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RADIOLOGICAL RESURVEY OF ANIMALS, SOILS AND GROUNDWATER AT BIKINI ATOLL, 1969-1970

By

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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.

Abstract

The results of radiometric and radiochemical analyses of samples, exclusive of land plants, collected at Bikini Atoll in 1969 and 1970 are presented and discussed. Average values in pCi/g wet for radionuclides in food items collected in 1969 were: 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 Eneu Islands were 12 pCi/g wet and .05 pCi/g wet, respectively. There are no striking differences between average values for edible foods of marine origin, including the sea birds, compared with values reported in 1967. 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. Tritium levels in groundwater are within the range of values for continental surface water samples. 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.

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1. 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, the Bikini people moved 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 seafoods 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 (Welander, 1967; Welander et al., 1967). 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 include reduction of coconut crab population, because of high content of ^{90}Sr, and covering the village area at Bikini Island with coral gravel from the beaches, which is consistent with local custom and provides 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 cleanup. Additional monitoring was necessary because dense vegetation on Bikini and Eneu 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 was 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 Environmental

Protection Agency's Western Environmental Research Laboratory (EPA/WERL, formerly USPHS/SWERL) took the responsibility for external radiation measurements, and for the collection and analysis of those land plants that are food items; the U of W Laboratory of Radiation Ecology was asked to sample and analyze other biological and environmental samples in 1969. Additional samples were collected in 1970, with the emphasis on air filters and soil samples. The former were analyzed and reported by the EPA (SWRHL-111r). This report presents the results of the Laboratory's anlayses.

2. 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 that might be eaten by returning Bikinians, except for land plants. Additional samples, for example, soils, crater sediments and groundwater, 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 that would be eaten when the Bikinians return. A fourth kind of reef fish, groupers, was also collected as representative 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 Eneu 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 samples 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 in the vicinity of Nam (Charlie) Islet. The larger species were found near Bikini Island.

* For a list of common names and scientific names, see Table 20.

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 terms 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.

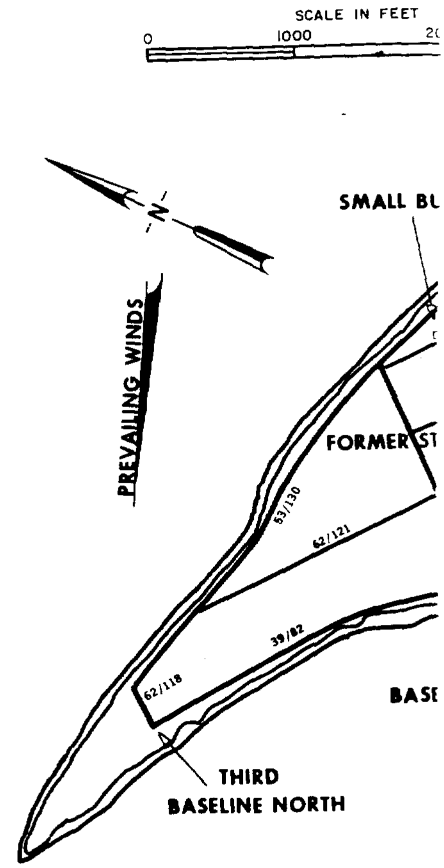
Groundwater was collected by driving half-inch pipe with well points into the soil. The well-point sites on Bikini and Eneman Islands were in areas found to be the most radioactive by the EPA/WERL personnel. On Nam I., the well point was driven in a low area near the center of the Island. Existing wells were sampled at Eneu. Attempts to obtain groundwater at Aerokoj were unsuccessful. Water samples were collected from existing wells at Eneu I. and from the cisterns constructed at Bikini I. in 1969.

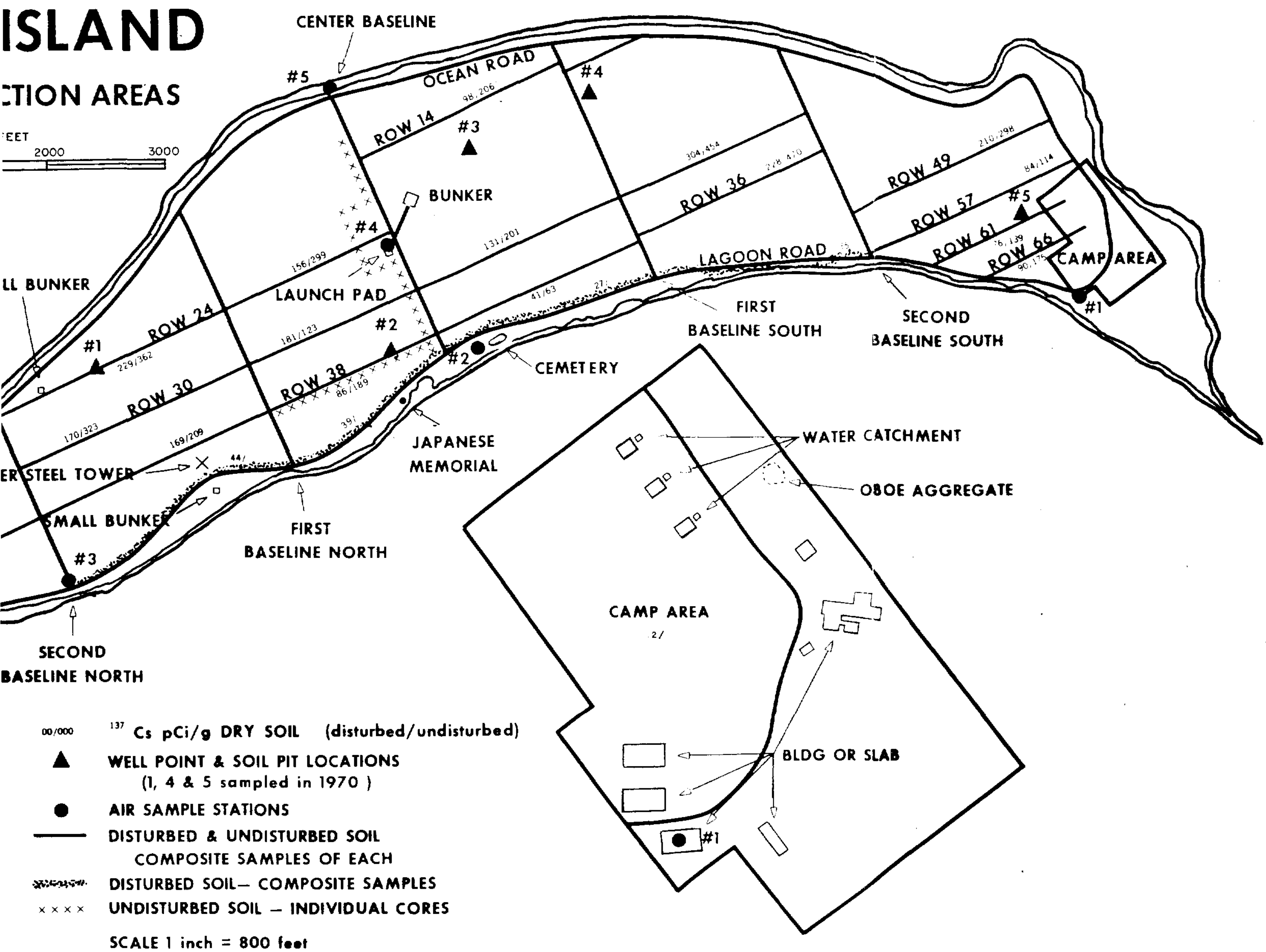
In 1969, soil samples were taken by one-inch depth increments to depths of ten inches or more near each well point. All depth increments for two sets of samples from Eneman were anlayzed but only the surface one inch or other sets of samples were analyzed. In addition to samples from soil pits at the 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.

