PROVING GROUND

An Account of the Radiobiological Studies in the Pacific, 1946-1961

by

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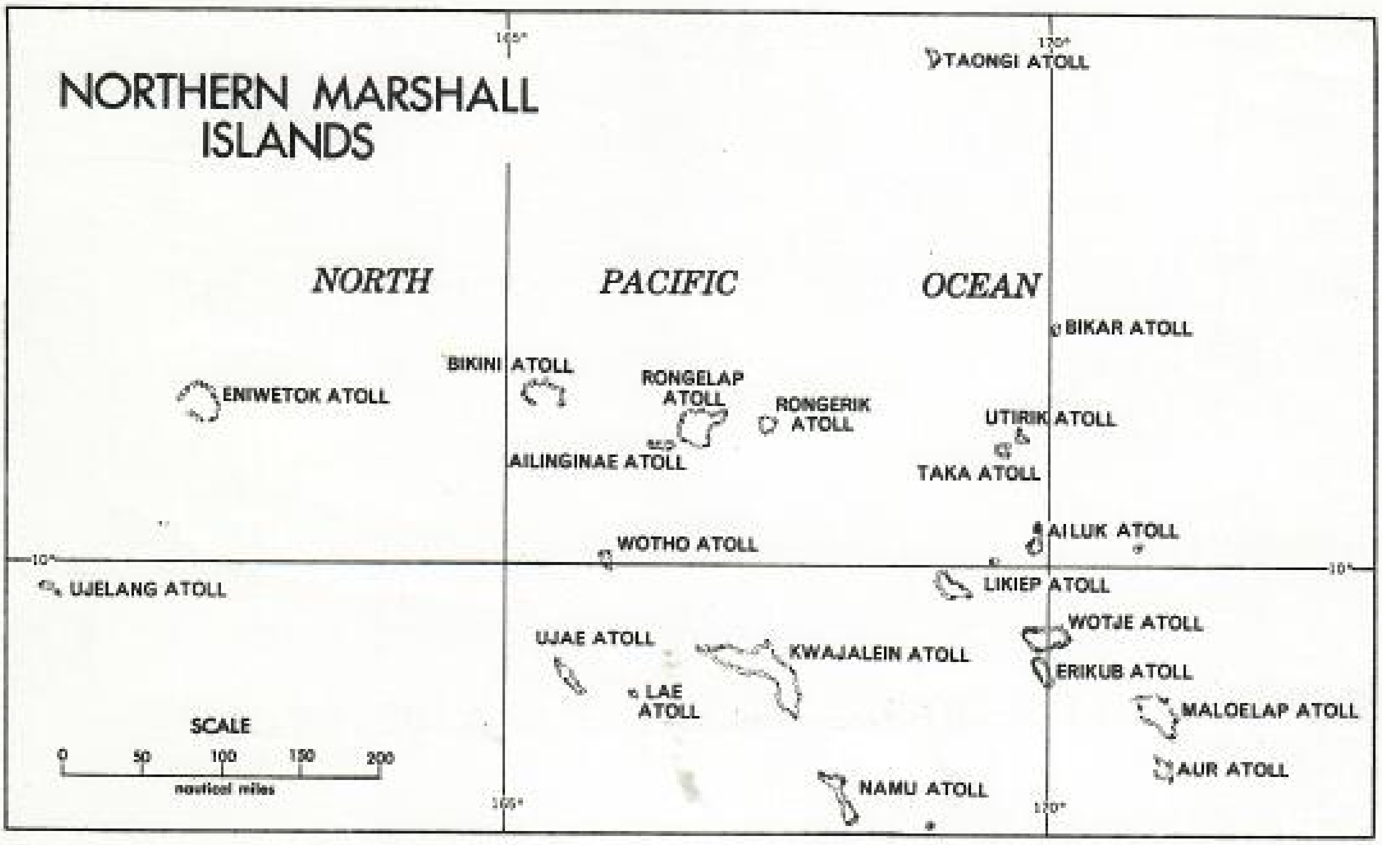
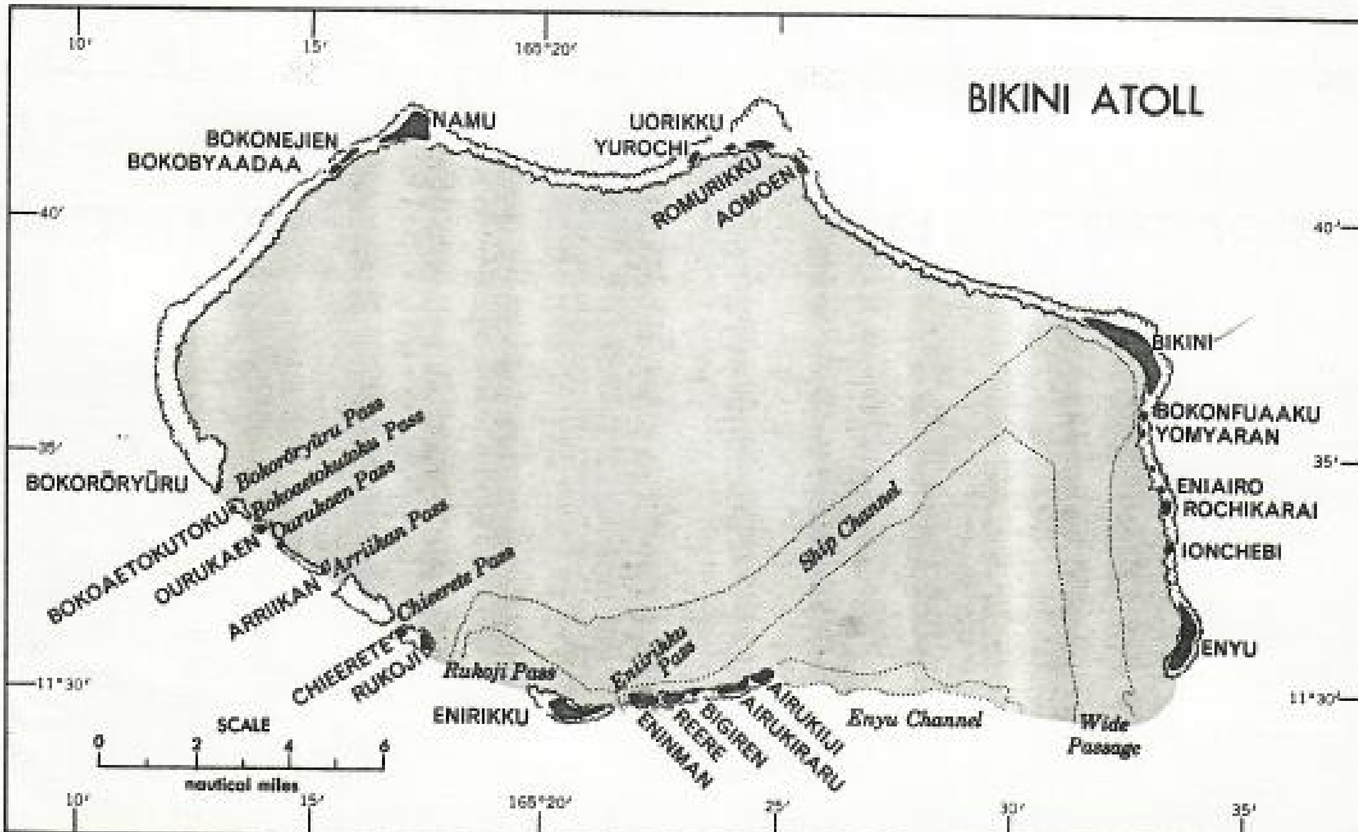

NORTHERN MARSHALL ISLANDS
NORTH
PACIFIC
OCEAN
165°
170°
10°
TAONGI ATOLL
BIKAR ATOLL
BIKINI ATOLL
ENIWETOK ATOLL
RONGELAP ATOLL
RONGERIK ATOLL
UTIRIK ATOLL
AILINGINAE ATOLL
TAKA ATOLL
AILUK ATOLL
WOTHO ATOLL
UJELANG ATOLL
LIKIEP ATOLL
WOTJE ATOLL
UJAE ATOLL
KWAJALEIN ATOLL
ERIKUB ATOLL
LAE ATOLL
MALOELAP ATOLL
SCALE
0 50 100 150 200
nautical miles
AUR ATOLL
NAMU ATOLL


BIKINI ATOLL
NAMU
BOKONEJIEN
BOKOBYAADAA
UORIKKU
YUROCHI
ROMURIKKU
AOMOEN
BIKINI
BOKONFUAAKU
YOMYARAN
ENIAIRO
ROCHIKARAI
IONCHEBI
ENYU
BOKORÖRYÜRU
Bokororyuru Pass
Bokoaetokutoku Pass
Ourukaen Pass
Arriikan Pass
Chieerete Pass
BOKOAETOKUTOKU
OURUKAEN
ARRIIKAN
CHIEERETE
RUKOJI
Rukoji Pass
Enirikku Pass
Ship Channel
ENIRIKKU
ENINMAN
REERE
BIGIREN
AIRUKIJI
AIRUKIRARU
Enyu Channel
Wide Passage
SCALE
0 2 4 6
nautical miles
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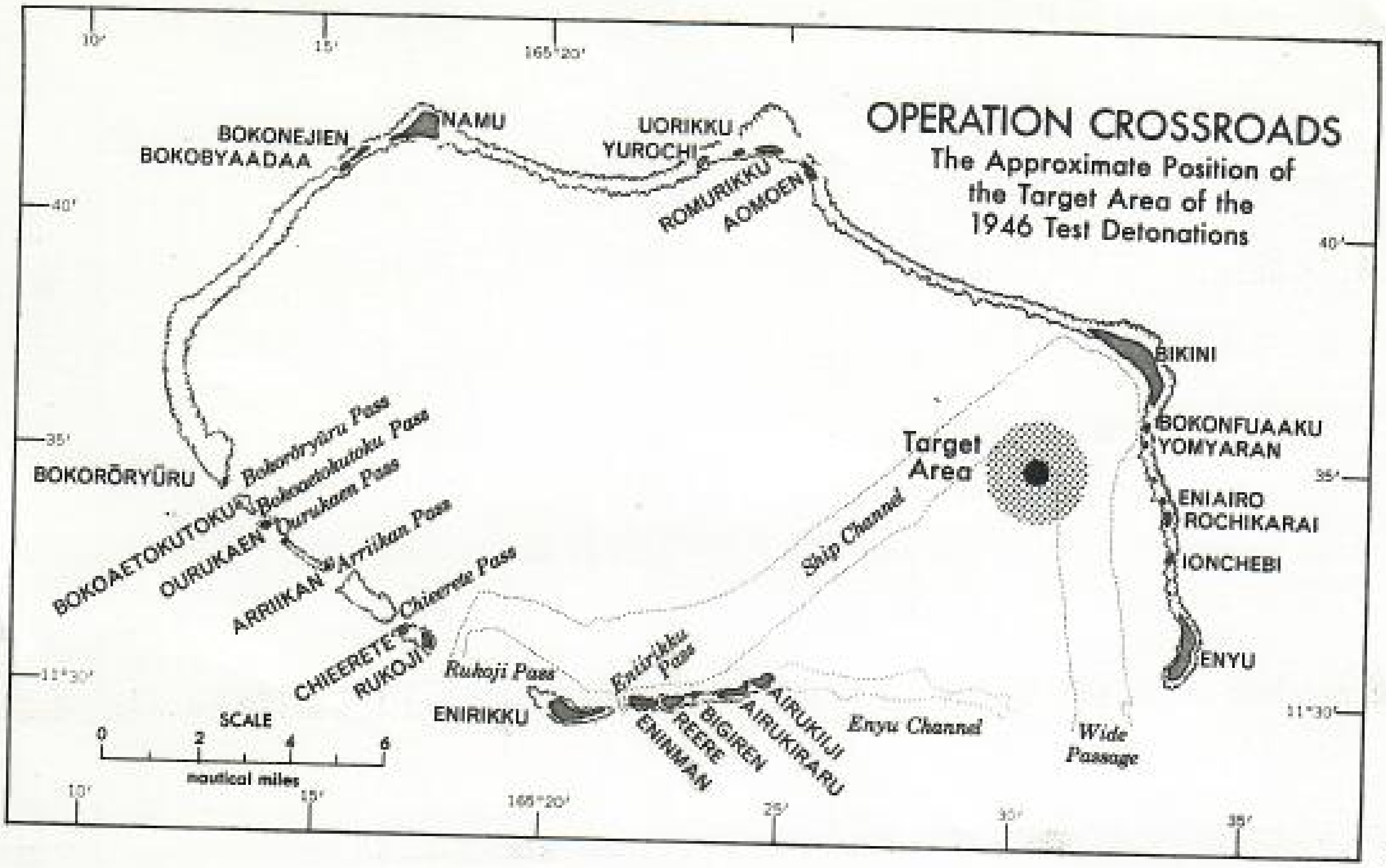
35′
40′
11°30′


