NVO-269-8

407855

RADIOLOGICAL RESURVEY OF ANIMALS, SOILS AND GROUNDWATER AT BIKINI ATOLL, 1969

by
Edward E. Held

University of Washington
College of Fisheries
Laboratory of Radiation Ecology
Seattle, Washington

Allyn H. Seymour
Director

November 1969

Work done under Contract AT(26-1)-269 with the
United States Atomic Energy Commission

Abstract

The results of radiometric and radiochemical analyses of samples, exclusive of land plants, collected at Bikini Atoll in 1969 are presented and discussed. Average values for radionuclides in food items in pCi/g wet are: reef fish, ^{60}Co-2.6, ^{90}Sr-.08, ^{137}Cs-.13; pelagic fish, ^{60}Co-.94; spiny lobster, ^{60}Co-.12; giant clams, ^{60}Co-24; curlews, ^{60}Co-.94, ^{137}Cs-380; turnstones, ^{60}Co-7.7, ^{137}Cs-56; terns, ^{60}Co-1.1, ^{137}Cs-.08. Average concentrations of ^{90}Sr in the muscle of coconut crabs from Bikini and Enyu Islands were 12 pCi/g wet and .05 pCi/g wet, respectively. There are no striking differences between the 1967 and 1969 average values for edible foods of marine origin, including the sea birds. Predominant radionuclides in undisturbed soils in 1969 are ^{55}Fe, ^{60}Co, ^{65}Zn, ^{90}Sr, ^{125}Sb, ^{137}Cs and ^{207}Bi. In the crater sediments ^{55}Fe, ^{60}Co, ^{90}Sr, and ^{207}Bi predominate. There are quantitative and qualitative differences in radionuclide content associated with the feeding habit of fish and there appears to be an increasing concentration of some radionuclides with increasing age of fish and clams. The radionuclide content of bird species presents a sharp contrast, both qualitatively and quantitatively, associated with feeding habit. It appears that some ^{60}Co and ^{207}Bi is being transported eastward by the bottom current in the lagoon. Silver-108m, previously unreported in fallout, was found in the hepatopancreas of the spiny lobster. The present levels of radionuclides and their distribution at Bikini are not likely to change significantly except for decrease in amounts, due to physical decay.

C O N T E N T S

TABLES

Page

FIGURES

APPENDIX TABLES

RADIOLOGICAL RESURVEY OF ANIMALS, SOILS AND GROUNDWATER AT BIKINI ATOLL, 1969

INTRODUCTION

Bikini Atoll was a site for atmospheric tests of nuclear devices from 1946 to 1958. The population of 166 Bikinians was moved from the atoll in March, 1946, first to Rongerik Atoll, then to Kwajalein Atoll; in November, 1948, a final move was made to Kili Island. The land area at Kili is about one-tenth that at Bikini Atoll and there is no lagoon. Therefore, access to Kili is difficult, often impossible, and sea foods are scarce.

The results of a radiological resurvey of Bikini in 1964 by the University of Washington's Laboratory of Radiation Biology indicated that Bikini might be radiologically safe for permanent habitation. A request from the High Commissioner of the Trust Territories of the Pacific to the Atomic Energy Commission in 1966 to rehabilitate Bikini resulted in an extensive survey of the atoll in the spring of 1967. This survey emphasized external radiation measurements, including in situ gamma-ray spectrometry, although some food items were collected to supplement data from the 1964 survey. The 1967 survey party included personnel from the Atomic Energy Commission's Health and Safety Laboratory, the Division of Biology and Medicine, the U. S. Naval Radiological

Defense Laboratory, the Trust Territory, and the University of Washington.

The data were summarized by DBM and were presented to a panel of experts assembled by DBM for evaluation of potential radiological hazards. Most of the participants in the 1967 survey attended the presentation to provide details not included in the summary.

The panel concluded that Bikini could be safely reoccupied, but recommended some restrictions and suggested things to be done to rehabilitate the atoll. These included restriction of coconut crabs from the diet, because they contain high concentrations of ^{90}Sr, and covering the village area at Bikini Island with coral gravel from the beaches, to provide a shield against radiation from the soil. The panel also recommended that old structures and other such debris from the tests be removed from the islands and beaches and that the island be further monitored during the clean-up. Additional monitoring was necessary because dense vegetation on Bikini and Enyu Islets, especially, made it impractical to survey more than a few transects across the islands in 1967.

The panel's recommendations were made to the Chairman of the Atomic Energy Commission who informed the Secretary of the Interior, the administrator for the Trust Territory of the Pacific.

The clean-up phase of the rehabilitation of Bikini Atoll was begun in February, 1969, by Joint Task Force Eight. The AEC Nevada Operations Office is responsible for certification of the clean-up portion of the rehabilitation program, which was carried out under guidelines approved by the AEC Division of Operational Safety. At the request of NVOO, the U. S. Public Health Service took the responsibility for external radiation measurements, and for the collection and analysis of those land plants which are food items; the U of W Laboratory of Radiation Ecology was asked to sample and analyze other biological and environmental samples. This report presents the results of the Laboratory's analyses.

SELECTION OF SAMPLES AND SAMPLING SITES

The sampling program was based on the objective of obtaining data for evaluation of potential radiological hazards to man. The samples were limited, for the most part, to things which might be eaten by returning Bikinians, except for land plants. Some additional samples, for example soils, crater sediments and ground water, were taken to provide data for estimating the future distribution and amounts of radionuclides in the biota.

The fish collected are in two main categories: the reef fish and the pelagic, or "troll-caught" fish. The reef fishes are usually collected by throw nets by the Marshallese and are important items in their diet.

Of the more than 700 species of reef fishes at Bikini Atoll, we selected three species commonly eaten by the Marshallese and representative of three feeding habits: the mullet,* a plankton feeder; the convict surgeonfish, a grazing herbivore; and the goatfish, a bottom-feeding carnivore. The specific radionuclides found in fish and their concentrations are often associated with feeding habit, hence this was a necessary consideration in selecting samples representative of the kinds of fish which would be eaten when the Bikinians return. A fourth kind of reef fish, groupers, was also collected as respresentative of the higher order carnivores.

The troll-caught fishes are all high-order carnivores and fall into two broad subcategories: resident lagoon fish, ulua and dogtooth tuna; and migratory fish, yellowfin tuna. All were caught in or near Enyu Pass. Bikinians who were part of the clean-up crew cut filets from the yellowfin tuna and preserved them by salting. They said tuna is one of their favorite fish and, presumably, would fish for tuna if they return to Bikini.

The invertebrates sampled were the spiny lobsters (langouste), coconut crab and "giant" clams (Tridacna sp., and Hippopus hippopus). Some of the species of Tridacna never exceed a few centimeters in length, and only the smaller species were found

* For a list of common names and scientific names, see Appendix Table 16.

in the vicinity of Nam (Charlie) Islet. The larger species were found near Bikini Island.

In response to a special request to check the levels of radioactivity at Aerokoj Islet, received during the survey, the land hermit crab, a known concentrator of ^{90}Sr, was collected. Since coconut crabs are both an indicator organism and a food item, they would have been sampled instead of hermit crabs, but coconut crabs were not found on Aerokoj.

Thousands of terns nest at Bikini Atoll, mostly on the western islets. Both the birds and their eggs will be used as food. The terns almost always feed at sea, outside the lagoon or reefs. On the other hand, the curlews and turnstones feed along the shores and on the reef, and the curlew also eats the seeds of an endemic shrub, Scaevola serica, or the beach magnolia. Although the curlews and turnstones are transients and are present in small numbers, at most a few hundred, they contain the highest levels of radionuclides among the birds. Curlews, turnstones, noddy terns, and fairy terns were sampled.

Rats are not used as food but they are the only mammal living on the atoll, and a few were taken to determine their radionuclide content.

Groundwater was collected by driving half-inch pipe with well points into the soil. The well point sites on Bikini and

Eneman Islands were in areas found to be the most radioactive by the U. S. Public Health Service personnel. On Nam I. the well point was driven in a low area near the center of the island. Existing wells were sampled at Enyu. Attempts to obtain groundwater at Aerokoj were unsuccessful.

Soil samples were taken by one-inch depth increments to depths of ten inches or more near each well point. All depth increments for two sets of samples from Eneman were analyzed but only the surface one-inch of other sets of samples were analyzed. In addition to samples from soil pits at the well points, surface samples also were taken at Aomen and Oroken.

Sediments from the Bravo Crater were taken by dredge from depths of 40, 120, 140, and 160 feet.

ANALYTICAL METHODS

Gamma-Ray Spectrometry

All of the samples were analyzed by gamma-ray spectrometry. They were counted for at least 100 minutes with a 3 x 3-inch NaI(Tl) crystal used in conjunction with a 256-channel analyzer. Selected samples were counted for 1,000 minutes, either with a 3 x 3-inch detector or a detector system consisting of two opposing 5 x 5-inch crystals operating as a summing spectrometer.

Most of the biological samples were oven dried, ground and compressed in polyvinyl chloride (PVC) pipe to a volume resulting in a density of 1.0. Small samples, spiny lobster hepatopancreas for example, were ashed, dissolved in hydrochloric acid, and sealed in PVC pipe.

Oven-dried soil samples were compressed to a density of 1.35 in PVC pipe.

Spectrum resolution was done by Schonfeld's (1965) method of least squares. A set of previously prepared reference spectra for the different geometries and radionuclides was used. All values were corrected for decay to the date of collection. The error given for individual values is the 95% error.

Strontium-90 Analyses

Strontium-90 was determined by measuring the equilibrium concentration of its ^{90}Y daughter. Yttrium-90 was separated by solvent extraction and precipitation techniques (Petrow, 1965), with stable yttrium serving as both a carrier and a yield determinant. Recoveries ranged from 80 to 100%.

Iron-55 Analyses

Iron-55 was separated and purified by a combination of solvent extraction and electrodeposition techniques (Palmer and Beasley, 1967). Recoveries generally exceeded 90%. Counting was done by X-ray spectroscopy with a proportional counter in conjunction with a multichannel analyzer.

Bismuth-207 Analyses

The solvent extraction techniques of Sill and Willis (1965) were used for separating and purifying ^{207}Bi. Bismuth-212 was used as a yield determinant.

Plutonium-238, 239 Analyses

Plutonium-238,239 was separated by a combination of solvent extraction and anion exchange techniques (McCowan and Larsen, 1960; Kressin and Waterbury, 1962), with electrodeposition as the final step in the separation. Plutonium-236* was used to determine yield. A quantitative separation of plutonium from the coraline soils and sediments is exceptionally difficult and it is therefore essential that ^{236}Pu be used as a yield determinant and that counting be done by alpha spectrometry.

Tritium Analyses

Well water samples were measured for tritium content by a liquid scintillation technique with a minimum level of detection of 200 tritium units.

RESULTS AND DISCUSSION

The predominant radionuclides in the terrestrial organisms are ^{137}Cs and ^{90}Sr, whereas the marine organisms contain mainly

* Provided by the USAEC Health and Safety Laboratory, New York.

^{60}Co and ^{55}Fe. The concentrations of these radionuclides in edible portions of organisms range from undetectable amounts to the following maximum values:

^{137}Cs - 2260 pCi/g dry in the muscle tissues of a curlew from Nam I.

^{90}Sr - 204 pCi/g dry in the hepatopancreas of a coconut crab from Bikini I.

^{60}Co - 219 pCi/g dry in muscle and mantle tissue of a giant clam near Bikini I.

^{55}Fe - 40,900 pCi/g dry in the liver of an ulua.

The range in the amount of a radionuclide in the same tissue from the same species at the same islet is wide. When detectable amounts of radionuclides are present, the minimum and maximum values often differ by factors of four or five and sometimes by a factor of ten. The values for concentration of radionuclides in individual samples are given in Appendix Tables 1 through 15. Average values and ranges are given in text Tables 1 through 15.

Dry weights were used for the basic calculations because the true water content of some samples is difficult to determine. The average concentrations of radionuclides were converted to a wet-weight basis for convenience in calculating daily intake from the diet; the conversions were made by using average wet to dry weight ratios for each kind of sample.

The mean values for ^{90}Sr, ^{137}Cs, ^{60}Co, ^{65}Zn and ^{54}Mn in diet items at Bikini Atoll in 1967 were given in the Radiological Report on Bikini Atoll by Gustafson in 1968, and are listed in Table 1 with the average values determined from the 1968 samples. Three hundred fourteen-day ^{54}Mn and 245-day ^{65}Zn have been omitted from Table 1 because no detectable amounts of these radionuclides were found in the 1969 samples, and ^{55}Fe has been added, by using values for 1967 samples from an addendum to the 1968 report.

The 1967 values for fish include reef fish and troll-caught fish, whereas the 1969 data in Table 1 are for reef fish only. The average values for ^{60}Co in the muscle of troll-caught fish were,

Yellowfin tuna	0.15 pCi/g wet
Ulua	1.7 " "
Dogtooth tuna	0.04 " "

Thus, the 1969 values for fish in Table 1 are greater than if the values for troll-caught fish were included in the averages.

In Table 1 the data for giant clams are for 1969 samples taken from the vicinity of Bikini I. Clams were also collected around Nam I. but they were of a small species which is rarely eaten; also, the level of ^{60}Co in the Nam I. clams was lower than in the Bikini I. clams, presumably because the latter were older clams which had accumulated ^{60}Co for several years. No data for clams were available in 1967, but the maximum value for ^{60}Co in the edible portion of clams in 1964 was 73 pCi/g wet (Bonham, 1967).

