0.057	0.061	---	0.12	0.088	---
	Range	.024-.059	.032-.076	.049-.065	0.029-0.093	---	---	---	---
	No.	109/10	21/2	18/2	5/2	---	5/1	2/1	---
Ru ¹⁰³	Mean	1.2	1.5	---	1.4	---	---	---	---
	Range	.93-1.6	1.5-1.6	---	---	---	---	---	---
	No.	109/8	21/2	---	5/1	---	---	---	---
I ¹³¹	Mean	15.	19.	---	21.0	1.5	---	---	---
	Range	10.-24.	18.0-20.0	---	---	---	---	---	---
	No.	109/6	21/2	---	5/1	6/1	---	---	---
Co ⁵⁷	Mean	0.038	0.034	---	0.027	---	0.092	---	---
	Range	.022-.091	.033-.035	---	.026-.029	---	---	---	---
	No.	109/7	21/2	---	5/2	---	5/1	---	---

*Mean and range of only those samples with values significantly greater than the background count.

**Total number of samples/samples significantly greater than the background count.

***No activity significantly greater than the background count.

Table 6. Radioactivity of nine gamma-emitting radionuclides in liver of fish collected in the vicinity of Christmas Island, March through August, 1962. Values expressed in picocuries per gram of wet tissue at time of collection.

Radionuclide		Yellowfin	Bigeye	Skipjack	Shark	Marlin	Wahoo	Albacore	Sailfish
Ba-La ¹⁴⁰	Mean*	1.5	2.1	3.0	---	---	---	---	---
	Range*	0.31-4.8	1.0-3.1	1.7-4.3	---	---	---	---	---
	No.**	106/25	20/5	14/2	---	---	---	---	---
K ⁴⁰	Mean	2.8	3.0	3.1	2.0	2.2	3.4	1.4	2.4
	Range	1.0-5.3	2.3-4.2	2.0-4.2	1.6-2.4	1.4-3.1	2.4-4.4	---	1.5
	No.	106/103	20/18	14/14	7/6	6/6	3/3	1/1	1/1
Co ⁶⁰	Mean	0.32	0.38	0.20	0.47	0.26	0.35	0.082	---
	Range	0.055-1.2	0.17-0.78	0.14-0.25	0.18-0.76	0.063-0.68	0.30-0.44	---	---
	No.	106/103	20/18	14/9	7/6	6/6	3/3	1/1	---
Zn ⁶⁵	Mean	1.2	0.71	1.1	0.33	0.56	3.9	0.47	---
	Range	0.23-3.8	0.29-2.9	0.30-1.8	---	0.35-1.2	2.1-5.8	---	---
	No.	106/103	20/17	14/13	7/1	6/6	3/2	1/1	---
Zr-Nb ⁹⁵	Mean	0.16	0.073	0.36	---	0.077	---	---	---
	Range	0.043-0.65	---	0.15-0.99	---	---	---	---	---
	No.	106/35	20/1	14/6	---	6/1	---	---	---
Ca ¹³⁷	Mean	0.12	0.060	0.17	---	0.067	---	---	---
	Range	0.042-0.48	0.044-0.080	0.058-0.46	---	---	---	---	---
	No.	106/41	20/4	14/6	---	6/1	---	---	---
Ru ¹⁰³	Mean	0.17	---	0.28	---	---	---	---	---
	Range	0.063-0.35	---	0.24-0.33	---	---	---	---	---
	No.	106/5	---	14/2	---	---	---	---	---
I ¹³¹	Mean	0.66	---	16.0	---	---	---	---	---
	Range	0.23-3.1	---	---	---	---	---	---	---
	No.	106/10	---	14/1	---	---	---	---	---
Co ⁵⁷	Mean	0.12	0.12	0.071	0.16	0.083	0.13	0.030	---
	Range	0.033-0.43	0.41-0.24	0.046-0.12	0.068-0.29	0.032-0.25	0.092-0.19	---	---
	No.	106/95	20/17	14/5	7/6	6/6	3/3	1/1	---

*Mean and range of only those samples with values significantly greater than the background count.

**Total number of samples/samples significantly greater than the background count.

***No activity significantly greater than the background count.

Table 7. Strontium-90, strontium units and calcium content of fish collected in the vicinity of Christmas Island, March through August, 1962.

Sta. no.	Date of collection	Species	Tissue	Sr ⁹⁰ pc/g wet	Strontium units wet wt.	Mg Ca/g of wet sample
61	8-1-62	Wahoo	Light muscle	0.042±0.024	84.±48.	0.50
65	8-2-62	Yellowfin tuna	Light muscle	nsd*	nsd	0.12
73	8-4-62	Yellowfin tuna	Light muscle	nsd	nsd	0.15
61	8-1-62	Yellowfin tuna	Dark muscle	nsd	nsd	0.24
65	8-2-62	Yellowfin tuna	Dark muscle	0.038±0.022	110.±64.	0.34
73	8-4-62	Yellowfin tuna	Dark muscle	0.034±0.021	26.±16.	1.3
61	8-1-62	Yellowfin tuna	Liver	0.053±0.029	110.±63.	0.46
65	8-2-62	Yellowfin tuna	Liver	nsd	nsd	0.59

*No significant data.