OPERATION CROSSROADS
The Approximate Position of the Target Area of the 1946 Test Detonations
NAMU
BOKONEJIEN
BOKOBYAADAA
UORIKKU
YUROCHI
ROMURIKKU
AOMOEN
BIKINI
BOKONFUAAKU
YOMYARAN
ENIAIRO
ROCHIKARAI
IONCHEBI
ENYU
Target Area
Ship Channel
Enyu Channel
Wide Passage
BOKORŌRYŪRU
Bokorōryūru Pass
Bokoaetokutoku Pass
Ourukaen Pass
Arriikan Pass
Chieerete Pass
BOKOAETOKUTOKU
OURUKAEN
ARRIIKAN
CHIEERETE
RUKOJI
Rukoji Pass
Enirikku Pass
ENIRIKKU
ENINMAN
REERE
BIGIREN
AIRUKIJI
AIRUKIRARU
SCALE
0
2
4
6
nautical miles
10′
15′
165°20′
25′
30′
35′
40′
35′
11°30′

and *Pensacola,* and destroyers such as the *Hughes* were hit hard. Other ships, including the *Nevada,* the target vessel, escaped with only moderate damage. Surviving ships showing signs of irradiation were washed down in the course of fire-fighting and salvage operations, which began as soon as radiological patrols had scouted the target area. By 2:30 P.M. on July 2 Admiral Blandy had declared the lagoon safe for re-entry by all ships, and by the evening of Able Day eighteen of the target ships had been reboarded by special teams assigned to recover scientific instruments and to bring off test animals that had been placed throughout the target fleet.

The second device was exploded in Test Baker at 8:35 A.M., July 25 (Bikini time). The intervening days had been devoted to assessment of damage sustained by target vessels, to salvaging and re-equipping ships not too badly damaged for use with the underwater test, and to making preliminary examinations of test animals. Test Able had been observed by 114 representatives of press, radio, news picture services, and magazines. Before Test Baker, thirty-nine of these, and eight members of the Congressional delegation, returned to the United States. The preparations for Test Baker included rearrangement of the target ships about the small landing craft, the LSM 60, beneath which, at a depth of ninety feet—approximately half the distance to the lagoon bottom—the atomic device would be suspended.[14] Elaborate arrangements were made for measuring water pressure and wave height. A final rehearsal was held on July 19. Although a weather front threatened on July 24 to disrupt the projected detonation schedule, the chance seemed good that the front would move away and Admiral Blandy decided early on the morning of that day to order the test program to proceed. Most of the support ships evacuated the lagoon on the evening before Baker Day, standing off Bikini at a distance of a dozen or so miles. The last vessels moved out through Enyu Passage shortly after 6 A.M. on July 25. In the center of the target array was the LSM 60 bearing a tall antenna designed to receive the line-of-sight electronic signal that would detonate the device beneath her hull.

Test Baker was the first occasion in which an atomic device was exploded in such a way that fission products were mixed with water and thus returned in great measure to the area of detonation.

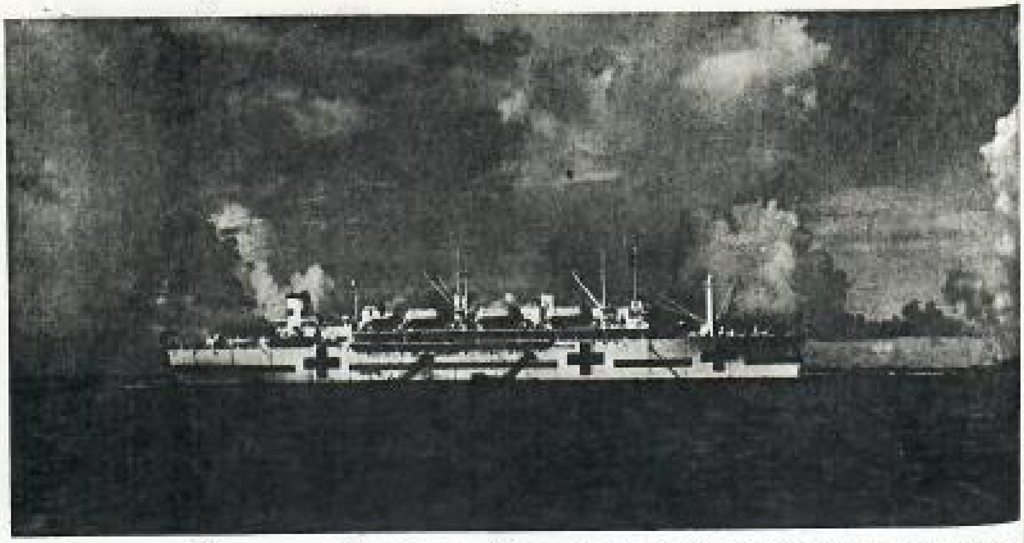
SHOCK TO TURTLES – FISH

The air burst of July 1, despite the damage it had inflicted, scarcely had prepared observers for the wrath of sound, light, and volcanic shock that erupted within the lagoon. At the moment of explosion a giant bubble, brilliantly lighted within by incandescent materials, burst from the surface of the water to be followed by an "opaque cloud" which quickly covered about half of the ships of the target fleet. Within seconds the cloud had vanished and a hollow column 2,200 feet in diameter and containing some 10 million tons of water rose from the surface of the lagoon to a height of more than a mile. The 26,000-ton battleship *Arkansas,* broadside to the LSM 60 but more than 500 feet away, was lifted and upended in the column before she was plunged to the bottom. At the base of the column was a tumult of foam several hundred feet high, and the descent of the water back into the lagoon set up a base surge from which rolled waves eighty to one-hundred feet high. The waves subsided rapidly as they proceeded outward, and the highest wave recorded at Bikini Island, three miles away, was seven feet, not sufficiently high to pass over the island or to cause damage there. The victims of the explosion, beyond the *Arkansas,* included the carrier *Saratoga,* which sank after seven and one-half hours; a landing ship, a landing craft, and an oiler; submerged submarines, including the *Apogon;* and the already-damaged battleship *Nagato,* which went down five days later. The destroyer *Hughes* and the transport *Fallon,* seriously crippled and listing, were beached.

Radioactivity in the waters of the lagoon was intense. The volume immediately after the burst was estimated in the round, by the Evaluation Board, to be the equivalent of "many hundred tons of radium." The target ships were drenched by radioactive substances as the tremendous pillar of water crashed back into the lagoon. As the weight of the column subsided, the target area became a maelstrom of radioactive debris, and at the bottom of the lagoon was a shallow basin half a mile wide from which the force of the explosion had scooped hundreds of thousands of tons of sludge and coral-algal sediment. The upper levels of the lagoon waters remained highly radioactive for days and large areas were impenetrable by the small craft engaged in attempting to outline the swirling areas of contamination. After four days it still was not safe for inspection parties to spend any useful time at the target area or to board surviving ships floating there. Within the waters, and particularly in the tons of sludge again settling to the lagoon floor, were radioactive contaminants whose disposition would present problems of greater complexity than anyone at that point in time might have guessed.

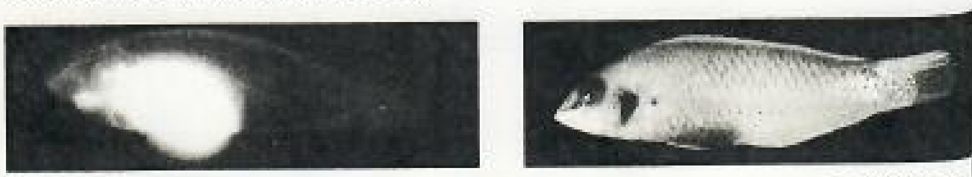
Before the Baker test, all discussions of probable effect were theoretical. Questions relating to underwater shots apparently had been debated at length while the Operation Crossroads plan was in the process of development. The debate, however, had turned principally on questions of physical effect and on the creation of a test that would yield new information on force and pressure. One view seems to have been that a detonation only slightly beneath the surface of the water would be particularly ineffective because, as was stated in a subsequent report, "neither the air pressure wave nor the water pressure wave would be maximized, and it is possible that a curtain of spray might be thrown up which would actually screen off a large part of the pressure wave in air and nearly all the thermal radiation, gamma radiation, and neutron radiation."[16] In an approximate sense, this is what actually happened at Test Baker, in which the atomic device was exploded at a medium depth in the lagoon, but in the Baker case a major percentage of the long-lived fission materials also was mixed with water and suspended minerals and was captured and retained by the lagoon. The pre-Crossroads expectation may have been substantially correct, for the water erupting into the stupendous column did screen and dampen the effect of radioactivity at the instant of the detonation, but the possible long-term result either was utterly unforeseen or placed in such conjectural terms that its relevance, even to strategic considerations, was not understood.

For a week after Test Baker the radiological teams patrolled Bikini lagoon. The work of the biologists, however, soon turned from monitoring to sampling and analysis. Among the teams on the *Haven* were representatives of other laboratories who were beginning to share a curiosity about the disposition of radioactivity in a biotic system. Warren, still interested in the problems that had produced the program at Hanford, was eager to see the problems pursued at Bikini. Accordingly, there was formed informally within the Radiological Safety Section a "Division of Radiobiology."



U.S.S. *Haven*, headquarters ship of the Radiological Safety Section, in Bikini lagoon, 1946 *(Joint Task Force One)*

Members of Radiobiology Division aboard *Haven*, 1946: from left, Bradner, Welander, Pautzke, White, Donaldson *(Joint Task Force One)*



Autoradiograph of wrasse (75 mm) collected August 8, 1946, near Aomoen and Bikini Island *(Laboratory of Radiation Biology)*

The Division was setting itself to investigate the presence of radioactivity in an aquatic biological web of extreme complexity.* At the base of the ocean food chains are the plankton—phytoplankton and zooplankton, vegetable and animal—and the algae. Most of the marine plants are in the phylum Thallophyta, composed of primitive plants having no true root, stem, or leaf, and which includes the algae and fungi. The simplest forms of the invertebrates begin with the Protozoa, single-celled organisms which include the Dinoflagellata, a borderline group having characteristics of both animals and plants, and the Foraminifera, which are planktonic in life and whose rudimentary skeletal structures ultimately sink to the bottom of the ocean where their fossil remains are found in geological strata. There are more than 1,200 species of Foraminifera, and 18,000 living and extinct species have been catalogued. In the waters are thousands of groups and species of invertebrate organisms, multicellular animals such as the sponges, of which there are some 2,500 species; the Arthropoda, including the copepods, which comprise about 70 per cent of the zooplankton; the gastropods, which are shelled creatures, using a foot for creeping; and the cephalopods, which include the octopi. The vertebrates include the primitive fishes, the sharks, and the rays; the true fishes, predominantly carnivorous; the reptiles, including the sea turtles; and the Cetacea, among whose members are the whales and dolphins.