The land crabs are listed separately for Bikini I. and Enyu I. because the panel convened by the DBM in 1968 recommended, on the basis of the data then available, that coconut crabs be omitted from the Bikini diet. Thirteen crabs collected at Enyu I. in 1969 were analyzed for ^{90}Sr and gamma emitters; the levels of all radionuclides are sufficiently low that a reconsideration of the restriction for Enyu I. is indicated.

The species of birds are listed separately for 1969 because an average value for all birds would be a poor estimate of the potential intake, since few curlews or turnstones are available.

In general, there are no striking differences between the 1967 and 1969 average values of radionuclides for edible portions of foods of marine origin, including the sea birds. The differences tend to show a decline in radionuclide content in 1969, but there are not sufficient data to provide a basis for a reasonable estimate of rates of decline because of the large variability in the data and the many poorly defined factors involved in the uptake and retention of radionuclides by organisms in the natural environment of Bikini. Some basic biological information such as rates of growth and life spans of the fishes is not known and the chemical form in which the radionuclides are present in the lagoon waters can only be surmised. We do not even know, for example, whether the radionuclides and their stable isotopes are present in the same chemical form. Furthermore, there are no uncontestable data on the trace element content of lagoon waters and probably will not be until the techniques of sampling and processing seawater samples is greatly improved. However, some hypotheses can be made and conclusions can be drawn from certain data.

All of the fallout radionuclides at Bikini are found in the surface of undisturbed soils. The predominant radionuclides in 1969 were ^{55}Fe, ^{60}Co, ^{65}Zn, ^{90}Sr, ^{125}Sb, ^{137}Cs, and ^{207}Bi. In the crater sediments only four predominate: ^{55}Fe, ^{60}Co, ^{90}Sr, and ^{207}Bi, although many more are present in smaller quantities. The soils and sediments are now the principal reservoirs of radionuclides at Bikini. The radionuclides are available to the land animals through the vegetation, or other animals, where there is selection of specific radionuclides, or through direct ingestion of soil. In the latter case, the animal selects certain radionuclides from a wider variety of nuclides than is in the vegetation.

Similarly, the marine animals may ingest radionuclides by eating another organism or by ingesting sediments. In addition, the marine organism may absorb radionuclides directly from the water, or radionuclides may be adsorbed on the surface of the animal. Although adsorption is an important means of contamination of organisms by fresh fallout, it is probably no longer important at Bikini, where the last significant fallout occurred in 1958. The astronomically large surface area presented by the masses of branching corals and their associated flora and fauna must have removed, from the water, all adsorbable radionuclides not already removed by the plankton soon after fallout.

The land organisms contain primarily the long-lived fission products ^{137}Cs and ^{90}Sr and, as expected, these radionuclides are found associated with those tissues or organs which contain potassium and calcium, respectively, since cesium and potassium behave similarly in metabolism, as do strontium and calcium.

There are quantitative and qualitative differences in radionuclide content of organisms associated with feeding habit. The goatfish, a bottom-feeding carnivore, contains more ^{60}Co and ^{207}Bi than the convict surgeonfish, a grazing herbivore, or the mullet, a plankton feeder (Tables 2 and 3). Higher order carnivores, the grouper and ulua, also contain more ^{60}Co and ^{207}Bi (Table 4) than the convict surgeonfish; however, the differences may be associated with age as well as with feeding habit.

The smaller, and presumably younger, reef fish of a species contain less ^{90}Sr than the larger fish of the same species

(Appendix Table 11). Presumably, the ^{90}Sr is being accumulated throughout the life of the fish and a steady state has not been reached. The values for ^{90}Sr in the ulua (Appendix Table 12) and the reef fish cannot be directly compared because the bone of the ulua was analyzed for ^{90}Sr and only whole eviscerated reef fish were analyzed. However, a comparison of Appendix Table 11 and 12 shows that there can be no great difference in ^{90}Sr content between larger, older fish of even the grazing herbivore and the higher order carnivore. On the basis of the differences between ^{60}Co content of goatfish and ulua, it might be assumed that there is an increasing concentration of the radionuclide in the ascending food chain. However, this is evidently not true for ^{90}Sr. The discrepancy probably exists because information is lacking on the radionuclide content of other organisms on which the ulua feed and which could well concentrate ^{60}Co, for example, squid.

Another example of increasing concentration of a radionuclide probably associated with age is the concentration of ^{60}Co in the kidney of the giant clams Tridacna sp. and Hippopus hippopus (Appendix Table 9). By far the highest levels of ^{60}Co, as much as 4,000 pCi/g dry, in any organism at Bikini Atoll is in the kidney of these clams. Obviously, there must be an accumulation of ^{60}Co in the kidney and the longer the clam lives in an environment where ^{60}Co is available, the more ^{60}Co it accumulates in the kidney, if ^{60}Co has a long biological half-life. This is not a concentration through the food web since the clams are filter feeders.

The radionuclide content of bird species presents a sharp contrast, both qualitatively and quantitatively, associated with feeding habit (Table 8 and Appendix Table 10). The fairy terns and noddy terns feed mostly at sea outside the lagoon and contain small amounts of fallout radionuclides, less than the amount of naturally occurring ^{40}K. They contain barely detectable amounts of ^{137}Cs. The curlew, on the other hand, feeds on the reef and on Scaevola sp. seeds, and consequently contains relatively large amounts of ^{137}Cs, as much as 2,300 pCi/g dry in muscle. The turnstones also feed along the beaches and on the reef, and contain both ^{60}Co and ^{137}Cs. The source of ^{137}Cs for the turnstones is not known, although it could be by direct ingestion of sand particles. The yellowfin tuna, which are feeding on essentially the same organisms as the terns, contain about the same levels of ^{60}Co as the fairy terns. The ^{60}Co levels in the noddy terns are somewhat higher but still are of the same order of magnitude. Thus the area in which an animal is feeding is a factor affecting its radionuclide content, as expected, in relation to the distance from the source of the radionuclide.

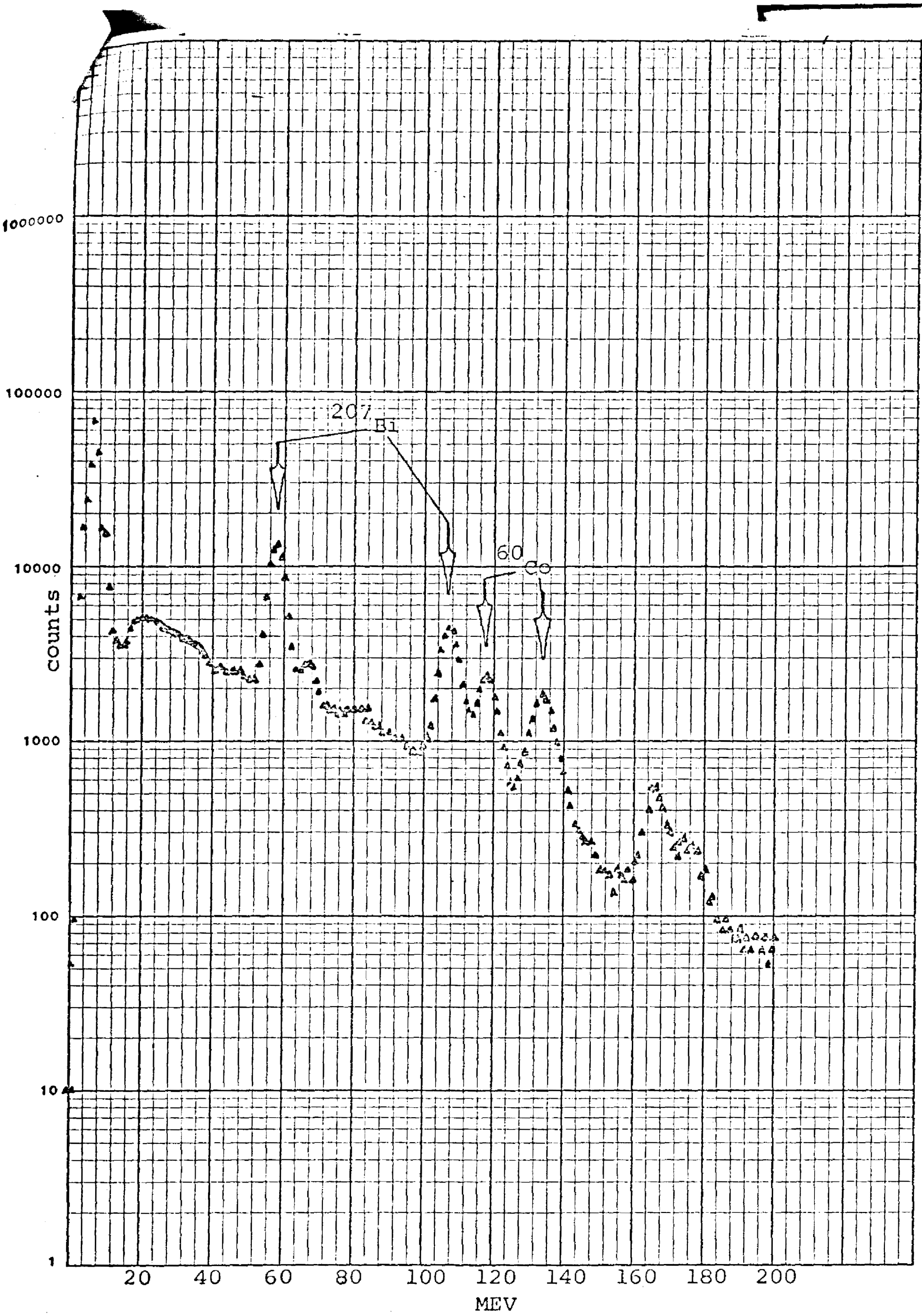

Fig. 1. Gamma-ray spectrum of sediment from Bravo Crater collected at a water depth of 160 feet, August, 1969.

The source of ^{60}Co for the tuna must be Bikini Atoll and not worldwide fallout because we analyzed tissues from 214 tuna, including 75 yellowfin tuna, taken from the Japanese tuna fishery during 1968 and 1969, and found no ^{60}Co (NVO-269-7, Annual Report). In contrast, the ^{55}Fe concentrations in the dark muscle of the tuna from the Japanese fishery ranged from 3.3 to 1600 pCi/g dry, most of the values fell in the range of 101 to 500 pCi/g dry. It appears, therefore, that a major amount of the ^{55}Fe in the Bikini tuna is from worldwide fallout.

One of the principal sources of radionuclides at Bikini is Bravo Crater in the reef adjacent to and southwest of Nam I. Figure 1 shows a gamma-ray spectrum of sediment taken from a depth of 160 feet. Clearly, ^{60}Co and ^{207}Bi predominate among the gamma emitters. In most soils, ^{137}Cs is the most abundant radionuclide. An intermediate condition exists at the southwestern end of Eneman I., where a low area is occasionally overwashed by seawater, and at the high tide line, where the ^{137}Cs is being leached from the soil.

The retention of ^{60}Co and ^{207}Bi by the sediments is reflected in the fact that the bottom-feeding goat-fish in the vicinity of the craters contain ten times more ^{60}Co than the herbivorous convict surgeonfish and plankton feeding mullet. However, some ^{60}Co is being transported eastward by the bottom current in the lagoon either in solution or associated with fine (colloidal?) particles, because the difference in ^{60}Co content between convict surgeonfish and mullet in the vicinity of Bravo Crater and 16 miles eastward near Bikini I. is only by a factor less than two.

And, at the same time, the difference in ^{60}Co content between the goatfish from near the crater and those at Bikini I. is by a factor of about ten.

It appears that the physical redistribution of ^{207}Bi is similar to that of ^{60}Co, but since the levels of ^{207}Bi are lower than those of ^{60}Co by a factor of about 20, we are at the limits of detection, with the method used, for samples distant from the crater. The use of larger samples, chemical separation and more sensitive counting methods would make it possible to determine ^{60}Co:^{207}Bi ratios in sediments, lagoon water and organisms in different parts of the lagoon. These ratios would indicate whether transported radionuclides were primarily in solution or on particles. If the ratios remained constant, that would be a strong indication of transport on particles. The results of analyses of selected samples for ^{207}Bi by gamma-ray spectrometry and by chemical separation are compared in Table 13. Bismuth-207 will be a useful tracer in the future because it has a long half-life, 30 years compared to 5.2 years for ^{60}Co.

Plutonium-239, with a half-life in excess of 24,000 years, is another potentially useful tracer. The samples analyzed for plutonium were selected on the bases of collection location and content of gamma-emitting radionuclides, which indicate the greatest likelihood of the presence of plutonium. The values given in Table 14, therefore, probably are maximum values for each type of sample. The ratios of $^{239,240}Pu$ to ^{238}Pu approach 2:1 at Eniman I. and are about 15:1 in Bravo Crater. Bikini I. soils contained no detectable ^{238}Pu, although they contained the highest concentration of $^{239,240}Pu$ of the samples analyzed. The presence of $^{239,240}Pu$ and ^{207}Bi in goatfish viscera is consistent and probably results from direct ingestion of fine particles of sediment during feeding. The absence of ^{238}Pu in goatfish viscera as compared with the sediment merely reflects a low concentration of this radionuclide, below the limits of detection.

Although none of the 1969 samples were analyzed for the X-ray emitter ^{63}Ni, this radionuclide was found in concentrations of 80 d/m/g dry weight in Bravo Crater sediment collected in 1967 (Beasley and Held, 1969). Nickel-63 is of particular interest as a tracer since it has a half-life of 92 years. In addition, the clam kidney accumulates ^{63}Ni, as it does ^{60}Co, and is therefore an indicator organism for the presence of ^{63}Ni.