"unsorted" (Appendix Table 2). "Unsorted" and "remainder" samples contained essentially the same types of organisms.

The radioactivity found in the unsorted and remainder plankton samples is plotted in Figure 2. The radionuclides zinc-65, zirconium-niobium-95, and cerium-141,144, because they occurred most frequently in the samples and are representative of the results as a whole, are plotted in the scatter diagram. Detectable amounts of zirconium-niobium-95 and cerium-141,144 were found in more than 70 of 120 samples. Zinc-65 was found in 19 of 120 samples.

The graph shows that there was considerable variation in levels of radioactivity in the samples and indicates an increase in samples collected late in the surveys north and west of Christmas Island. The samples which showed the highest levels of radioactivity were collected in July and August at stations 51 through 55, 68, 80, 84, 85, and 86. All of these were surface samples. Some of the stations are as far north as $19^{\circ}42'N$ and as far west as $161^{\circ}40'W$. The radioactivity in the samples ranged from 1 to 687 pc/g dry weight for zirconium-niobium-95 at station 53, 1 to 120 pc/g for cerium-141,144 at station 86 and 1 to 29 pc/g for zinc-65 at station 28.

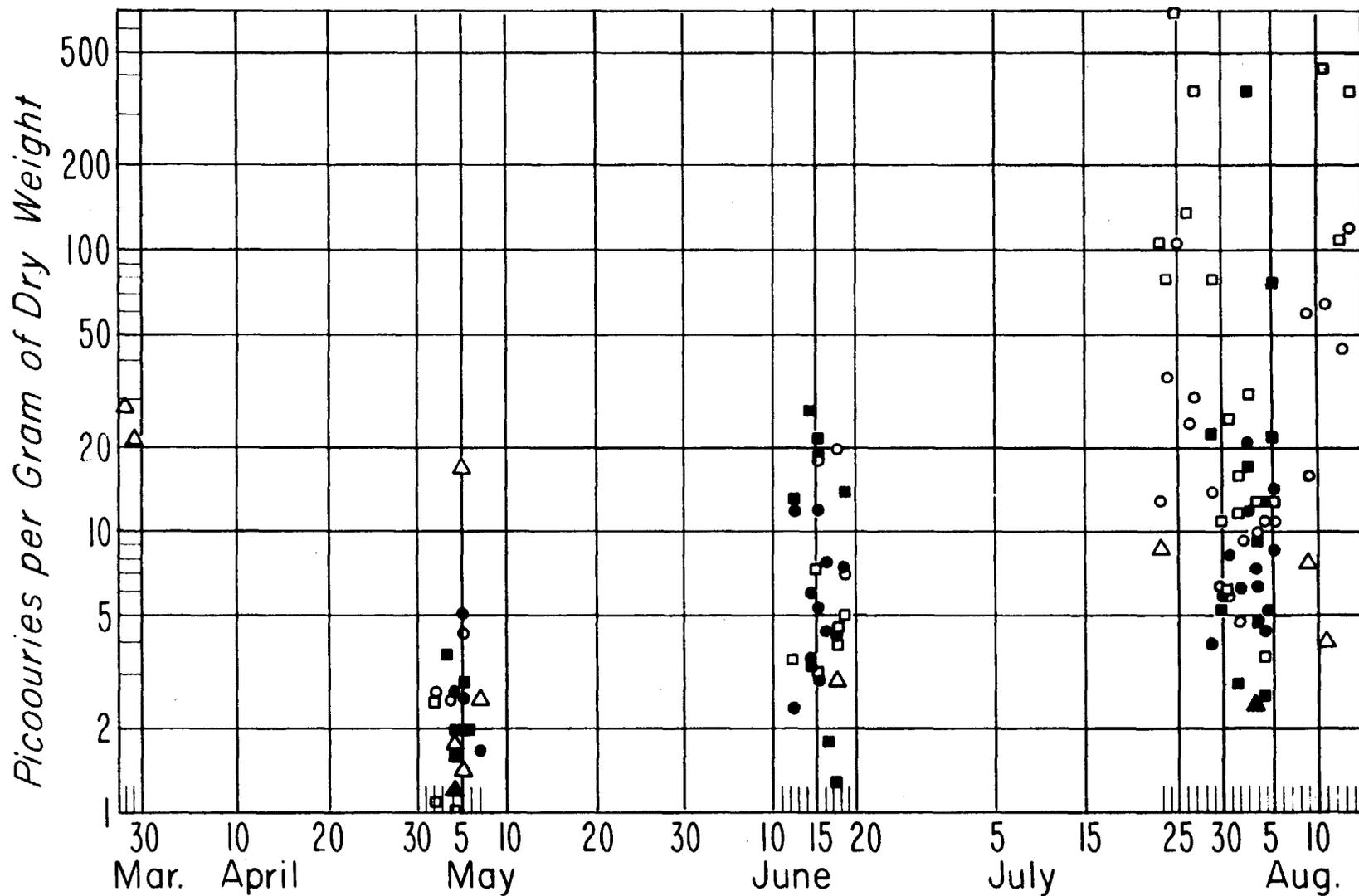


Fig. 2. Radionuclides in plankton from the central Pacific, March-August, 1962. Comparison of Zn^{65} (triangles), Zr^{95} - Nb^{95} (squares) and $Ce^{141,144}$ (circles) in plankton based on date of collection. Open circles, squares and triangles indicate surface samples; solid figures indicate samples from 50 meters.

