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The Northern Marshall Islands Radiological Survey: Sampling and Analysis Summary

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July 23, 1981

Lawrence Livermore National Laboratory

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CONTENTS

THE NORTHERN MARSHALL ISLANDS RADIOLOGICAL SURVEY: SAMPLING AND ANALYSIS SUMMARY

ABSTRACT

A radiological survey was conducted in the Northern Marshall Islands to document remaining external gamma exposures from nuclear tests conducted at Enewetak and Bikini Atolls. An additional program was later included to obtain terrestrial and marine samples for radiological dose assessment for current or potential atoll inhabitants.

This report is the first of a series summarizing the results from the terrestrial and marine surveys. Here we discuss the sample collection and processing procedures and the general survey methodology as well as present a summary of the collected samples and radionuclide analyses. In other reports we will address the radionuclide concentrations in cistern water, groundwater, marine species, soil, plants, and animals and the estimated doses via these pathways; the analytical methods and quality control program; the data bank; and the estimated dose from all the exposure pathways for each atoll (i.e., external gamma, marine, drinking water, terrestrial, and inhalation).

Over 5400 samples were collected from the 12 atolls and 2 islands and prepared for analysis including 3093 soil, 961 vegetation, 153 animal, 965 fish composite samples (average of 30 fish per sample), 101 clam, 50 lagoon water, 15 cistern water, 17 groundwater, and 85 lagoon sediment samples. A complete breakdown by sample type, atoll, and island is given here.

The total number of analyses by radionuclide are 8840 for ^{241}Am, 6569 for ^{137}Cs, 4535 for $^{239+240}Pu$, 4431 for ^{90}Sr, 1146 for ^{238}Pu, 269 for ^{241}Pu, and 114 each for ^{239}Pu and ^{240}Pu. A complete breakdown by sample category, atoll or island, and radionuclide is also included.

INTRODUCTION

A radiological survey was conducted from September through November of 1978 at 12 atolls and 2 islands in the Northern Marshall Islands selected by the Department of Energy (DOE). The primary purpose was to document remaining external gamma exposures for those atolls that may have received fallout from nuclear tests conducted at Enewetak and Bikini Atolls. In the latter stages

of planning, an additional program was included to obtain terrestrial and marine samples for a radiological dose assessment for current or potential inhabitants of the atolls.

Therefore the objectives of the Northern Marshall Islands survey and assessment program were as follows.

- Obtain aerial photos and aerial radiological maps of the Northern Marshall Islands atolls and islands.
- Obtain samples of soil, water, vegetation, food crops, animals, marine life, lagoon water, and lagoon sediments.
- Process, analyze, and determine the radionuclide concentration of the collected environmental samples.
- Prepare reports describing the estimated doses for alternate living patterns at the atolls and islands.

The Lawrence Livermore National Laboratory (LLNL) was responsible for the technical direction of the survey, subsequent sample processing, analytical work, and publishing of results. The Nevada Operations Office (NVOO) of the DOE was responsible for program management in the planning phases and interaction with other United States agencies and departments and the government and people of the Marshall Islands.

The external gamma aerial survey was conducted from the major support vessel, the U.S.N.S. Wheeling, by EG&G with the support of the naval helicopter group HC-1 Detachment 3 from the North Island Naval Air Station, San Diego, California. The EG&G detector and data analysis systems were mounted on one of two helicopters (Sikorski H-3) carried by the Wheeling and flown on 46-m grid lines over the islands at each atoll. A complete report of the external gamma measurement program and the results is available as part of the Northern Marshall Islands survey assessment.[1]

The survey was conducted in three legs of about 20-d each. The sequence of atolls and islands visited during each leg is shown in Fig. 1 and listed in Table 1. The first leg of the survey included Rongelap, Taka, Utirik, Bikar, Rongerik, and Ailinginae Atolls. The second leg included Likiep, Ailuk, and Wotho Atolls and Jemo and Mejit Islands. On the concluding third leg we surveyed Ujelang and Bikini Atolls and made a limited stop at Enewetak Atoll.

The terrestrial and marine programs were conducted with small boats and the helicopters using the Wheeling as an operation base. The time available for the terrestrial and marine surveys was dictated primarily by the length of

time to fly the aerial survey. This was usually only a few days at each atoll, and the scope of the terrestrial and marine efforts was determined accordingly. Though the Wheeling provided an excellent base for the aerial survey, operating from a large ship that cruised a considerable distance from shore limited the scope of the terrestrial and marine surveys because of the time required to reach the atolls and islands in the small boats. Also because of the limited lifting capacity of the helicopters, the terrestrial support equipment had to be small and the rate of sample collection and the ability to reach certain islands or areas of islands was reduced.

The second helicopter aboard ship was used when possible to help distribute equipment and marine and terrestrial crews around the atolls. However, a certain amount of downtime was required for each helicopter and it was necessary to always have one flying the aerial survey. Thus, using helicopters for support of the marine and terrestrial surveys even for limited periods required careful planning. It was a considerable effort for the Navy mechanics, reduced in number from the normal complement, to keep the helicopters in operating condition. During the second leg of the survey only one was usable and it was dedicated to the aerial survey. Thus only the small boats were available to conduct the terrestrial and marine surveys. During the third leg the second helicopter was available and because of adverse weather conditions, became essential to the terrestrial and marine programs.

We attempted to collect the maximum possible number of terrestrial and marine samples from as many islands as possible with the time available. All samples were returned to LLNL for processing and the analytical work was conducted both at LLNL and contract laboratories. The procedures for sample collection and the number and type of samples collected by island and atoll are summarized here. In addition we have listed the total number of analyses by radionuclide of the samples collected during the survey.

This report is the first of a series summarizing the results from the terrestrial and marine surveys. The aerial survey data has been published independently by EG&G.[1] In other reports of the series we will address the radionuclide concentrations in cistern water and groundwater and the estimated doses via ingested water; the radionuclide concentration in marine species and the associated estimated doses from the marine pathway; the radionuclide concentration in soil, plants, and animals at each of the atolls and islands and the estimated doses via the terrestrial foodchain; the analytical methods and

quality control program; the data bank; and the estimated dose from all the exposure pathways for each atoll (i.e., external gamma, marine, drinking water, terrestrial, and inhalation).

SAMPLE COLLECTION PROCEDURES

TERRESTRIAL SAMPLES

The primary purpose of the field collections was first, to take a representative sample of the locally grown food supplies available to the local populations and second, to determine the radionuclide concentrations in animals and plants relative to soils for an entire island and atoll.

When sampling an inhabited atoll or one used for agriculture, DOE representatives arranged for purchase of local food items to be used as samples. In most cases, local residents were hired to assist LLNL field crews in their collection.

Representative samples of available local food supplies consisted of livestock, food grown in gardens, and food plants adjacent to the village. Soil samples were taken in the root zone of all food plant samples. Coconuts are the most common and abundant of the food plants and therefore became our indicator species. To determine relative radionuclide concentrations for the rest of an island or for uninhabited islands, coconuts were collected along transects or on random grid patterns to obtain samples from the total island area. When found by field teams, coconut crabs, Pandanus, breadfruit, and Tacca (arrowroot) were collected along with the coconuts. All vegetation and animal samples were frozen aboard ship and returned to LLNL for processing and analysis.

Vegetation and Animal Sampling

In nearly all cases, plant samples collected were the edible portions of plants representing different elements of the local diet. Some plants were collected in greater numbers than others because they were present in larger quantities and usually constituted a more significant part of the diet. The majority of the vegetation samples collected were fruits of coconuts, papaya, Pandanus, breadfruit, banana, Morinda, and squash. Roots of Tacca and taro and leaves from Scaevola, breadfruit, Pisonia, and Messerschmedia trees were also collected.

Coconut palm Cocos nucifera is widespread throughout the Northern Marshall Islands and must be considered the dominate food plant. Individual trees varied in height, but the ones selected had coconuts within 25 ft of the ground. Occasionally we were able to hire local men to climb the trees and pick coconuts at heights of 45 ft. A coconut sample consisted of five coconuts from one or all three stages of coconut used in the diet--drinking nut, copra nut, and sprouting nut.