In the mid-Pacific, as in the vicinity of Bikini, the identifiable species of fish total more than 600 and in the open ocean the number has been estimated at more than 1,000. Most species are carnivorous, but some, like the goatfish, the mullet, and the surgeonfish, are herbivorous, feeding on marine vegetation and plankton, and a few, the parrot fish, the triggerfish, and the puffer, are omnivores. The food chains may be short and relatively simple. The surgeonfish, for example, is an herbivore feeding on algae, but he in turn is preyed upon by sharks and grouper, the larger, far-ranging carnivores. The simple protozoa are fed upon by gastropods, which become the prey of small carnivores such as the cardinal fish. The carnivorous goatfish feeds only on organisms found in the shallower areas of the ocean, and this also is the habit of the wrasse. But the food chains may not only be infinitely more com-

*Names of pertinent scientific species are listed in Appendix II.

plicated but further confused by the seasonal character of the feeding habits of some of the species. Along each of the strands of this ecological web are species of plants and animals important to man, species of plants that live in the ocean-conditioned soils of the islands and of molluscs, crustacea, and fish—sharks, tuna, barracuda, herring, tarpons, jacks, mackerel, pike, and snappers—that are elements in the diet of people who live on the Pacific or on the lands about its rim.

In such an environment, Bikini's lagoonal contamination, after the first days, was comprehensible only in relation to the biological uptake of fission products. In waters containing such a variety of biological forms, only ingested radioactivity—activity within the organs and tissues of living creatures or assimilated by aquatic plants—could provide clues to the condition of the atoll. Fish or other creatures killed by blast, heat, or massive doses of external radioactivity were not to be found in large numbers because they had been lost in the waters or consumed by the rapacious life of the lagoon. It was with the question of biological uptake that the Division of Radiobiology became concerned. The investigations were crude and, by later standards, wholly inadequate. It was not without significance, however, that the group achieved so early a measure of identity. Nowhere in the tables of organization of Joint Task Force One was there a specific radiobiological section. The Division of Radiobiology of the Radiological Safety Section was, in fact, a commissioned-in-the-field group composed of members of the Applied Fisheries staff and others who, under Warren's direction, organized themselves to pursue biological evidence of Test Baker radiation phenomena.

Early in August, Welander reported:

> On and after Baker Day, 25 July 1946, the Radiobiological Survey party under the leadership of Dr. L. R. Donaldson has taken biological specimens consisting of fish, clams, sea cucumbers, coral, and algae from various parts of the lagoon and the surrounding area for the purpose of determining the amounts of radioactive substances in these animals and plants. Tissues or parts of the above specimens were analyzed in the Tablet Counting Laboratory on board the U.S.S. *Haven* under the direction of Dr. W. Langham and Mr. J. Martens.
>
> In no case were any of the biological specimens taken within the lagoon entirely free of radioactive contamination. In general, the algae proved to have the highest activity and in consequence fish and other animals

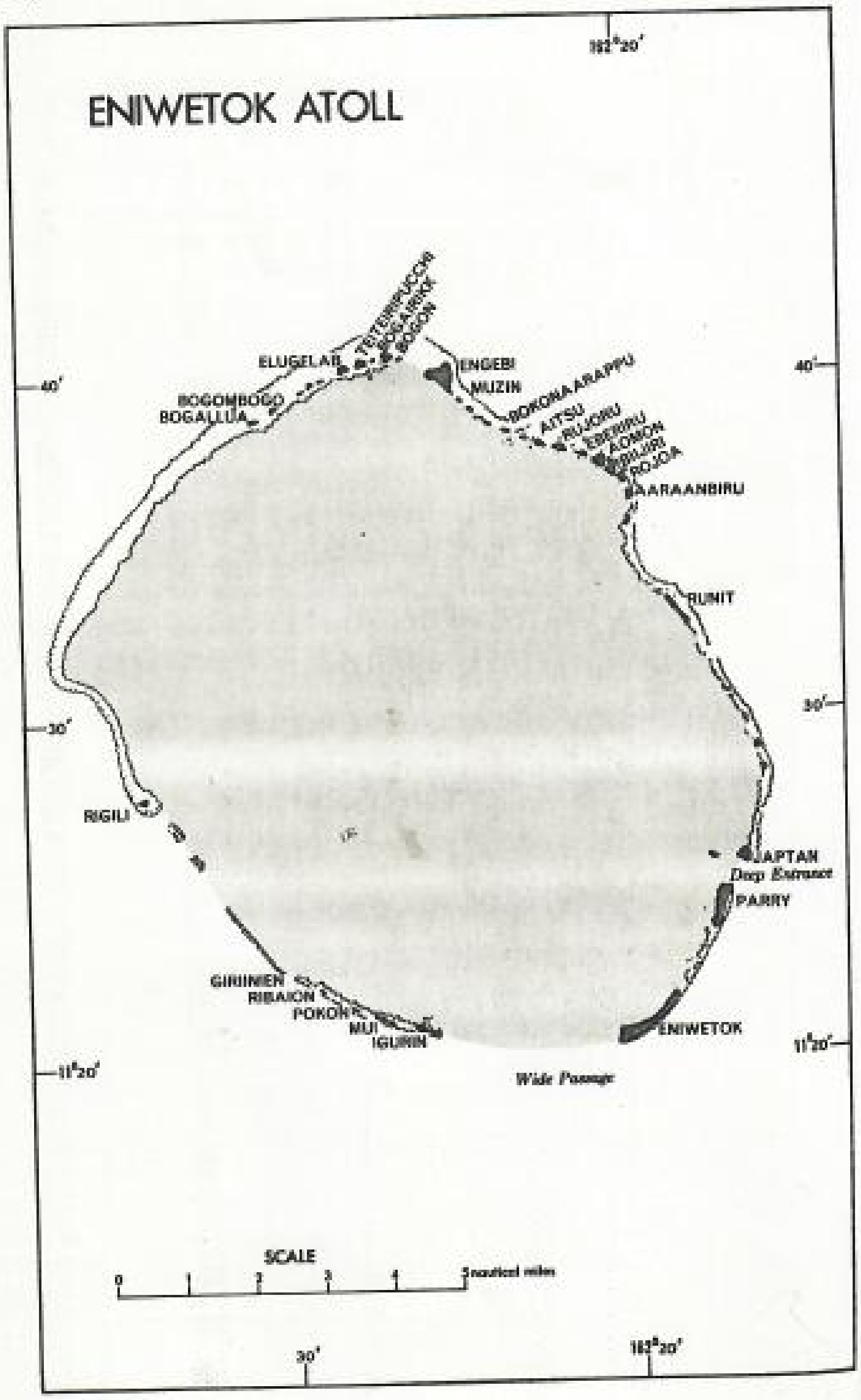
feeding on the algae also show high activity. Such analyses included beta and gamma measurements which presuppose the presence of alphas. However, the current low beta and gamma counts do not indicate any reduction in alpha activity.

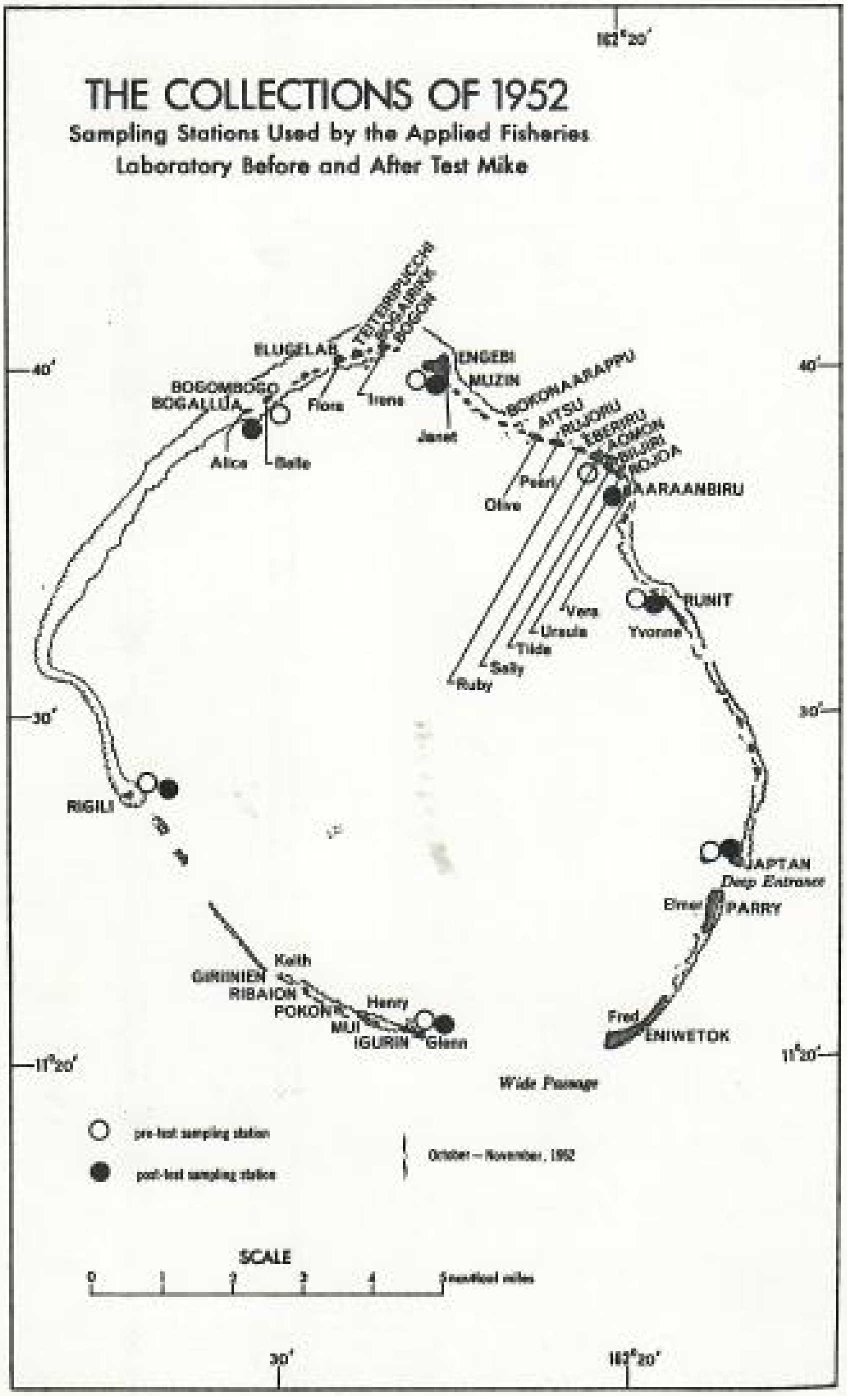
Because of the highly poisonous nature of the fission products, and the increasing difficulty of detecting alpha emitters in the tissues of these marine animals, it is recommended that no fish, mollusk, or other marine animal taken within 100 miles of Bikini lagoon be used as food.[16]

X

Plotting boards were used on the *Mount McKinley*, the task force flagship, to maintain records of the outlines of radioactivity developing within the lagoon. The biological dispositions of radioactivity could not be so outlined, but they had a bearing, nevertheless, on considerations of interest to the Navy. Support vessels returning to the lagoon after the underwater test had reported almost immediately the presence of radioactive contamination in water systems, in marine growths attached to the ships' hulls, and even in shipboard areas presumably inaccessible to contamination. The levels of radioactivity in the lagoon were found to be rising at night and falling in daylight hours, a circumstance later realized as attributable to the vertical movement of lagoonal plankton in response to light. Hulls of the vessels showed so much evidence of contamination that orders were issued two days after Baker for all personnel to move back from them, to sleep and work away from possibly contaminated bulkheads. Scrubdowns and changes of clothing had been ordered in the posttest period for persons returning from off-ship duty, yet contamination was found on handrails, in the galleys, and in the shipboard laboratories where scientists worked with instruments and samples. The necessity for frequent changes of clothes and boots exhausted Navy supplies. The monitor boats became contaminated as they worked long hours at surveys conducted among the units of a Bikini fleet that included the empty, battered, untouchable survivors of atomic explosion. The task force attitude was one of alert interest in every facet of the problem on which the scientific staffs could possibly shed any light, yet the biological base of many of the contamination problems was not yet fully realized.