In 1970, composite soil samples were taken to a depth of one inch from undisturbed and disturbed areas along rows at Bikini I. and on representative transects east and west of the airstrip at Eneu I. (Figs. 1 and 2). The subsamples combined in each composite sample were taken at intervals of 100 paces with coring devices of 3.5 inches diameter and one-inch depth. One north-south transect and one east-west transect were resampled and the subsamples were retained and analyzed individually to indicate the variability between subsamples. In the Base Camp area on Bikini Island, 16 samples were taken at 25-foot intervals on a 100 x 100-foot grid and combined as a composite sample. An additional 20 samples were taken and retained as individual samples for gamma-ray spectrum analysis. Samples from soil profiles were taken at well points 1, 4, and 5.

BIKINI IS

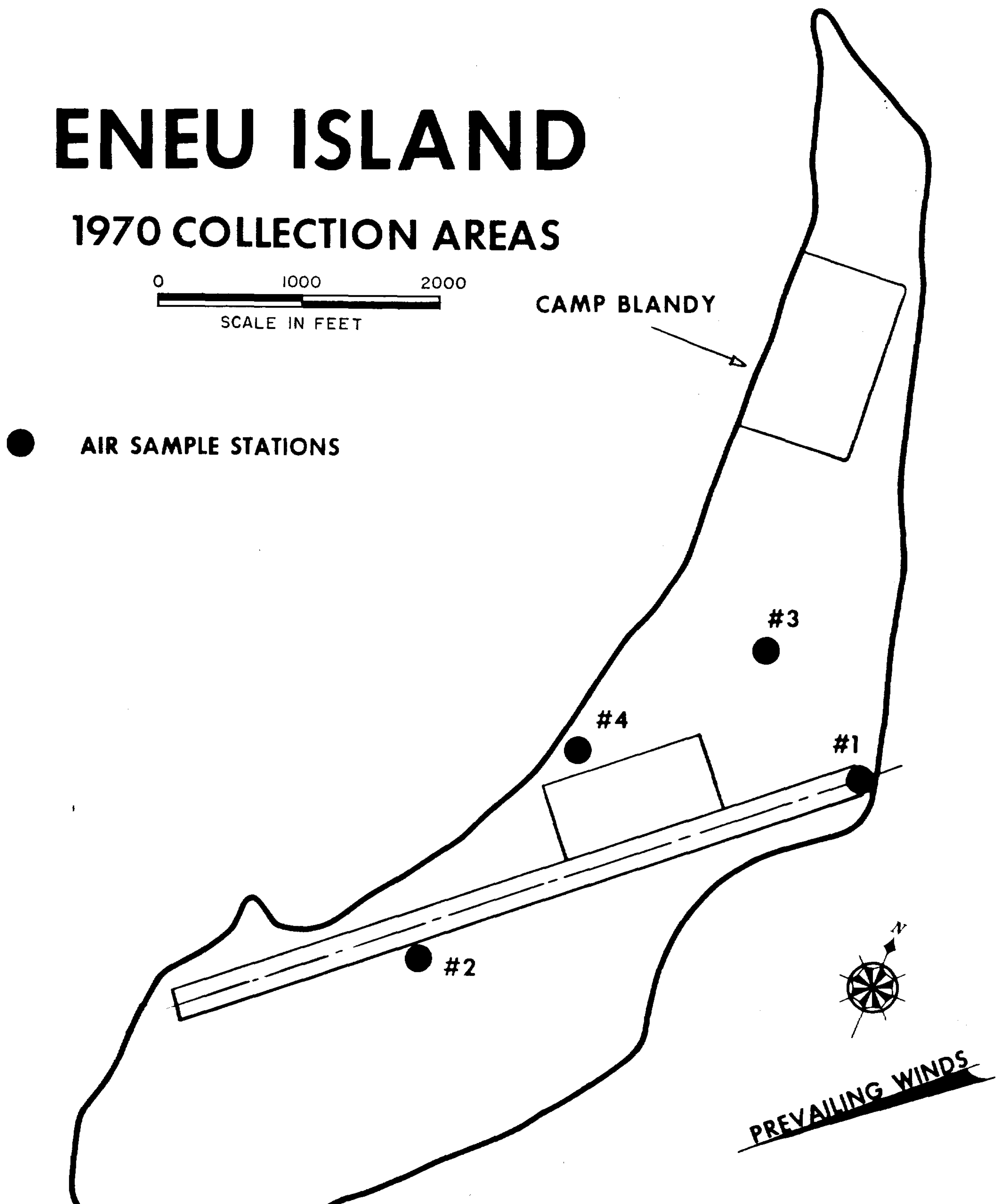
1970 COLLECTIC





ISLAND
:TION AREAS
'EET
2000
3000
CENTER BASELINE
#5
OCEAN ROAD
98/206
ROW 14
#3
#4
BUNKER
#4
156/299
LAUNCH PAD
131/201
304/454
228/470
ROW 36
ROW 49
210/298
84/114
ROW 57
#5
ROW 61
76/139
ROW 66
90/175
CAMP AREA
#1
LAGOON ROAD
FIRST
BASELINE SOUTH
SECOND
BASELINE SOUTH
LL BUNKER
ROW 24
#1
229/362
181/123
#2
41/63
27
#2
CEMETERY
ROW 30
170/323
ROW 38
86/189
39
169/209
JAPANESE
MEMORIAL
ER STEEL TOWER
44
SMALL BUNKER
FIRST
BASELINE NORTH
#3
SECOND
BASELINE NORTH
WATER CATCHMENT
OBOE AGGREGATE
CAMP AREA
2/
BLDG OR SLAB
#1
00/000 137 Cs pCi/g DRY SOIL (disturbed/undisturbed)
WELL POINT & SOIL PIT LOCATIONS
(1, 4 & 5 sampled in 1970)
AIR SAMPLE STATIONS
DISTURBED & UNDISTURBED SOIL
COMPOSITE SAMPLES OF EACH
DISTURBED SOIL– COMPOSITE SAMPLES
× × × × UNDISTURBED SOIL – INDIVIDUAL CORES
SCALE 1 inch = 800 feet

FIGURE 1.



ENEU ISLAND
1970 COLLECTION AREAS
0
1000
2000
SCALE IN FEET
CAMP BLANDY
AIR SAMPLE STATIONS
#3
#4
#1
#2
N
PREVAILING WINDS

FIGURE 2.

3. 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(TI) 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 were used. All values were corrected for decay to the date of collection. The error given for individual values is the two-sigma, propagated counting 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 coralline 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.

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

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.

4. RESULTS AND DISCUSSION

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

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

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

The range in the concentration 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 Tables 1 through 19.

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.

4.1 FOODS

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, 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 are 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 are greatly improved. However, some hypotheses can be made and conclusions can be drawn from certain data.

4.2 SOILS

All of the fallout radionuclides at Bikini are found in the surface of undisturbed soils. The predominant radionuclides are ^{55}Fe, ^{60}Co, ^{90}Sr, ^{125}Sb, ^{137}Cs and ^{207}Bi (Tables 1-5).