Drinking coconuts are utilized for both eating and drinking by the Marshallese. The juice is very sweet and the meat soft and palatable. The drinking coconut stage is the most difficult to identify. The outer fiberous husk is green to yellow in color, the inner husk is saturated with water, while the seed coat or shell is cream colored and firm. Inside the shell the meat (endosperm) is not fully formed and is gelatinous, sweet, and nutritious. The juice generally fills the seed cavity completely and is often under pressure.

Copra nuts are used for food flavoring in many areas of the Pacific as well as for oil that is of commercial value. Customarily the juice is discarded and the meat grated and squeezed. The extract is used to prepare coconut cream to be combined with other foods. The drained copra meat is usually fed to the livestock, which are later consumed by the people. The husk is ordinarily yellowish brown to gray brown and is beginning to dry and shrivel. The woody seed coat is dark brown and the meat is fully formed, white, and firm. Less than one-half of the seed cavity contains juice and its flavor is bland. The eye of the copra nut shows no sign of sprouting and the cotyledon has not yet begun to grow.

Sprouting coconuts are utilized as food by the Marshallese who eat the spongy, pastry-like cotyledon or embryo food that fills the interior of the seed cavity. This embryo food absorbs moisture and nutrients from the seed cavity (meat and juice) to support the growth of the germinating coconut's leaf sheath and root. Sprouting coconuts are characterized by a 1- to 15-in. leaf sheath, roots, and a grayish-brown shriveled husk.

Pandanus was the second most common food plant encountered and both wild and cultivated varieties were collected. Though wild varieties are not utilized as food, they are an important indicator plant to estimate the radionuclide concentrations in the edible species. Cultivated Pandanus is highly prized throughout the Marshall Islands for its sweet, spicy-flavored juice that is extracted from its numerous keys or phalanges, which are sections

of the fruit. The juice may be used immediately or dried as fruit leather and stored for later consumption. Pandanus samples usually consisted of two large fruits; fully matured fruits were collected when available.

Breadfruit was collected from most of the inhabited islands because it is another important food plant cultivated by the Marshallese. Ripe breadfruit are either baked or fried. It is also dried and preserved in the ground to be cooked later. Yellow to yellowish-green ripe breadfruit were collected whenever possible. A sample usually included five fruits.

Other vegetation collected were papayas, squash, bananas, and Tacca. Tacca is a perennial plant with root tubers that are processed into a starchy material to be cooked or preserved for later use. These food crops are not as common in the diet as coconut, breadfruit, and Pandanus.

Animal samples collected by field teams, with the exception of coconut crabs, were purchased from the Marshallese by the DOE representatives. The purchased animals were always either pigs or chickens, which represent the major source of meat protein outside of imported canned meats.

The pigs were moved to a contamination-free area, and biologists wearing surgical gloves carefully dissected from the animals the major organs: heart, liver, lung, kidneys, sternum, cartilage, spleen, skin, muscle tissue, bone, and reproductive organs. The organs were carefully removed to avoid contact with the animal skin, transferred to plastic bags, labeled, and then frozen. The major organs removed from the chicken were muscle, liver, bones, skin, gizzard, and heart.

Coconut crabs were sometimes discovered by field team members while collecting plant samples. These large land crabs were usually found in areas isolated from local population centers because they are considered a great delicacy and taken for food whenever discovered. Only the muscle and hepatopancreas tissue was removed from the coconut crab.

Soil Sampling

In most cases, soil profile samples were collected in the root zone of sampled plants so that radionuclide concentrations measured in the plant tissue could be compared to concentrations in the soil. While the total soil volume utilized by the plant roots could not possibly be sampled, profiles taken through the root zone are representative of the radionuclide concentration encountered by the plant's roots.

The soil profile increments of 0 to 5, 5 to 10, 10 to 15, 15 to 25, 25 to 40, and 40 to 60 cm are those developed on previous LLNL Marshall Islands surveys, so they can easily be compared with the bulk of data previously collected from Enewetak and Bikini Atolls. We have found that a 40-cm depth encompasses most of the active root zone of the subsistence crops that we have sampled in the Northern Marshall Islands. A trench was dug with a backhoe or shovel radially from the trees to minimize root damage. After the sidewall of the trench was scraped to avoid any possible contamination from the digging process, samples were collected from the sidewall. The 0-to-5-cm sample was collected from a surface area about 25 cm on a side. The area was then expanded by about 10 cm on each side and cleared to a depth of 5 cm. The upper surface (1 to 2 cm) of this enlarged region (35 by 35 cm) was then cleared to ensure that neither surface soil nor soil from a preceding increment had fallen onto it. The next sample was then taken from the entire depth of the increment (i.e., 5 to 10 cm) for an area of about 25 cm^2 within the enlarged region. This procedure was repeated until the final depth increment of 40 to 60 cm had been collected. A total of approximately 500 to 900 g of soil was collected for each profile increment.

Many soil profiles were collected at sites around the islands where no associated plant samples were taken. These profiles were collected in the same manner described above. While the sample profile sites are selected more or less randomly, it is advantageous to choose a relatively undisturbed site with litter and surface soil intact.

MARINE SAMPLES

Water Sampling

Large-volume seawater samples (56.5 liter) were taken from various locations in each lagoon. All samples were filtered through a 1-μ cylindrical fiber-cartridge filter into 15-gal plastic barrels to separate particulates. Groundwater (well water) and cistern water (rainwater from dwelling roofs) samples (56.5 liter) were collected whenever available at the atolls. The groundwater was filtered through 1- and 0.4-μ filters to separate particulates. Cistern water was not filtered. All water samples and corresponding particulates (filters) were sent to LLNL for processing.

Sediment Sampling

Sediment samples were also collected at those locations sampled for water and from other locations around the inner perimeter of the lagoons. A hand-held Ponar grab sampler was used, and the undisturbed top layer was subsampled to a depth of 3 cm, placed in plastic bags, frozen, and sent to LLNL.

Fish and Invertebrate Sampling

Throw nets were used exclusively to catch reef fish at the atolls. Large pelagic and benthic fish were collected on sport fishing gear using feathered jigs or baited hooks while trolling in the lagoons. Edible clams were collected by hand (free diving) in shallow areas of each lagoon. The fish and clams were returned to the research vessel, segregated by species, placed in plastic bags, and frozen. The samples were shipped frozen to LLNL for storage and eventual processing.

Specific species were collected because they are commonly eaten by the Marshallese; relatively abundant at all atolls and at different locations within an atoll; have different feeding habits; and for some, represent species for which previous radiological data were available at Enewetak and Bikini. It was not always possible, however, to obtain a sufficient number of the same species at every location we sampled.

Various reef fish were collected. Mullet Crenimugil crenilabis and Neomyxus chaptalii are herbivorous, detrital feeders that ingest considerable quantities of bottom sediment along with food. Convict surgeonfish Acanthurus triostegus are herbivorous browsers feeding on small algal fronds and filamentous algae that grow on reef rock or on the base of dead coral. The unicornfish Naso lituratus, also a herbivore, browses on larger seaweed growing on sandy and rocky areas. Rabbitfish Siganus rostratus are herbivorous browsers but will occasionally feed on fleshy items found in garbage dump areas. Rudderfish Kyphosus cinerascens are strictly herbivorous browsers. All of the above fish belong to the second trophic level.[2] Goatfish Mulloidichthys samoensis consume fossorial and other benthic fauna including small clams, crustaceans, other invertebrates, and small fish. This species belongs to the third trophic level.[2] Threadfin Polydactylus sexfilis feed strictly on benthonic fauna and also belong to the third trophic level.[2]

Parrotfish Scarus sordidus are common reef-dwelling, grazing omnivores feeding on live coral heads and occasional algae. Parrotfish are in the fourth trophic level.[2]

Four species of clams, Tridacna gigas, Tridacna squamosa, Tridacna crocea, and Hippopus hippopus were collected. These large invertebrates are sessile, filter-feeding mollusks that live on the lagoon bottom and coral reefs.