Another long-lived radionuclide, ^{108m}Ag, with a half-life of approximately 100 years, has been identified for the first time among the radionuclides at Bikini. This radionuclide was detected from the gamma-ray spectrum of the hepatopancreas of

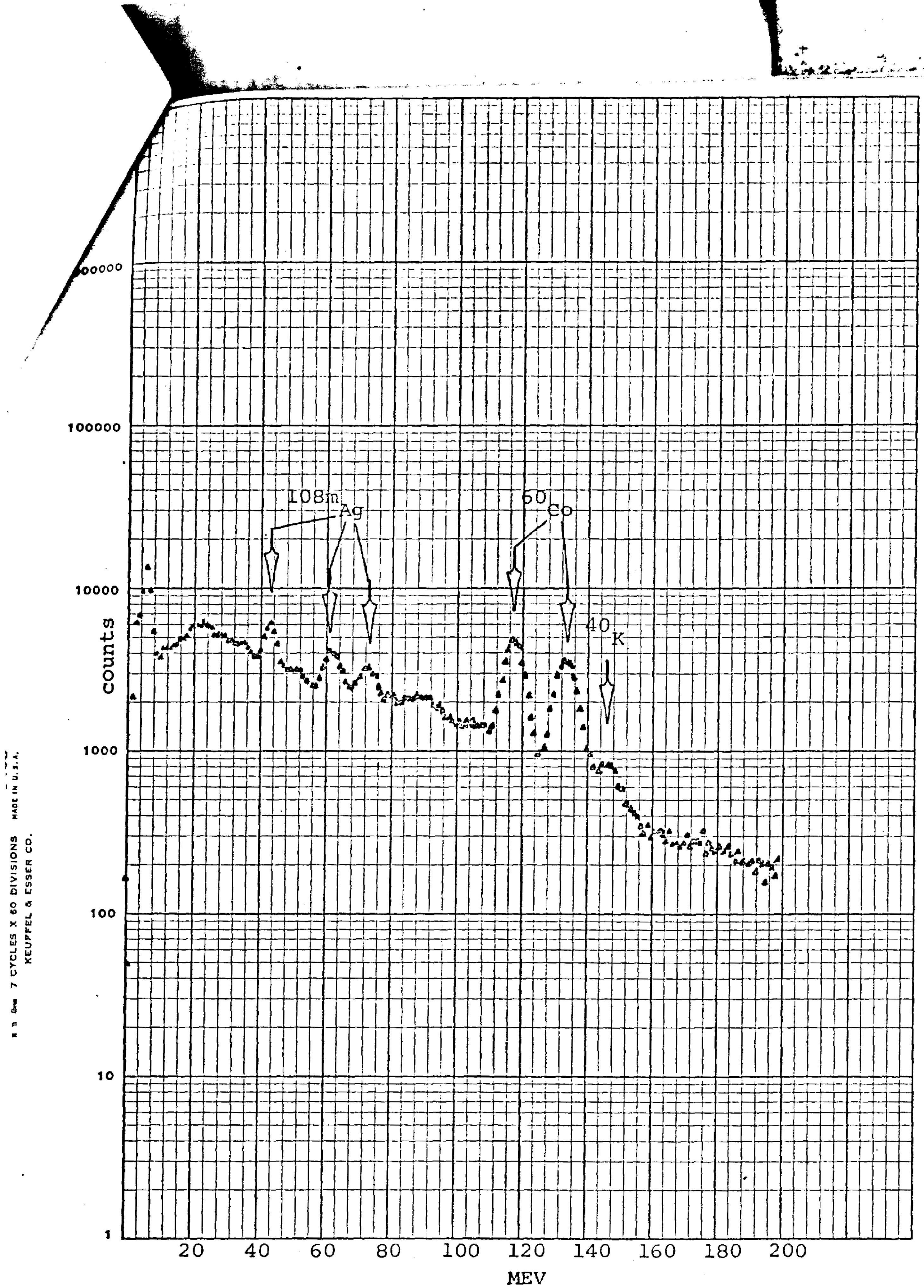

Fig. 2. Gamma-ray spectrum of spiny lobster hepatopancreas from Bikini Atoll, 1969.

spiny lobsters collected in 1969 (Fig. 2). Although the identity of ^{108m}Ag has not been confirmed by chemical separation, there is little doubt of its presence because the spiny lobster hepatopancreas is known to concentrate 260-day ^{110m}Ag (Seymour, 1963). Thus, ^{108m}Ag is another potentially useful long-lived tracer with its indicator organism.

Tritium in well water is present at low concentrations; the maximum value found was 14 pCi/ml, or 4300 tritium units, at Nam I., whereas at Bikini and Enyu Islands the concentration was 2 pCi/ml, or approximately 600 T.U. (Table 15). These values fall within the range of tritium concentrations in surface waters of the United States in 1966 reported by Moghissi and Porter (1968). Koranda (1965) has shown that there is approximately 10^4 times more tritium in bound water than in loose water in soils at Eniwetok Atoll, but that there is little exchange of the bound water with the loose water. Hence it is probable that there will be no major changes in the tritium concentration of well water at Bikini Atoll.

Bikini can be expected to remain a useful area for the study of the redistribution of radionuclides for at least several decades. This is especially true since rapid advances are being made in the technology of radionuclide detection.

The present levels of radionuclides and their distribution at Bikini are not likely to change significantly except for a decrease in amounts from physical decay. Exceptions are expected where physical disturbances occur during the replanting on land. If one of the rare typhoons should strike Bikini, there would be a major redistribution of the fine sediments, either a redistribution within the lagoon, a flushing from the lagoon, or both.

Table 1
Average Values of Radionuclides in Food Items Other Than Land Plants at Bikini Atoll, 1967(1) and 1969

pCi/g wet

Diet Item	^{55}Fe '67	^{55}Fe '69	^{60}Co '67	^{60}Co '69	^{90}Sr '67	^{90}Sr '69	^{137}Cs '67	^{137}Cs '69
Fish, muscle	100		3.7		.19		.32	
" , eviscerated whole(2)		18		2.6		.08		.13
Fish, liver	9200*	382*	44.7		-		nd	
" , viscera(2)		120		13.3		-		nd
Spiny lobster(3,4)		2.5	.11	.12	.04	-	.02	nd
Giant clams(5)		5.9		24		-		nd
Coconut crabs, muscle			10		19		72	
" " " (Bikini)		1.2		.65		12		181
" " " (Enyu)		.8		.14		.05		16
Coconut crabs, "liver" (Bikini)		41		7.8		62		170
" " " (Enyu)		16		1.5		5.1		16
Birds, muscle, all species	100	110	3.5		.13		26.5	
" " , curlew		24	.94			-		380
" " , turnstone		105	7.7			-		56
" " , terns		155	1.1			-		.08

(1) Radiological Report on Bikini Atoll. Philip F. Gustafson, Division of Biology and Medicine, USAEC, Washington, D.C., April 1968.

(2) Reef fish only.

(3) The heading, "Clams or Lobster" was used in the 1968 table, but it has been established that the values given are for spiny lobsters from Bikini I. only.

(4) The 1969 value includes spiny lobsters from Nam I. The average values for ^{60}Co for lobsters from Bikini I. is .07 pCi/g wet.

(5) Clams from near Bikini I. only. Only small clams, not usually eaten, were found off Nam. The maximum value for ^{60}Co was 29 pCi/g wet.

*Jacks only

nd - not detectable

Table 2

Radionuclides in Eviscerated Whole Reef Fish
Collected at Bikini Atoll, June 1969

Average Values

		pCi/g dry						pCi/g wet		
Island		^{60}Co		^{137}Cs		^{90}Sr		^{60}Co	^{137}Cs	^{90}Sr
Common Name	N*	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Avg.	Avg.
Bikini										
Mullet	3	3.9	2.9-4.6	.21	.12-.38	.10	.05-.12	1.1	.06	.03
Goatfish	2	2.8	2.6-2.9	nd**		.06	.05,.07	.79		.02
Surgeon	3	1.7	1.3-2.1	.73	.64-.84	.16	.16,.16***	.48	.21	.04
Enyu										
Goatfish	2	.45	nd,.90	.08	nd-.17	not done		.13	.02	
Nam										
Mullet	4	12	8.8-19	.78	.58-1.1	.39	.33-.50	3.4	.22	.11
Goatfish	2	32	31,32	.31	nd-.62	.77	.61,.93	9.0	.09	.22
Surgeon	5	2.7	1.6-4.3	.70	.28-1.2	.35	.09-.86	.76	.20	.10
Pilotfish	1	5.0		nd		not done		1.4		
Bikini										
Avg. of Avgs.		2.8		.31		.11		.79	.09	.03
Nam										
Avg. of Avgs. (except pilotfish)		16		.60				4.5	.17	

*Number of samples.
**nd, Not detectable. Value taken as zero in computing averages.
***Two samples only analyzed for ^{90}Sr.

Table 3

Gamma-Emitting Radionuclides in Viscera of Reef Fish
Collected at Bikini Atoll, June 1969

Average Values

		pCi/g dry						pCi/g wet		
Island		^{60}Co		^{137}Cs		^{207}Bi		^{60}Co	^{137}Cs	^{207}Bi
Common Name	N*	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Avg.	Avg.
Bikini										
Mullet	3	9.2	5.7-11	.81	.61-1.1	.08	nd-.23	2.6	.23	.02
Goatfish	2	20	17-24	nd		nd		5.6		
Surgeon	3	9.7	6.2-12	1.6	.78-2.3	nd		2.7	.44	
Enyu										
Goatfish	2	5.8	5.6-6.1	nd		.13		1.6		.04
Nam										
Mullet	4	18	13-22	1.3	1.2-1.4	.30	.16-.43	5.0	.36	.08
Goatfish	2	216	172-260	nd		11	9.7-12	60		3.1
Surgeon	5	11	6.0-13	1.4	.81-2.1	.24	nd-.57	3.1	.39	.07
Flagtail	1	13				.57		3.6		.16
Bikini										
Avg. of Avgs.		13		.80		.03		3.6	.22	.01
Nam										
Avg. of Avgs. (except flagtail)		82		.90		3.8		23	.25	1.1

*Number of samples.

Table 4

Gamma-Emitting Radionuclides in Troll-Caught Fish, Bikini Atoll, March and June 1969

Averages Values

pCi/g dry

Common Name	Tissue	No. of Samples*	^{40}K Avg.	^{40}K Range	^{60}Co Avg.	^{60}Co Range	^{137}Cs Avg.	^{137}Cs Range
Yellowfin tuna	Light muscle	16	14	13-16	.09	nd-.26	.24	nd-1.3
	Dark muscle	16	11	9.0-12	1.0	.08-4.6	.10	nd-.32
	Liver	16	10	8.6-12	1.3	.21-5	.06	nd-.26
	Bone	15	1.4	nd-3.4	.06	nd-.22	.02	nd-.16
Ulua (Jacks)	Light muscle	4	15	12-18	.68	.52-.90	1.2	.83-1.6
	Dark muscle	4	11	9.6-12	12	6.7-20	.53	.49-.58
	Liver	4	14	11-18	100	26-203	.27	nd-.81
	Bone	3	1.5	nd-2.3	.17	nd-.27	.09	nd-.26
Dogtooth tuna	Light muscle	7	13	10-18	1.1	.77-1.6	.71	.32-1.3
	Dark muscle	1	13		4.1		.49	
	Liver	7					.54	.27-1.2
	Bone	1	5.8		.20		.15	

*Individual fish

Table 5

Gamma-Emitting Radionuclides in Coconut Crabs
Collected at Bikini Atoll, June 1969

Average Values

Island	Tissue	No. of Samples	^{60}Co Avg. (pCi/g dry)	^{60}Co Range (pCi/g dry)	^{137}Cs Avg. (pCi/g dry)	^{137}Cs Range (pCi/g dry)
Bikini	Muscle	6	2.7	1.1-3.5	759	429-933
	"Liver"	6	14	5.2-23	305	122-470
	Skeleton	6	nd*	nd-.34	134	86-209
Enyu	Muscle	13	.59	nd-1.3	70	32-240
	"Liver"	13	2.6	.76-4.8	29	11-95
	Skeleton	13	.06	nd-.18	9.9	3.9-30
Oroken	Muscle	5	.70	.47-1.1	89	52-123
	"Liver"	5	3.5	2.0-6.4	74	39-118
	Skeleton	5	.09	nd-.16	24	17-28

* A single significant value was 0.34 ± 0.27

Table 6

Gamma-Emitting Radionuclides in Spiny Lobsters
Collected at Bikini Atoll, June 1969

Average Values

Island	Tissue	No. of Samples	pCi/g dry ^{40}K Avg.	^{40}K Range	^{60}Co Avg.	^{60}Co Range
Enyu	Muscle	5	12	8.7-15	.30	nd-.45
	"Liver"	5	nd		10	6-12
	Skeleton	5	3.0	2.2-4.0	.22	nd-.80
Namu	Muscle	8	13	8.8-17	.75	.37-1.1
	"Liver"	8	nd		28	15-37
	Skeleton	8	3.3	nd-5.5	.32	.14-.58
	Remainder	8	5.0	2.7-8.5	1.9	.75-2.8

Table 7

Co-60

Tridacna and Hippopus (Giant Clams)
Collected at Bikini Atoll, June 1969 (1)

Average Values

Islet	Tissue	n	pCi/g dry Avg.	pCi/g dry Range
Bikini	Muscle and mantle	5	115	49-219
	Viscera	5	116	41-193
	Kidney	5	2350	1390-4000
Nam	Muscle and mantle	4 (2)	74	16-134
	Viscera	4 (2)	64	30-118
	Kidney	4 (2)	1020	375-2150

(1) No other gamma-emitting radionuclides were detected except naturally occurring ^{40}K.