Between June 14, when the Applied Fisheries group arrived at the atoll, and June 29, two days before Test Able, members had collected a total of 1,926 fish to be used as controls and in subsequent studies of the normal Bikini fish population. From July 2 1946


ENIWETOK ATOLL
162°20′
40′
30′
11°20′
ELUGELAB
BOGOMBOGO
BOGALLUA
ENGEBI
MUZIN
BOKONAARAPPU
AITSU
RUJORU
EBERIRU
AOMON
BIJIRI
ROJOA
AARAANBIRU
RUNIT
JAPTAN
Deep Entrance
PARRY
ENIWETOK
Wide Passage
RIGILI
GIRIINIEN
RIBAION
POKON
MUI
IGURIN
SCALE
0
1
2
3
4
5 nautical miles


THE COLLECTIONS OF 1952
Sampling Stations Used by the Applied Fisheries Laboratory Before and After Test Mike
162°20′
40′
30′
11°20′
ELUGELAB
BOGOMBOGO
BOGALLUA
Flora
Irene
ENGEBI
MUZIN
Janet
Alice
Belle
BOKONAARAPPU
AITSU
RUJORU
ENIWETOK
Pearl
Olive
AARAANBIRU
RUNIT
Vera
Ursula
Tilde
Sally
Ruby
Yvonne
RIGILI
JAPTAN
Deep Entrance
Elmer
PARRY
Keith
GIRIINIEN
RIBAION
POKON
MUI
IGURIN
Henry
Glenn
Fred
Wide Passage
pre-test sampling station
post-test sampling station
October — November, 1952
SCALE
0
1
2
3
4
5 nautical miles
30′
162°20′

Eberiru, Aomon, Biijiri, and Rojoa Islands on Eniwetok's northeast reef, 1959 *(Holmes & Narver, Inc.)*

The "Henry-Keith Complex"—Mui, Pokon, Ribaion, and Giriinien Islands—southwest rim, Eniwetok, 1959 *(Holmes & Narver, Inc.)*

day the survey group, accompanied by four members of the task force staff and a RadSafe radiation monitor, took a landing craft to Aaraanbiru Island, five miles north of Runit but two miles below the Aomon-Biijiri station. Before the collecting was started, Lowman and others made a short trip to Rojoa Island, midway between Aoman and Aaraanbiru, to set rattraps and to bring in several short birds for dissection. Radioactivity at Rojoa was at 300 milliroentgens per hour and the visit was no longer than necessary.[8]

After the collections at Aaraanbiru, only one day remained. On that day, November 8, the survey team, proceeding north from Parry in the LCM, would do whatever could be done in the way of getting specimens at the remaining stations in the northerly atoll areas and near the Mike site. The first stop was at Rojoa to pick up the rattraps left there the previous day, but the traps were, disappointingly, entirely empty. At Engebi the group went ashore on an island where the sense of desolation was deepened by the presence of the reinforced concrete building, ruptured and shaken but still standing, on the island flat that had been swept by the blast and by the succeeding surge of water. The body of a bird was seen, but no living animals and only the stumps of vegetation. Held took away a bucket of beach sand for use in later experiments, and some collections of burned vegetation were made, but on the inland areas the survey meters indicated radiation was at 2 to 2.5 roentgens per hour, and the team soon moved off the land into the shallow lagoon waters to spread rotenone for the fish sampling. Among the specimens collected were fish which seemed to have been burned. On each of these fish the skin was missing from one side as if, as field notes said at the time, the animal "had been dropped in a hot pan."[9]

The work at Engebi finished, the party took the LCM westward through the turbid waters of the shot islands and past the Mike crater, which had the appearance of a new deep channel into the lagoon and the depth of which, after the churning of the sludge had subsided, had been estimated at fifteen fathoms. When the LCM, turning southwest, stood off the beach of Bogombogo and Bogallua, three miles from the Mike site, the effect of the energy that had been released a week before was startingly evident. On the survey team's visit to Bogombogo on October 25 the island had been heavily laden by stands of coconut palms and thickly populated by birds. Then it had seemed ideal as a downwind station for sampling after Test Mike, and the group had expected to return there in due time, to make posttest collections. But when members of the team saw Bogombogo again on November 8 the extent of their miscalculation was terribly clear. The island had been stripped of vegetation by the force and heat of the blast. Palm trees had been burned down to the roots. All animal life, so far as members of the team could tell, had been snuffed out. The same was true of Bogallua. The radiobiologists made a collection of fish in the coral shallows on the lagoon side of Bogallua and then, loading their gear aboard the LCM, moved back down the lagoon to the *Oakhill*, which was scheduled to participate the following day in test runs for the King shot evacuation. On Monday, November 10, while members of the group were packing their equipment and specimens for shipment, Lowman and Welander returned to Rojoa to pick up the rattraps left there several days earlier. This time the traps held six specimens.

III

At Runit, at Aomon-Biijiri, at Engebi, at Bogombogo-Bogallua, even at Rigili, it had been apparent that the radiation problem presented by the Mike shot was of an entirely new order of magnitude. This was not to say that it was different radiobiologically. But, as in other years, the radiobiologists had no clues to the total potential contamination to be expected or to the kinds of radioactive materials they might encounter.[8] Their task, even in the face of the new condition created by nuclear fusion, was circumscribed and immediate and consisted only of attempting to discover, after the biotic samples had been returned to the Laboratory, what kinds of radioactivity and in what amounts had been placed by the Mike shot at the threshhold of Eniwetok's biological system. When the counting began, the levels of radioactivity now would be expressed in thousands—frequently in millions—of disintegrations per minute. And, while the higher counts obviously resulted from the fact that collections were made so soon after the theromonuclear blast, it also would become obvious that large amounts of nuclides were involved and that the process of biological absorption already had begun.

The winds of November 1, blowing from the east-northeast, had carried the fallout, as had been anticipated, across the west side of the atoll, and it was there, on the eighteen miles of reef extending from the test site to Rigili that the heaviest contamination probably would be found. This, as it turned out, was true, although not altogether as precisely as the assumption would suggest, for in addition to the very much greater range of effect of the hydrogen bomb there seemed to be other factors, unexplainable but perhaps related to processes of biological uptake, which had altered the local distribution picture even in the week after detonation.

The specimens and samples collected at Eniwetok were frozen and returned by air to Seattle, the pretest batch by Bonham, who flew back to the Laboratory before Mike was detonated. When all the samples had been returned, the counting and analysis proceeded on an around-the-clock schedule—24 hours a day, seven days a week—from November 24 to December 12, 1952. All members of the staff participated in the process. All of the specimens and samples collected after Test Mike were handled in this period, and most of the samples from the pretest collections were counted (because radioactive materials present before Test Mike consisted altogether of long-lived isotopes remaining from the Sandstone and Greenhouse tests) after December 12 but before the end of the month. Because the samples had been gathered in a period of relatively rapid decay of radioactivity, corrections necessarily had to be made for this factor, and the date to which corrections were made was set arbitrarily as December 1, a month after the Mike shot and near the midpoint of the over-all counting period for the Mike samples. The curve from which correction factors were determined was the curve of radiation decay for a sample of sand dredged at a depth of thirty feet from the lagoon near Rojoa and Aaraanbiru on November 7. In general terms, the problem was to determine the degree of long-lived contamination existing in Eniwetok Atoll before Test Mike —the slight but measurable contamination still inhabiting the biological system as a result of earlier tests—and then to measure, for the purpose of assessing probable future biological hazard, the level of contamination present at any manageable point in time, in this case December 1, a month after the thermonuclear shot.

At the base of the contamination puzzle was the water of Eniwetok lagoon. The sampling of water which had been started before Test Mike was resumed on the afternoon of November 3, two days after the Mike shot and immediately after the *Oakhill* returned to her anchorage. The November-December analysis of water showed that samples taken after Test Mike contained radioactivity "several hundred times" greater than the pretest samples, the values rising as the distance from the test site decreased. The counts were not high—the highest 350 disintegrations per minute per milliliter for a sample at Bogombogo—but the pattern was clearly discernible.* For reasons which were not known, the level of radiation even in a pretest water sample was highest off Bogombogo, where the sample depth was forty-five feet.

Radioactivity counted in plankton, algae, and the invertebrates produced a number of interesting questions.

The plankton hauls were made with conical nets a half meter in diameter at the mouth and two meters long. These were towed behind the LCM (usually for a distance of one and one-half miles in an hour) at a predetermined depth in the selected sampling areas. Catches of plankton were small whether the net was fine (173 meshes per inch) or coarse (74 meshes per inch), but the survey team made examinations of the character of the catches—which usually were composed of Foraminifera, snails, copepods, worms, and eggs—to discover if the types of organisms in the nets were determining the variations in counts between hauls and between stations. Frequently there were differences in the catches, but regardless of these there seemed to be a specific relationship between the kinds of organisms present and the amounts of radiation found in the sample. The team made "paired hauls," in which nets of fine and course meshes were towed about the same lagoonal area at the same time. While the composition of the catches thus tended to be similar, the radioactivity often varied in amount. In a posttest paired haul at Bogallua the radioactivity of the sample from the finer net exceeded by seven times—1,160,000 distintegrations per minute per gram compared to 155,000—the

*A rainwater sample was collected 33 hours after Test Mike off Eniwetok Island. The 450-cc sample was evaporated and counted on November 4, 87 hours after the shot, using a Victoreen survey meter with a 1-inch end window tube (window thickness 1.8 mg/cm²). The maximum count was 10,000 per minute.

value of the plankton from the coarser net. Until microscopic examination disclosed no essential differences in the plankton in the two nets, it was presumed that tiny organisms escaping the larger mesh were being caught in the smaller. It was concluded, however, that the finer mesh was capturing inanimate radioactive particles suspended in the lagoonal waters. All of the pre-Mike plankton tows had resulted in hauls containing low but measurable amounts of residual radioactivity still inhabiting the planktonic life zone as a result of Operations Sandstone and Greenhouse, but the post-Mike plankton samples were more radioactive by 200 to 300 times. The postshot samples from the various stations disclosed a pattern of distribution that recalled the unexpected transport of radioactivity about Bikini lagoon, for the fine-mesh sample from Igurin, at the southern tip of the atoll and farthest from the test site, showed a higher count (140,000 dmg) than those at Rigili (71,000 dmg), Aaraanbiru (100,000 dmg), and Runit (48,000 dmg), each of which was much nearer the point of detonation.

Among the algae there proved to be a uniformity of posttest results that was in itself intriguing. The collection included five species of blue-green, fourteen species of green, three species of brown, and seven species of red algae. Before Test Mike, specimens most radioactive were those gathered on or near the islands on which atomic tests already had been held, and the levels of activity were not altogether inconsequential. One specimen found in a stagnant pool on Eberiru Island proved to contain activity counting 54,000 disintegrations per minute per gram (wet weight), and counts in three others from the Runit tide flats averaged 31,000.[10] But in the post-Mike sampling the results seemed to show only that algae samples taken from islands nearer the test site, Aomon, Engebi, Bogallua—those lying, that is, within a radius of nine miles of the shot island—reflected much higher counts but no significant differences in contamination by area or by species. Algae from the more distant and protected areas, such as Japtan (away from the direction of fallout) showed only trace amounts of radioactivity, but the counts of all specimens from Bogallua averaged 5,200,000 per minute (the highest was 14,000,000) while at Engebi the average was 4,000,000, and at Aomon 3,600,000.[11] Of the seven species common to the stations, none showed activity consistently higher than others. The radioactivity of the coralline algae—for example, *Jania*—which contains large amounts of calcareous matter, was not different in the degree of contamination from the succulent forms, such as *Caulerpa,* from the same station. The counts, of course, were gross counts of beta radioactivity, and it developed, both in radiochemical analyses and in examination of autoradiographs, that much of the contamination at that early period following the blast was the result of surface contamination of the "speck" variety—most of it composed of highly insoluble fission products such as cerium, ruthenium, zirconium, and the trivalent rare earths. But, as autoradiographs showed, washing and scrubbing the specimens failed to reduce materially the radioactivity present. A proportion of the contamination was from fission products, not products of the fusion process. The amounts, even when the counts reached levels of millions, were not observably injurious to the vegetable forms (all living algae seemed on inspection to be in normal health and color), but the fission product contamination nevertheless was at a very much higher level than had been noted at Bikini or following the subsequent atomic shots at Eniwetok. The average post-Mike contamination was higher in the algae than in any other group.