Larger benthic, midwater, and surface carnivores were also occasionally collected from the lagoons. Grouper Epinephelus sp. are benthic carnivores of the third trophic level that feed on small fish and invertebrates.[2] Jacks Caranx melampygus and Elegatis bipinnulatus (rainbow runner) are fast-swimming carnivores that feed on small fish and squid. Elegatis bipinnulatus may occasionally eat swimming crustacea. Snappers Aprion virescens (grey snapper) and Lutjanus bohar (red snapper) are hovering midwater-to-surface carnivores. Another snapper Letherinus kallopterus (pigfish) is a bottom dweller feeding primarily on benthonic crustacea. Jacks and snappers are in the fourth trophic level.[2] Tuna Euthynnus affinis (bonito), Thunnus albacares, and Gymnosarda nuda and mackerel Grammatorcynus billineatus are large, rapid-swimming carnivores feeding on small fish and any other prey of proper size. They represent species of the fifth trophic level.[2]

SAMPLE LOG

All marine samples except water and all terrestrial vegetation and animal samples were double bagged in plastic, frozen, and returned to LLNL. Soil samples were double bagged and sent unfrozen to LLNL. All samples were carefully labeled as to location and time of collection. Detailed log books were completed at the end of each day of sampling so that precise records were available indicating the type of sample, location from which it was collected, date, and other pertinent information.

SAMPLE PROCESSING PROCEDURES

TERRESTRIAL SAMPLES

Soil Samples

Soil samples were the largest category of all the samples collected. The soil-processing laboratories were carefully surveyed for possible radioactive

contamination. Air filter samples and swipe samples were taken around the processing area. This monitoring program continued throughout our entire processing phase.

Each soil profile produced six soil samples except in cases where it was impossible to get to the deeper depths because of coral bed rock. There were approximately 516 profiles collected and some 3093 soil samples were processed in the soil preparation laboratory between January and September of 1979.

The soil samples were received in large plastic bags wrapped tightly with plastic tape with a field log number and location written on the bag and tape. The pertinent information from the field log books on the location, the collection date, and the appearance of each sample was recorded in laboratory log books.

The samples were unwrapped and put in 1-gal cans. The description and field log number on the bag was recorded on the can and the wet weight of the soil was determined. Sample weights varied from 0.5 to 1 kg. The soil samples were dried in large commercial ovens at 75°C for 48 h. The samples were then removed and the dry weight was measured. They were placed back in the ovens for an additional 24 h after which they were again weighed. If a constant weight resulted, the sample was considered dry. If not, it was placed back in the ovens for an additional 24 h. Eight 1-in. steel grinding balls were placed in the 1-gal can of dry soil and the cover was securely taped to prevent it from coming off during mixing. The entire assembly was then covered with a galvanized steel jacket held in place by two large rubber O-rings to prevent the can from being damaged. The samples were ball milled continuously for 48 h to produce a homogenous sample. After ball milling, fractions of the soil samples were canned for gamma spectrometry.

All soil canning was performed in fume hoods. Before each sample was canned the fume hood was vacuumed and clean paper inserted. After canning all the soils from an atoll, the hood was washed completely with soap and water and rinsed with Radiacwash. The soil lab area was then steam cleaned and canning of soils from another atoll would begin.

The finely ground soil was packed tightly in an aluminum can (0.25-mm thick). Two sizes of cans were used. The first (referred to as a tuna can) was 4-cm high and 8.3 cm in diameter with a volume of 219 cm^3. The second (referred to as a bean can) was 4.6-cm high and 8 cm in diameter with a volume of 231 cm^3.

The canning process involved packing the can with soil as discussed above; sealing; weighing; and labeling the can with a log number that had the year and month the sample was taken, depth increment, a code for whether radioactive or stable element analysis was to be done, island and atoll designations, and a sequence number. After canning, the sample was sent for analysis by gamma spectrometry. When gamma counting was completed, the sample in the can was sent to a contract laboratory for wet chemistry. Blind duplicates and standards were included with each group of samples sent for analysis. A complete report on the quality control program using blind duplicates and standards will be a part of this series of reports.[3] The quality control program was conducted independently by Dr. C. D. Jennings of the Western Oregon State College.

Vegetation Samples

Most vegetation samples were a composite of one or more individual fruits. A coconut sample consisted of five coconuts. They were dissected into meat and juice. A papaya sample consisted of 20 papayas that were dissected into meat, skin, and seeds. A *Pandanus* sample consisted of two *Pandanus* fruits; the keys of the *Pandanus* were extracted and the juice was squeezed from them. The ends of the *Pandanus* keys were also kept for analysis. A breadfruit sample consisted of 5 breadfruit, a banana sample was 3 bunches of bananas, a squash sample consisted of 1 squash fruit, and there were about 20 *Morinda* fruit to a sample. The breadfruit, banana, squash, and *Morinda* fruits were dissected into meat and skin. The *Tacca* and taro root samples consisted of five tubers. They were also dissected into meat and skin. The leaves of the *Messerschmedia*, *Scaevola*, breadfruit, and *Pisonia* trees were cut into small segments.

To ensure no cross contamination with the soil samples, the fruit processing and canning was conducted in a different laboratory. Between January and September 1979, 961 vegetation samples were processed.

The vegetation samples were received frozen and maintained frozen at LLNL until processed. They were in large plastic bags wrapped with tape with a field log number and location indicated on the bag. The information on the sample was recorded in the sample log books. They were processed by atoll, island, and fruit type.

Before the plant samples were dissected, the fruits and roots were washed very carefully to remove any adherent soil particles. The plant samples were dissected into different segments (i.e., meat, skin, and seeds). These

segments were put into plastic containers that were identified with the field log number, segment name, field description, and container number. Wet weights of the samples were determined.

The samples were subsequently freeze-dried to remove the water from the vegetation. Each day ice was removed from the condenser and when ice ceased to form on the condenser, the samples were considered dried.

After freeze-drying, the sample dry weights were determined. The dried vegetation material was ground to a homogeneous texture in Waring blenders. These homogenous samples were pressed into the aluminum tuna and bean cans until a uniform density was achieved. Samples insufficient in volume to fill a can were packaged into vials, which had a volume of 42 cm^3.

The cans were then sealed and a log number was given to each sample. The log number had the year and month the sample was taken, plant type, a code for whether radioactive or stable element analysis was to be done, island and atoll designations, and a sequence number. Sample weights were recorded for calculation of specific radionuclide concentrations. The cans were first sent for gamma spectrometry analysis and then to a contract laboratory for analysis requiring radiochemical separations.

Coconut and Pandanus juices were processed by a slightly different procedure. The coconut juice was poured from the coconut; the Pandanus juice was squeezed from the Pandanus keys at 50,000 psi. The juices were measured, transferred to 1-liter beakers, and formaldehyde added to prevent bacterial degredation. The beakers were placed in mechanical convection ovens at 40°C and the liquid evaporated to a volume of approximately 200 ml. The juice was then poured into the tuna can. To ensure that all material was removed from the sides and bottom of the beaker, the beaker was acid rinsed during transfer. Formaldehyde was again added to prevent bacterial action in the can. The can was sealed and weighed.

Blind duplicates and standards were included with each set of samples sent for analysis.

Animal Samples

The animal samples were processed in the same manner as were the vegetation samples, the only difference being that formaldehyde was pipetted into the tuna or bean can after the sample had been pressed.

The animals were the smallest category of samples collected and processed. There were 153 samples processed between September and December of 1979. Blind duplicates and standards were included with each set of samples sent for analysis.

MARINE SAMPLES

Water Samples

Filtered water samples were transferred to large, plastic processing containers (100 liter), acidified, and standardized carrier solutions added. The radionuclides were separated from the water using published procedures.[4] The particulate fractions (filters) were dry ashed at 450°C and gamma counted. Then they were dissolved and specific radionuclides separated by standard procedures.[4]

Sediment Samples

Frozen sediment samples were thawed, weighed wet, and dried in ovens at 90°C. After the dry weight was determined, the sediment was homogenized using a shaker-type ball mill and placed in containers for radioanalysis by gamma spectrometry.

Fish and Invertebrate Samples

Biological samples from each location were numerically counted and partially thawed. The total weight and standard length or fork length of each fish was usually measured. The sex of each fish was determined and then it was dissected into muscle, bone, stomach contents, liver, skin, and remaining viscera. Each separated tissue and organ of the species from the same catch was pooled. Gills were separated from the fish but not analyzed. Our experience prior to 1978 showed the gills were sometimes contaminated with sediment. The gills are not eaten and there could be little academic information gained from their analysis because of the possible contamination. Clams were weighed, measured (total length), and dissected. The tissues removed for analysis included muscle, mantle, kidney, and remaining viscera. After the wet weight

was determined, each fish and clam tissue sample was dried in ovens at 90°C to constant dry weight and dry ashed in muffle furnaces at 450°C for approximately 72 h. The grey-white ash was then homogenized and placed in suitable counting containers. In some instances the samples were too small to achieve suitable counting efficiency and were stored for future analysis if needed.