(2) Two samples consisted of 3 individuals pooled and one sample consisted of 2 individuals pooled.

Table 8

Gamma-Emitting Radionuclides in Birds
Collected at Bikini, 1969

Average Values

Species and Tissue	No. of Samples	pCi/g dry ^{60}Co Avg.	pCi/g dry ^{60}Co Range	pCi/g dry ^{137}Cs Avg.	pCi/g dry ^{137}Cs Range	pCi/g wet* ^{60}Co Avg.	pCi/g wet* ^{137}Cs Avg.
Curlew							
Muscle	3	2.8	nd-6.3	1174	520-2260	.94	395
Liver	3	5.9	nd-11	992	605-1510	2.1	348
Turnstone**							
Muscle	1	23		165		7.7	56
Liver	1	40		98		14	34
Noddy tern***							
Muscle	1	4		.46		1.3	.15
Liver	1	7.6		nd		2.7	nd
Fairy tern***							
Muscle	1	.87		nd		.29	nd
Liver	1	1.2		nd		.42	nd

*Calculated from pCi/g dry using average wet:dry ratios.
**Tissues from 6 birds pooled.
*** " " 5 " ".

Table 9

Radionuclides in the Surface One-Inch of Soil Collected
at Bikini Atoll, June 1969

Sample No.	Island	Location	pCi/g dry ^{60}Co	^{125}Sb	^{137}Cs	^{207}Bi	^{90}Sr	^{55}Fe
506	Bikini	W-P-1	42±1.2[1]	67±11	1220±8.0	-[2]	462	173
507	"	W-P-2	9.3±.41	12±4.3	499±3.3	-	256	36
504	"	W-P-3	43±2.0	88±43	1740±15	-	830	149
505	Nam	W-P-1	1.4±.19	6.0±1.5	63±.18	-	17.6	8.4
756	Aomen	-	17±.45[3]	20±1.7	29±.74	.59±.27		144
755	Enyu	Camp Blandy	.39±.13	-	6.0±.27	.25±.12		
757	Oroken	-	17±.41	32±1.7	24±.69	.44±.25		132
758	Aerokoj	S-11	1.2±.14	-	2.0±.77	-		35
481	Aerokoj	S-6	.28±.11	-	.69±.15	.21±.10	5.6	5.5

(1) 95% counting error.
(2) Value less than the 95% counting error.
(3) ^{65}Zn 2.1±1.4

Table 10

Radionuclides in Soil Collected from the Most Radioactive Part of Eneman Islet, June 1969

Sample No.	Depth (Inches)	pCi/g dry ^{60}Co	^{65}Zn	^{125}Sb	^{137}Cs	^{207}Bi	^{90}Sr	^{55}Fe
500	0-1	186±5.8(1)	65±24	304±25	19±6.5	8.9±4.5	109	522
496	1-2	63±2.2	17±5.7	66±6.5	4.7±1.6	2.5±1.1	56	177
495	2-3	71±2.0	16±5.1	57±5.5	4.7±1.5	2.3±1.0	52	189
503	3-4	79±1.6	22±4.9	51±4.1	4.7±1.2	1.7±.82	52	253
498	4-5	47±1.2	15±3.5	38±3.1	4.3±.92	1.9±.62	50	144
502	5-6	12±.53	5.6±1.5	7.6±1.8	4.7±.57	-(2)	49	64
497	6-7	7.0±.41	3.5±1.4	4.9±1.5	4.7±.49	.65±.29	49	31
501	7-8	5.1±.41	3.3±1.3	3.0±1.6	4.4±.53	.44±.29	57	28
499	8-9	4.1±.37	3.2±1.3	4.0±1.5	3.4±.49	-	51	26
494	9-12	3.2±3.5	2.8±1.2	2.4±1.4	3.0±.45	-	46	28
493	12-17	4.1±3.1	2.7±1.1	3.6±1.2	4.0±3.9	.34±.22	59	26

(1) 95% counting error.
(2) Value less than the 95% counting error.

Table 11

Radionuclides in Soil Collected on the Seaward Shore of Eneman Islet, June 1969

Sample No.	Depth (Inches)	pCi/g dry ^{60}Co	^{65}Zn	^{125}Sb	^{137}Cs	^{207}Bi	^{90}Sr
489	0-1	9.0±.80	7.7±2.9	29±3.5	4.1±1.0	2.5±.63	13
490	1-2	9.4±.94	8.8±3.1	28±4.3	3.9±1.1	1.5±.65	18
487	2-3	6.9±.57	6.1±.20	21±2.4	2.9±.67	1.4±.41	13
491	3-4	7.1±.61	4.6±2.2	20±2.5	3.0±.73	1.7±.45	16
492	5-6	5.4±.51	4.2±1.6	11±2.4	1.9±.55	.51±.35	10
484	6-7	7.0±.70	5.6±2.4	16±3.1	2.5±.80	.74±.47	
485	7-8	6.2±.47	4.2±1.6	14±1.9	2.0±.51	1.1±.33	14
488	8-9	6.5±.59	4.8±1.8	12±2.5	1.8±.63	3.9±.39	17
486	9-10	8.8±.71	6.1±1.1	20±2.9	2.2±.74	.89±.45	14
482	10-11	7.4±.61	3.7±1.8	15±2.5	2.2±.65	.76±.39	14
483	11-14	4.9±.35	3.5±1.2	9.7±2.7	1.2±.37	.77±.25	11

Table 12

STRONTIUM-90 IN SAMPLES COLLECTED
AT BIKINI ATOLL, MARCH, JUNE, AUGUST, 1969

Average Values and Range

	N[a]	pCi/g dry Avg.	pCi/g dry Range	pCi/g wet[b] Avg.
Coconut Crabs				
Muscle				
Enyu I.	13	2.0	(0.6-3.4)	0.05
Bikini I.	6	50.1	(16.4-99.0)	12
Oroken I.[c]	5	8.9	(4.9-14.9)	2.1
Rukoji I.[c]	3	75.2	(36.6-144)	18
"Liver"				
Enyu I.	13	9.6	(3.0-28)	5.1
Bikini I.	6	117	(38.3-204)	62
Oroken I.[c]	5	21.3	(15.4-30.0)	11
Rukoji I.[c]	3	116	(57.2-164)	61
Skeleton				
Enyu I.	8	97.2	(72.6-113)	75
Bikini I.	6	1410	(912-2035)	1100
Oroken I.[c]	5	346	(184-571)	270
Rukoji I.[c]	3	2330	(1200-3870)	1800
Troll Caught Fish				
Yellowfin Tuna				
Light muscle	3	<0.1	(<0.1-0.29)[d]	<.03
Dark muscle	3	<0.1		<.03
Bone	3	<0.1		<.04
Ulua (Jack)				
Light muscle	3	<0.1		<.03
Dark muscle	3	<0.1		<.03
Bone	3	1.4	(1.1-1.9)	0.6

(a) Number of individuals.
(b) Converted from dry weight by using average wet:dry weight ratios.
(c) Collected May, 1967.
(d) Two samples contained <0.1 pCi/g dry and one sample contained 0.29 ± 0.06 pCi/g dry. We think the sample was contaminated when being ground.

Table 13

Bismuth-207 in Soils and Sediment Collected at Bikini Atoll, 1969

Sample		Location	Type	pCi/g dry Gamma Spectrum (σ = 95%)	pCi/g dry Chemical Analyses
25488		Eneman	Soil 8-9"	0.39±0.40	0.62±0.25
25500	1	Eneman	Soil 0-1"	8.9 ±4.5*	0.79±0.26
25500	2	"			0.96±0.51
25504	1	Bikini	Soil 0-1"	None	0.74±0.26
25504	2	"	Well point 3		0.46±0.36
25506	1	Bikini	Soil 0-1"	None	1.07±0.31
25506	2	"	Well point 1		0.60±0.26
25652	1	Namu	Crater	50.0±1.2	56.8 ±0.6
25652	2	"	Sediment		53.3 ±0.6

* High value due to the presence of ^{102}Rh which was not included in the reference spectra.

Table 14

Plutonium in Soil, Sediment and Fish Collected at Bikini Atoll, 1969

Sample Number		Location	Type	$^{239,240}Pu$ (pCi/g dry)	^{238}Pu (pCi/g dry)	Yield (%)
25500	1	Eneman	Soil 0-1"	75.3±3.0	48.4±1.9	18.9±0.5
25500	2			82.9±2.7	50.5±1.6	11.9±0.4
25488	1	Eneman	Soil 8-9"	9.4±0.4	4.1±0.2	20.6±0.6
25488	2			9.2±0.4	4.2±0.2	39.1±1.1
25504	1	Bikini	Soil 0-1"	115.4±4.9	-*	18.0±0.5
25504	2		(well point 3)	107.4±4.2	-	6.9±0.2
25505	1	Bikini	Soil 0-1"	129.8±4.8	-	61.9±1.7
25506	2		(well point 1)	129.5±7.7	-	6.6±0.2**
25652	1	Nam	Crater	66.6±1.8	4.5±1.0	3.37±0.2
25652	2		Sediment	53.0±2.4	3.5±0.8	3.44±0.1
25662	1	Nam	Goatfish Viscera	13.5±0.4	-	12.8±0.4
25664	1	Nam	Goatfish Viscera	29.0±1.1	-	10.7±0.3

σ = 68%
* none detectable
** portion of sample lost in processing

Table 15

Tritium and Cesium-137 in Well Water Samples Collected at Bikini Atoll, June, 1969

Sample #	Island	Area	Tritium (pCi/ml)	Cesium-137 (pCi/ml)
25777	Eneman	WP-1	6.7 ± .59	-*
25778	Bikini	WP-1B	1.6 ± .50	1.2 ± .05
25779	"	WP-1A	1.9 ± .59	1.0 ± .04
25780	"	Alternate WP	2.0 ± .50	.78± .04
25781	Enyu	Camp Blandy	2.1 ± .54	.09± .02
25782	Nam	WP-1	14 ± .68	.85± .04

* Not detectable

Table 16

Iron-55 in Biological Samples Collected at
Bikini Atoll, June 1969
Average Values

Collection Site	Common Name	Tissue or Organ	No. of Samples	pCi/g dry Avg.	pCi/g dry Range
Bikini I.	Surgeon	Whole (Eviscerated)	2	52	18-85
Enyu I.	Goatfish	Whole (Eviscerated)	2	81	74-87
Bikini I.	Mullet	Viscera	3	108	22-228
"	Goatfish	"	2	416	391-442
"	Surgeon	"	2	199	148-250
Enyu I.	Goatfish	"	2	1250	828-1670
Nam I.	Mullet	"	3	237	122-348
"	Surgeon	"	3	297	239-404
Enyu I.	Grouper	Muscle	4	13	7.7-18
Nam I.	"	"	1	38	
Enyu I.	"	Liver	4	14,700	9,090-25,600
Enyu Pass	Yellowfin tuna	Light muscle	16	29	8.5-62
"	Ulua	" "	3	210	72-214
"	Dogtooth tuna	" "	1	116	
"	Yellowfin tuna	Dark muscle	16	334	108-867
"	Ulua	" "	3	2,950	1,290-3,630
"	Dogtooth tuna	" "	1	915	

[redacted] 16 (continued)

Collection Site	Common Name	Tissue or Organ	No. of Samples	pCi/g dry Avg.	Range
Enyu Pass	Yellowfin tuna	Liver	16	374	75-894
"	Ulua	"	3	23,400	8,190-40,900
"	Dog tooth tuna"		1	1,528	
Bikini I.	Coconut crab	Muscle	3	5.2	2.4-9.4
Enyu I.	"	"	9	3.3	1.1-7.2
Oroken I.	"	"	5	13	5.6-15
Bikini I.	"	"Liver"	2	74	65-82
Enyu I.	"	"	5	28	15-44
Oroken I.	"	"	5	54	38-60
Enyu I.	Spiny lobster	Muscle	3	1.4	.96-2.1
Nam I.	"	"	5	11	5.5-17
Enyu I.	"	"Liver"	3	74	59-96
Nam I.	"	"	5	205	32-420
Enyu I.	"	Skeleton	2	1.0	ns*-2.1
Nam I.	"	"	3	2.8	ns - 4.4
Nam I.	"	Remainder	5	18	4.0-32
Bikini I.	Giant clam	Muscle & mantle	5	27	16-51
Nam I.	" "	"	3	85	43-108
Bikini I.	" "	Viscera	5	47	35-58
Nam I.	" "	"	4	105	ns - 219
Bikini I.	" "	Kidney	5	469	163-709

* Less than the 95% counting error. Taken as zero in computing average.