The story of the invertebrates did not differ from that of the algae in the distribution of contamination by stations, yet there were vast differences, as it proved, in contamination by species and by the organs and tissues of the specimens. By station, the specific activity of individual samples varied from background levels at Japtan to 15,000,000 disintegrations per minute per gram for the sand from the gut of a sea cucumber picked up at Engebi. One piece of coral (genus *Acropora)* collected at Bogallua on November 8 was discovered, after initial examination by autoradiograph, to contain specific activity of approximately 100,000,000 counts per minute per gram. A peculiarity of this piece of coral was that attached to it were three highly radioactive nodules which seemed of foreign origin. The nodules did not appear to be part of the coral but were so well attached that when one of them was removed for counting it could not be separated from the coral without being broken. The unashed hollow sphere weighed 1 milligram and yielded 100,000 disintegrations per minute. It was considered possible that these bodies were cysts produced by the coral itself to wall off irritating radioactive particles, or that they were rapidly growing neoplastic growths which had concentrated a great amount of radioactivity since the time of the blast.[12]

With such evidence of the ingestion of radioactive materials by organisms at the lower end of the food chains, the question remained of the uptake of radioactivity by the larger animal and vegetable forms—by fish, by birds, by rats, by the vegetation on the islands.

The collections of fish at the seven stations ranged in number from 26 to more than 300 depending on the success of the poisoning and the varieties of species present. Species selected for radioanalysis were those most common to all stations and representative of marine feeding habits and, although most of the fish were the sedentary reef dwellers, a few types which live on the open, sandy lagoon bottom—goatfish, jacks, and flatfish—also were saved for ashing and counting. A total of 237 specimens representing 58 species, 33 genera, and 22 families finally were counted for radioactivity on 768 plates.[13]

In the gross counts of whole-fish radioactivity by station, the higher level of activity was discernible at once. A surgeonfish captured at Engebi before Test Mike had a total count of 30 per minute per gram of wet weight; the surgeon specimen taken from the same area after the Mike shot had a count of 110,000. The preshot blenny from Engebi counted 850, the postshot fish of the same species showed contamination of 340,000 counts per minute per gram. The average of all post-Mike specimens from Engebi was 280,000 counts per minute, the highest average of any station.[14] An analysis of fish tissues by station disclosed that radioactivity ingested by the animals—and revealed in muscle, bone, skin, and liver—was greatest at Bogallua, downwind, west and south, of the Mike site and in the path of the westward flowing turbidity emanating from the Mike crater where Elujelab formerly had stood. Although Bogallua and Engebi are about the same distance from the shot site, activity in fish tissues at Bogallua was four to eighteen times that of the tissues of specimens from Engebi.[15] The broad circumstance seemed clear, especially in view of earlier experience—the fish living in the waters to the west of the atoll were ingesting, in the first week after Test Mike, radioactive materials carried westward by the cycling waters. In general, the omnivores had taken into themselves by far the heaviest doses of

Eniwetok Marine Biological Laboratory (EMBL) on Parry Island, Eniwetok Atoll, in 1959 *(Holmes & Narver, Inc.)*

The "Gene complex" on Eniwetok's north rim showing Test Mike crater in 1959 *(Holmes & Narver, Inc.)*

Autoradiograph of Eniwetok plankton sample, collected November 8, 1959, and exposed eight days activity—far more, for example, than the carnivores, which seemed to indicate that the greater variety of their diet, which included plant forms already contaminated, multiplied their exposure to radioactivity present in the environment.

When the collecting and the subsequent analyses moved into the domain of the land animals—the rats living in burrows amid atoll vegetation, the terns nesting in the bushes and shrubs, and the shore birds feeding on the beaches—the survey team encountered not only new evidence of the wider impact of the thermonuclear weapon but also, in one instance, the small shadow of what would become a larger question.

The survey group had attempted, not always with success, to gather samples of rats and birds at each major station. The mid-Pacific rat *(Rattus exulans)* is a creature which lives in burrows beneath clumps of grass or under the beach magnolia bushes. From the time of the resurvey at Bikini in 1949 Lowman had experimented with various kinds of traps which could be placed at the entrances of the burrows or along the paths about the small and local feeding grounds. Since the rats live only in vegetated areas and rarely venture far from their underground homes in the shallow coral sands, their place in the contamination spectrum, although uncertain, was presumed to be correlated to that of the plants of their habitat. As for birds, the variety is not large, and the collection of specimens was limited primarily to terns—the white fairy tern *(Gygis alba)*, the noddy tern *(Anous stolidus)*, species which usually remain close to the nesting ground, and others including the sooty tern *(Sterna fuscata)*, the crested tern *(Sterna bergii)*, and the arctic tern *(Sterna paradisaea)*. Occasionally other specimens would be taken, such as the golden plover *(Pluvialis dominica fulva)* or the turnstone *(Arenaria interpes morinella)*, shore birds of migratory habit. The terns live almost altogether on small fish plucked from the water, the shore birds on insects and small crustacea found on the beaches.

The problems of radioanalysis presented by rats and birds were utterly different—different in the availability of specimens, in the variations in diet, and in the degree of certainty with which it was possible to assume some basic relationship between the contamination of the earth and the animal. Yet assays of the organs and tissues of the bird and rat specimens established patterns of similarity and difference that could be explained only in terms of feeding habits.

Before Test Mike, rat specimens had been collected on Engebi, Biijiri, and Rojoa. After the shot, they were found only on Biijiri, and there, nine miles from the shot site, they were ill and lethargic and, unnaturally, sitting or walking on the open sands in broad daylight, so sick that no traps were needed for their capture. No rats at all were found on Engebi, yet it was there, much later, that one of the most interesting problems would arise. The exposure of Engebi to the effects of the Mike shot made it seem impossible that rats had survived. The view was expressed in a subsequent summary by Lowman, who said that there was "little probability" that rats had lived through the heat, the shock wave, the rush of water, and the nuclear radiations that Mike had inflicted on the island. Members of the rat colonies apparently did live through the holocaust, however, and the questions presented by this circumstance would intrigue the investigators for years. (4)

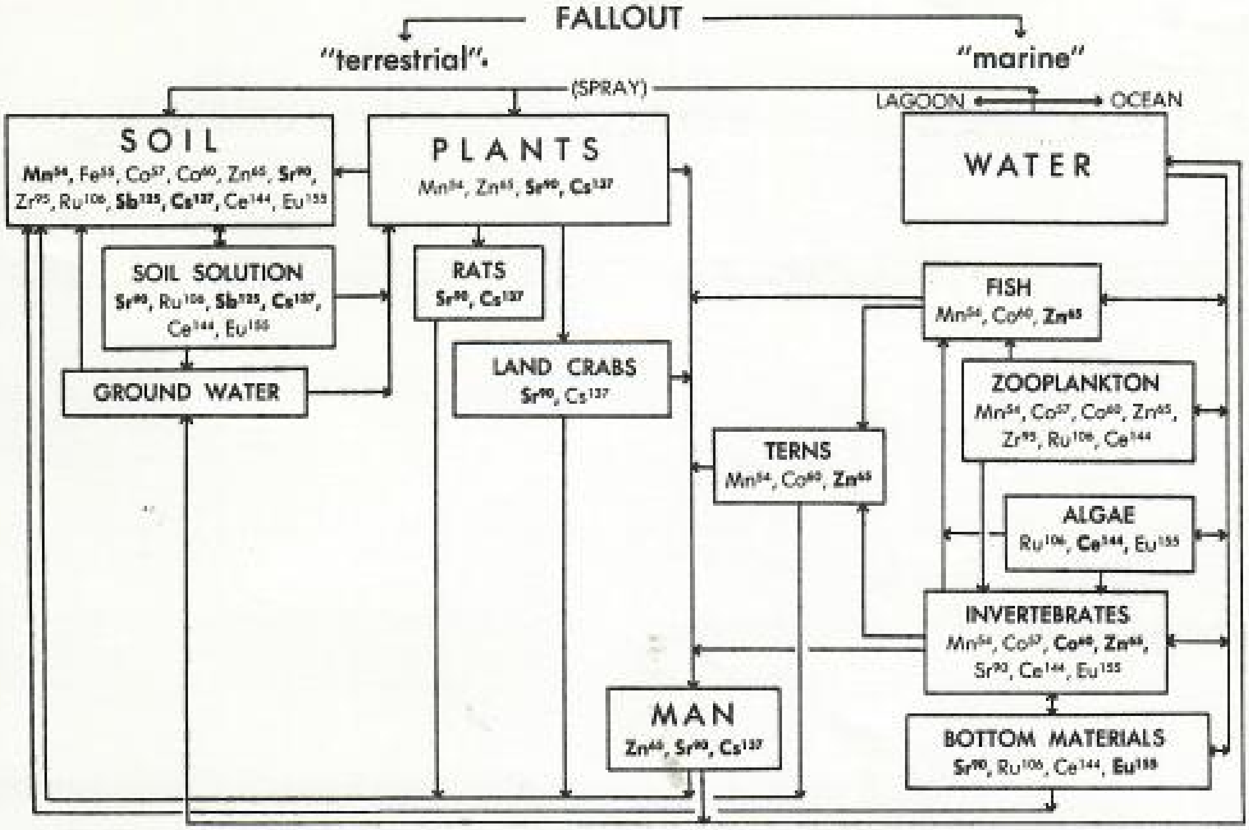
The radioactivity detected in the organs of birds and rats collected before Test Mike was of a very low order, although it was of interest that no activity at all was found in the bones. But after the Mike shot, analysis of the specimens in relation to the islands from which they were taken and to the presence of radioactivity in their tissues disclosed, first, a pattern reflecting the general contamination of the environment—that is, whether the point of collection was near the test site or downwind from it—and, second, and more significantly, degrees of internal contamination indicating the effects of food habits and the ingestion and retention of activity by the animals. A comparative study of the amounts of activity ingested by shore birds and rats, both of which subsist on insects, seeds, and grasses, and of shore birds and terns, whose diets are dissimilar, showed that fission product contamination was present in each of these species—just as it was present in the organisms of the sea—within days, even hours, after the nuclear detonation.

IV

Members of the Laboratory field team had but six days after the Mike shot to make their biological samplings at seven stations about an atoll twenty-two miles in length and eighteen miles across 22×18 at its widest part. They were more experienced by 1952, and they had gained a familiarity with Eniwetok in two previous surveys there. But in an ocean entity of such dimensions and one shaken and churned by the world's first thermonuclear explosion, the allotment of time was exceedingly small and the collection of specimens, even though it numbered hundreds, scarcely was more than the merest beginning of a task of observation whose ramifications were becoming ever more complicated. Even so, the program of radioassay which began in November of that year, including the making of hundreds of autoradiographs and of radiochemical analyses, was quite as much as the Laboratory's small staff could handle. The report of the Mike shot results was completed and forwarded to the scientific director on June 10, 1953.[16]

The questions surrounding the position of the radiobiological programs in the Pacific still were not reconciled within the Division of Biology and Medicine in 1953. Operation Ivy had demonstrated the potential dimensions of the need. The Applied Fisheries Laboratory, as Pearson had pointed out in 1952, had unique experience at the test atolls. Yet the programs in the Pacific, as they had evolved, seemed incompletely developed. The Laboratory held the view that, even though it existed outside the mainstream of Pacific testing activity, it had done everything possible to draw to the attention of the Division the necessity for continuous and detailed studies. On its part, the Division, as would be revealed shortly, believed that the concepts and the delineation of program requirements had to flow from the Laboratory, which had the depth of experience. In the annals of the proving ground, as in those of the Laboratory, the discussions and decisions of 1952 and 1953 would assume a new significance when the tests of 1954 placed the proving ground, for the first time, into the realm of international relations.

The appointment of Bugher as head of the Division of Biology and Medicine had occurred during the final months of preparation for Operation Ivy. In the process of familiarizing himself with Division operations, he had attended a Bio-Medical Program directors' meeting at Hanford and later had observed at Eniwetok, before and after the Mike test, the radiobiological operations that were within the realm of his responsibility. There was no reason or need for Bugher to visit the Laboratory in Seattle, and it was



Distribution of fallout radioisotopes at Rongelap Atoll, 1959, the dominant isotopes indicated in bold-faced type. (From data by Held, 1961.)

suggested two further approaches, the first the establishment of controlled greenhouse experiments in which plant responses to altered nutritional conditions could be observed, and the second the plotting at Rongelap of a number of reserved areas in which fertilizer experiments could be conducted in the field. Tests for nitrogen at Rongelap indicated a high nitrogen content in certain plants even when these were found growing in sand along the beaches, and this observation opened up a study of the nitrogen cycle in the atoll soils.