All samples (except the filtered water) were first counted on Ge (Li) gamma spectrometers. A large number were split; a fraction was retained at LLNL and the remainder, along with blanks, duplicates, and standards, sent to a contract laboratory for analysis.

SUMMARY OF THE COLLECTED SAMPLES

Over 5400 soil, animal, vegetation, fish, clam, sediment, cistern water, and groundwater samples were collected from the 12 atolls and 2 islands and prepared for analysis during the Northern Marshall Islands survey field operations. The number of total samples that were prepared for analysis are listed in Tables 2 and 3. Duplicate samples sent for analysis are listed in Table 4.

The terrestrial samples are summarized according to major category, atoll, and island in Table 5. A summary of fish and clam samples arranged by atoll and island appears in Tables 6 to 8. The water and sediment sample summary appears in Table 9.

A more detailed breakdown of plant, animal, fish, and clam samples by atoll and island is listed in Tables 10 through 36. The summary for each atoll is accompanied by a figure showing the atoll and code letter and numbers for islands (Figs. 2-16). Thus, it is possible to determine the number of samples collected at various regions of the atoll.

SUMMARY OF RADIONUCLIDE ANALYSES

We analyzed most samples for ^{90}Sr, ^{137}Cs, $^{239+240}Pu$, and ^{241}Am. In some samples ^{238}Pu and ^{241}Pu were also measured. Gamma-spectrometry measurements were made on all separated samples at LLNL using a variety of Ge (Li)-diode detector systems. Counting times were usually 1000 min or longer for each sample.

A general-purpose computer program, GAMANAL, was used for the data reduction of all generated spectra. The program searches a library of long-lived nuclear explosion products, activation products, and naturally occurring radionuclides to identify radionuclides from any observed photopeak in the gamma spectra. It also generates an upper limit amount of specific radionuclides based on those spectra regions where signals would be seen if the radionuclides were present in detectable quantities. For example, listed in Table 37 are the detection limit values for various radionuclides based on the average weight of marine tissue shown for a counting period of 1000 min. For an average-size fish bone sample, ^{137}Cs would not have been detected by gamma spectrometry if the concentration was less than 11 pCi/kg dry weight. A more complete description of the gamma equipment used, calibration, sensitivity of detection, uncertainties, and methods for setting upper limits is given in Ref. 5. The total gamma-spectroscopy analyses are summarized in Table 38.

Wet chemistry analyses performed by standard methodology are summarized according to radionuclide and atoll or island in Table 39. The total 26,018 analyses, both gamma spectroscopy and wet chemistry, are summarized in Table 40 according to radionuclide and atoll or island.

DISCUSSION

It has taken a considerable effort to process and analyze the thousands of samples collected during the 3-mo survey. The processing alone took a full 12 mo and was completed in December of 1979. A vigorous analytical and quality control program has been underway since June of 1979. The final analytical results were completed in July of 1981.

The data bank resulting from the analyses of these samples provides the basis for estimating the radiological doses for inhabitants or potential inhabitants of the atolls. The assessments might also indicate areas where more data (and therefore samples) are required to fill a gap that occurred in the survey sample collection or to refine a critical assessment.

ACKNOWLEDGMENTS

The DOE-supported Northern Marshall Islands survey of 1978 was accomplished through the efforts of a great many people.

Victor Noshkin acted as cotechnical director and chief scientist on the first leg of the survey. His contribution to the planning phases of the project and coordination of the field survey on the first leg was invaluable. John Tipton of EG&G not only conducted a very successful aerial survey program, but did an excellent job as chief scientist on the second leg of the survey.

Roger Ray, Robert Keller, and John Stewart of the NVOO of the DOE did an excellent job in coordinating the project with other United States Government agencies and the Marshall Islands Government as well as handling the major logistics. Their efforts helped make for a smooth-running survey.

The thousands of samples returned to LLNL for analysis were collected by a group of dedicated people who spent many hours on the islands and lagoons at the atolls for as many days as was required to complete each leg of the survey. It was the superb effort of these people that enabled us to collect over 5400 samples to provide a base for making subsequent radiological dose assessments for the food chains at the atolls. The following people are commended for their outstanding work: William Phillips, Stanley Thompson, John Rehder, Regina Davis, Jim Schweiger, John Koranda, Dave McIntyre, Dave Hosmer, Ken Marsh, Paul Davis, Bob Spies, Jack Dawson, Bill Burke, Walt Martin, Bruce Clegg, Jim Johnson, Jack McNabb, Cleo Fry, Don Homan, Arnold Gazlay, and Gale Holladay from LLNL; Bima Akeke and Reynold DeBrum from the Trust Territory Government; Art Johnson from the University of Washington; and Jack Vandervort, Gerald Doran, and Otis Reed from the United States Environmental Protection Agency.

Another part of the survey included an attempt to develop more information on the average diet at some of the atolls. The Brookhaven National Laboratory took responsibility for this phase of the survey. Jan Naidu directed the dietary survey effort and Nathaniel Greenhouse and Evelyn Craighead supported him in the study.

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radiation survey--series II); and J.E. Jobst, N.A. Alcorn, D.E. Freed, A.L. McGibbon, K.W. Peek, D.B. Smith, and H.G. Smith (aerial radiation survey--series III).

The efforts of these people led to a very detailed and elegant picture of the external exposure in the Northern Marshall Islands. The aerial survey provides the data for estimating the external exposure to the inhabitants or future inhabitants of the atolls. The entire EG&G staff are complimented for their brillant performance.

A most critical phase of the terrestrial and marine program was the processing of over 5400 samples. It took 12 mo to complete this task and the following people are commended for their performance and perserverance to conclude the task in a 12-mo period: Jim Becker, Marie Cavaliere, Pat Cigliuti, Joane Davis, Regina Davis, Ray Jenkins, Pete Kellaris, Carl Latkin, Lee Llevano, Maryanne Loquist, Sue Oleson, John Rehder, Brian Springer, Carol Stoker, Stan Thompson, Patrick Yoshihiro, and Ora Lowe.

It was no small task to plan, field, and conduct the survey; process and analyze the thousands of samples; reduce the data from the aerial, terrestrial, and marine surveys; and develop the assessments. All of the above people are highly commended for bringing the entire project to a very successful conclusion.

William L. Robison
Technical Director
Northern Marshall Islands Survey

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JAS/adf/mat

APPENDIX: FIGURES AND TABLES

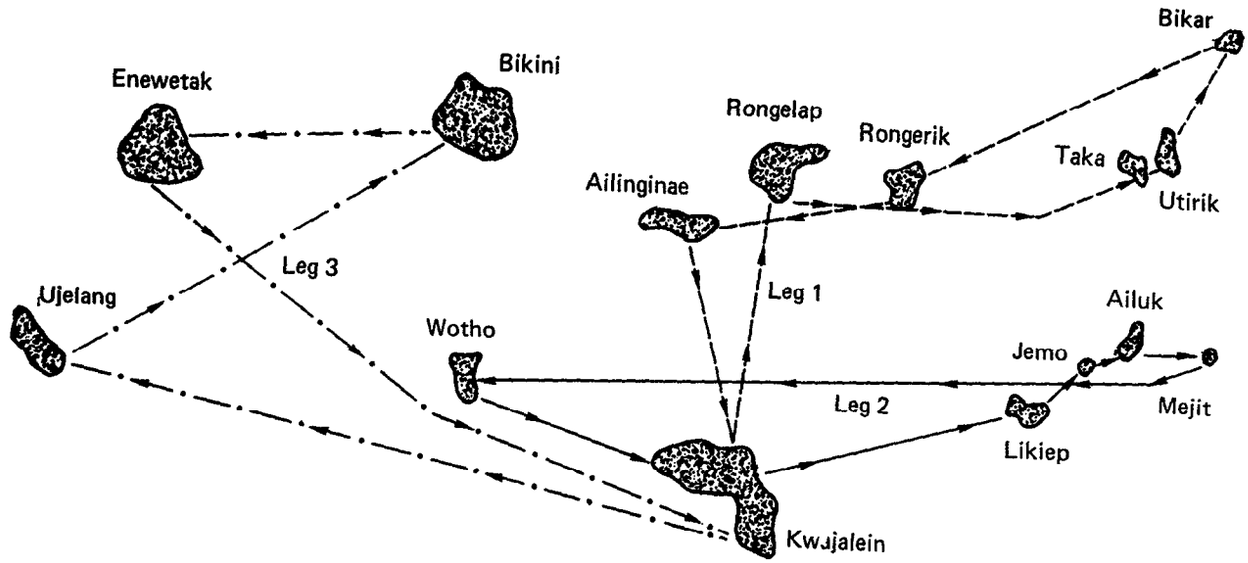

FIG. 1. Sequence of atolls and islands visted during the Northern Marshall Islands Survey.