In the Bravo Crater sediment, ^{60}Co and ^{207}Bi are the predominant radionuclides, although others are present in small quantities. The soils and sediments are the principal reservoirs of radionuclides at Bikini.

The concentrations of radionuclides, other than plutonium, in surface soil samples collected in 1969 are given in Table 1. The samples were taken from areas where the highest gamma dose rates were measured and hence are maximum values. Differences in proportions of different radionuclides at the islets sampled are obvious. The unusually low concentrations of ^{137}Cs relative to other radionuclides in the Eneman samples result from periodic flooding of the area by tidal water and consequent leaching away of ^{137}Cs (Tables 2 and 3).

The results of gamma-ray spectrum analyses of the composite and individual samples collected in 1970 are given in Table 4. In general, radionuclide concentrations are lower in bulldozed areas than in undisturbed areas. The exceptions to this generality are not surprising, since the lowest and highest values for individual samples from single transects differ by factors of more than ten. Fallout radionuclides in undisturbed atoll soils remain concentrated at the surface for many years (Held et al., 1965; Welander, 1967). The surface ten centimeters at wellpoint four at Bikini Island were sampled by one-half centimeter increments in 1970, and the samples show a gradient of decreasing radionuclide content with increasing depth (Table 5).

Soil samples analyzed for plutonium were generally selected from areas containing the highest concentrations of gamma-emitting radionuclides. Exceptions were samples from the camp area at Bikini I. and along the runway at Eneu I.

The results of the plutonium analyses are given in Table 6; ^{137}Cs concentrations are included in the table because they indicate a correlation between ^{137}Cs and ^{239,240}Pu concentrations in samples from Bikini I.

The ratios of ^{239,240}Pu to ^{238}Pu approach 2:1 at Eneman I. and are about 15:1 in Bravo Crater sediment. Bikini soils contained no detectable ^{238}Pu, although they contained the highest concentrations of ^{239,240}Pu of the samples analyzed.

4.3 ORGANISMS

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. 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 organism. 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 all adsorbable radionuclides not already removed from the water by the plankton soon after fallout.

The land organisms contain primarily the long-lived fission products ^{137}Cs and ^{90}Sr (Welander, 1967; Welander et al., 1967; Smith and Moore, 1971). 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. We determined the ^{137}Cs content of tissues of rats collected at Bikini in 1969 and 1970, and the range of ^{137}Cs concentrations in pCi/g dry weight was 340 to 827 in muscle tissue; values for muscle, lung, liver and bone are given in Table 7.

The coconut crabs which are terrestrial, except during their larval stages, contain mostly ^{137}Cs from among the gamma-emitting radionuclides (Table 8) and are concentrators of ^{90}Sr (Table 9).

The spiny lobster, a strictly marine crustacean, contains no detectable ^{137}Cs or ^{90}Sr and only small amounts of ^{60}Co (Table 10).