Table 16 (continued)

Collection Site	Common Name	Tissue or Organ	No. of Samples	pCi/g dry Avg.	Range
Nam I.	Giant clam	Kidney	3	182	133-287
Nam I.	Curlew	Muscle	3	72	18-143
"	Turnstone	Muscle	1	312	
"	Curlew	Liver	3	2610	312-5810
"	Turnstone	Liver	1 (1)	2820	
Oroken I.	Noddy tern	Muscle	1 (2)	497	
"	Fairy tern	"	1 (2)	425	
"	Noddy tern	Liver	1 (2)	1220	
"	" "	"	1 (2)	763	
"	Eggs	Albumin	2 (3)	12	9.1-15
"	"	Embryo & yolk	1 (3)	300	

(1) Six birds pooled.
(2) Five " "
(3) Nine or ten eggs pooled per sample.

ACKNOWLEDGEMENTS

I wish to thank the staff of the Laboratory of Radiation Ecology, whose work produced the data that made this report possible. I wish especially to thank Dr. Thomas Beasley, who supervised all of the radiochemical analyses and who did many of them himself. Dr. Allyn Seymour and Dr. Beasley were of great help in planning the collections and in interpreting the results of the survey.

I am grateful to Dr. Beasley, Rodney Eagle, Terrence Jokela, and Raymond Lusk for their part in the field collections.

I appreciate the cooperation of personnel of Joint Task Force Eight and Holmes & Narver, Inc., and recognize that the field collections would not have been successfully completed without their help.

We exchanged samples in the field with Drs. John Harshbarger and Donald Squires of the Smithsonian Institution and thank them for samples of coconut crabs from Oroken Island and rats from Bikini Island.

Dr. Jack Tobin, Trust Territory of the Pacific, made valuable suggestions regarding the collections and was instrumental in obtaining the services of two Bikini people to assist with the collections.

William Moore, U.S. Public Health Service, accompanied us during most of the collections and pointed out areas giving the highest external radiation measurements; well water and soil samples were collected from these areas.

The final guidelines for the survey were developed during a preliminary survey of Bikini Atoll in March, 1969 with Frank Cluff and Donald Hendricks, Nevada Operations Office, and Alan Smith, U. S. Public Health Service.

REFERENCES

Beasley, Thomas M. and Edward E. Held. 1969. Nickel-63 in marine and terrestrial biota, soil, and sediment. Science 164:1161-1163.

Bonham, Kelshaw. 1967. Radioactivity in invertebrates, p. 77-95. In Arthur D. Welander, Kelshaw Bonham, Ralph F. Palumbo, Stanley P. Gessel, Frank G. Lowman, William B. Jackson, Raul McClin, Gary B. Lewis Bikini-Eniwetok studies, 1964. Part II Radiobiological studies. U.S. AEC Report UWFL-93.

Gustafson, Philip F. 1968. Radiological report on Bikini Atoll. U.S. Atomic Energy Commission, Division of Biology and Medicine. (April). 26 p. MS.

Koranda, J.J. 1965. Preliminary studies of the persistence of tritium and ^{14}C in the Pacific Proving Ground. Health Physics 11:1445-1457.

Kressin, I.K. and G.R. Waterbury. 1962. The quantitative separation of Pu from various ions by anion exchange. Anal. Chem. 34:1598-1601.

McCown, J.J. and R.P. Larsen. 1960. Radiochemical determination of cerium by liquid-liquid extraction. Anal. Chem. 32:587-599.

Moghissi, A.A. and C.R. Porter. 1968. Tritium in surface waters of the United States, 1966. U.S. Dept. of Health, Education and Welfare, Public Health Service, Radiological Health Data and Reports 9(7):337-339.

Palmer, H.E. and T.M. Beasley. 1967. Iron-55 in man and the biosphere. Health Physics 13:889-895.

Petrow, Henry G. 1965. Rapid determination of strontium-90 in bone ash via solvent extraction of yttrium-90. Anal. Chem. 37:584-586.

Seymour, Allyn H. 1963. Radioactivity of marine organisms from Guam, Palau, and the Gulf of Siam, 1958-1959, p. 151-157. In Vincent Schultz and Alfred W. Klement, Jr. (ed.) Radioecology. Reinhold, N.Y. and Amer. Inst. Biol. Sci., Washington, D.C.

Sill, Claude and Conrad P. Willis. 1965. Radiochemical determination of lead-210 in mill products and biological materials. Anal. Chem. 37:1661-1671.

Appendix Table 1

Gamma-Emitting Radionuclides in Eviscerated Whole Reef Fish
Collected at Bikini Atoll, June 1969

Sample No.	Island	Common Name	No. of Fish	Size Range (mm)	pCi/g dry			
					^{40}K	^{60}Co	^{65}Zn	^{137}Cs
630	Bikini	Mullet	5	200-255	8.0 ± 1.3	4.6 ± .13	-	.12± .11
632			13	150-175	8.0 ± 1.1	2.9 ± .10	-	.38± .09
634			5	250-300	8.4 ± 1.3	4.2 ± .13	-	.12± .11
657		Goatfish	2	185-190	11 ± 2.0	2.9 ± .17	-	-
659			8	190-220	12 ± 1.2	2.6 ± .10	1.2 ± .43	-
603		Surgeon	15	110-135	7.1 ± .96	1.7 ± .08	.34± .29	.84± .09
605			16	94-115	9.5 ± 1.1	2.1 ± .09	.59± .35	.64± .10
607			4	132-152	6.6 ± 1.0	1.3 ± .08	.40± .29	.70± .09
751	Enyu	Goatfish	8	208-242	11 ± 1.5	.90± .10	-	.17± .11
753			7	205-245	11 ± 1.5	-	-	-
622	Nam	Mullet	16	150-175	8.5 ± 1.3	8.8 ± .16	1.1 ± .61	1.1 ± .14
624			15	160-200	8.1 ± 1.9	19 ± .31	.97± .96	.58± .24
626			8	235-260	7.8 ± 1.6	9.2 ± .23	-	.68± .18
628			8	195-260	8.2 ± 1.4	9.9 ± .19	-	.76± .16
661		Goatfish	4	200-250	13. ± 2.7	31. ± .45	-	.62± .33
663			3	230-250	13 ± 2.5	32 ± .43	2.1 ±1.4	-
609		Surgeon	4	158-175	4.9 ± 1.4	3.3 ± .13	1.2 ± .51	.40± .12
611			6	130-155	8.7 ± 1.6	4.3 ± .15	-	1.2 ± .15
613			15	112-135	9.5 ± 1.2	3.0 ± .10	-	1.2 ± .12
615			25	95-110	8.7 ± 1.0	1.5 ± .08	.44± .27	.40± .08
617			19	90-105	9.6 ± 1.0	1.6 ± .07	-	.28± .08
619		Pilot fish	8	193-214	6.8 ± 1.0	5.0 ± .12	1.3 ± .45	-

Appendix Table 2

Gamma-Emitting Radionuclides in Reef Fish Viscera Collected at Bikini Atoll, June 1969

Sample No.	Island	Common Name	No. of Fish	Size Range (mm)	^{40}K	^{60}Co	^{137}Cs	^{207}Bi
631	Bikini	Mullet	5	200-255	8.2 ± 2.5	11 ± .29	.61 ± .24	–
633			13	150-175	8.1 ± 2.2	5.7 ± .22	.72 ± .19	.23 ± .13
635			5	250-300	5.2 ± 1.9	11 ± .27	1.1 ± .20	–
658		Goatfish	2	185-190	15 ± 8.4	24 ± .69	–	–
660			8	190-220	14 ± 4.9	17 ± .57	–	–
604		Surgeon	15	110-135	19 ± 3.3	11 ± .35	2.3 ± .31	–
606			16	94-115	20 ± 4.5	12 ± .43	1.6 ± .37	–
608			4	132-152	17 ± 6.9	6.2 ± .57	.78 ± .55	–
752	Enyu	Goatfish	8	208-242	11 ± 1.7	6.1 ± .15	–	–
754			7	205-245	15 ± 1.2	5.6 ± .11	–	.13 ± .07
623	Nam	Mullet	16	150-175	4.7 ± 1.7	13 ± .26	1.4 ± .20	.29 ± .13
625			15	160-200	4.4 ± 2.4	22 ± .37	1.3 ± .27	.43 ± .17
627			8	235-260	6.0 ± 1.7	19 ± .29	1.2 ± .24	.33 ± .14
629			8	195-200	7.0 ± 2.2	17 ± .33	1.2 ± .24	.16 ± .16
662		Goatfish	4	200-250	15 ± 11	172 ± 2.2	–	9.7 ± 1.0
664			3	230-250	32 ± 20	260 ± 3.7	–	12 ± 1.7
610		Surgeon	4	158-175	17 ± 3.1	9.5 ± .31	.81 ± .27	.27 ± .18
612			6	130-155	21 ± 4.5	13 ± .47	2.0 ± .41	–
614			15	112-135	18 ± 3.9	12 ± .41	2.1 ± .37	.36 ± .24
616			25	95-110	14 ± 4.9	6.0 ± .45	.50 ± .39	–
618			19	90-105	16 ± 2.2	13 ± .20	1.4 ± .19	.57 ± .13
620		Pilot fish	8	193-214	13 ± 2.9	28 ± .39	–	.43 ± .19

Appendix Table 3

Gamma-Emitting Radionuclides in Groupers Collected at Enyu and Nam Islands, Bikini Atoll, March and June, 1969

Sample No.	Island	Tissue	No. of Fish	Size Range (mm)	pCi/g dry ^{40}K	^{60}Co	^{137}Cs
708	Enyu	Muscle	1	400	13 ± 2.5	.22± .15	.45± .19
706		Liver			-	49 ± 2.4	-
707		Bone			-	-	.14± .12
705		Muscle	2	280,300	13 ± 2.7	.40± .17	.33± .20
703		Liver			-	149 ±14	-
704		Bone			5.1± 1.6	-	-
747		Muscle	1	380	17 ± 2.3	.15± .13	.61± .17
746		Liver			-	43 ± 3.5	5.0 ±3.9
748		Bone			5.0± 3.1	.32± .20	-
711		Muscle	2	310,330	16 ± 1.1	.32± .07	.46± .08
709		Liver			-	48 2.2	-
710		Bone			2.6± 1.1	-	.26± .08
621	Nam	Muscle	3	150-280	17 ± 2.2	.32± .13	.37± .16
427	"	Muscle	1		17 ± .61	.30± .04	3.6 ± .07
428	"	Liver			-	97 ± 1.1	-

Appendix Table 4

Gamma-Emitting Radionuclides in Troll-Caught Fish, Bikini Atoll, June 1969

Common Name	Sample No.	Tissue	^{40}K	^{60}Co	^{65}Zn	^{137}Cs
Yellow fin tuna	548	Light muscle	14 ± 1.3	.26± .07	.31± .29	.23± .09
	528	Dark muscle	10 ± 2.2	4.6 ± .20	-	.32± .17
	568	Liver	12 ± 2.2	5.0 ± .20	2.3 ± .76	.15± .17
	508	Bone	(not counted)*			
	549	Light muscle	13 ± 1.1	.10± .05	-	-
	529	Dark muscle	12 ± 1.8	.62± .11	-	.14± .12
	569	Liver	9.6± 1.8	1.4 ± .12	1.6 ± .53	-
	509	Bone	2.0± 1.5	.14± .10	.85± .41	-
	550	Light muscle	14 ± 1.5	-	-	.21± .10
	530	Dark muscle	12 ± 1.2	.14± .06	.38± .27	-
	570	Liver	9.8± 1.1	.40± .07	1.7 ± .29	.09± .08
	510	Bone	-	.15± .12	-	.16± .14
	551	Light muscle	14 ± 1.4	-	-	.12± .09
	531	Dark muscle	11 ± 1.3	.08± .07	-	-
	571	Liver	8.6± 2.7	.84± .19	2.2 ± .82	.26± .24
	511	Bone	-	.22± .12	-	-
	552	Light muscle	14 ± 1.5	.20± .08	-	.23± .10
	532	Dark muscle	9.2± 1.3	1.4 ± .09	.39± .33	.19± .09
	572	Liver	9.8± 1.5	1.4 ± .11	1.6 ± .45	-
	512	Bone	2.4± 1.3	.11± .09	-	-
	553	Light muscle	15 ± 1.2	-	-	.13± .08
	533	Dark muscle	9.0± 1.6	.38± .10	-	-
	573	Liver	10 ± 1.6	.62± .11	2.0 ± .47	.16± .12
	513	Bone	2.1± 1.6	-	.88± .41	-

*Contaminated with muscle tissue.