TABLE 1. Atolls and islands where marine and terrestrial samples were collected in the Northern Marshall Islands survey.

Atoll or island	Number of islands	Survey days
	FIRST LEG	
	Field Days: September 18, 1978 to October 6, 1978	
Rongelap	9	7
Taka	3	1
Utirik	3	4
Bikar	3	1
Rongerik	6	2
Ailinginae	9	3
TOTAL	32	18
	SECOND LEG	
	Field Days: October 13, 1978 to October 28, 1978	
Likiep	7	4
Jemo	1	1
Ailuk	8	4
Mejit	1	1
Wotho	3	2
TOTAL	20	12
	THIRD LEG	
	Field Days: November 2, 1978 to November 16, 1978	
Ujelang	8	2
Bikini	14	8
Enewetak	2	1
TOTAL	24	11

TABLE 2. Total number of soil, vegetation, animal, fish, and clam tissue samples prepared for analysis; arranged by atoll or island.

Atoll or island	Number of samples prepared for analysis[a]					
	Soil	Vegetation	Animal	Fish	Clam	TOTAL
Rongelap	398	143	28	149	10	728
Taka	53	17	--	42	10	122
Utirik	271	116	22	42	12	463
Bikar	41	8	--	54	6	109
Rongerik	161	58	1	84	10	314
Ailinginae	225	79	2	90	12	408
Likiep	266	103	24	79	8	480
Jemo and Mejit	66	32	23	30	--	151
Ailuk	262	102	24	54	6	448
Wotho	174	48	15	60	7	304
Ujelang	279	114	14	42	8	457
Bikini	891	127	--	179	12	1209
Enewetak	6	14	--	60	--	80
TOTAL	3093	961	153	965	101	5273

[a]Values for animals, fish, and clams are the number of tissues and organs prepared for analysis.

TABLE 3. Total number of water and sediment samples prepared for analysis; arranged by atoll or island.

Atoll or island	Number of samples prepared for analysis				
	Lagoon water	Cistern water	Groundwater	Lagoon sediment	TOTAL
Rongelap	7	2	2	9	20
Taka	2	--	--	4	6
Utirik	4	1	1	6	12
Bikar	3	--	--	4	7
Rongerik	4	--	--	6	10
Ailinginae	4	1	--	10	15
Likiep	4	3	3	9	19
Jemo and Mejit	2	1	2	6	11
Ailuk	4	3	3	8	18
Wotho	4	1	1	7	13
Ujelang	5	1	1	5	12
Bikini	7	2	4	11	24
TOTAL	50	15	17	85	167

TABLE 4. Number of duplicate samples sent for analysis.

Atoll or island	Number of samples sent for analysis					
	Soil	Vegetation	Animal	Fish and clam	Water[a]	Lagoon sediments
Rongelap	42	15	1	14	--	1
Taka	4	--	--	5	--	--
Utirik	29	8	1	5	--	1
Bikar	6	--	--	4	--	--
Rongerik	18	6	--	10	--	1
Ailinginae	24	5	--	7	--	1
Likiep	30	8	--	12	--	1
Jemo	--	--	--	3	--	--
Ailuk	30	5	1	4	1	1
Mejit	6	--	1	--	1	--
Wotho	18	4	--	5	--	1
Ujelang	28	7	2	4	--	--
Bikini	127	10	--	--	--	--
TOTAL	362	68	6	73	2	7

[a]Lagoon or cistern water or groundwater. Does not include samples of blanks, spiked standards, or equatorial Pacific surface-water samples.

TABLE 5. Summary of terrestrial and marine samples prepared for analysis; arranged by major category, atoll, and island.

Location	Island number[b]	Number of samples prepared for analysis[a]					
		Soil	Vegetation	Animal	Reef fish	Pelagic and benthic fish	Clam
Rongelap Atoll							
Naen Is.	F-1	42	12	--	17	--	--
Yugui Is.	F-5	6	5	--	18	--	--
Loniuflal Is.	F-7	25	11	1	--	--	--
Auknen Is.	F-9	--	--	--	18	--	--
Kabelle Isl.	F-13	30	11	--	12	--	6
Mellu Is.	F-23	22	11	4	12	--	--
Enjaetok Is.	F-33	36	11	--	12	--	4
Rongelap Is.	F-42	158	64	22	12	--	--
Arbar Is.	F-43	59	10	2	--	--	--
Eniran (Busch) Is.	F-46	--	--	--	6	--	--
Tufa Is.	F-47	--	--	--	12	--	--
Borukka Is.	F-49	20	8	--	--	--	--
Lagoon	--	--	--	--	--	30	--
TOTAL		398	143	28	119	30	10
Taka Atoll							
Waatowerikku Is.	H-1	--	--	--	6	--	3
Taka Is.	H-4	47	16	--	6	--	6
Eluk Is.	H-5	6	1	--	18	--	1
Lagoon	--	--	--	--	--	12	--
TOTAL		53	17	--	30	12	10
Utirik Atoll							
Piji Is.	I-1	--	--	--	6	--	12
Eerukku Is.	I-2	--	--	--	6	--	--
Pigrak Is.	I-3	48	22	--	--	--	--
Utirik Is.	I-6	165	66	22	--	--	--
Aon Is.	I-8	58	28	--	18	--	--
Lagoon	--	--	--	--	--	12	--
TOTAL		271	116	22	30	12	12

TABLE 5. (Continued.)

Location	Island number[b]	Number of samples prepared for analysis[a]					
		Soil	Vegetation	Animal	Reef fish	Pelagic and benthic fish	Clam
Bikar Atoll							
Namar Is.	D-1	22	4	--	24	--	6
Namani Is.	D-2	6	1	--	--	--	--
Bikar Is.	D-4	13	3	--	18	--	--
Lagoon	--	--	--	--	--	12	--
TOTAL		41	8	--	42	12	6
Rongerik Atoll							
Jedibberbib Is.	G-1	6	6	--	18	--	6
Latoback Is.	G-2	25	8	1	--	--	--
Bigonattam Is.	G-5	12	2	--	--	--	--
Rongerik Is.	G-6	40	14	--	12	--	4
Enewetak Is.	G-11	66	24	--	18	--	--
Bock Is.	G-12	12	4	--	6	--	--
Lagoon	--	--	--	--	--	30	--
TOTAL.		161	58	1	54	30	10
Ailinginae Atoll							
Bokonikaiaru Is.	C-5	--	--	--	18	--	--
Majokoryaan Is.	C-8	14	4	--	--	--	--
Knox Is.	C-10	18	6	--	--	--	--
Ucchuwanen Is.	C-15	12	4	--	6	--	6
Kuobuen Is.	C-18	18	4	--	--	--	--
Ribinouri Is.	C-19	23	6	--	12	--	--
Enibuk Is.	C-23	52	24	--	--	--	--
Mogiri Is.	C-24	34	11	1	12	12	6
Manchinikon Is.	C-25	18	8	--	--	--	--
Sifo Is.	C-27	36	12	1	18	--	--
Lagoon	--	--	--	--	--	12	--
TOTAL		225	79	2	66	24	12

TABLE 5. (Continued.)