Sea Water

A total of 79 sea water samples were collected and analyzed. The data are given in Appendix Table 3 and summarized in Table 8.

As in the samples of fish tissues and plankton, the levels of radioactivity were low and the 95 per cent counting error was often very high. In more than two-thirds of the counts of the water samples that were significantly greater than the background count, the 95 per cent counting error was more than 50 per cent of the value of the count. In addition, two-thirds of the radionuclides sampled showed no detectable levels of radioactivity (see Appendix Table 3).

The radionuclides ruthenium-103, zirconium-niobium-95, and cerium-141,144 were present in highest amounts and occurred most frequently in the sea water samples. A few samples contained barely detectable amounts of zinc-65, cesium-137, and cobalt-60. The strontium-90 levels in five water samples analyzed were also very low, ranging from 0.034 pc/l to 0.193 pc/l.

The data in Table 8 indicate also that in the mixed layer above the thermocline the radioactivity was less at the surface than in the layers immediately above and below the thermocline.

Potassium Analyses

More than 600 samples of fish tissue, plankton, nekton,

Table 8. Radioactivity of five gamma-emitting radionuclides in sea water collected in the vicinity of Christmas Island, March through August, 1962. Values expressed in picocuries per liter of sea water.

Depth (meters)		Zn ⁶⁵	Zr-Nb ⁹⁵	Cs ¹³⁷	Ru ¹⁰³	Ce ^{141,144}
0	Average*	6.9	36.	8.7	54.	18.
	Range	4-13	1-96	1-22	1-330	2-46
	Number**	(24/7)	(24/16)	(24/3)	(24/9)	(24/16)
25	Average	21.	124.	9.0	570.	86.
	Range	--	28-180	--	320-990	29-138
	Number	(11/1)	(11/5)	(11/1)	(11/3)	(11/6)
50	Average	16.	90.	6.5	421.	45.
	Range	4-27	1-340	4-9	5-1100	23-91
	Number	(16/2)	(16/10)	(16/2)	(16/6)	(16/7)
100	Average	74.	189.	9.0	393.	124.
	Range	23-124	7-590	7-11	19-800	3-270
	Number	(15/2)	(15/7)	(15/2)	(15/3)	(15/7)
200	Average	--	--	12.	9.0	--
	Range	--	--	1-23	--	--
	Number	(2/0)	(2/0)	(2/2)	(2/1)	(2/0)
300	Average	--	305.	--	642.	90.
	Range	--	57-510	--	350-1400	39-120
	Number	(11/0)	(11/4)	(11/0)	(11/4)	(11/4)

*Average of only those samples with activity greater than the background count.

**Total number of samples/samples significantly greater than the background count.

and water were analyzed for radioactivity. Of these, more than 500 showed some potassium-40 activity. The levels of radioactivity of potassium-40 averaged 3.4 and 2.8 pc/g of wet tissue for dark muscle of yellowfin and bigeye tuna, respectively. The levels in other species were similar, but the ranges indicate considerable variation in each. The level in light muscle of both yellowfin and bigeye tuna was 3.9 pc/g of wet tissue. These values are almost twice as great as the values determined for similar tissues and species of fish by Chakravarti and Joyner (1960). They obtained values of 1.89 and 1.92 pc/g of wet weight for dark and light muscle, respectively; the values were based on the amount of stable potassium as determined by flame spectrophotometry.

Flame spectrophotometry analyses of 10 samples of mixed light and dark muscle of yellowfin tuna, with an average potassium-40 count of 3.48 pc/g wet weight, resulted in a count of 2.73 pc/g as calculated from the amount of stable potassium present. It would appear that these levels of activity of potassium-40 are high, and also that there is a great deal of variation in the potassium content in fish muscle.

SUMMARY AND CONCLUSIONS

Four oceanic surveys within 600 miles of Christmas Island were made, March through August, 1962, prior to, during and

after the Dominic test series to determine the radionuclide content in pelagic fish, plankton and sea water.

Analyses of 107 yellowfin tuna and 62 other species of pelagic fishes showed that during this period there was little change, if any, in levels of radioactivity in samples of light muscle, dark muscle, and liver tissue. More of the liver samples were radioactive and the liver tissue contained a greater number of radionuclides than the muscle tissue, but the amount of any one radionuclide in a sample was the same for all tissues. The levels of radioactivity of these radionuclides averaged less than the potassium-40 content of the tissues and in most cases were barely detectable.

Plankton samples collected during the latter part of the operation contained slightly higher levels of radioactivity, especially zirconium-niobium-95 and cerium-141,144, as well as a greater variety of radionuclides. It appears that measurable, but very low levels, of comparatively short-lived radionuclides in the plankton were due to fallout from the tests at Christmas Island.

Analysis of sea water samples revealed no increase in either the number of radionuclides present in each sample or in the levels of radioactivity during the period of study.

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Appendix Table 1. Common and scientific names of fish collected during the cruises of the Charles H. Gilbert, March through August, 1962.