Appendix Table 4 (continued)

Common Name	Sample No.	Tissue	^{40}K	^{60}Co	^{65}Zn	
Yellow fin tuna	554	Light muscle	15 ± 1.2	-	-	.19± .08
	534	Dark muscle	12 ± 1.6	.35± .09	-	.13± .10
	574	Liver	11 ± 1.3	.52± .08	1.8 ± .33	-
	514	Bone	-	-	.61± .49	-
	555	Light muscle	13 ± 1.3	-	-	.09± .08
	535	Dark muscle	9.3± 1.3	.10± .07	-	.19± .09
	575	Liver	11 ± 1.4	.21± .08	2.1 ± .37	.14± .10
	515	Bone	-	.22± .14	1.3 ± .63	-
	556	Light muscle	14 ± 1.4	.13± .07	.39± .31	.23± .10
	536	Dark muscle	11 ± 1.7	1.2 ± .12	-	.14± .12
	576	Liver	9.6± .96	1.2 ± .07	1.8 ± .27	-
	516	Bone	-	-	1.2 ± .43	-
	557	Light muscle	15 ± 1.2	-	-	.25± .08
	537	Dark muscle	11 ± 1.8	1.0 ± .12	-	-
	577	Liver	10 ± .86	.96± .06	1.9 ± .25	.11± .06
	517	Bone	3.3± 1.7	.13± .11	1.1 ± .45	-
	558	Light muscle	14 ± .57	.13± .03	-	.13± .04
	538	Dark muscle	11 ± 1.7	1.4 ± .12	.47± .43	-
	578	Liver	12 ± 1.4	1.6 ± .09	1.9 ± .37	-
	518	Bone	2.4± 1.9	-	1.0 ± .49	.15± .13
	559	Light muscle	16 ± 1.1	.10± .05	.25± .22	1.3 ± .10
	539	Dark muscle	11 ± 1.6	1.3 ± .11	-	.13± .11
	579	Liver	12 ± 1.7	1.6 ± .12	2.3 ± .51	-
	519	Bone	3.4± 1.5	-	.45± .39	-
	560	Light muscle	14 ± 1.7	.12± .08	-	.12± .11
	540	Dark muscle	11 ± 1.4	.55± .08	-	-
	580	Liver	9.1± 1.6	.65± .10	.97± .41	-
	520	Bone	1.7± 1.5	-	.66± .41	-

Appendix Table 4 (continued)

Common Name	Sample No.	Tissue	^{40}K	^{60}Co	^{65}Zn	[illegible]
Yellow fin tuna	561	Light muscle	15 ± 1.3	.13± .06	–	.28± [illegible]
	541	Dark muscle	10 ± 1.8	.49± .11	–	.21± .13
	581	Liver	10 ± .84	.72± .05	1.5 ± .22	–
	521	Bone	3.0± 1.5	–	.55± .39	–
	562	Light muscle	15 ± 1.3	.17± .06	–	.09± .08
	542	Dark muscle	12 ± 1.4	2.1 ± .11	–	–
	582	Liver	11 ± 1.2	1.8 ± .10	2.4 ± .39	.12± .09
	522	Bone	–	–	.84± .37	–
	563	Light muscle	14 ± 1.3	.12± .07	–	.17± .09
	543	Dark muscle	9.8± 2.4	.91± .16	–	.18± .17
	583	Liver	10 ± 1.1	1.5 ± .08	1.7 ± .31	.16± .08
	523	Bone	3.1± 2.2	–	.73± .59	–
Ulua	564	Light muscle	15 ± 1.6	.63± .09	–	.83± .12
	544	Dark muscle	10 ± 2.7	6.7 ± .27	–	.53± .24
	584	Liver	18 ± 8.4	26 ± .92	–	.81± .73
	524	Bone	2.3± 1.8	.27± .12	–	–
	565	Light muscle	18 ± 1.7	.90± .10	–	1.3 ± .15
	545	Dark muscle	9.6± 2.7	20 ± .41	–	.58± .27
	585	Liver	11 ± 9.4	203 ±2.2	10 ±6.3	–
	525	Bone	–	.25± .13	–	.26± .14
	566	Light muscle	14 ± 1.4	.52± .08	–	1.6 ± .14
	546	Dark muscle	12 ± 2.5	8.4 ± .27	–	.49± .22
	586	Liver	13 ± 7.1	73 ±1.2	–	–
	526	Bone	2.3± 2.2	–	–	–
	432	Light muscle	12 ± .57	.84± .04	–	2.0 ± .05
	431	Dark muscle	3.4± .61	9.7 ± .08	–	.72± .07
	430	Liver	–	88 ± .88	3.8 ±2.4	–

Appendix Table [illegible] (Continued)

Common Name	Sample No.	Tissue	^{40}K	^{60}Co	^{65}Zn	
Dog tooth tuna	415	Light muscle	13 ± .61	1.3 ± .04	-	.54± [illegible]
	416	Liver	80 ±1.3	21 ± .20	1.4 ± .65	.33± .14
	417	Light muscle	15 ±1.1	.84± .07	-	1.3 ± .90
	418	Liver	7.1±2.2	26 ± .31	3.2 ± .92	.65± .22
	419	Light muscle	10 ± .86	.80± .06	-	.68± .07
	420	Liver	7.8±1.9	34 ± .35	1.2 ± .96	.36± .22
	421	Light muscle	13 ± .49	1.2 ± .03	-	.64± .04
	422	Liver	7.6±2.0	23 ± .31	1.2 ± .88	.27± .22
	423	Light muscle	12 ± .63	1.6 ± .04	.31± .14	1.1 ± .05
	424	Liver	6.6±2.5	29 ± .41	3.8 ±1.2	.64± .27
	425	Light muscle	12 ± .59	.92± .04	-	.32± .04
	426	Liver	11 ±2.2	15 ± .27	1.2 ± .82	.34± .20
	567	Light muscle	18 ±1.2	.77± .06	-	.42± .08
	547	Dark muscle	13 ±3.9	4.1 ± .31	-	.49± .29
	587	Liver	12 ±3.9	12 ± .45	1.4 ± .14	1.2 ± .35
	527	Bone	5.8±1.9	.20± .12	-	.15± .13

Appendix Table 5

Gamma-Emitting Radionuclides in Coconut Crabs
Collected at Bikini Island, June 1969

Sample Number	Tissue	pCi/g dry	
		^{60}Co	^{137}Cs
463	Muscle	3.5 ± .65	869 ± 8.8
433	Liver	20 ±1.2	457 ± 6.1
464	Skeleton	–	150 ± 2.2
466	Muscle	3.2 ± .88	753 ±11
434	Liver	23 ±1.6	470 ± 7.8
467	Skeleton	–	136 ± 1.4
451	Muscle	1.1 ± .59	698 ± 9.2
436	Liver	10 ± .74	319 ± 4.1
452	Skeleton	–	86 ± 1.1
459	Muscle	3.5 ± .59	933 ± 8.2
441	Liver	5.2 ± .39	122 ± 1.9
460	Skeleton	.26± .16	209 ± 1.1
461	Muscle	2.0 ± .55	429 ± 5.3
442	Liver	13 ± .55	154 ± 2.4
462	Skeleton	–	117 ± 1.7
474	Muscle	2.8 ± .98	870 ±13
445	Liver	15 ± .80	306 ± 4.1
475	Skeleton	.34± .27	105 ± 1.9

Appendix Table 6

Gamma-Emitting Radionuclides in Coconut Crabs
Collected at Enyu Island, March and June 1969

Sample No.	Tissue	pCi/g dry ^{40}K	^{60}Co	^{137}Cs
400	Muscle	8.3 ± 1.4	1.3 ± .10	99 ± .67
401	Liver	4.0 ± 1.3	4.8 ± .15	33 ± .43
402	Skeleton	-	-	11 ± .27
403	Muscle	7.2 ± 1.5	.44± .09	58 ± .63
404	Liver	1.0 ± .55	.76± .04	11 ± .13
405	Skeleton	-	-	8.7 ± .12
406	Muscle	6.9 ± 3.1	.78± .22	61 ± .88
407	Liver	2.3 ± 1.2	1.6 ± .09	13 ± .17
408	Skeleton	1.7 ± .92	.12± .06	8.8 ± .14
409	Muscle	-	-	240 ±2.5
410	Liver	-	1.8 ± .24	95 ±1.2
411	Skeleton	-	-	30 ± .47
412	Muscle	3.5 ± 3.1	.66± .23	69 ± .92
413	Liver	-	1.9 ± .15	21 ± .39
414	Skeleton	-	.18± .10	12 ± .29
455	Muscle	6.3 ± 1.8	.49± .11	48 ± .65
444	Liver	4.0 ± 1.7	2.3 ± .14	25 ± .39
456	Skeleton	2.2 ± 1.0	-	9.1 ± .24
468	Muscle	7.5 ± 1.9	.66± .13	33 ± .57
438	Liver	4.6 ± 1.4	2.9 ± .13	18 ± .31
469	Skeleton	1.0 ± .92	.13± .06	6.4 ± .20
472	Muscle	8.3 ± 2.4	1.1 ± .17	63 ± .94
437	Liver	2.9 ± 1.9	2.3 ± .15	24 ± .37
473	Skeleton	1.4 ± 1.1	.15± .07	11 ± .29
449	Muscle	7.1 ± 2.4	.49± .15	43 ± .78
439	Liver	3.4 ± 1.7	3.4 ± .17	22 ± .45
450	Skeleton	.66± .47	-	4.3 ± .07
470	Muscle	8.3 ± 1.8	.58± .11	32 ± .51
435	Liver	3.9 ± 1.6	3.4 ± .15	16 ± .35
471	Skeleton	-	.08± .07	6.6 ± .22

pendix Table 6 (continued)

Sample No.	Tissue	^{40}K (pCi/g dry)	^{60}Co (pCi/g dry)	^{137}Cs (pCi/g dry)
453	Muscle	7.4 ± 2.0	.19 ± .12	39 ± .65
443	Liver	4.2 ± 2.2	2.5 ± .18	21 ± .45
454	Skeleton	-	.08 ± .04	7.2 ± .15
447	Muscle	8.0 ± 3.5	.54 ± .24	58 ± 1.0
446	Liver	9.0 ± 3.3	4.2 ± .29	46 ± .92
448	Skeleton	1.4 ± .84	-	3.9 ± .14
457	Muscle	7.0 ± 3.7	.40 ± .24	63 ± 1.2
440	Liver	4.1 ± 1.8	2.1 ± .15	28 ± .45
458	Skeleton	2.5 ± 1.9	-	9.4 ± .41

Appendix Table 7

Gamma-Emitting Radionuclides in Coconut Crabs
Collected at Oroken Islet, August 1969

Sample No.	Tissue	pCi/g dry ^{40}K	^{60}Co	^{137}Cs
588	Muscle	5.4 ± 4.5	.75± .33	108 ± 2.4
590	Liver	6.5 ± 3.1	3.0 ± .29	97 ± 1.5
589	Skeleton	-	.16± .09	27 ± .51
591	Muscle	11 ± 3.3	1.1 ± .24	123 ± 1.7
593	Liver	6.7 ± 4.3	6.4 ± .45	118 ± 1.8
592	Skeleton	-	.07± .06	25 ± .29
594	Muscle	10 ± 5.1	.47± .33	61 ± 1.6
596	Liver	5.2 ± 2.7	2.0 ± .24	39 ± .90
595	Skeleton	-	.08± .06	17 ± .26
597	Muscle	4.4 ± 3.1	.64± .22	52 ± 1.1
599	Liver	4.0 ± 2.5	4.1 ± .27	59 ± 1.0
598	Skeleton	-	.12± .08	22 ± .35
600	Muscle	7.0 ± 2.9	.54± .19	99 ± 1.3
602	Liver	4.7 ± 2.5	2.1 ± .22	56 ± 1.0
601	Skeleton	1.3 ± .98	-	28 ± .37

Gamma-Emitting Radionuclides in Spiny Lobsters Collected at Bikini Atoll, June 1969

Sample No.	Island	Tissue	pCi/g dry ^{40}K	pCi/g dry ^{60}Co*
719	Enyu	Muscle	13 ± 1.5	.36± .09
718		Liver	-	11 ±2.4
720		Skeleton	2.2± 1.0	.80± .07
722		Muscle	15 ± 2.5	-
721		Liver	-	6.0 ±2.0
723		Skeleton	3.0± 1.9	-
725		Muscle	8.7± 2.2	.45± .13
724		Liver	-	12 ±1.5
726		Skeleton	2.9± .80	.13± .05
728		Muscle	12 ± 2.2	.43± .14
727		Liver	-	11 ±2.7
729		Skeleton	3.0± .84	.08± .05
731		Muscle	12 ± 2.2	.24± .13
730		Liver	-	12 ± .69
732		Skeleton	4.0± .78	.08± .05
681	Nam	Muscle	12 ± 2.7	.69± .17
680		Liver	-	24 ±2.5
682		Skeleton	2.1± 1.2	.31± .08
683		Remainder	2.7± 2.5	1.2 ± .19
685		Muscle	8.8± 2.4	.37± .16
684		Liver	18 ±16	15 ±1.4
686		Skeleton	3.4± .94	.14± .06
687		Remainder	3.8± 1.1	.75± .08
689		Muscle	14 ± 2.5	.66± .16
688		Liver	-	35 ±2.2
690		Skeleton	3.9± 1.1	.28± .07
691		Remainder	5.2± 2.4	2.0 ± .19
697		Muscle	13 ± 2.7	.72± .18
696		Liver	-	32 ±3.5
698		Skeleton	4.8± 1.1	.27± .07
699		Remainder	6.0± 2.0	1.8 ± .15

...ndix Table 8 (continued)

Sample No.	Island	Tissue	pCi/g dry ^{40}K	^{60}Co*
693		Muscle	17 ± 5.7	1.1 ± .37
692		Liver	–	27 ± 2.4
694		Skeleton	5.5± 2.4	.24± .15
695		Remainder	4.3± 2.7	2.1 ± .21
669		Muscle	12 ± 5.1	.96± .33
668		Liver	–	27 ± 8.2
670		Skeleton	3.4± 1.3	.31± .08
671		Remainder	4.4± 2.9	2.4 ± .24
673		Muscle	12 ± 2.9	.90± .20
672		Liver	18 ±12	37 ± 1.2
674		Skeleton	–	.58± .14
675		Remainder	5.1± 1.4	2.8 ± .13
677		Muscle	15 ± 2.2	.62± .13
676		Liver	–	28 ± 1.6
678		Skeleton	3.4± 1.3	.46± .09
679		Remainder	8.5± 2.5	2.5 ± .22

* Possibly includes a minor contribution from ^{108m}Ag which was not included in the reference spectra for spectrum reduction.