Location	Island number[b]	Number of samples prepared for analysis[a]					
		Soil	Vegetation	Animal	Reef fish	Pelagic and benthic fish	Clam
Likiep Atoll							
Rikuraru Is.	L-2	72	26	--	--	--	--
Mere Is.	L-3	--	--	--	6	--	--
Jeltonet Is.	L-13	18	7	--	--	--	--
Jiebaru Is.	L-30	33	14	--	--	--	--
--	L-31	--	--	--	--	--	4
Likiep Is.	L-37	71	24	24	6	--	--
Agony Is.	L-45	18	10	--	--	--	--
Etoile Is.	L-47	18	8	--	--	--	--
--	L-50	--	--	--	18	--	4
Kapenor Is.	L-55	36	14	--	28	--	--
--	L-58	--	--	--	18	--	--
Lagoon	--	--	--	--	--	3	--
TOTAL		266	103	24	76	3	8
Jemo and Mejit							
Jemo Is.	S-1	18	6	--	24	--	--
Mejit Is.	R-1	48	26	23	6	--	--
TOTAL		66	32	23	30	--	--
Ailuk Atoll							
Kapen Is.	A-1	24	8	--	12	--	--
Enijabro Is.	A-2	24	8	--	--	--	--
Enejelar Is.	A-4	28	10	--	--	--	--
Bigen Is.	A-7	22	10	--	--	--	--
Ajeleb Is.	A-11	--	--	--	18	--	2
Aliet Is.	A-20	23	10	--	6	--	--
Bererjan Is.	A-33	22	8	--	--	--	--
Ailuk Is.	A-51	77	33	24	--	--	--
Agulve Is.	A-53	42	15	--	12	--	--
Lagoon	--	--	--	--	--	6	4
TOTAL		262	102	24	48	6	6

TABLE 5. (Continued.)

Location	Island number[b]	Number of samples prepared for analysis[a]					
		Soil	Vegetation	Animal	Reef fish	Pelagic and benthic fish	Clam
Wotho Atoll							
Medyeron Is.	M-1	48	6	--	12	--	3
Wotho Is.	M-4	90	31	15	--	--	--
Ruisuwaa Is.	M-12	--	--	--	18	--	--
Kabben Is.	M-17	36	11	--	18	--	4
Lagoon	--	--	--	--	--	12	--
TOTAL		174	48	15	48	12	7
Ujelang Atoll							
Pokon Is.	J-5	18	5	--	6	--	--
--	J-13	12	4	--	--	--	--
Daisu Is.	J-17	35	14	--	--	--	--
Ujelang Is.	J-18	129	62	14	6	--	4
Burle Is.	J-20	13	5	--	--	--	--
Eimnlapp Is.	J-22	22	4	--	12	--	4
Ennimenetto Is.	J-23	20	10	--	--	--	--
Kalo Is.	J-25	30	10	--	--	--	--
Lagoon	--	--	--	--	--	18	--
TOTAL		279	114	14	24	18	8

TABLE 5. (Continued.)

Location	Island number[b]	Number of samples prepared for analysis[a]					
		Soil	Vegetation	Animal	Reef fish	Pelagic and benthic fish	Clam
Bikini Atoll							
Nam Is.	B-1	196	--	--	24	--	--
Iroij Is.	B-2	59	--	--	--	--	--
Odrik Is.	B-3	29	--	--	--	--	--
Lomilik Is.	B-4	94	--	--	--	--	--
Aomen Is.	B-5	50	--	--	24	--	--
Bikini Is.	B-6	78	32	--	12	--	4
Rojkere Is.	B-10	18	--	--	12	--	8
Eneu Is.	B-12	21	89	--	18	--	--
Aerokoj Is.	B-13	71	4	--	18	--	--
Lele Is.	B-15	22	--	--	--	--	--
Eneman Is.	B-16	36	--	--	--	--	--
Enidrik Is.	B-17	188	--	--	24	--	--
Lukoj Is.	B-18	17	--	--	--	--	--
Jelete Is.	B-19	12	2	--	--	--	--
Borkdrlul Is.	B-23	--	--	--	12	--	--
Lagoon	--	--	--	--	--	35	--
TOTAL		891	127	--	144	35	12
Enewetak Atoll							
Belle Is.	E-2	6	2	--	18	--	--
Enjebi Is.	E-10	--	12	--	12	--	--
Aomon Is.	E-19	--	--	--	6	--	--
Bunit Is.	E-24	--	--	--	12	--	--
Enewetak Is.	E-37	--	--	--	12	--	--
TOTAL		6	14	--	60	--	--

[a]Values for animals, fish, and clams are the number of tissues and organs prepared for analysis.

[b]Corresponds to islands shown in Figs. 2 to 16.

TABLE 6. Summary of reef fish samples collected; arranged by atoll and island.

Location	Number of fish collected								
	Mullet[a]	Mullet[b]	Convict surgeon-fish	Unicorn-fish	Rabbit-fish	Rudder-fish	Goat-fish	Thread-fin	Parro-fish
Rongelap									
F-1[c]	--	18 (16)[d]	51 (50)	--	--	--	13 (13)	--	--
F-5	4 (2)	--	42 (36)	--	--	--	--	--	15 (0)
F-9	13 (0)	--	--	--	--	--	43 (30)	--	--
F-13	--	15 (0)	--	--	--	--	59 (51)	--	--
F-23	12 (9)	--	44 (38)	--	--	--	--	--	--
F-33	--	--	45 (22)	--	--	--	65 (43)	--	--
F-42	--	--	45 (33)	--	--	--	53 (46)	--	--
F-46	--	--	27 (9)	--	--	--	--	--	--
F-47	12 (9)	--	22 (15)	--	--	--	--	--	--
Taka									
H-1	--	34 (33)	--	--	--	--	--	--	--
H-4	--	20 (11)	33 (20)	--	--	--	--	--	--
H-5	--	16 (16)	26 (24)	--	--	--	--	--	--
Utirik									
I-1	--	--	--	--	--	--	76 (73)	--	--
I-2	--	--	--	--	--	23 (9)	--	--	--
I-8	--	--	3 (0)	--	--	--	--	7 (8)	1 (1)
Bikar									
D-1	3 (0)	7 (1)	7 (4)	--	--	--	--	--	2 (1)
D-4	--	60 (52)	55 (34)	--	--	--	--	--	6 (1)
Rongerik									
G-1	--	15 (9)	64 (61)	--	--	--	--	6 (1)	--
G-6	--	--	45 (20)	--	--	--	19 (10)	--	--
G-11	--	20 (14)	45 (32)	--	--	--	--	--	2 (2)
G-12	--	--	67 (63)	--	--	--	--	--	--

TABLE 6. (Continued.)

Location	Number of fish collected								
	Mullet[a]	Mullet[b]	Convict surgeon-fish	Unicorn-fish	Rabbit-fish	Rudder-fish	Goat-fish	Thread-fin	Parrot-fish
Ailinginae									
C-5	5 (3)	--	16 (8)	--	--	--	28 (21)	--	--
C-15	--	--	--	--	--	--	64 (43)	--	--
C-19	14 (9)	--	26 (21)	--	--	--	--	--	--
C-24	--	--	26 (18)	--	--	--	--	--	9 (1)
C-27	3 (1)	14 (12)	73 (51)	--	--	--	--	--	--
Lagoon	--	37 (25)	41 (12)	--	--	--	--	--	4 (2)
Likep									
L-3	--	--	--	--	13 (11)	--	--	--	--
L-37	8 (8)	--	--	--	--	--	28 (22)	--	--
L-50	11 (11)	--	36 (32)	--	--	--	25 (16)	--	--
L-55	7 (5)	--	14 (7)	--	--	25 (24)	--	--	1 (0)
L-58	--	--	48 (21)	--	--	--	56 (8)	--	22 (19)
Jemo Is.									
S-1	--	--	71 (35)	12 (7)	--	--	--	28 (13)	--
Ailuk									
A-1	7 (5)	--	17 (14)	--	--	--	--	--	--
A-11	18 (2)	--	24 (9)	--	--	--	45 (30)	--	--
A-20	--	--	--	--	--	--	31 (23)	--	--
A-53	7 (5)	--	--	--	--	--	23 (17)	--	--
Mejit Is.									
R-1	--	--	--	--	--	70 (20)	--	--	--
Wotho									
M-1	--	55 (43)	--	--	--	--	22 (19)	--	4 (0)
M-12	--	37 (25)	41 (12)	--	--	--	--	--	4 (2)
M-17	3 (1)	--	89 (49)	--	--	--	43 (9)	--	--
Ujelang									
J-5	--	--	--	--	--	--	26 (10)	--	--
J-8	--	--	--	--	--	--	31 (10)	--	--
J-22	--	17 (17)	20 (13)	--	--	--	--	--	--

TABLE 6. (Continued.)