<u>Common name</u>	<u>Scientific name</u>
Albacore tuna	<u>Thunnus alalunga</u>
Bigeye tuna	<u>Thunnus obesus</u>
Black marlin	<u>Makaira ampla</u>
Flying fish	<u>Cypselurus suttoni</u> and <u>Progonichthys albimaculatus</u>
Sailfish	<u>Istiophorus orientalis</u>
Sharks	<u>Pterolamniops longimanus</u> , <u>Isurus glaucus</u> , <u>Eulamia</u> <u>floridanus</u> , and <u>Prionace</u> <u>glauca</u>
Skipjack tuna	<u>Katsuwonus pelamis</u>
Wahoo	<u>Acanthocybium solandri</u>
Yellowfin tuna	<u>Thunnus albacares</u>

Appendix Table 2. Radionuclides in plankton collected in the vicinity of Christmas Island during Operation Dominic, 1962. Values and the 95 per cent counting error expressed in picocuries per gram of dry weight at time of collection.

Sta. no.	Depth (m)	Vol. of water (m ³)	Type of sample	Dry weight (g)	Ba-La 140	K-40	Co-60	Zn-65	Zr-Nb 95	Cs-137	Ru-103	I-131	Co-57	Ce 141-144
1	0	--*	Unsorted	1.015	nd**	50.±3.	nd	29.±6.	nd	nd	nd	nd	nd	nd
2	0	--	"	1.027	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
3	0	--	"	1.965	nd	nd	nd	21.±6.5	nd	nd	nd	nd	nd	nd
4	0	--	"	1.146	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
5	0	1177	"	8.40	nd	8.6±5.0	nd	nd	2.5±1.1	nd	1.4±1.4	nd	nd	2.7±2.0
5	50	1054	"	14.38	nd	13.±4.5	nd	nd	1.1±0.76	nd	nd	62.±48.	nd	nd
7	73	--	Lantern fish	5.900	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
7	73	--	Crustacea	12.010	nd	17.±12.	nd	nd	2.4±1.5	nd	nd	nd	nd	nd
7	73	--	Jellyfish	0.740	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
7	73	--	Remainder	0.510	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
9	50	1305	Unsorted	13.56	nd	14.±4.7	nd	nd	3.7±0.85	nd	1.6±1.2	nd	nd	nd
12	50	1564	"	12.38	nd	11.±5.9	nd	nd	2.0±1.2	nd	nd	nd	nd	nd
14	0	943	"	19.21	7.4±6.0	9.7±2.9	nd	1.8±0.90	1.0±0.56	nd	nd	nd	nd	2.5±1.1
14	50	1267	"	18.74	nd	7.5±0.70	nd	1.2±1.0	1.6±0.37	nd	nd	nd	nd	2.6±1.6
15	73	--	Lantern fish	3.400	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
15	73	--	Crustacea	8.840	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
15	73	--	Jellyfish	2.560	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

*Volume of water not measured

**Detected activity is less than two standard deviations of the net activity

Appendix Table 2. (continued)

Sta. no.	Depth (m)	Vol. of water (m ³)	Type of sample	Dry weight (g)	Ba-La 140	K-40	Co-60	Zn-65	Zr-Nb 95	Cs-137	Fu-103	I-131	Co-57	Ce 141-144
18	50	1975	Unsorted	19.88	nd	8.9 [±] 1.9	nd	nd	2.9 [±] 0.32	nd	0.43 [±] 0.42	nd	nd	2.6 [±] 0.76
19***	0	1060	Lantern fish	6.790	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
19***	0	1060	Jellyfish	3.230	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
19***	0	1060	Remainder	18.22	nd	6.8 [±] 0.98	nd	1.4 [±] 0.62	nd	nd	nd	nd	nd	4.5 [±] 2.1
19	50	1596	Unsorted	12.95	12.1 [±] 8.1	3.9 [±] 0.86	nd	17.1 [±] 5.2	nd	nd	nd	nd	nd	6.1 [±] 2.2
22	50	1778	"	13.16	nd	nd	nd	nd	2.5 [±] 1.2	nd	nd	nd	nd	nd
23***	0	1060	Lantern fish	8.820	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
23***	0	1060	Jellyfish	1.660	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
23***	0	1060	Remainder	3.790	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
24***	50	--	Lantern fish	0.490	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
24***	50	--	Crustacea	1.300	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
24***	50	--	Jellyfish	0.260	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
24***	50	--	Remainder	0.930	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
27	50	1723	Unsorted	15.54	nd	13.1 [±] 0.82	nd	2.5 [±] 1.8	nd	nd	nd	nd	nd	1.7 [±] 1.6
30	50	1872	"	13.760	nd	5.7 [±] 4.5	.50 [±] 1.45	nd	3.6 [±] 0.90	nd	nd	nd	nd	2.4 [±] 1.9
31***	50	1870	"	7.230	nd	15.1 [±] 7.7	nd	nd	13.1 [±] 1.6	nd	4.5 [±] 1.9	nd	nd	12.1 [±] 3.3
33	100	2025	"	7.080	nd	26.1 [±] 11.	0.98 [±] 0.97	nd	27.1 [±] 2.7	1.2 [±] 1.2	nd	nd	nd	6.2 [±] 4.3
35	100	--	Lantern fish	1.310	nd	31.1 [±] 7.	nd	nd	nd	nd	nd	nd	nd	nd
35	100	--	Crustacea	0.520	nd	nd	8.2 [±] 5.8	nd	nd	nd	nd	nd	nd	38.1 [±] 2.3.
35	100	--	Pyrosoma	3.400	nd	nd	nd	5.4 [±] 4.1	nd	nd	nd	724.1 [±] 581.	nd	nd