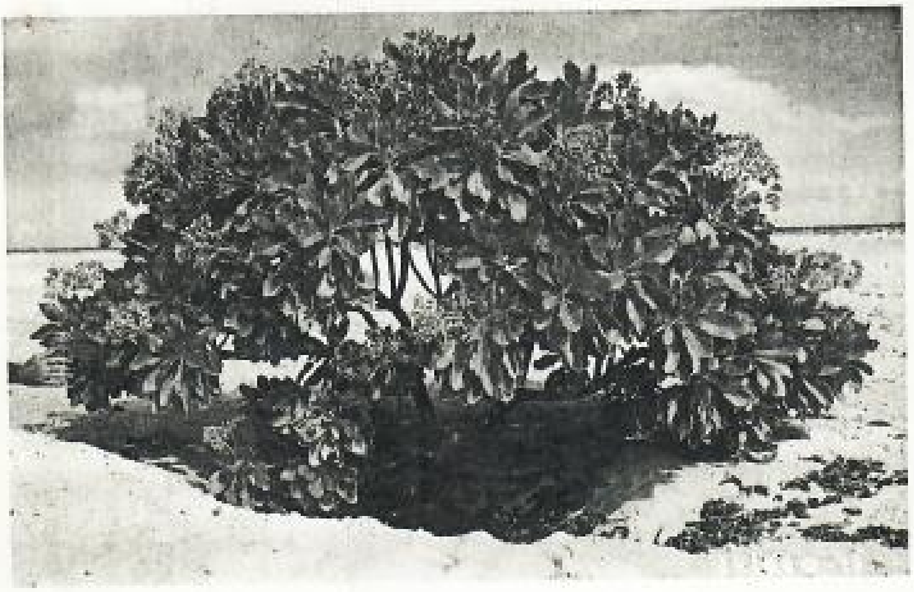
The four field observations of 1958 and 1959 permitted intensive samplings of radioactivity on and beneath the surface of the land areas. Samplings by one-inch increments conducted along island transects at four separate points in time showed that more than 75 per cent of the gross beta radioactivity was in the top inch of Rongelap soil. A few samples were taken at one-fourth inch increments, and in some instances 50 per cent of the radioactivity was found in the top one-fourth inch. The vertical distribution of strontium 90 followed the same pattern as that of gross beta activity.[24] The horizontal variation in radioactivity was found to vary widely. In extreme cases samples taken within distances of a few meters, from the same soil types and with the same vegetative cover, were found to vary by as much as a factor of ten. In 1960, complete isotopic analyses were made of samples representing each of six major soil types at the atoll.

The lysimeter leachates, collected from four installations on Rongelap Island and two on Kabelle, were analyzed for nitrogen, phosphorous, potassium, calcium, and gamma-emitting radioisotopes. Radioisotopes detected were ruthenium 106-rhodium 106, antimony 125, cesium 137, cerium 144-polonium 144, and europium 155, but reliable quantitative estimates could be made only for cesium 137 and antimony 125, the latter collected at depths where the soil contained no measurable radioactivity above background.[25] In "recent deposit" soil, only antimony 125 (the presence of which had been discovered for the first time in 1957) was found in the leachates. Analysis for strontium 90 indicated that its movement was enhanced by the presence of potassium chloride.[26] Throughout the investigation soil chemistry presented difficulties arising from the coralline-foraminiferal character of the materials and the naturally high calcium content. Not all of these difficulties were overcome, but a procedure to determine calcium carbonate by gas evolution was used in analyses of organic matter. Broadly, the lysimeter studies revealed that there was only a slight downward movement of minerals, even in the porous soils in which leaching was a function of the natural land-water relationship.

The studies of land plants evolved from the original mapping and description of the plant communities at Rongelap, although in the processes of radiochemical analysis priority was given to food plants. Complete radiochemical analyses were made for all samples of pandanus, tacca (arrowroot), breadfruit, squash, and coconut samples. Cesium 137 was found to be the dominant isotope in these plants, accounting for 70 to 99 per cent of the total activity. Strontium 90 accounted for most of the remaining activity, although manganese 54, zinc 65, and cerium 144 were found in minute amounts in samples from the more highly radioactive northern islands.[27] All plant samples through 1959 were counted for gross beta activity and, while there were definite geographical and species differences, no seasonal variations or changes with time were apparent.

The need to determine the mobility of strontium 90 and cesium 137, elements of singular interest in relation to the original contamination, gave direction to the plant sampling. The results of the analyses of the 1958 samples, and observation of the initial effects of the greenhouse experiments, indicated that there were marked differences in the amounts of strontium 90, cesium 137, potassium, and calcium found in the terminal and basal leaves. Thereafter, collections in the field included both types of leaves from the same plants. Cesium 137 moved into the terminal leaves more readily than did strontium 90, yet it was less mobile than potassium. This observation led to an extension of the use of fertilization plots in the field, where tests indicated that the addition of potassium as a plant nutrient reduced markedly the uptake of cesium 137. Fertilizer plots were established at Rongelap in both cultivated and uncultivated areas. With the assistance of Morriss, plots were set apart in coconut stands and certain trees marked so that repeated collections could be made from the same individuals.

A search for aberrant or atypical plants was made on most of the islands of Rongelap during the survey of September, 1959, and a number of examples of such plants were found and photographed. Yet, as had been discovered a decade before in the resurveys of Eniwetok after Operation Sandstone, it was necessary to resist the temptation to ascribe such aberrations to the effects of radioactivity alone. Multiheaded and branched coconut palm trees were found on Naen and Yugui Islands. A single double-headed palm about three feet high was discovered at Jabwan on the south end of Rongelap Island, but even the Rongelapese (who had observed other such phenomena and who were as concerned about them as they were worried about poisonous fish) said that this particular development had been caused by mechanical damage. Palms with twisted fronds were found on Rongelap, Kabelle, Gejen, Lomuilal, Yugui, Aerik, and Naen Islands, and it was noted that these occurred with greater frequency on the islands that had been more highly contaminated.[28] Dying coconut trees were in every stand of palms, again with greater frequency in the northern islands, and the same was true of palms with "pencil point," or tapering, stems. Dead or dying specimens of *Suriana, Guettarda, Scaevola, Messerschmidia,* and *Pemphis* were more prevalent in the northern islands, and a strikingly aberrant example of *Messerschmidia,* possessing only a few chlorotic terminal leaves, was found on a sand spit on Lomuilal Island. Yet despite the multiplicity of these examples, it could not be presumed, much less established, that these effects were caused by radioactivity. In general, the vegetation was in poorer condition on the northern islands, which had received about ten times as much initial contamination, than on the islands along the eastern edge and to the south of Rongelap. But it also was probable that other factors were at work. The soils of the northern islands are less well developed than elsewhere. The nitrogen content of the best northern soils averaged only 0.26 per cent compared to 0.57 to 1.71 per cent in the south. This in turn would indicate that vegetation had been sparser in the north for a considerable period of time, and there was evidence of recent overwashings of portions of the northern land, particularly at Lomuilal.[29] Finally, aberrations of island growth were known to be far from rare, even where radioactive contamination never had been a factor. Many examples are cited in the literature of tropical areas. In 1960,



(Above) *Messerschmidia* in wash area, Kabelle Island, Rongelap, a plant used in studies of root systems and growth rate *(Laboratory of Radiation Biology)*

(Left) Lysimeter plate used in soil studies, Kabelle Island, showing extent of root growth in Rongelap soil, 1959 *(Laboratory of Radiation Biology)*

(Below) *Messerschmidia*, Rongelap, showing meagre side growth, 1959 *(Laboratory of Radiation Biology)*

Morriss reported finding two multiheaded palms at Ujelang Atoll, southwest of Eniwetok, which is within the sphere of operations of the proving ground but which never had received fallout. On balance, it seemed probable that radioactivity, if it played a role in creating the observable condition of Rongelap's vegetation, was merely one of a number of factors tending to cause an increase in the numbers of aberrant plants.

The repeated surveys at Rongelap had permitted increasingly precise observations of the differences of uptake of radionuclides by organisms of land and water, differences first noted at Bikini, confirmed at Eniwetok, and extended during the ocean surveys of 1956. Long before it had been established as a general conclusion that cesium 137 and strontium 90 were the principal long-lived fission product isotopes found in the land organisms and that zinc 65, cobalt 60, manganese 54, and iron 55—nonfission products and elements which, in stable form, were in short supply in the marine environment—were those characteristically predominant in marine organisms. The distribution of radioisotopes in the biota had been found to vary from organism to organism and to be greatly different character in marine and terrestrial organisms taken from the same geographical area. Few of the induced radioisotopes were present in the plants growing in the soils, or in the tissues of the rats which feed on land plants. But in the plankton, the marine invertebrates, and in the fishes, induced radioisotopes frequently contributed up to 100 per cent of the total activity.[30] In the realm of the connections between water and land lay further questions that could be pursued in Rongelap's mildly irradiated environment. One of these connections was traced through the birds.

Richard's surveys of the birds at Rongelap provided a listing of species encountered with estimates of probable numbers and notes on feeding, nesting, breeding, and residence or migratory habits. The birds of significant interest were subject to grouping, as had been observed earlier, into categories incorporating the migratory shore birds and the resident sea birds. The migrants included species common to the atolls, such as the golden plover American and the ruddy turnstone, and those less frequently noted, the bristle-thighed curlew and the wandering tattler. The residents included the omnipresent noddy tern, the whitecapped noddy, and the white tern. It was Richardson's belief that the shore birds probably were winter residents whose southern migration tended to stop in the Marshalls in autumn and that these species probably had not contributed significantly to the development of soils and vegetation over the centuries, not only because of their intermittent presence but because they are small in size and population and live principally on the island beaches. But the numerous resident terns, excepting, perhaps, the sooty tern, which typically establishes its colonies on barren and wind-swept points, undoubtedly had helped to build the atolls and were important in the cycles of atoll life, because it is their habit to nest and breed in the inner parts of the islands where there are thick stands of *Pisonia* and *Messerschmidia* trees. The three most numerous terns, the noddy, the white-capped noddy, and the white, were noted as apparently entirely piscivorous, living on small fish caught in the lagoon or in the open sea. Their wastes and undigested food deposited in the nesting areas of plant growth seemed certain to be necessary to the development of plant life and thus to the growth of the islands themselves.

In an effort to establish an estimate of the ecological importance of the common terns, Richardson made population studies from which he might calculate the tern's contribution to island nutrients. On Kabelle Island, which has an area of some 2,400 square meters, he found that in 1959 there were 700 to 900 adult white terns, 500 to 600 noddy terns, and 200 to 300 white-capped noddy terns. Assuming that each bird would eat at least half of its own weight each day (a conservative assumption), he calculated that on Kabelle in a single year the white terns would deposit 35,000 pounds of waste, the noddy terns 51,000 pounds, and the white-capped noddy 10,000 pounds. Thus on this single medium-sized island the resident members of only three species of terns would deposit each year in the stands of vegetation approximately 48 tons of nutrients.[31] Richardson concluded that there seemed

> clearly to be a relationship between the greatest concentration of breeding birds, the most extensive stands of large trees, and the best-developed soils. . . . The sequences in the development of these relationships is problematical, but one may think of them as evolving together, even though a relatively barren island would, at first, attract few birds. If certain factors, as availability of sub-surface water and protection from salt spray, led to

denser vegetation in the inner parts of islands, the population of birds could then greatly accelerate the development of soils and larger and larger trees.

The food of the terns came from the lagoon and the open sea, and the island soil accordingly was being fertilized by wastes whose origins were oceanic. But the immediate significance was in the contribution of birds to the circulation of radioactivity. Repeated analyses demonstrated that within these wastes were nonfission products—primarily cerium 144 and iron 55—characteristically captured principally by marine life but now made available by the birds to island vegetation. The terns were agents for the transport of minerals from water to soil to vegetation. The tagged materials illuminated the process.