Location	Number of fish collected								
	Mullet[a]	Mullet[b]	Convict surgeon-fish	Unicorn-fish	Rabbit-fish	Rudder-fish	Goat-fish	Thread-fin	Parrotfish
Bikini									
B-1	12 (11)	18 (13)	4 (0)	--	--	--	33 (25)	--	--
B-5	8 (5)	24 (12)	20 (12)	--	--	--	22 (11)	--	--
B-6	--	--	55 (31)	--	--	--	39 (26)	--	--
B-10	--	--	46 (30)	--	--	--	42 (32)	--	--
B-12	--	21 (13)	64 (45)	--	--	--	42 (38)	--	--
B-13	8 (3)	--	31 (18)	--	--	--	37 (20)	--	--
B-17	9 (0)	18 (9)	--	--	--	--	37 (11)	--	5 (0)
B-23	--	35 (23)	--	--	--	--	47 (36)	--	--
Enewetak									
E-2	--	17 (9)	22 (13)	--	--	--	22 (17)	--	--
E-10	--	--	54 (26)	--	--	--	26 (12)	1 (0)	--
E-19	--	--	46 (27)	--	--	--	--	--	--
E-24	22 (18)	--	51 (15)	--	--	--	--	--	--
E-27	--	--	8 (3)	3 (2)	--	--	--	--	--
TOTAL[e]	186	461	1523	15	13	118	1097	41	72

[a] *Crenimugil crenilabis*.

[b] *Neomyxus chaptalii*.

[c] Lettered numbers correspond to islands shown in Figs. 2 to 16 and listed in Table 5.

[d] Number of males in parenthesis determines number of females by difference.

[e] Total reef fish collected was 3526.

TABLE 7. Summary of pelagic and benthic fish samples collected; arranged by atoll and island.

Location	Number of fish collected								
	Grouper	Jack	Rainbow runner	Grey snapper	Red snapper	Snapper (pigfish)	Bonito	Tuna	Mackerel
Rongelap									
Lagoon	--	--	1 (1)	1 (0)[a]	--	--	2 (2)	--	2 (1)
Taka									
H-1[b]	--	--	--	--	--	2 (0)	--	--	--
Lagoon	--	1 (0)	--	--	--	--	--	--	--
Utirik									
I-8	1 (0)	--	--	--	--	--	--	--	--
Lagoon	1 (1)	1 (1)	--	--	--	--	--	--	--
Bikar									
Lagoon	--	4 (3)	--	--	--	--	--	--	--
Rongerik									
Lagoon	1 (1)	1 (0)	--	2 (1)	--	--	--	2 (0)	1 (0)
Ailinginae									
C-24	1 (0)	--	--	--	--	2 (2)	--	--	--
Lagoon	--	--	1 (1)	--	--	--	--	--	1 (0)
Likep									
Lagoon	--	--	--	--	--	--	--	--	1 (0)
Ailuk									
Lagoon	--	--	--	--	--	--	--	--	1 (0)
Wotho									
Lagoon	--	--	1 (1)	1 (1)	--	--	--	--	--

TABLE 7. (Continued.)

Location	Number of fish collected								
	Grouper	Jack	Rainbow runner	Grey snapper	Red snapper	Snapper (pigfish)	Bonito	Tuna	Macker
Ujelang									
J-5	--	14 (0)	--	--	--	--	--	--	--
J-18	--	73 (47)[c]	--	--	--	--	--	--	--
Lagoon	--	1 (0)	--	--	--	--	--	--	--
Bikini									
Lagoon	--	1 (0)	--	2 (1)	2 (1)	--	--	--	1 (0)
TOTAL[d]	4	94	3	6	2	4	2	2	7

[a]Number of males in parenthesis determines number of females by difference.

[b]Lettered numbers correspond to islands shown in Figs. 2 to 16 and listed in Table 5.

[c]Juvenile jacks.

[d]Total pelagic and benthic fish collected was 124.

TABLE 8. Summary of clam samples collected; arranged by atoll and island.

Location	Number of clams collected			
	Tridacna gigas	Tridacna squamosa	Tridacna crocea	Hippopus hippopus
Rongelap				
F-13[a]	--	--	--	2
F-33	--	--	--	1
Taka				
H-1	--	--	--	1
H-4	--	--	--	1
H-5	1	--	--	--
Utirik				
I-1	--	--	15	4
Bikar				
D-1	--	--	2	1
Rongerik				
G-1	--	--	--	1
G-6	--	--	--	1
G-11	1	--	--	--
Ailinginae				
C-15	--	1	--	--
C-24	--	1	--	--
Likep				
L-31	--	2	--	--
L-50	--	--	--	2
Ailuk				
A-11	--	--	2	--
Lagoon	--	1	--	--
Wotho				
M-1	--	--	--	1
M-17	--	--	--	1

TABLE 8. (Continued.)

Location	Number of clams collected			
	Tridacna gigas	Tridacna squamosa	Tridacna crocea	Hippopus hippopus
Ujelang				
J-22	--	--	8	--
Bikini				
B-6	--	--	2	--
B-10	--	--	8	1
TOTAL[b]	2	5	37	19

[a]Lettered numbers correspond to islands shown in Figs. 2 to 16 and listed in Table 5.

[b]Total clams collected was 63.

TABLE 9. Summary of water and sediment samples collected; arranged by atoll and island.

Atoll or island	Lagoon water[a]	Cistern water	Ground-water	Lagoon sediment[b]
Rongelap	F-1,[c] F-7, F-9, F-23, F-33, F-42, F-47	F-42 (2)	F-42 (2)	F-1, F-7, F-9, F-13, F-23, F-33, F-42, F-47
Taka	H-1, H-5	--	--	North section, H-1, H-4, H-5, pass
Utirik	North section (2), I-1, I-7	I-6	I-6	North section (2), I-1, I-6, I-8, I-7
Bikar	D-1, north of D-1, D-4	--	--	D-1, north of D-1, D-3, D-4
Rongerik	G-1, G-4, G-6, G-12	--	--	G-1, G-2, G-4, G-6, G-9, G-12
Ailinginae	C-4, C-5, C-12, C-24	C-23	--	C-2, C-3, C-4, C-5, C-10, C-15, C-17, C-19, C-24, C-27
Likiep	L-2, L-37, L-50, L-55,	L-2, L-37 (2)	L-2 (2), L-37	L-2, L-10, L-13, L-32, L-37, L-50, L-54, L-55, L-57
Jemo	Leeward side	--	--	Leeward side (4)
Ailuk	A-2, A-20, A-51, A-53,	A-2, A-51 (2)	A-2, A-51 (2)	A-2, A-10, A-20, A-35, A-51, A-52, A-53, reef north of A-53
Mejit	Leeward side	1	1, lake	Leeward side (2)
Wotho	M-1, M-3, M-17, M-20	M-3	M-3	M-1, M-3, M-12, M-17, M-18, M-19, M-20

TABLE 9. (Continued.)

Atoll or island	Lagoon water[a]	Cistern water	Ground-water	Lagoon sediment[b]
Ujelang	J-5, J-17, J-18, J-22, J-25	J-18	J-18	J-1, J-5, J-18, J-22, J-25
Bikini	B-1, B-6, B-10, B-12, B-13, B-17, B-22	B-6, B-12	B-1, B-6, B-12, B-17	B-1 (2), B-6, B-10, B-12, B-13, B-17, B-18, B-21, B-22, B-23
TOTAL	50	15	17	85

[a]Lagoon water (surface sample) collected near the designated island.

[b]Sediment collected near designated island at water depths of 3 to 6 m.

[c]Lettered numbers correspond to islands shown in Figs. 2 to 16 and listed in Table 5.