***Trawl

Appendix Table 2. (continued)

Sta. no.	Depth (m)	Vol. of water (m ³)	Type of sample	Dry weight (g)	Ba-140	K-40	Co-60	Zn-65	Zr-115	Cs-137	Ru-103	I-131	Co-57	Ce 141-144
35	100	--	Salps	0.670	nd	nd	nd	nd	nd	nd	16.4±1.1	nd	nd	112.4±1.
36	0	1488	Crustacea	20.610	nd	10.4±1.4	1.1±0.41	nd	9.8±1.1	nd	nd	nd	nd	9.4±1.9
36	50	2014	Pyrosoma	2.410	nd	24.4±1.7	nd	nd	nd	nd	7.9±1.7	nd	nd	nd
36	50	2014	Salp	36.36	nd	16.4±2.5	nd	nd	4.7±0.49	0.25±0.20	0.77±0.61	nd	nd	4.3±1.0
36	50	2014	Remainder	14.270	nd	7.5±6.3	nd	nd	3.3±1.4	nd	nd	nd	nd	3.6±2.6
39	50	1452	Jellyfish	3.420	nd	14.4±1.2	1.7±1.1	nd	12.4±1.9	nd	nd	nd	nd	12.4±5.7
39	50	1452	Remainder	6.310	nd	10.4±8.6	nd	nd	7.4±1.6	nd	nd	nd	nd	5.4±3.6
40	0	1814	Unsorted	3.700	nd	nd	2.0±1.7	nd	3.2±1.7	nd	3.2±2.0	nd	nd	18.4±7.6
40	50	1205	"	11.670	nd	16.4±5.7	nd	nd	21.4±1.4	0.61±0.49	nd	nd	nd	3.2±2.4
43	50	1223	"	4.410	nd	nd	nd	nd	nd	nd	nd	nd	nd	7.8±4.6
44	0	1792	"	12.640	nd	13.4±1.9	nd	nd	nd	nd	nd	nd	nd	nd
44	50	1067	"	8.450	nd	11.4±6.7	nd	nd	1.8±1.2	nd	nd	nd	nd	4.5±2.7
45	60	--	Pyrosoma	4.450	nd	nd	nd	3.6±3.1	nd	nd	nd	nd	nd	nd
48	50	1271	Unsorted	4.360	nd	12.4±7.0	0.79±0.69	nd	4.6±1.4	nd	nd	nd	nd	nd
49	0	2155	"	6.300	nd	nd	1.3±1.0	3.0±2.7	4.0±1.0	1.6±.90	2.5±1.2	1.7±1.0	nd	20.4±.5
49	50	1016	Jellyfish	5.700	nd	10.4±0.97	nd	nd	1.3±1.1	nd	1.8±1.2	nd	nd	4.4±0.92
50	0	2149	"	1.200	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
50	0	2149	Remainder	19.000	nd	9.6±1.3	0.77±0.40	nd	5.1±0.99	nd	nd	nd	nd	7.2±1.8
50	50	1868	"	4.210	nd	nd	nd	nd	14.4±6.8	0.77±0.61	nd	nd	nd	7.5±4.4
50	50	1868	Jellyfish	6.020	nd	nd	nd	5.9±4.0	nd	nd	nd	nd	nd	nd
51	0	2272	Lantern fish	2.467	nd	nd	nd	12.4±6.6	13.4±2.	nd	nd	nd	nd	9.4±8.7
51	0	2272	Remainder	4.011	nd	nd	nd	8.6±6.4	13.4±5.	nd	nd	nd	nd	13.4±9.1

Appendix Table 2. (continued)