Appendix Table 9

Gamma-Emitting Radionuclides in *Tridacna* and *Hippopus* (Giant Clams)
Collected at Bikini Atoll, June 1969

Sample No.	Islet	Species	Shell Length	Tissue	pCi/g dry ^{40}K	pCi/g dry ^{60}Co
713	Bikini	T. squamosa	354mm	Muscle & Mantle	9.0 ± 3.9	49 ± .76
714				Viscera	11 ± 3.9	41 ± .67
712				Kidney	-	1980 ± 19
716			350mm	Muscle & Mantle	19 ± 11	219 ± 2.5
717				Viscera	9.1 ± 4.1	72 ± .90
715				Kidney	-	4000 ± 49
647		H. hippopus	380mm	Muscle & Mantle	15 ± 6.9	107 ± 1.4
646				Viscera	13 ± 8.6	193 ± 1.9
645				Kidney	-	2060 ± 17
644			304mm	Muscle & Mantle	16 ± 7.4	122 ± 1.5
643				Viscera	16 ± 9.0	139 ± 1.7
642				Kidney	-	1390 ± 13
641			295mm	Muscle & Mantle	17 ± 6.3	79 ± 1.2
640				Viscera	16 ± 8.2	135 ± 1.7
639				Kidney	-	2330 ± 27
667	Nam	T. crocea	95mm,	Muscle & Mantle	20 ± 7.6	100 ± 1.5
666			108mm,	Viscera	25 ± 11	118 ± 2.0
665			111mm	Kidney	-	722 ± 8.4
702			120mm,	Muscle & Mantle	-	134 ± 2.0
701			140mm,	Viscera	-	70 ± 1.0
700			160mm	Kidney	-	2150 ± 27

Appendix Table 9 (continued)

Sample No.	Islet	Species	Shell Length	Tissue	pCi/g dry	
					^{40}K	^{60}Co
656	Nam	T. Crocea	80,83mm	Muscle & Mantle	12 ± 9	45 ± 1.2
655				Viscera	20 ± 8.0	39 ± .76
654				Kidney	-	826 ± 11
638		H. hippopus	210mm	Muscle & Mantle	5.9 ± 4.1	16 ± .47
637				Viscera	9.7 ± 4.3	30 ± .59
636				Kidney	-	375 ± 5.1

Appendix Table 10

Gamma-Emitting Radionuclides in Birds and Eggs Collected at Bikini Atoll June and August, 1969

Sample No.	Islet	Common Name	No. of Individuals	Tissue	^{40}K (pCi/g dry)	^{60}Co (pCi/g dry)	^{65}Zn (pCi/g dry)	^{137}Cs (pCi/g dry)
736	Nam	Curlew		Muscle	-	6.3 ± 1.5	-	2260 ±24
737				Liver	-	11 ± 2.5	-	1510 ±22
738				Muscle	-	-	-	520 ± 6.5
739				Liver	-	-	-	605 ± 8.4
740				Muscle	-	2.1 ± .59	-	741 ± 7.6
741				Liver	-	6.7 ± 1.5	12 ± 5.5	860 ±11
749		Turnstone	6	Muscle	14 ± 7.8	23 ± 1.0	-	165 ± 2.9
750			6	Liver	-	40 ± 2.2	-	98 ± 3.9
742	Oroken	Noddy tern	5	Muscle	9.1± 3.1	4.0 ± .24	-	.46± .28
743			5	Liver	9.7± 4.5	7.6 ± .31	1.7± 1.2	-
744		Fairy tern	5	Muscle	-	.87± .51	-	-
745			5	Liver	9.2± 7.6	1.2 ± .47	-	-
759		Eggs	9	Shell	-	-	-	-
760			9	Yolk	-	.19± .06	.80± .24	-
761			9	Albumin	8.5± 1.4	-	-	.16± .11
762			9	Embryo & Yolk	2.7± 1.4	.12± .09	-	.19± .11
763			10	Shell	-	-	-	-
764			10	Yolk	2.1± .94	.43± .07	.60± .25	-
765			10	Albumin	7.7± 1.7	-	-	-
766			10	Embryo & Yolk	-	-	-	-
767			3	Shell	-	.22± .14	-	-
768			3	Embryo & yolk	4.5 ± .67	.21± .04	.75± .17	-
769		Residue in water in which eggs were boiled			34 ±5.5	5.3 ± .39	-	1.1 ± .41

Strontium-90 in Eviscerated Whole Reef Fish
Collected at Bikini Atoll, June 1969

Sample Number	Species	Location	No. of fish in sample	Length	pCi/g dry weight
25609	Convict surgeon	Nam	4	158-175mm	0.86 ± 0.05*
25611	" "	"	6	130-155mm	0.37 ± 0.02
25613	" "	"	15	112-135mm	0.27 ± 0.04
25615	" "	"	25	95-110mm	0.14 ± 0.02
25617	" "	"	19	90-105mm	0.09 ± 0.03
25621	Grouper (muscle)	Nam	3	41,62,78mm	0.29 ± 0.06
25622	Mullet	"	16	150-175mm	0.50 ± 0.05
25624	Mullet	"	15	160-200mm	0.35 ± 0.04
25628	Mullet	"	8	195-260mm	0.33 ± 0.04
25619	Flagtail	"	8	193-214mm	0.23 ± 0.04
25661	Goatfish	"	4	200-250mm	0.93 ± 0.03
25663	Goatfish	"	3	230-250mm	0.61 ± 0.03
25605	Convict surgeon	Bikini	16	94-115mm	0.16 ± 0.04
25607	" "	"	4	132-152mm	0.16 ± 0.04
25630	Mullet	"	5	220-255mm	0.12 ± 0.04
25632	Mullet	"	13	150-175mm	0.05 ± 0.04
25634	Mullet	"	5	250-300mm	0.12 ± 0.04
25657	Goatfish	"	2	185,190mm	0.07 ± 0.02
25659	Goatfish	"	8	190-220mm	0.05 ± 0.02

* Error is 1 σ

Appendix Table 12

^{90}Sr in Troll Caught Fish
Enyu Pass
June, 1969

Sample Number		Tissue	pCi/g dry weight
25562	yellow fin	light muscle	<0.1
25542		dark muscle	<0.1
25522		bone	<0.1
25559	yellow fin	light muscle	0.29 ± 0.03
25539		dark muscle	<0.1
25519		bone	<0.1
25558	yellow fin	light muscle	<0.1
25538		dark muscle	<0.1
25518		bone	<0.1
25564	ulua	light muscle	<0.1
25544		dark muscle	<0.1
25524		bone	1.1 ± 0.3
25565	ulua	light muscle	<0.1
25545		dark muscle	<0.1
25525		bone	1.1 ± 0.2
25566	ulua	light muscle	<0.1
25546		dark muscle	<0.1
25526		bone	1.9 ± 0.4

Appendix Table 13

Strontium-90 in Birgus latro (coconut crabs) Collected at Bikini Island, Bikini Atoll, June 1969

Sample Number	Sex	Carapace Length (cm)	Tissue	pCi/g dry	
25463	-	-	Muscle	30.8 ± 0.4	28.1 ± 0.4
25433			Liver	203 ± 3	206 ± 3
25464			Skeleton	1283 ± 13	1268 ± 13
25466	-	-	Muscle	15.9 ± 0.7	16.8 ± 0.8
25434			Liver	38.9 ± 0.4	37.7 ± 0.4
25467			Skeleton	932 ± 13	891 ± 13
25451	Male	4.35	Muscle	44.3 ± 1.2	42.4 ± 1.4
25436			Liver	86.6 ± 2.1	91.1 ± 2.1
25452			Skeleton	1307 ± 18	1368 ± 14
				1031 ± 15	
25459	-	-	Muscle	36.2 ± 1.0	36.3 ± 1.0
25441			Liver	42.3 ± 0.7	42.3 ± 0.7
25460			Skeleton	1027 ± 10	994 ± 10
25461	Female	5.0	Muscle	76.0 ± 0.9	76.3 ± 0.9
25442			Liver	129 ± 1	113 ± 1
25462			Skeleton	1943 ± 28	1920 ± 27
				2040 ± 29	
25474	-	-	Muscle	100 ± 1	98 ± 1
25445			Liver	208 ± 3	196 ± 3
25475			Skeleton	1940 ± 20	2131 ± 22

Appendix Table 14

Strontium-90 in Birgus latro (coconut crabs) Collected at Enyu Islet, Bikini Atoll, June 1969

Sample Number	Sex	Carapace length (cm)	Tissue	pCi/g dry	
25455	Male	7.8	Muscle	1.5 ± 0.3	0.9 ± 0.3
25444			Liver	3.1 ± 0.2	2.9 ± 0.2
25456			Skeleton	76.2 ± 0.8	73.0 ± 1.1
				58.0 ± 0.8	69.4 ± 0.8
25468	Male	7.4	Muscle	1.3 ± 0.3	1.4 ± 0.3
25438			Liver	6.8 ± 0.2	6.4 ± 0.3
25469			Skeleton	116 ± 2	117 ± 2
				105 ± 2	
25472	Male	7.3	Muscle	2.3 ± 0.3	2.3 ± 0.3
25437			Liver	5.9 ± 0.3	7.3 ± 0.3
25473			Skeleton	112 ± 2	106 ± 2
25449	Male	7.0	Muscle	1.0 ± 0.2	0.8 ± 0.2
25439			Liver	7.5 ± 0.3	6.9 ± 0.2
25450			Skeleton	114 ± 2	101 ± 2
				99.8 ± 1.1	
25470	Male	6.9	Muscle	1.0 ± 0.3	1.2 ± 0.2
25435			Liver	8.2 ± 0.4	7.3 ± 0.3
25471			Skeleton	82.6 ± 1.3	80.8 ± 1.3
25453	Male	6.6	Muscle	0.8 ± 0.2	0.6 ± 0.2
25443			Liver	8.5 ± 0.4	7.3 ± 0.3
25454			Skeleton	83.3 ± 0.8	83.8 ± 1.1
25447	Male	6.5	Muscle	1.8 ± 0.2	2.1 ± 0.1
25446			Liver	14.4 ± 0.2	14.1 ± 0.2
25448			Skeleton	105 ± 1	99.1 ± 1.1
25457	Male	5.9	Muscle	2.2 ± 0.3	2.2 ± 0.3
25440			Liver	12.8 ± 0.2	14.5 ± 0.2
25458			Skeleton	114 ± 2	109 ± 2

Table 14 (continued)

Strontium-90 in Birgus latro (coconut crabs) Collected at Enyu Islet, Bikini Atoll, March 1969

Sample Number	Sex	Carapace Length (cm)	Tissue	pCi/g dry	
25400	Male	14.5	Muscle	2.7 ± 0.4	4.0 ± 0.4
25401			Liver	33.3 ± 1.3	22.6 ± 0.9
25403	Male	15.0	Muscle	2.1 ± 0.1	2.3 ± 0.2
25404			Liver	4.7 ± 0.2	4.9 ± 0.2
25406	Male	7.0	Muscle	2.9 ± 0.1	
25407			Liver	7.7 ± 0.1	
25409	Female	8.0	Muscle	3.1 ± 0.3	
25410			Liver	7.2 ± 0.1	
25412	Female	6.5	Muscle	2.8 ± 0.1	
25413			Liver	7.1 ± 0.1	

Appendix Table 15

^{90}Sr in Coconut Crabs
Oroken Island
June, 1969

Sample Number	Tissue	pCi/g dry weight
25588	muscle	9.1 ± 0.8
25590	hepatopancreas	30.0 ± 1.1
25589	exo-skeleton	482 ± 17
25591	muscle	8.8 ± 0.8
25593	hepatopancreas	16.2 ± 0.6
25592	exo-skeleton	267 ± 9
25594	muscle	4.9 ± 0.7
25596	hepatopancreas	15.4 ± 0.6
25595	exo-skeleton	184 ± 6
25597	muscle	14.9 ± 1.1
25599	hepatopancreas	21.1 ± 0.8
25598	exo-skeleton	571 ± 19
25600	muscle	6.8 ± 0.9
25602	hepatopancreas	24.0 ± 0.9
25601	exo-skeleton	228 ± 8

Appendix Table 16

Iron-55 in Samples Collected at Bikini Atoll, 1969

pCi/g dry

Sample No.	Collection Site	Common Name	Tissue or Organ	Aliquot #1	Aliquot #2	Avg.
25605	Bikini I.	Surgeon	Whole (Eviscerated)	84±2.0	86±2.1	85
25607	"	"	"	19±1.1	16±1.0	18
25751	Enyu I.	Goatfish	"	72±2.0	75±2.0	74
25753	"	"	"	90±2.2	84±2.1	87
25631	Bikini I.	Mullet	Viscera		22±1.2	22
25633	"	"	"	62±1.2	84±5.0	73
25635	"	"	"	224±6.1	232±6.2	228
25658	"	Goatfish	"	465±21	418±20	442
25660	"	"	"	385±4.9	397±4.7	391
25604	"	Surgeon	"	148±4.3		148
25608	"	"	"	268±6.7	232±6.7	250
25752	Enyu I.	Goatfish	"	828±7.8		828
25754	"	"	"	1670±35		1670
25623	Nam I.	Mullet	"	126±2.7	117±2.6	122
25627	"	"	"	349±.84	347±3.7	348
25629	"	"	"	235±3.1	244±3.1	240
25610	Nam I.	Surgeon	"	400±6.6	409±6.7	404
25614	"	"	"	249±5.5		249
25616	"	"	"	239±7.4		239