There are quantitative and qualitative differences in the 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 detritus feeder (Tables 11, 12 and 13). Higher order carnivores, the grouper and ulua, also contain more ^{60}Co (Table 14) 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 (Table 15). Presumably, the ^{90}Sr is being accumulated throughout the life of the fish and a steady state has not been reached.

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 <u>Tridacna</u> sp. and <u>Hippopus hippopus</u> (Table 16). By far the highest levels of ^{60}Co, as much as 4,000 pCi/g dry, in any organism at Bikini Atoll are 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 17). 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. 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, similar to the values for yellowfin tuna from Bikini (Table 18). It appears, therefore, that a major amount of the ^{55}Fe in the Bikini tuna is from worldwide fallout.

4.4 CRATER SEDIMENTS

One of the principal sources of radionuclides at Bikini is Bravo Crater in the reef adjacent to and southwest of Nam I. Figure 3 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. The most abundant radionuclide in soils is ^{137}Cs, and an intermediate condition exists at the southwestern end of Eneman I., where a low area is occasionally overwashed by seawater, and 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 goatfish in the vicinity of the craters contain ten times more ^{60}Co than the herbivorous convict surgeonfish and detritus-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 surgeon fish and mullet in the vicinity of the Bravo Crater and 16 miles eastward near Bikini I. is only by a factor of less than two. At the same time, the ^{60}Co concentrations in goatfish from near the crater and those at Bikini I. differ by a factor of about ten.

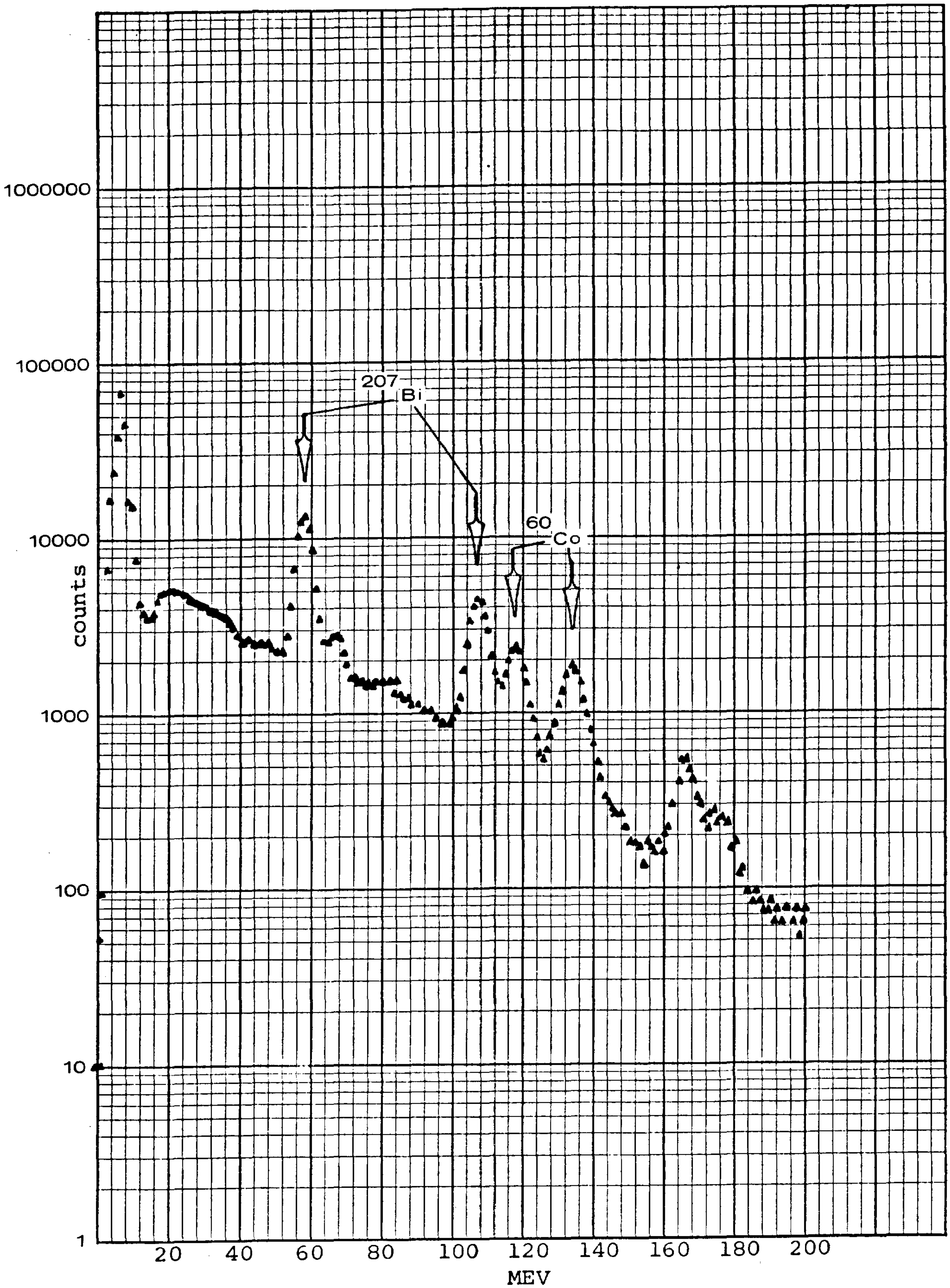

Fig. 3. Gamma-ray spectrum of sediment from Bravo Crater collected at a water depth of 160 feet, August, 1969.

It appears that the physical redistribution of ^{207}Bi in the lagoon 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 19. 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 at Bikini. The presence of $^{239,240}Pu$ and ^{207}Bi (Table 12) in goatfish viscera is consistent and probably results from direct ingestion of fine particles of sediment during feeding. Two samples of goatfish viscera collected at Nam I. in 1969 contained ^{239}Pu in concentrations of 13 pCi/g dry and 29 pCi/g dry. 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 or 1970 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 accumulated ^{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 125 years, has been identified for the first time among the radionuclides at Bikini (Beasley and Held, 1971). This radionuclide was first detected from the gamma-ray spectrum of the hepatopancreas of spiny lobsters collected in 1969 (Fig. 4), and quantitative analysis of pooled samples from Eneu I. in June, 1969, and Bikini I. in June, 1970, gave results of 0.50 ± 0.13 pCi/g dry, respectively. The spiny lobster hepatopancreas is a known concentrator of silver isotopes (Seymour, 1963). Thus, ^{108m}Ag is another potentially useful long-lived tracer, with its indicator organism.