Sta. no.	Depth (m)	Vol. of water (m ³)	Type of sample	Dry weight (g)	Ba-140	K-40	Co-60	Zn-65	Zr-Nb 95	Ce-137	Ru-103	I-131	Co-57	Ce 141-144
52	0	1789	Lantern fish	0.801	nd	nd	nd	nd	186.±46.	nd	nd	nd	nd	92.±24.
52	0	1789	Remainder	1.336	nd	nd	nd	nd	77.±28.	nd	nd	nd	nd	35.±15.
53	0	1838	Lantern fish	1.244	nd	nd	nd	12.±11.	28.±17.	nd	96.±76.	nd	nd	15.±14.
53	0	1838	Remainder	0.959	nd	nd	nd	nd	687.±32.	4.4±2.5	187.±39.	nd	nd	104.±17.
54	0	1551	Lantern fish	2.547	nd	nd	nd	7.1±6.8	nd	nd	nd	nd	nd	nd
54	0	1551	Remainder	3.592	nd	nd	nd	nd	133.±17.	1.8±1.7	nd	nd	nd	24.±11.
55	0	2293	Lantern fish	3.307	nd	nd	nd	nd	131.±17.	nd	nd	nd	nd	19.±14.
55	0	2293	"	0.899	nd	nd	nd	nd	62.±22.	3.6±2.8	nd	nd	nd	nd
55	0	2293	Pyrosoma	0.727	nd	nd	nd	nd	370.±34.	3.3±3.1	270.±110.	nd	nd	04.±20.
55	0	2293	Salps	0.470	nd	nd	nd	nd	1500.±95.	nd	nd	nd	nd	150.±43.
55	0	2293	Remainder	5.281	nd	nd	nd	nd	360.±24.	nd	nd	nd	nd	30.±10.
56	0	2310	Lantern fish	3.174	nd	18.±9.8	nd	nd	nd	nd	nd	nd	nd	nd
56	0	2310	Pyrosoma	4.87	nd	nd	nd	nd	22.±3.9	0.57±0.52	nd	nd	nd	6.7±3.4
56	0	2310	Remainder	12.406	nd	7.2±7.0	nd	nd	78.±3.0	1.0±0.83	nd	nd	nd	14.±4.3
56***	50	1482	Lantern fish	0.431	nd	nd	13.±8.6	nd	nd	nd	48.±36.	nd	nd	nd
56***	50	1482	Siphonophores	0.532	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
56***	50	1482	Remainder	13.918	nd	6.3±5.7	0.79±0.54	nd	22.±1.9	nd	nd	nd	nd	4.0±2.6
58	0	2292	Lantern fish	9.636	nd	7.7±6.0	nd	nd	nd	nd	nd	nd	nd	nd
58	0	2292	Jellyfish	1.586	nd	nd	nd	nd	5.1±5.0	nd	nd	nd	nd	nd
58	0	2292	Remainder	10.753	nd	nd	nd	nd	11.±1.6	nd	nd	nd	nd	6.2±3.3
58	50	2011	Pyrosoma	0.518	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Appendix Table 2. (continued)

Sta. no.	Depth (m)	Vol. of water (m ³)	Type of sample	Dry weight (g)	Ba-La 140	K-40	Co-60	Zn-65	Zr-Nb 95	Cs-137	Ru-103	I-131	Co-57	Ce 141-144
58	50	2011	Remainder	18.11	nd	12.±4.7	nd	nd	5.5±1.0	nd	nd	nd	nd	5.7±2.1
60	0	1570	Lantern fish	0.967	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
60	0	1570	Remainder	7.579	nd	nd	nd	nd	6.2±2.0	nd	nd	nd	nd	6.1±4.2
60	50	1705	"	11.078	nd	15.±3.6	0.64±0.41	nd	25.±0.96	nd	nd	nd	nd	8.1±1.9
63	50	1194	Unsorted	5.617	nd	nd	nd	nd	2.9±2.4	nd	nd	nd	nd	nd
64	0	1941	Lantern fish	5.941	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
64	0	1941	Jellyfish	1.034	nd	nd	nd	nd	11.±5.6	nd	nd	nd	nd	31.±12.
64	0	1941	Remainder	4.868	nd	nd	nd	nd	16.±2.3	1.3±0.93	nd	nd	nd	4.8±3.6
64***	50	2064	Jellyfish	0.326	nd	nd	nd	nd	38.±21.	nd	nd	nd	nd	nd
64***	50	2064	Remainder	11.51	66.±55.	10.±6.9	nd	nd	12.±1.6	nd	nd	nd	nd	6.2±3.1
67	50	1414	Unsorted	4.386	nd	nd	nd	nd	17.±3.6	nd	nd	nd	nd	12.±7.5
68	0	1083	Lantern fish	0.458	nd	nd	nd	nd	nd	11.±1.	nd	nd	nd	94.±33.
68	0	1083	Remainder	6.58	nd	13.±2.	nd	nd	32.±2.9	nd	nd	nd	nd	9.2±5.0
68	50	1046	Unsorted	5.804	nd	nd	nd	nd	360.±15.	nd	nd	nd	nd	21.±7.4
71	50	1165	"	3.542	nd	nd	nd	nd	9.0±3.2	nd	nd	nd	nd	7.6±6.5
72	0	2151	Jellyfish	0.210	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
72	0	2151	Remainder	6.213	nd	nd	nd	nd	13.±2.4	1.0±0.96	nd	nd	nd	9.8±5.1
72	0	2151	Lantern fish	19.90	nd	14.±4.3	nd	nd	nd	nd	nd	nd	nd	nd
72	50	2164	Pyrosoma	6.01	nd	10.±7.0	nd	nd	2.3±1.3	nd	nd	nd	nd	2.9±2.9
72	50	2164	Remainder	12.109	nd	nd	nd	2.4±2.0	4.7±1.3	nd	nd	nd	nd	6.6±2.9
75	50	1549	Unsorted	7.043	nd	nd	nd	nd	13.±2.1	1.3±0.88	nd	nd	nd	5.3±4.5

Appendix Table 2. (continued)