Appendix Table 16 (continued)

Sample No.	Collection Site	Common Name	Tissue or Organ	#1	#2	Avg
25708	Enyu I.	Grouper	Muscle	15±1.1	14±1.1	14
25705	"	"	"	7.6±.77	7.8±.78	7.7
25747	"	"	"	16±1.1	20±1.2	18
25711	"	"	"	13±.76	13±.75	13
25621	Nam I.	"	"	38±2.2		38
25706	Enyu I.	"	Liver	9,480±36		9,480
25703	"	"	"	14,500±124		14,500
25746	"	"	"	25,600±106		25,600
25709	"	"	"	9,100±32		9,100
25548	Enyu Pass	Yellowfin tuna	Light muscle	59±.8	59±.84	59
25549	"		" "	34±1.2		34
25550	"	"	" "	13±.7		13
25551	"	"	" "	13±2.1		
25552	"	"	" "	63±1.3	62±1.3	62
25553	"	"	" "	20±1.2	22±1.3	21
25554	"	"	" "	18±.7	21±.7	20
25555	"	"	" "	9.1±.63	8.0±.89	8.5
25556	"	"	" "	45±1.0	39±.94	42
25557	"	"	" "	30±1.3	31±1.4	30
25558	"	"	" "	34±.99	39±1.1	36
25559	"	"	" "	33±.99	29±.82	31
25560	"	"	" "	16±1.1	20±1.2	18
25561	"	"	" "	23±.74	12±.58	18
25562	"	"	" "	42±.73	47±1.0	44
25563	"	"	" "	17±.60		17
25564	"	Ulua (Jack)	" "	341±3.7	349±3.8	345
25565	"	"	" "	236±1.6	192±2.0	214
25566	"	"	" "	72±1.4		72

Appendix Table 16 (continued)

Sample No.	Collection Site	Common Name	Tissue or Organ	#1	#2	Avg.
25567	Enyu Pass	Dogtooth tuna	Light muscle	116±3.1		116
25528	"	Yellowfin tuna	Dark muscle	775±5.9	959±6.5	867
25529	"	"	" "	290±3.6	280±3.5	285
25530	"	"	" "	173±2.9	169±2.9	171
25531	"	"	" "	128±3.6		128
25532	"	"	" "	532±3.4	554±3.5	543
25533	"	"	" "	210±2.2	213±2.3	212
25534	"	"	" "	174±2.0	187±2.1	180
25535	"	"	" "	109±1.6	106±1.6	108
25536	"	"	" "	406±4.0	413±4.3	410
25537	"	"	" "	324±3.8	359±4.0	342
25538	"	"	" "	394±4.1	396±4.1	395
25539	"	"	" "	390±2.8	396±2.8	393
25540	"	"	" "		272±2.6	272
25541	"	"	" "	209±2.2	205±2.7	207
25542	"	"	" "	428±2.9	630±3.5	529
25543	"	"	" "		299±45	299
25544	"	Ulua (Jack)	" "	2860±8		2860
25545	"	"	" "	3630±12		3630
25546	"	"	" "	1255±7.2	1331±7.4	1293
25547	"	Dogtooth tuna	" "	915±10		915
25568	"	Yellowfin tuna	Liver	888±7.5	900±7.6	894
25569	"	"	"	323±3.9		323

Appendix Table 16 (continued)

Sample No.	Collection Site	Common Name	Tissue or Organ	#1	#2	Avg.
25570	Enyu Pass	Yellowfin tuna	Liver	202±3.1	222±3.3	212
25571	"	"	"	113±4.3	116±4.3	114
25572	"	"	"	915±6.3	877±6.2	896
25573	"	"	"	258±4.1	245±4.0	252
25574	"	"	"	431±5.3	401±5.1	416
25575	"	"	"	74±1.9	76±1.9	75
25576	"	"	"	431±5.3	452±5.4	442
25577	"	"	"	281±3.5	355±4.0	318
25578	"	"	"	423±5.2	418±5.1	420
25579	"	"	"	334±6.1	338±6.2	336
25580	"	"	"	207±3.7	213±3.7	210
25581	"	"	"	288±4.3	294±4.4	291
25582	"	"	"	534±66		534
25583	"	"	"	252±5.1	253±5.1	252
25584	"	Ulua (Jack)	"	21,700±48	20,750±49	2,240
25585	"	"	"	40,900±85		40,900
25586	"	"	"	8,170±47	8,210±47	8,190
25587	"	Dogtooth tuna	"	1520±13		1,520
25466	Bikini I.	Coconut crab	Muscle	9.6±.96	9.2±.95	9.4
25451	"	"	"	2.2±.67	2.6±.58	2.4
25459	"	"	"	5.1±1.8	2.4±1.7	3.8
25455	Enyu I.	"	"	2.2±.76	2.1±.22	2.2
25468	"	"	"	2.3±.78	3.4±.82	2.8
25472	"	"	"	8.6±.94	5.7±.88	7.2

Appendix Table 16 (continued)

Sample No.	Collection Site	Common Name	Tissue or Organ	#1	#2	[illegible]
25449	Enyu I.	Coconut crab	Muscle	2.8±.24	4.6±.84	3.7
25470	"	"	"	3.6±.82	2.1±.78	2.8
25453	"	"	"	3.0±.64	1.7±.60	2.4
25447	"	"	"	5.4±.69	5.4±.68	5.4
25457	"	"	"	1.4±.57	.79±.55	1.1
25400	"	"	"	2.2±.74		2.2
25588	Oroken I.	"	"	15±.87	15±.87	15
25591	"	"	"	14±.85	16±.88	15
25594	"	"	"	14±1.3	16±1.4	15
25597	"	"	"	5.3±.58	5.8±.59	5.6
25600	"	"	"	14±.92	13±.90	14
25434	Bikini I.	"	"Liver"	68±2.9	63±2.8	65
25436	"	"	"	86±6.8	77±5.8	82
25444	Enyu I.	"	"	17±.66	13±2.1	15
25438	"	"	"	43±2.5	34±1.7	38
25437	"	"	"	21±.55	18±1.8	20
25443	"	"	"	43±4.4	46±5.9	44
25440	"	"	"	25±1.4	24±1.5	24
25590	Oroken	"	"	59±2.2	61±2.2	60
25593	"	"	"	59±2.2		59
25596	"	"	"	49±2.0	47±2.0	48
25599	"	"	"	64±2.2	65±2.2	64
25602	"	"	"	39±1.8	38±1.8	38

Appendix Table 16 (continued)

Sample No.	Collection Site	Common Name	Tissue or Organ	#1	#2	Avg.
25722	Enyu I.	Spiny	Muscle	.71±.47	3.4±.63	2.1
25725	"	lobster	"	1.3±.71	.61±.69	.96
25731	"	"	"	ns*	2.0±.72	1.0
25681	Nam I.	"	"	9.4±.84	9.6±.83	9.5
25685	"	"	"	5.5±.84	5.5±.83	5.5
25689	"	"	"	17±.89		17
25673	"	"	"	15±1.5		15
25677	"	"	"	5.9±1.1		5.9
25724	Enyu I.	Spiny	"Liver"	96±4.1		96
25727	"	lobster	"	59±4.8		59
25730	"	"	"	66±2.0		66
25680	Nam I.	"	"	237±9.5		237
25684	"	"	"	32±1.7		32
25688	"	"	"	420±9.9		420
25672	"	"	"	269±6.5		269
25676	"	"	"	67±4.6		67
25729	Enyu I.	"	Skeleton	ns		
25732	"	"	"	1.6±.66	2.5±.69	2.1
25690	Nam I.	"	"	4.3±.81	3.9±.80	4.1
25674	"	"	"	3.5±.79	5.4±.84	4.4
25678	"	"	"	ns		
25683	Nam I.	"	Remainder	18±1.1	17±1.1	18
25687	"	"	"	4.2±.83	3.8±.82	4.0

*Non-significant

Appendix Table 16 (continued)

Sample No.	Collection Site	Common Name	Tissue or Organ	#1	#2	Avg.
25691	Nam I.	Spiny lobster	Remainder	28±1.1	30±1.2	29
25699	"	"	"	34±1.4	31±1.7	32
25679	"	"	"	8.1±.93	9.7±.89	8.9
25713	Bikini I.	Giant clam	Muscle and mantle	22±1.2	21±1.2	22
25716	"	"	"	52±1.7	50±1.7	51
25647	"	"	"	24±1.1		24
25644	"	"	"	20±.36	26±.62	23
25641	"	"	"	18±1.1	15±.28	16
25667	Nam I.	"	"	104±1.5		104
25702	"	"	"	43±1.1		43
25656	"	"	"	108±3.4		108
25714	Bikini I.	"	Viscera	44±1.6	42±1.6	43
25717	"	"	"	59±1.8	57±1.8	58
25646	"	"	"	53±1.6	57±1.6	55
25643	"	"	"	43±1.9	44±.48	44
25640	"	"	"	29±1.3	41±.62	35
25666	Nam I.	"	"	150±2.6		150
25701	"	"	"	ns		ns
25655	"	"	"	219±6.2		219
25637	"	"	"	48±1.9	55±2.3	51
25712	Bikini I.	"	Kidney	489±4.9		489
25715	"	"	"	601±10	594±10	598
25645	"	"	"	162±3.5	164±3.5	163
25642	"	"	"	708±13	710±13	709
25639	"	"	"	377±4.8	383±4.8	380

Appendix Table 16 (continued)

Sample No.	Collection Site	Common Name	Tissue or Organ	#1	#2	Avg.
25665	Nam I.	Giant clam	Kidney	133±2.6		133
25700	"	"	"	126±3.1		126
25654	"	"	"	287±13		287
25736	"	Curlew	Muscle	143±.42		143
25738	"	"	"	18±.46		18
25740	"	"	"	54±1.0		54
25749	"	Turnstone	"	312±3.3		312
25737	"	Curlew	Liver	5,810±25		5,810
25739	"	"	"	312±5.6		312
25741	"	"	"	1,720±14		1,720
25750	"	Turnstone	"	2,820±24		2,820
25742	Oroken I.	Noddy tern	Muscle	497±3.8		497
25744	"	Fairy tern	"	425±3.5		425
25743	"	Noddy tern	Liver	1,220±8.7		1,220
25745	"	Fairy tern	"	763±6.5		763
25761	"	Egg	Albumin	15±1.5		15
25765	"	"	"	9.1±.33		9.1
25766	"	"	Embryo and yolk	300±6.5		300

Appendix Table 16 (continued)

Sample No.	Collection Site	Common Name	Tissue or Organ	#1	#2	Avg.
			Location			
25506	Bikini I.	Soil 0-1"	Well point #1	182±4.3	164±4.1	173
25507	"	" "	" " #2	36±2.2	37±2.2	36
25504	"	" "	" " #3	154±4.0	144±4.0	149
25505	Nam I.	" "	" " #1	11±1.6	5.6±1.4	8.4
25756	Aomen I.	" "		138±2.6	151±2.6	144
25757	Oroken I.	" "		115±2.6	149±3.0	132
25758	Aerokoj I.	" "	S-11	34±2.4	35±2.4	35
25481	"	" "	S-6	5.0±1.5	6.0±1.5	5.5
25500	Eneman I.	" 0-1"	Well point #1	512±7.2	533±7.3	522
25496	"	" 1-2"	" " "	166±3.9	188±4.1	177
25495	"	" 2-3"	" " "	183±4.5	195±4.6	189
25503	"	" 3-4"	" " "	241±5.1	265±5.3	253
25498	"	" 4-5"	" " "	148±4.1	140±4.3	144
25502	"	" 5-6"	" " "	66±2.9	62±2.9	64
25497	"	" 6-7"	" " "	29±.62	33±2.4	31
25501	"	" 7-8"	" " "	29±2.3	26±2.2	28
25499	"	" 8-9"	" " "	29±2.3	22±2.2	26
25494	"	" 9-12"	" " "	30±2.0	26±1.9	28
25493	"	" 12-17"	" " "	29±2.0	23±1.9	26
			Water depth			
25649	Bravo Crater	Sediment	40'	57±2.6	31±2.0	44
25650	"	"	120'	76±2.6	68±.62	72
25648	"	"	145-150'	717±7.6	729±7.6	723
25653	"	"	155-160'	952±8.7	924±8.6	938

Appendix Table 17

List of Common and Scientific Names of Organisms Collected at Bikini Atoll, 1969

Common Name	Scientific Name
Algae	Caulerpa urvilliana
Barracuda	Sphyranea sp.
Clam	Tridacna crocea
Clam, killer	Tridacna squamosa
Clam, horsefoot	Hippopus hippopus
Coconut crab	Birgus latro
Convict surgeonfish	Acanthurus triostegus
Crab, hermit	Coenobita perlatus
Crab, shore	Grapsus grapsus
Curlew	Numenius tahitiensis
Goatfish	Mulloidichyhys auriflamma
Grouper	Epinephelus sp.
Mullet	Neomyxus chaptali
Parrotfish	Scaridae
Pilotfish	Kyphosus cinerascens
Rat	Rattus sp.
Skipjack	Euthynnus yaito
Snapper	Lutjanidae
Spiny lobster (langouste)	Panulirus sp.
Tern, fairy	Gygis alba
Tern, noddy	Anous stolidus
Tuna, dogtooth	Gymnosarda nuda
Tuna, yellowfin	Thunnus albacares
Turnstone, ruddy	Arenaria interpres
Ulua (jack)	Caranx sp.