The survey of September, 1959, produced a more complete examination of lagoon ecology than had been possible earlier. Invertebrates were gathered at thirteen islands. Reef fish were observed and collected principally at Rongelap and Kabelle, but emphasis was placed on collections of goatfish and on other organisms upon which the goatfish were observed to be feeding. Plankton was collected by continuous pumping at the surface between eighty-nine stations in the lagoon. Twenty-four hour collections of plankton were made at three depths at three of the stations. Bottom cores, made with equipment designed at the University of Washington Department of Oceanography, were recovered at seventy-four stations.[28] No further field collections would be made until 1961.

THE RADIONUCLIDE CONTENT OF MARINE BIOLOGICAL SAMPLES FROM THE PACIFIC PROVING GROUND AREA

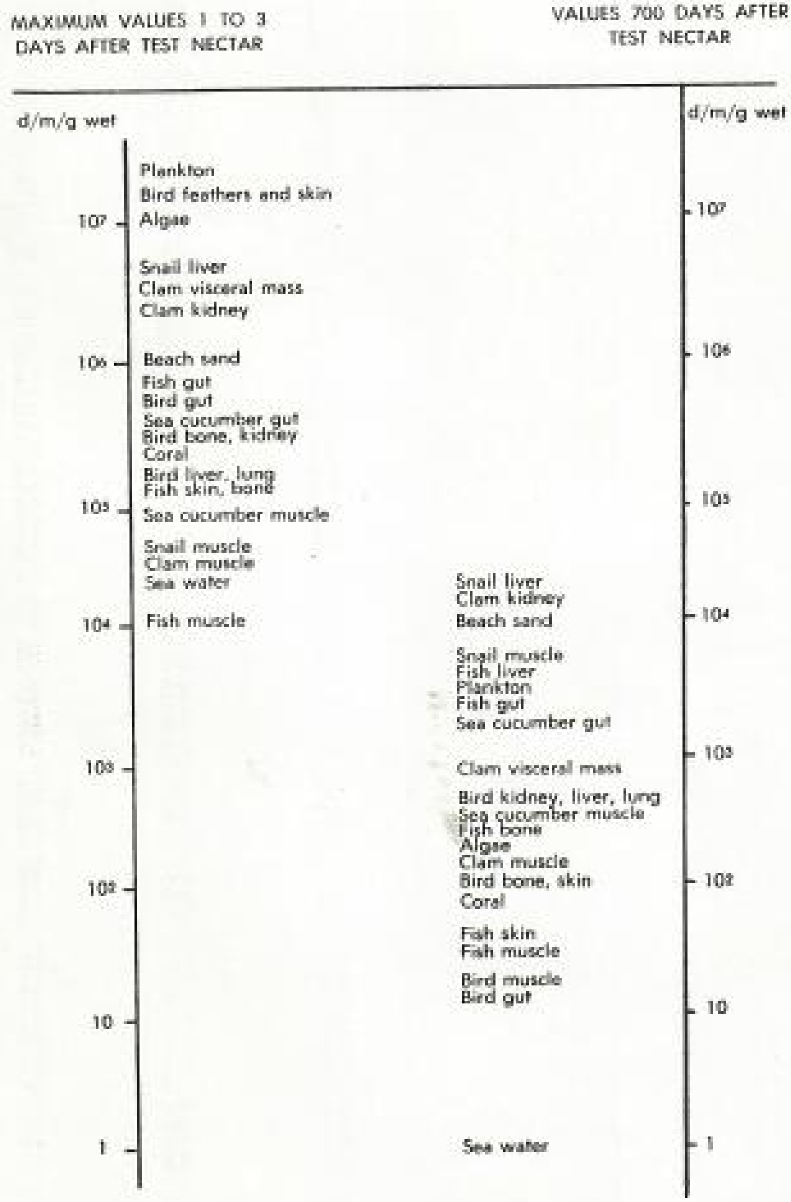
Per Cent of Radioactivity of Total Sample

	Sample number	1000's of d/m/g	Mn^{54}	Fe^{55}	Fe^{59}	Co^{57}	Co^{58}	[illegible]	Sr^{89}
Plankton									
Samples: *Marsh**	7-9	75	< 1	19	0	10	15	[illegible]	0
Area: At sea, Eniwetok to Guam.	13-15	29	< 1	19	0	8	14	[illegible]	0
Date: Sept. 1-20, 1956.	43-46	108	< 1	13	0	16	26	[illegible]	0
Radioactivity: Total as disintegrations	50-53	127	< 1	28	0	6	11	[illegible]	0
per minute per gram of ashed sample.	57-59	48	< 1	39	0	5	6	[illegible]	0
Samples: *Collett*†	2	718		0	1	8	40	[illegible]	0
Area: At sea, Eniwetok to Guam.	3	16,127		4	< 1	1	5	[illegible]	0
Collection: Aug. 8-14, 1958.	4	2,318		24	1	6	24	[illegible]	0
Radioactivity: d/m/g dry weight.	36	2,680		4	< 1	3	16	[illegible]	0
Algae									
Halimeda;‡ Eniwetok, July 22, 1956.		1,600				< 1	< 1		
Caulerpa;† Eniwetok, June 25, 1958.		321**				0	0		
Udotea;† Bikini, Aug. 28, 1958.		29**				0	0		
Invertebrates									
Clam kidney;§ Eniwetok, Sept. 22, 1956, d/m/g wet weight.	I	1,600	2	74	< 1	10	9	[illegible]	0
Tridacna (clam) visceral mass;† Eniwetok, Sept. 27, 1958.		376**				1	5	[illegible]	
Fish									
Liver homogenate;§ Bikini, Sept. 22, 1956, d/m/g wet weight.	II	18	6	15	0	8	4	[illegible]	0
Bonito liver;§ Bikini, Sept. 23, 1956, d/m/g wet weight.	III	50	2	56	< 1	3	1	[illegible]	0
Liver homogenate;§ Eniwetok, May–June, 1954.	IV	48	1	95	0	< 1	0	[illegible]	0
Reef fish liver;‖ Ailinginae Atoll, July 11, 1957, d/m/g wet weight.		2	1	26		22	4	[illegible]	
Flying fish muscle;† Aug., 1958, d/m/g dry weight.		15		0	1	2	11	[illegible]	
Flying fish liver;† Aug., 1958, d/m/g dry weight.		236		0	13	6	32	[illegible]	
Surgeonfish liver;† Bikini, Aug. 28, 1958.		38**				10	45	[illegible]	

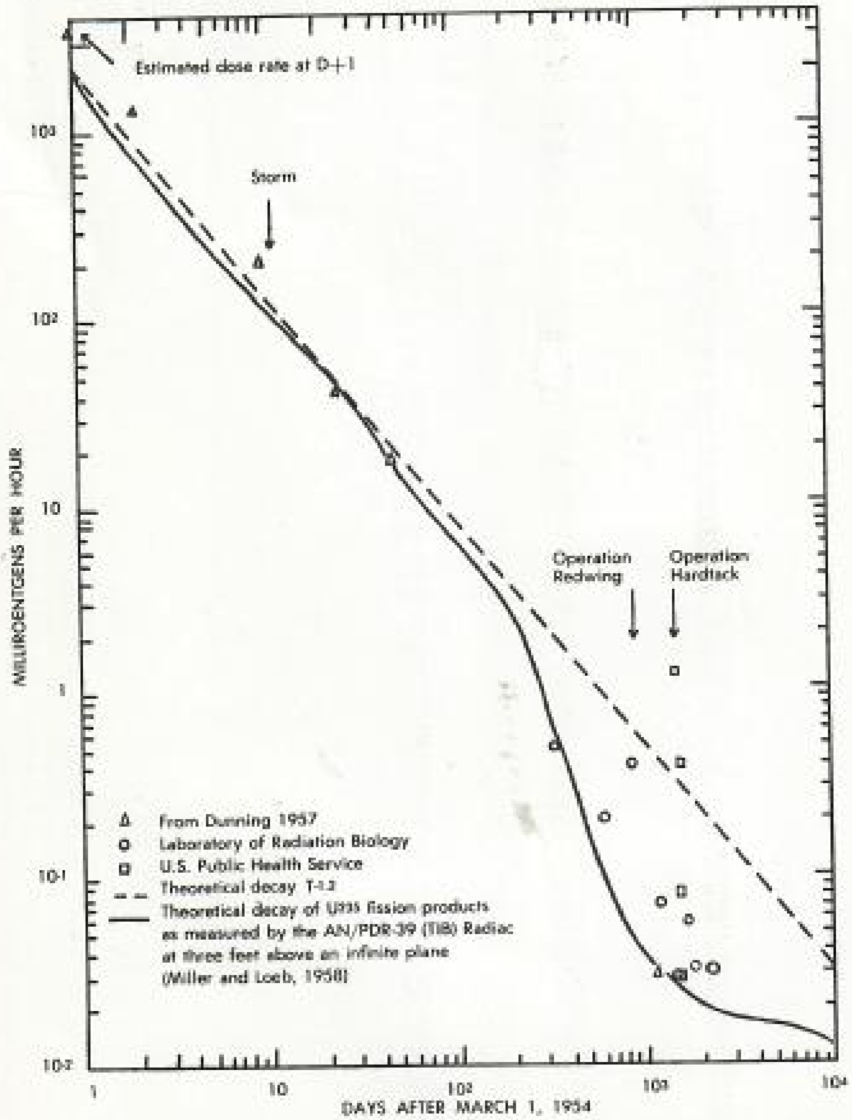
* Lowman, 1958.
† Lowman, *et al*, 1959.
‡ Palumbo, 1959.
§ Lowman, *et al*, 1957.
‖ Welander, 1958.
** gamma emitters only
†† unknown anions

A Selective Compilation by Allyn H. Seymour for Congressional Hearings on *Fallout From Nuclear Weapons Tests*, May 5-8, 1959

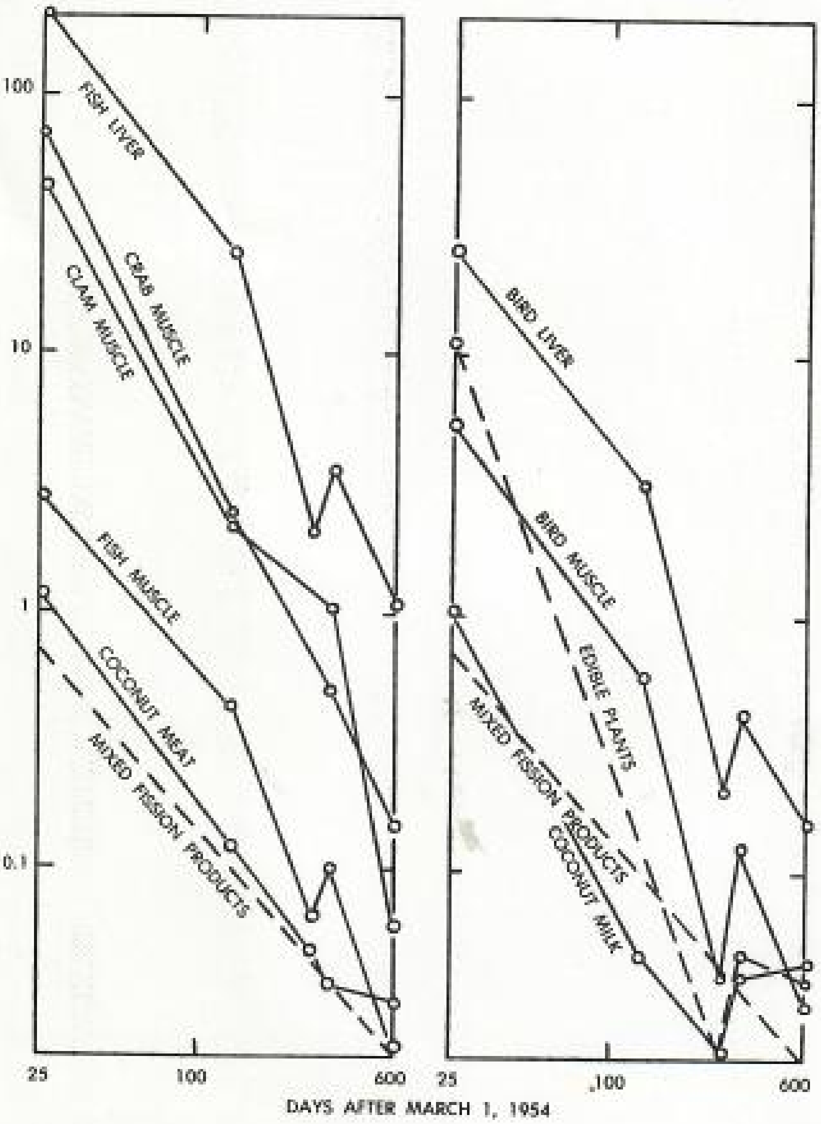
59	Co^{57}	Co^{58}	Sr^{89}	Sr^{90}	Y^{91}	Zr^{95} Nb^{95}	$Ru^{103+106}$ $Rh^{103+106}$	Ru^{106} Rh^{106}	Cs^{137} Ba^{137m}	Ba^{140} La^{140}	$Ce^{141+144}$ $Pr^{141+144}$	Ce^{144} Pr^{144}	W^{185}	Others
0	10	15	0	0		25		7				5		
0	8	14	0	0		44		0						
0	16	26	0	0		12		0				13		
0	6	11	0	0		14		0				8		
0	5	6	0	0		6		0						
1	8	40	0	0		5	3		0	24	0		0	3
1	1	5	0	0		2	2		0	1	0		83	2
1	6	24	0	0		3	1		0	33	0		0	5
1	3	16	0	0		2	1		<1	11	0		60	
	<1	<1			52	7		31				9		1
	0	0				72	6		0		15		7	
	0	0				32	12		0		57		0	
1	10	9	0	<1	3	<1		1	0			0		
	1	5				22	72		0		0		0	
0	8	4	0	0	0	0		0	0			0		<1††
1	3	1	0	0	0	<1		0	0			0		1††
0	<1	0	0	0	0	0		0	0			0		<1††
	22	4		0										6
1	2	11				<1	<1							
3	6	32				<1	<1							
	10	45				0	0		0	0			0	