Sta. no.	Depth (m)	Vol. of water (m ³)	Type of sample	Dry weight (g)	Ba-140	K-40	Co-60	Zn-65	Zr-95	Cs-137	Ru-103	I-131	Co-57	Co-141-144
76	0	1313	Lantern fish	3.221	nd	15.±1.1	nd	nd	nd	nd	nd	nd	nd	6.0±5.1
76	0	1313	Pyrosoma	2.602	nd	nd	nd	nd	nd	1.9±1.7	nd	nd	nd	nd
76	0	1313	Remainder	6.276	nd	nd	nd	nd	3.7±2.1	nd	nd	380.±350.	nd	11.±5.0
76	50	1192	Unsorted	10.026	nd	nd	1.1±0.74	nd	2.6±1.4	nd	nd	nd	nd	4.5±3.1
79	50	1423	"	9.660	nd	14.±6.3	nd	nd	76.±2.4	nd	nd	nd	nd	14.±2.9
80	0	1086	Lantern fish	2.480	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
80	0	1086	Pyrosoma	2.751	nd	nd	nd	nd	nd	nd	nd	290.±270.	nd	8.1±6.0
80	0	1086	Remainder	8.114	nd	19.±8.2	nd	nd	13.±1.8	nd	3.6±2.8	nd	nd	11.±4.0
80	50	1439	Unsorted	10.856	nd	8.6±7.1	nd	nd	22.±2.1	nd	nd	nd	nd	8.8±3.3
82	0	2153	Lantern fish	0.737	nd	nd	nd	nd	250.±36.	7.2±3.8	300.±110.	nd	nd	100.±25.
82	0	2153	Jellyfish	1.023	nd	nd	4.2±4.0	nd	5200.±140.	nd	nd	nd	nd	460.±39.
82	0	2153	Pyrosoma	5.41	nd	12.±7.7	nd	nd	12.±4.5	nd	nd	nd	nd	nd
82	0	2153	Remainder	5.151	nd	nd	1.8±1.6	7.6±7.2	60.±15.	nd	nd	nd	nd	16.±9.1
84	0	2296	Lantern fish	0.873	nd	nd	nd	nd	49.±34.	nd	nd	nd	nd	28.±21.
84	0	2296	Jellyfish	0.383	nd	nd	nd	nd	210.±50.	nd	290.±150.	nd	nd	77.±37.
84	0	2296	Remainder	4.095	nd	nd	1.8±1.5	11.±6.0	430.±20.	2.7±1.5	nd	nd	nd	64.±10.
85	0	2611	Unsorted	3.130	nd	nd	2.7±2.4	nd	110.±23.	nd	nd	nd	nd	44.±14.
86	0	1969	Lantern fish	0.964	nd	nd	3.6±2.6	nd	23.±22.	nd	nd	nd	nd	17.±15.
86	0	1969	Remainder	0.488	nd	nd	14.±9.2	nd	360.±49.	nd	210.±90.	nd	nd	120.±49.

Appendix Table 3. Gamma-emitting radionuclides in particulate and soluble fractions of sea water collected in the vicinity of Christmas Island, May through August, 1962. Values expressed in picocuries per liter at time of collection plus or minus the 95 per cent counting error.

Station and date	Depth	Zn ⁶⁵		Zr-103 ⁹⁵		Cs ¹³⁷		Ru ¹⁰³		Ce ^{141,144}		Other	
		Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.
6 5-2-62	0 m.	--	13 [±] 10	3.0 [±] 3.0	--	--	--	--	--	4.0 [±] 2.0	13 [±] 13	--	--
	25 m.	--	--	110 [±] 49	--	--	--	400 [±] 280	--	29 [±] 17	--	--	--
	50 m.	--	--	110 [±] 77	--	--	--	--	--	35 [±] 22	--	--	--
	100 m.	--	--	53 [±] 51	--	--	--	--	--	--	85 [±] 78	--	--
	300 m.	--	--	--	--	--	--	--	--	--	--	--	--
10 5-3-62	0 m.	--	--	96 [±] 27	--	1.0 [±] 1.0	11 [±] 2.0	330 [±] 170	--	12 [±] 6.0	--	--	--
	25 m.	--	--	--	--	--	9.0 [±] 7.0	--	--	--	--	--	--
	50 m.	--	--	110 [±] 40	150 [±] 120	--	--	--	--	31 [±] 20	--	--	--
	100 m.	--	--	--	590 [±] 200	--	11 [±] 11	--	--	--	270 [±] 89	--	--
	300 m.	--	--	--	--	--	--	--	--	--	--	--	--
13 5-4-62	0 m.	4.0 [±] 3.0	--	53 [±] 17	--	--	--	12 [±] 10	--	3.0 [±] 2.0	24 [±] 11	--	--
	25 m.	--	--	--	180 [±] 170	--	--	320 [±] 290	--	--	120 [±] 77	--	--
	50 m.	--	--	--	--	--	9.0 [±] 8.0	--	--	--	--	--	--
	100 m.	--	--	--	150 [±] 120	--	--	--	--	--	140 [±] 55	--	--
	300 m.	--	--	--	--	--	--	--	--	--	100 [±] 80	--	--
17 5-5-62	0 m.	--	--	--	--	--	--	--	--	46 [±] 17	--	*0.193 [±] 0.034 **7.0 [±] 4.0	
	25 m.	--	--	--	--	--	--	--	--	73 [±] 71	--	--	

*Sr⁹⁰
**Co⁶⁰

Appendix Table 3. (continued)