4.5 WATER

Tritium in well water is present at low concentrations; the maximum value found in 1969 was 14 pCi/ml, or 4300 tritium units, at Nam I., whereas at Bikini and Eneu Islands the concentration was 2 pCi/ml, or approximately 600 T. U. Samples taken in 1970 from well-points 4 and 5 and from the cistern at Bikini and from the well and cistern at Eneu all contained less than 400 T. U. These values fall within the range of tritium concentrations

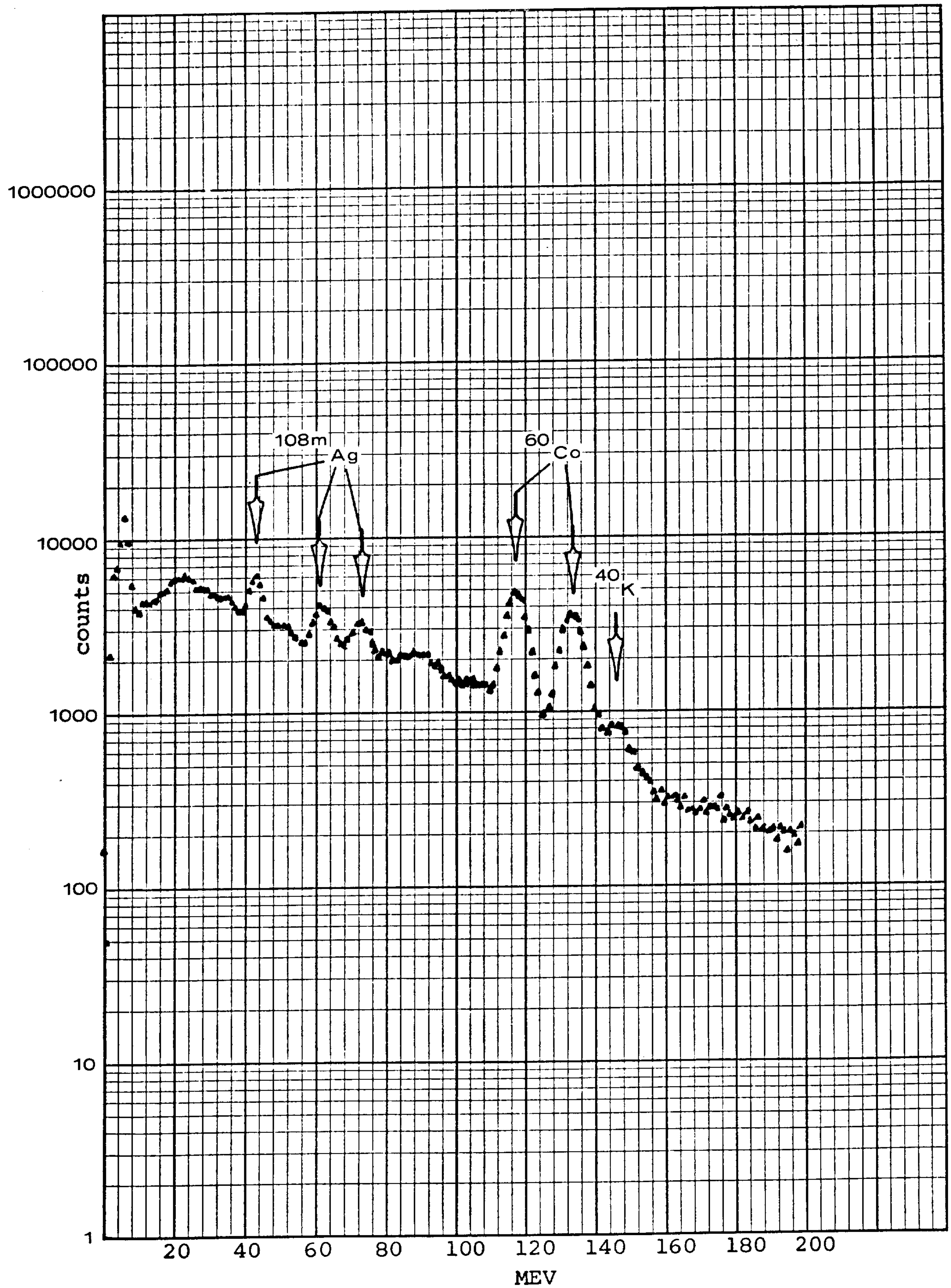

Fig. 4. Gamma-ray spectrum of spiny lobster hepatopancreas from Bikini Atoll, 1969.

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.

Algae collected from the wall of the drained cistern at Bikini I. in June 1970 contained 100 pCi/g dry weight of ^{95}Zr-^{95}Nb, presumably from the French nuclear tests in the South Pacific. Marine algae collected at the same time from the reefs at Eneu I. contained 0.1 pCi/g of ^{95}Zr-^{95}Nb dry weight.

4.6 CONCLUSIONS

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.