Decline of radioactivity in samples collected by the Applied Fisheries Laboratory following Test Nectar at Eniwetok in 1954, the first column showing radioactivity 1 to 3 days after the detonation and the second the levels of activity after 700 days.



Gamma dose rates on Rongelap Island at various points in time after March 1, 1954, as projected against theoretical decay curves drawn from standard sources.



Rates of decline of radioactivity in food items from collections at Rongelap Atoll between March 26, 1954, and October 22-23, 1955.

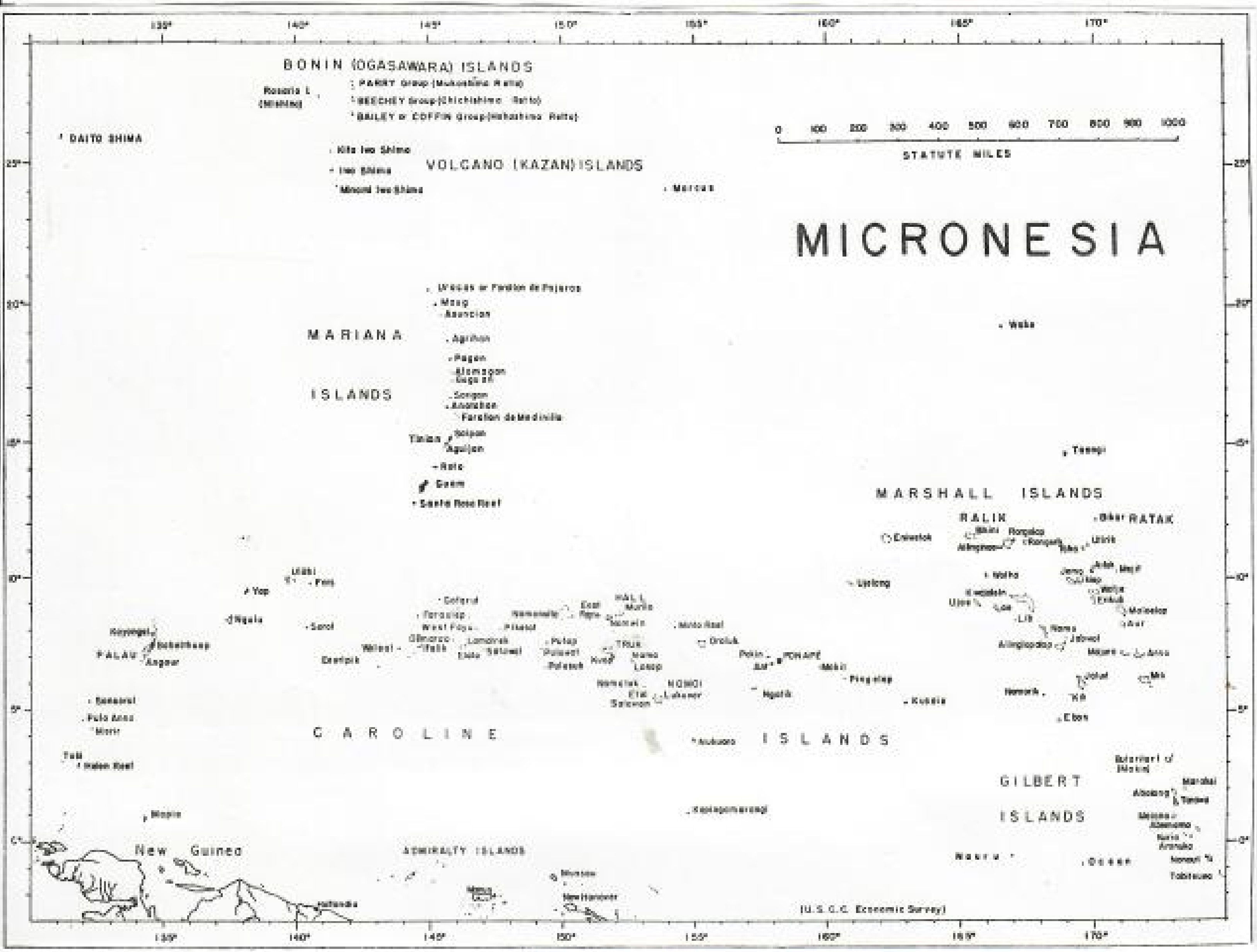
NO TURTLES LISTED

APPENDIX II

A SELECTED listing of biota commonly sampled for radioactivity in the Marshall Islands:

FISH

Family	*Genus and Species*	*Common Name*
Isuridae	*Carcharodon carcharias*	Great white shark
Orectolobidae	*Ginglymostoma ferrugineum*	Carpet shark, nurse shark
Triakidae	*Triaenodon obesus*	White tip shark
Carcharhinidae	*Carcharhinus melanopterus*	Black tip shark
	Carcharhinus menisorrah	Gray shark
Dussumieridae	*Spratelloides delicatulus atrofasciatus*	Round herring
Synodontidae	*Saurida gracilis*	Lizard fish
	Synodus variegatus	
Congridae	*Conger noordzieki*	Conger eel
Moringuidae	*Moringua abbreviata*	Worm eel
Muraenidae	*Gymnothorax buroensis*	Moray eel
	pictus	
	flavimarginatus	
	undulatus	
Belonidae	*Strongylura gigantea*	Needlefish



BONIN (OGASAWARA) ISLANDS
VOLCANO (KAZAN) ISLANDS
MICRONESIA
STATUTE MILES
DAITO SHIMA
Marcus
MARIANA
ISLANDS
Saipan
Guam
Santa Rosa Reef
Wake
MARSHALL ISLANDS
RALIK
RATAK
Eniwetok
Bikini
Rongelap
Utirik
Kwajalein
Jaluit
Mili
Ebon
Majuro
Arno
Ujelang
Yap
Ngulu
Sorol
PALAU
Angaur
Woleai
Ifalik
Eauripik
Satawal
TRUK
Nukuoro
PONAPE
Mokil
Pingelap
Kusaie
CAROLINE ISLANDS
GILBERT
ISLANDS
Nauru
Ocean
Tarawa
Marakei
Abaiang
Abemama
Kapingamarangi
New Guinea
ADMIRALTY ISLANDS
New Hanover
Hollandia
(U.S.C.C. Economic Survey)

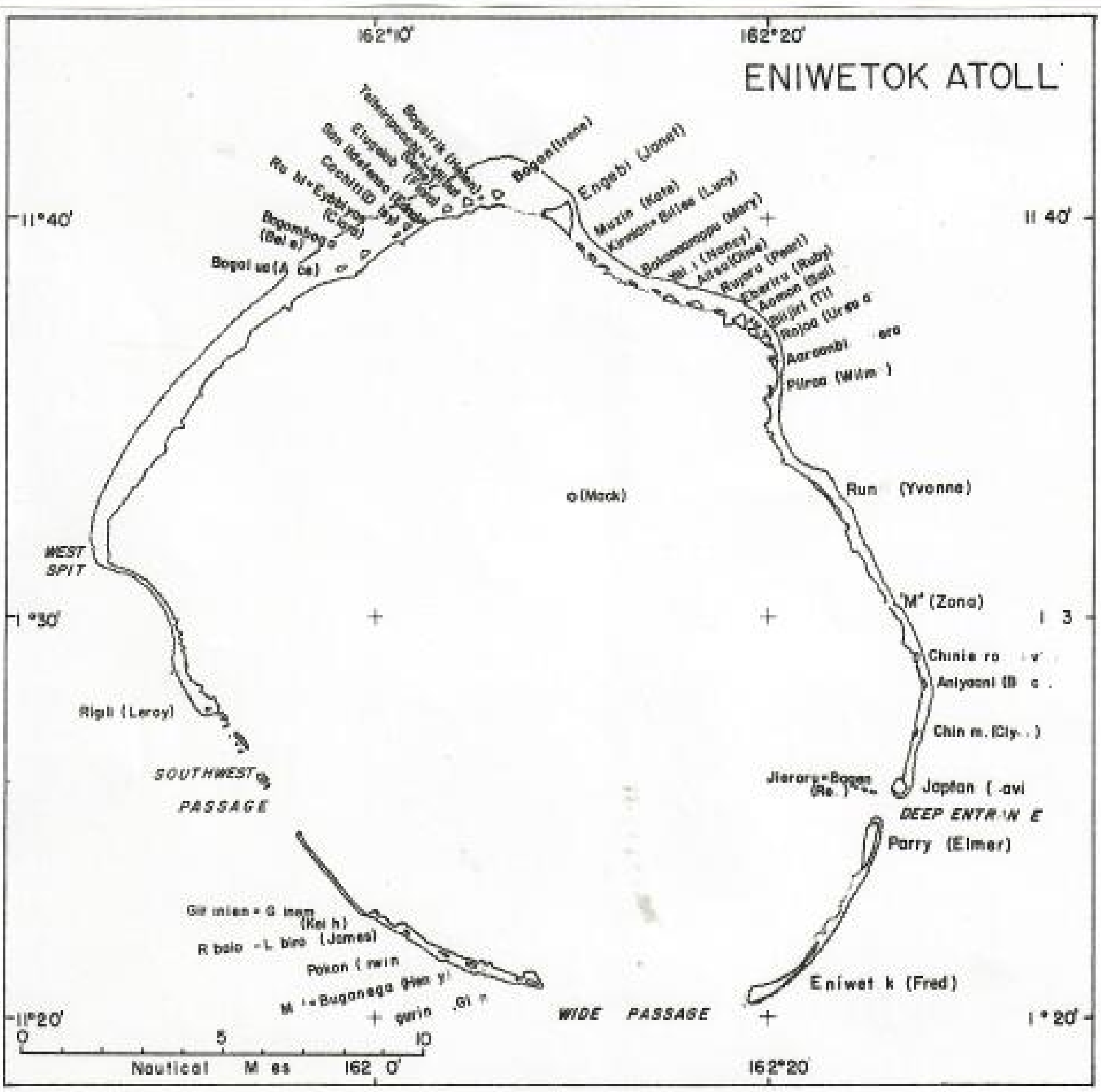


Fig. 6. Map of Eniwetok Atoll.