Station and date	Depth	Zn ⁶⁵		Zr-Nb ⁹⁵		Cs ¹³⁷		Ru ¹⁰³		Ce ^{141,144}		Other	
		Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.
17 5-5-62	50 m.	--	--	1.0 [±] 1.0	--	--	--	5.0 [±] 3.0	--	--	--	--	--
	100 m.	23 [±] 22	--	81 [±] 69	--	--	--	--	--	--	--	--	--
	300 m.	--	--	--	--	--	--	350 [±] 300	--	--	--	--	--
21 5-6-62	0 m.	--	--	48 [±] 8.0	36 [±] 14	--	--	46 [±] 44	--	7.0 [±] 3.0	13 [±] 6.0	--	--
	25 m.	--	--	--	180 [±] 150	--	--	--	--	--	92 [±] 68	--	--
	50 m.	--	--	--	340 [±] 120	--	--	--	850 [±] 700	--	--	--	--
	100 m.	--	--	--	--	--	--	360 [±] 310	--	--	--	--	--
	300 m.	--	--	--	--	--	--	--	--	--	--	--	--
26 5-7-62	0 m.	5.0 [±] 5.0	--	--	53 [±] 36	--	--	--	--	--	39 [±] 20	--	--
	25 m.	--	--	--	--	--	--	--	--	--	--	--	--
	50 m.	--	--	--	--	--	--	--	1100 [±] 760	--	79 [±] 74	--	--
	100 m.	--	--	--	--	--	--	--	--	--	--	--	--
	300 m.	--	--	--	380 [±] 120	--	--	--	1400 [±] 750	--	39 [±] 30	--	--
29 6-12-62	0 m.	--	--	--	71 [±] 56	--	--	--	--	--	--	--	--
	25 m.	--	--	--	--	--	--	--	--	--	--	--	--
	50 m.	27 [±] 20	--	59 [±] 46	--	--	--	--	--	--	91 [±] 70	--	--
	100 m.	--	--	--	--	--	--	--	--	--	98 [±] 71	--	--
	300 m.	--	--	32 [±] 27	240 [±] 81	--	--	--	--	--	--	--	--
34 6-14-62	0 m.	--	--	--	--	--	--	--	--	4.0 [±] 3.0	--	--	**2.0 [±] 1.0
	25 m.	--	--	--	--	--	--	--	--	--	--	--	--
	50 m.	--	--	--	--	--	--	180 [±] 170	--	--	--	--	--

Appendix Table 3. (continued)

Station and date	Depth	Zn ⁶⁵		Zr-Nb ⁹⁵		Cs ¹³⁷		Ru ¹⁰³		Ca ^{141,144}		Other	
		Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.
34 6-14-62	100 m.	--	--	--	--	--	--	--	--	--	150 [±] 98	--	--
	300 m.	--	--	--	--	--	--	360 [±] 200	--	--	--	--	--
38 5-16-62	0 m.	7.0 [±] 4.0	--	3.0 [±] 2.0	--	--	--	--	--	--	7.0 [±] 6.0	--	*0.034 [±] 0.023
	25 m.	--	--	--	28 [±] 24	--	--	--	--	26 [±] 23	38 [±] 33	--	--
	50 m.	--	--	--	--	--	--	220 [±] 160	--	--	--	--	--
	100 m.	--	--	--	340 [±] 79	--	7.0 [±] 6.0	--	800 [±] 360	--	120 [±] 44	--	--
	300 m.	--	--	--	510 [±] 91	--	--	--	450 [±] 370	--	120 [±] 39	--	--
42 6-16-62	0 m.	--	--	--	--	--	--	--	--	--	15 [±] 11	--	--
	25 m.	21 [±] 20	--	120 [±] 46	--	--	--	210 [±] 160	780 [±] 550	38 [±] 24	100 [±] 100	--	--
	50 m.	--	--	32 [±] 30	--	--	--	170 [±] 140	--	--	--	--	--
	100 m.	--	--	--	--	--	--	--	--	--	--	--	--
	300 m.	--	--	--	--	--	--	--	--	--	100 [±] 69	--	--
47 6-17-62	0 m.	--	--	--	--	--	3.0 [±] 2.0	1.0 [±] 1.0	--	--	--	--	--
	25 m.	--	--	--	--	--	--	--	--	--	--	--	--
	50 m.	--	--	--	--	--	--	--	--	--	--	--	--
	100 m.	24 [±] 19	100 [±] 47	--	--	--	--	--	--	--	--	--	--
	300 m.	--	--	57 [±] 27	--	--	--	--	--	--	--	--	--
56 7-29-62	0 m.	--	--	--	74 [±] 19	--	--	--	--	--	--	--	*0.057 0.036
57 7-30-62	0 m.	--	6.0 [±] 6.0	--	14 [±] 7.0	--	--	--	22 [±] 15	--	20 [±] 8.0	--	--
58 7-30-62	0 m.	--	--	--	5.0 [±] 3.0	--	--	--	10 [±] 6.0	--	9.0 [±] 3.0	--	--

Appendix Table 3. (continued)

Station and date	Depth	Zn ⁶⁵		Zr-Nb ⁹⁵		Cs ¹³⁷		Ru ¹⁰³		Ce ^{141,144}		Other	
		Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.
78 8-5-62	0 m.	--	--	--	--	--	--	--	--	--	--	--	--
	36 m.	--	--	--	35 [±] 29	--	--	--	--	--	--	--	--
	107 m.	--	--	--	--	--	--	19 [±] 12	--	3.0 [±] 3.0	--	**1.0 [±] 1.0	--