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Table 1

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

Sample No.	Island	Location	^{60}Co	^{125}Sb	^{137}Cs	^{207}Bi	^{90}Sr	^{55}Fe
					pCi/g dry			
506	Bikini	W-P-1	42±1.2[1]	67±11	1220±8.0	ns[2]	462	173
507	"	W-P-2	9.3±.41	12±4.3	499±3.3	ns	256	36
504	"	W-P-3	43±2.0	88±43	1740±15	ns	830	149
505	Nam	W-P-1	1.4±.19	6.0±1.5	63±.18	ns	17.6	8.4
756	Aomen	ns	17±.45[3]	20±1.7	29±.74	.59±.27		144
755	Eneu	Camp Blandy	.39±.13	ns	6.0±.27	.25±.12		
757	Oroken	ns	17±.41	32±1.7	24±.69	.44±.25		132
758	Aerokoj	S-11	1.2±.14	ns	2.0±.77	ns		35
481	Aerokoj	S-6	.28±.11	ns	.69±.15	.21±.10	5.6	5.5
500	Eneman	"hot" area	186±6[4]	304±25	19±7	8.9±4.5	109	522
489	Eneman	Seaward Shore	9.0±.80[5]	29±3.5	4.1±1.0	2.5±.63	13	

(1) Two-Sigma, propagated, counting error for single samples.
(2) Value less than the counting error.
(3) ^{65}Zn 2.1±1.4
(4) " 65±24
(5) " 7.7±2.9

Table 2

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) Two-sigma, propagated, counting error for single samples.
(2) Value less than the counting error.

Table 3

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±.36	14
483	11-14	4.9±.35	3.5±1.2	9.7±2.7	1.2±.37	.77±.25	11

The error values are the two-sigma, propagated, counting errors
for single samples.

Table 4

Cesium-137, Antimony-125 and Cobalt-60 in Bikini Atoll Soils Collected June 1970
Bikini Island

Depth 0-1" Composite Samples	Values in pCi/g dry Bulldozed Area			Undisturbed Area		
Centerline to 1st Baseline South	^{137}Cs	^{125}Sb	^{60}Co	^{137}Cs	^{125}Sb	^{60}Co
Row 14	98±1.9	11±3	3.8±.4	206±1	14±2	8.5±.3
Row 30	131±2	10±3	5.7±.4	201±2	17±3	8.2±.4
Row 41	41±.8	5.9±1.3	2.0±.2	63±1	3.9±1.5	1.9±.2
Lagoon Road	27±1	0.96±.94	0.30±.13			
1st Baseline South to 2nd Baseline South						
Row 14	437±3	30±3	16±.5	311±5	39±8	18±1
Row 30	304±3	23±4	11±.6	454±4	40±6	24±1
Row 36	228±3	14±4	6.6±.4	470±9	48±1	15±1.4
Lagoon Road	35±.4	0.9±0.6	ns			
2nd Baseline South to Camp Area						
Row 49	210±1	8.5±1.4	5.7±.2	298±2	16±3.1	8.8±.36
Row 57	84±1.4	8.3±2.1	2.5±.27	114±2	9.2±2.2	2.7±.25
Row 61	76±1	8.5±2	1.8±.3	139±2	9.6±3.6	3.3±.4
Lagoon Road and Row 66	90±.54	.98±.74	1.0±.12	175±2	3.4±2.4	2.5±.24

The error values are the two-sigma, propagated, counting errors for single samples.

Table 4 (continued)

Depth 0-1" Composite Samples	Values in pCi/g dry — Bulldozed Area			Undisturbed Area		
Centerline to 1st Baseline North	^{137}Cs	^{125}Sb	^{60}Co	^{137}Cs	^{125}Sb	^{60}Co
Row 24	156±3	14±4	4.2±.5	299±3	24±4	12±.5
Row 30	181±1.2	15±2	7.8±2.9	123±2	22±3	16±.7
Row 38	86±1.2	5.4±2	1.4±.2	189±3	16±5	4.6±.5
Lagoon Road	39±.7	1.6±1	.6±.1			
1st Baseline North to 2nd Baseline North						
Row 24	229±4	26±6	7.8±.7	362±4	29±5	24±.9
Row 30	170±3	20±4	7.8±.6	323±5	35±8	17±1
Row 38	169±1	12±2	6.1±.3	209±2	23±4	15±.5
Lagoon Road	44±.3	1.8±.6	.9±.1			
2nd Baseline North to 3rd Baseline North						
Row 24 and Seaward Beach Road to intersection with Row 38	53±1.0	3.4±1.6	1.3±.21	130±2	12±4	3.4±.4
Row 38 to intersection with Seaward Beach Road	62±.4	2.8±.7	1.1±.1	121±2	8.7±3.1	3.1±.4
Seaward Beach Road - 3rd Baseline North to Lagoon Road	62±1.1	5.4±1.8	1.7±.22	118±1.7	17±2.9	8.3±.4
Lagoon Road	39±.7	3.3±1	1.2±.15	82±.5	1.4±.65	.72±.11
Air Sampling Stations						
#1	26±.43	.96±.71	.58±.10			
#2	21±.24	.70±.48	.22±.10			
#3	37±1.1	3.3±2.0	.95±.28			
#4	20±.44	1.3±.78	.29±.11			
#5	54±.8	3.4±1.2	1.9±.2			

Table 4 (continued)

Depth 0-1" Individual Cores 1st Baseline North to Centerline		Values in pCi/g dry Bulldozed Area ^{137}Cs	^{125}Sb	^{60}Co	Undisturbed Area ^{137}Cs	^{125}Sb	^{60}Co
Row 38	1	181±.84	6.8±1.1	3.0±.17	316±2.6	6.7±3.2	2.2±.24
	2	360±3.8	21±5	6.9±.49	558±8.8	35±12	7.8±1.0
	3	106±2.0	27±3.6	15±.64	30±.33	.77±.59	.21±.12
	4	30±.46	1.1±.7	.13±.09	103±1.8	4.2±2.4	.28±.21
	5	78±1.4	5.4±2.1	1.5±.25	58±1.1	2.6±1.6	.28±.18
	6	7.3±.20	ns	neg	317±1.5	8.1±1.8	4.8±.24
	7	75±1.3	3.7±1.9	.73±.21	80±3.2	ns	.56±.44
	8	21±.82	neg	ns	77±1.2	5.0±1.8	.84±.19
	9	37±.39	1.3±.62	.21±.12	425±6.7	37±9.4	17±1.2
	10	65±1.1	3.0±1.5	.62±.17	293±2.6	10±3.5	5.8±.35
	11	22±.54	2.1±1.0	.38±.14	149±1.6	4.7±2.1	2.2±.22
	12	57±1.0	3.8±1.4	.76±.16	77±1.1	3.8±1.4	.39±.14
	13	97±.57	1.6±.72	.53±.12	195±3.2	12±4.4	1.1±.36
	14	196±2.0	8.6±2.5	2.0±.23	108±.63	1.0±.78	.40±.12
	15	24±1.0	ns	ns	225±2.2	5.4±2.5	.34±.17

Table 4 (continued)

Undisturbed

Along Centerline	Row	^{137}Cs	^{125}Sb	^{60}Co
Even 2-40	2	54±.45	1.2±.61	ns
Soil #58	4	152±1.6	10±2.2	3.1±.25
	6	61±1.1	2.4±1.7	ns
	8	152±1.7	6.9±2.3	2.0±.22
	10	102±2.4	8.5±3.7	2.2±.43
	12	88±1.3	4.6±1.8	1.4±.21
	14	66±.49	1.9±.67	.58±.12
	16	25±.49	1.2±.82	.25±.11
	18	93±1.6	3.6±2.2	.72±.22
	20	76±.60	ns	.38±.13
Soil #59	22	143±.93	ns	.67±.16
	24	36±.68	2.1±1.2	.52±.15
	26	63±1.2	3.3±1.8	.45±.20
	28	111±1.3	4.4±1.7	1.7±.19
	30	134±.88	2.4±1.1	.82±.16
	32	87±1.5	5.1±2.3	1.4±.25
	34	168±.91	2.0±1.2	1.4±.16
	36	324±1.6	7.2±2.0	5.4±.26
	38	52±.72	1.4±.98	.29±.11
	40	25±.53	1.7±.92	.36±.12

Table 4 (continued)

Camp Area Soil #60	Disturbed		
	^{137}Cs	^{125}Sb	^{60}Co
1	5.2±.18	ns	neg
2	4.0±.26	neg	ns
3	18±.26	neg	neg
4	18±.28	neg	.18±.13
5	13±.31	ns	.14±.09
6	14±.27	ns	neg
7	5.1±.16	ns	neg
8	4.2±.36	ns	.18±.16
9	.94±.22	neg	.17±.16
10	8.8±.23	.58±.55	neg
11	5.0±.21	neg	.11±.09
12	15±.48	1.2±.96	.31±.15
13	20±.45	ns	.17±.11
14	3.5±.22	ns	ns
15	.7±.19	neg	neg
16	.23±.09	.50±.42	neg
17	.51±.11	neg	neg
18	1.1±.16	ns	neg
19	2.2±.17	neg	neg
20	6.2±.23	neg	ns

Table 5

Gamma-Emitting Radionuclides in Soil from Well Point 4, Bikini Island, Collected June 1970

Soil #57	Depth Cm	^{60}Co	^{125}Sb	^{137}Cs
1	0 - .5	32±1.7	66±9.2	243±4.9
2	.5- 1.0	30±1.5	60±8.6	274±4.6
3	1.0- 1.5	15±.74	23±4.1	302±4.1
4	1.5- 2.0	6.3±1.1	23±8.0	264±4.7
5	2.0- 2.5	7.8±.95	18±6.6	239±4.1
6	2.5- 3.0	2.2±.77	8.2±4.7	218±4.4
7	3.0- 3.5	1.6±.74	13±6.0	205±3.7
8	3.5- 4.0	ns	22±21	147±12
9	4.0- 4.5	ns	5.3±4.2	145±3.7
10	4.5- 5.0	1.7±.39	3.4±2.0	111±1.7

The error values are the two-sigma, propagated counting errors for single samples.

Table 6

Plutonium and Cesium-137 in the Surface One Inch of Bikini Atoll Soils and Bravo Crater Sediment

	N	$^{239,240}Pu$ (pCi/g dry)	^{238}Pu (pCi/g dry)	^{137}Cs (pCi/g dry)
Bikini Island				
1967				
Soil Pit 1		5.1±0.3	ns	360±6
Soil Pit 5		117±7.4	ns	1200±18
Soil Pit 6		36±2	ns	49±1
1969				
Well Point 1		130±8	ns	1220±8
Well Point 2		27±2	ns	499±3
Well Point 3		111±5	ns	1740±15
1970				
1st BL* N to Centerline				
Row 24 Undisturbed	13	74±9	ns	299±2
Disturbed**	13	27±3	ns	156±3
1st BL N to 2nd BL N				
Row 30 Undisturbed	20	65±8	ns	323±5
Disturbed	21	56±8	ns	170±3
1st BL S to 2nd BL S				
Row 36 Undisturbed	18	87±14	ns	470±9
Disturbed	18	28±4	ns	228±3
Camp Area to Lagoon Rd.				
Row 66 Undisturbed	14	16±2	ns	175±2
Disturbed	14	6.2±0.9	ns	90±1
Base Camp, Random Sample	16	3.9±0.5	ns	0.2 to 18
Eneu Island				
1969				
Camp Blandy		.71±0.1	ns	6.0±0.3
1970				
North Central				
Undisturbed	5	35±4	ns	156±2
Disturbed	4	3.0±0.4	ns	21±0.5

Table 6 (continued)

	N	pCi/g dry $^{239,240}Pu$	^{238}Pu	^{137}Cs
Eneman Island				
1969				
SW Corner, 0-1" depth		79±3	49±2	19±6
8-9" depth		9.3±0.4	4.1±0.2	3.4±0.5
Bravo Crater				
1969		60±2	4.0±1	

N Number of subsamples in composite sample
ns Not detectable
* BL = Baseline
** Bulldozed planting strip

NOTE: Multiplication of the above values by 3×10^4 will give an approximate value in units of pCi/m^2.

Table 7

Cesium-137 in Rat Tissues Collected at Bikini
June 1969 and June 1970

Location	Number of Rats in Pooled Sample	Tissue	pCi/g dry
1969			
Bikini I.	5	Muscle	466±7
Aerokoj I.	1	Muscle	2.4±0.6
Aerokoj I.	1	Remainder	1.6±0.4
1970			
Bikini I.			
Camp Area	9	Muscle	827±10
"	"	Lung	705±15
"	"	Liver	627±10
"	"	Bone	187±1.9
Centerline Road			
Sample 1	19	Muscle	340±5.3
" 2	"	"	513±5.9
" 1	"	Lung	525±9.8
" 2	"	"	405±3.5
" 1	"	Liver	402±1.9
" 2	"	"	417±4.2
" 1	"	Bone	334±5.4
" 2	"	"	221±2.9

Table 8

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

Average Values

			pCi/g dry			
			^{60}Co		^{137}Cs	
Island	Tissue	No. of Samples	Avg.	Range	Avg.	Range
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
Eneu	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

** Hepatopancreas

Table 9

Strontium-90 in Samples Collected
At Bikini Atoll, March, June, August, 1969

Average Values and Range

	N(1)	pCi/g dry Avg.	Range	pCi/g wet(2) Avg.
Coconut Crabs				
Muscle				
Eneu I.	13	2.0	(0.6-3.4)	0.05
Bikini I.	6	50.1	(16.4-99.0)	12
Oroken I.	5	8.9	(4.9-14.9)	2.1
Rukoji I.(3)	3	75.2	(36.6-144)	18
"Liver" (5)				
Eneu I.	13	9.6	(3.0-28)	5.1
Bikini I.	6	117	(38.3-204)	62
Oroken I.	5	21.3	(15.4-30.0)	11
Rukoji I.(3)	3	116	(57.2-164)	61
Skeleton				
Eneu I.	8	97.2	(72.6-113)	75
Bikini I.	6	1410	(912-2035)	1100
Oroken I.	5	346	(184-571)	270
Rukoji I.(3)	3	2330	(1200-3870)	1800
Troll Caught Fish				
Yellowfin Tuna				
Light muscle	3	<0.1	(<0.1-0.29) (4)	<.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

(1) Number of individuals.
(2) Converted from dry weight by using average wet:dry weight ratios.
(3) Collected May, 1967.
(4) 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.
(5) Hepatopancreas.

Table 10

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

Average Values

Island	Tissue	No. of Samples	^{40}K Avg. (pCi/g dry)	^{40}K Range	^{60}Co Avg.	^{60}Co Range
Eneu	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

* Hepatopancreas

Table 11

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
Eneu										
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 12

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

Average Values

Island / Common Name	N*	pCi/g dry: ^{60}Co Avg.	^{60}Co Range	^{137}Cs Avg.	^{137}Cs Range	^{207}Bi Avg.	^{207}Bi Range	pCi/g wet: ^{60}Co Avg.	^{137}Cs Avg.	^{207}Bi 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	
Eneu										
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 13

Gamma-Emitting Radionuclides in Goatfish Collected at Nam Island, Bikini Atoll, May 1970

Tissue	pCi/g dry ^{60}Co	^{137}Cs	^{207}Bi
Eviscerated whole	13±.28	.72±.23	1.8±.16
Viscera	146±.90	.93±.42	3.9±.49
Muscle	12±.29	.78±.26	7.2±.23
Liver	397±2.5	ns	13±1.3
Bone	5.3±.12	.45±.08	1.1±.09
Kidney	349±6.9	ns	18±2.9
GIT	214±1.2	.89±.53	15±.66
Ovary	179±1.4	ns	3.8±.72
Skin	26±.51	ns	3.1±.27
Remains	35±.73	ns	3.1±.37

Table 14

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

Average Values

			pCi/g dry					
		No. of	^{40}K		^{60}Co		^{137}Cs	
Common Name	Tissue	Samples*	Avg.	Range	Avg.	Range	Avg.	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 15

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 0

Table 16

Cobalt-60 in Tridacna and Hippopus (Giant Clams) Collected at Bikini Atoll, June 1969[1]

Average Values

			pCi/g dry	
Islet	Tissue	n	Avg.	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 17

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.
*** Tissues from 5 birds pooled.

Table 18

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
Eneu 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
Eneu I.	Goatfish	"	2	1250	828-1670
Nam I.	Mullet	"	3	237	122-348
"	Surgeon	"	3	297	239-404
"	Goatfish	"	2	526	366-686
Eneu I.	Grouper	Muscle	4	13	7.7-18
Nam I.	"	"	1	38	
Eneu I.	"	Liver	4	14,700	9,090-25,600
Eneu 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	
"	Yellowfin tuna	Liver	16	374	75-894
"	Ulua	"	3	23,400	8,190-40,900
"	Dogtooth tuna	"	1	1,528	
Bikini I.	Coconut crab	Muscle	3	5.2	2.4-9.4

Table 18 (continued)

Collection Site	Common Name	Tissue or Organ	No. of Samples	pCi/g dry Avg.	pCi/g dry Range
Eneu I.	Coconut crab	Muscle	9	3.3	1.1-7.2
Oroken I.	"	"	5	13	5.6-15
Bikini I.	"	"Liver"**	2	74	65-82
Eneu I.	"	"	5	28	15-44
Oroken I.	"	"	5	54	38-60
Enue I.	Spiny lobster	Muscle	3	1.4	.96-2.1
Nam I.	"	"	5	11	5.5-17
Eneu I.	"	"Liver"**	3	74	59-96
Nam I.	"	"	5	205	32-420
Eneu 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
Nam I.	"	"	3	182	133-287

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

** Hepatopancreas

Table 18 (continued)

Collection Site	Common Name	Tissue or Organ	No. of Samples	pCi/g dry Avg.	Range
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 birds pooled.
(3) Nine or ten eggs pooled per sample.

Table 19

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

pCi/g dry

Sample		Location	Type	Gamma Spectrum	(σ = 95%)	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 20

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.