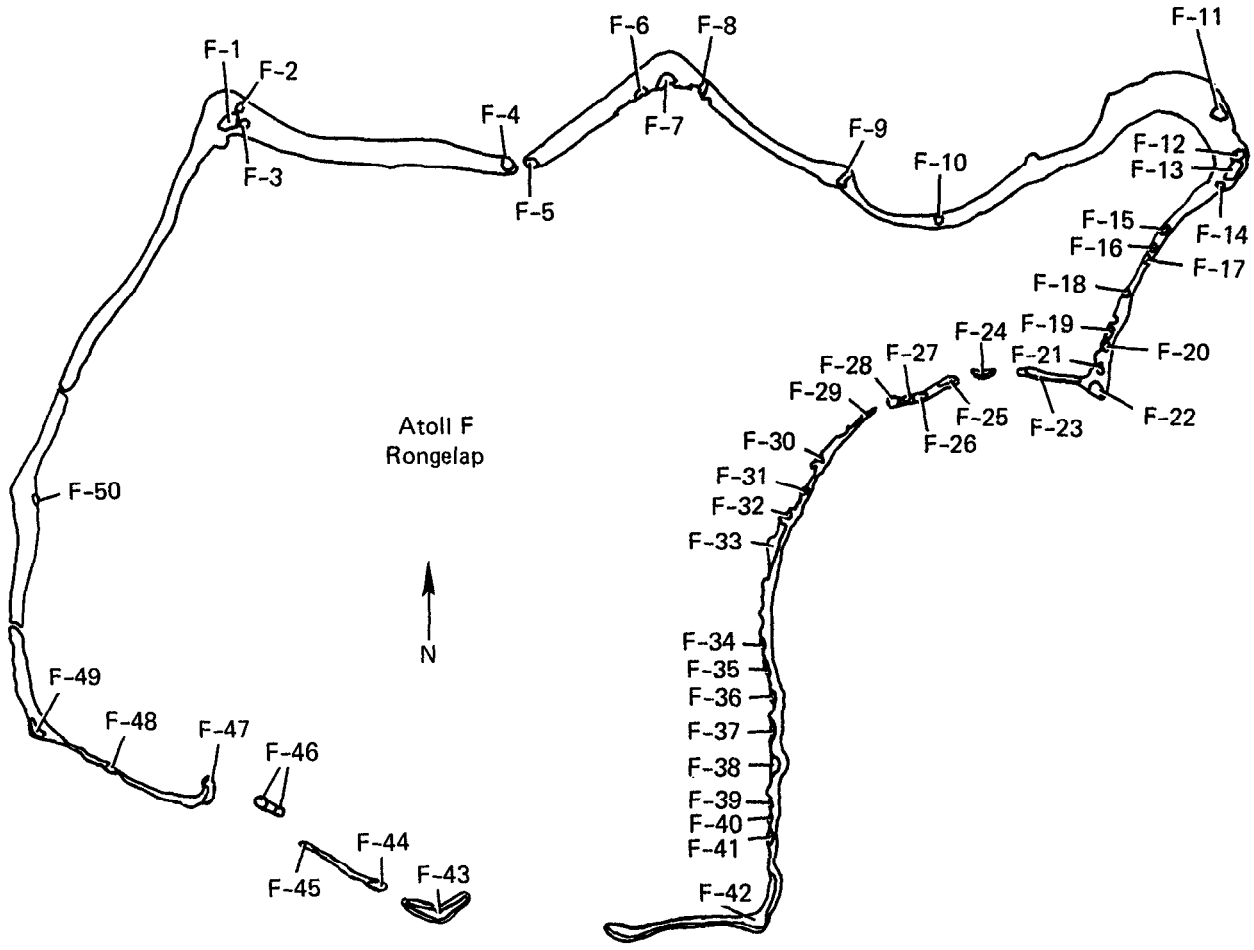

FIG. 2. Rongelap Atoll with code letter and numbers for the islands.

TABLE 10. Summary of soil, vegetation, and animal samples collected from Rongelap Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Naen Island (F-1)[a]	
Soil	42	42
Coconut	2 (11)[b]	5
Messerschmedia leaf	2	2
Sprouted coconut	1 (5)	2
Pandanus	1 (4)	2
Scaevola leaf	1	1
TOTAL		
Soil	42	42
Vegetation	7	12
	Yugui Island (F-5)	
Soil	6	6
Pandanus	2 (4)	4
Pandanus leaf	1	1
TOTAL		
Soil	6	6
Vegetation	3	5
	Loniuflal Island (F-7)	
Soil	25	25
Coconut	4 (22)	7
Tacca	1 (5*)[c]	2
Pisonia leaf	1	1
Pandanus	1	1
Coconut crab	1	1
TOTAL		
Soil	25	25
Vegetation	7	11
Animal	1	1

TABLE 10. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Kabelle Island (F-13)	
Soil	30	30
Coconut	4 (20)	8
Morinda fruit	1 (20*)	2
Sprouted coconut	1 (5)	1
TOTAL		
Soil	30	30
Vegetation	6	11
	Mellu Island (F-23)	
Soil	22	22
Coconut	3 (14)	5
Pandanus	2 (5)	4
Tacca	1 (5*)	2
Coconut crab	3	4
TOTAL		
Soil	22	22
Vegetation	6	11
Animal	3	4
	Enjaetok Island (F-33)	
Soil	36	36
Coconut	4 (20)	8
Pandanus	1 (4)	2
Morinda fruit	1 (20*)	1
TOTAL		
Soil	36	36
Vegetation	6	11

TABLE 10. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Rongelap Island (F-42)	
Soil	158	158
Coconut	21 (95)	40
Pandanus	9 (21)	18
Pandanus leaf	3	3
Breadfruit	1 (5)	2
Pisonia leaf	1	1
Chicken	1	6
Pig	2	16
TOTAL		
Soil	158	158
Vegetation	35	64
Animal	3	22
	Arbar Island (F-43)	
Soil	59	59
Pandanus	2 (5)	4
Coconut	1 (6)	2
Tacca	1 (5*)	2
Morinda fruit	1 (20*)	1
Pandanus leaf	1	1
Coconut crab	2	2
TOTAL		
Soil	59	59
Vegetation	6	10
Animal	2	2

TABLE 10. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Borukka Island (F-49)	
Soil	20	20
Pandanus	2 (5)	4
Coconut	1 (5)	2
Tacca	1 (5*)	2
TOTAL		
Soil	20	20
Vegetation	4	8

[a]Lettered numbers correspond to islands shown in accompanying figure.
[b]Numbers in parentheses are the actual number of individuals for the composite sample if there is greater than a one-to-one ratio.
[c]Numbers followed by an asterisk and within parenthesis are the estimated average number of individuals for the composite sample.

TABLE 11. Summary of fish samples collected from Rongelap Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
F-1[a]	Mullet (B)[b]	18	90±30	164±19	16	2
F-1	Convict surgeonfish	51	30±8	86±8	50	1
F-1	Goatfish	13	104±26	166±15	13	--
F-5	Mullet (A)[c]	4	724±80	322±12	2	2
F-5	Convict surgeonfish	42	33±10	85±9	36	6
F-5	Parrotfish	15	546±141	238±21	--	15
F-9	Mullet (A)	13	750±68	322±12	--	13
F-9	Goatfish	43	119±36	180±17	30	13
F-13	Mullet (B)	15	445±84	263±15	--	15
F-13	Goatfish	59	61±14	141±11	51	8
F-23	Mullet (A)	12	473±65	261±13	9	3
F-23	Convict surgeonfish	44	29±8	83±8	38	6
F-33	Convict surgeonfish	45	95±16	129±8	22	23
F-33	Goatfish	65	78±24	156±15	43	22
F-42	Convict surgeonfish	45	73±33	109±18	33	12
F-42	Goatfish	53	79±22	154±12	46	7
F-46	Convict surgeonfish	27	73±22	113±12	9	18
F-47	Mullet (A)	12	665±187	298±29	4	8
F-47	Convict surgeonfish	22	49±14	97±12	15	7
Lagoon	Rainbow runner	1	1983±66	538±62 (*)[d]	1	--
Lagoon	Grey snapper	1	670	4917	--	1

TABLE 11. (Continued.)

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
Lagoon	Bonito	1	525	3002 (*)	1	--
Lagoon	Bonito	1	575	3884 (*)	1	--
Lagoon	Mackerel	2	1406±440	518±53 (*)	1	1
TOTAL		604	85.5 kg[e]	--	421	183

[a]Lettered numbers correspond to islands shown in accompanying figure and listed in Table 5.

[b]Mullet (B): Neomyxus chaptalii.

[c]Mullet (A): Crenimugil crenilabis.

[d]Numbers followed by an asterik that is within parenthesis are the fork length.

[e]The average weights are multiplied by the respective number of samples and then totaled.

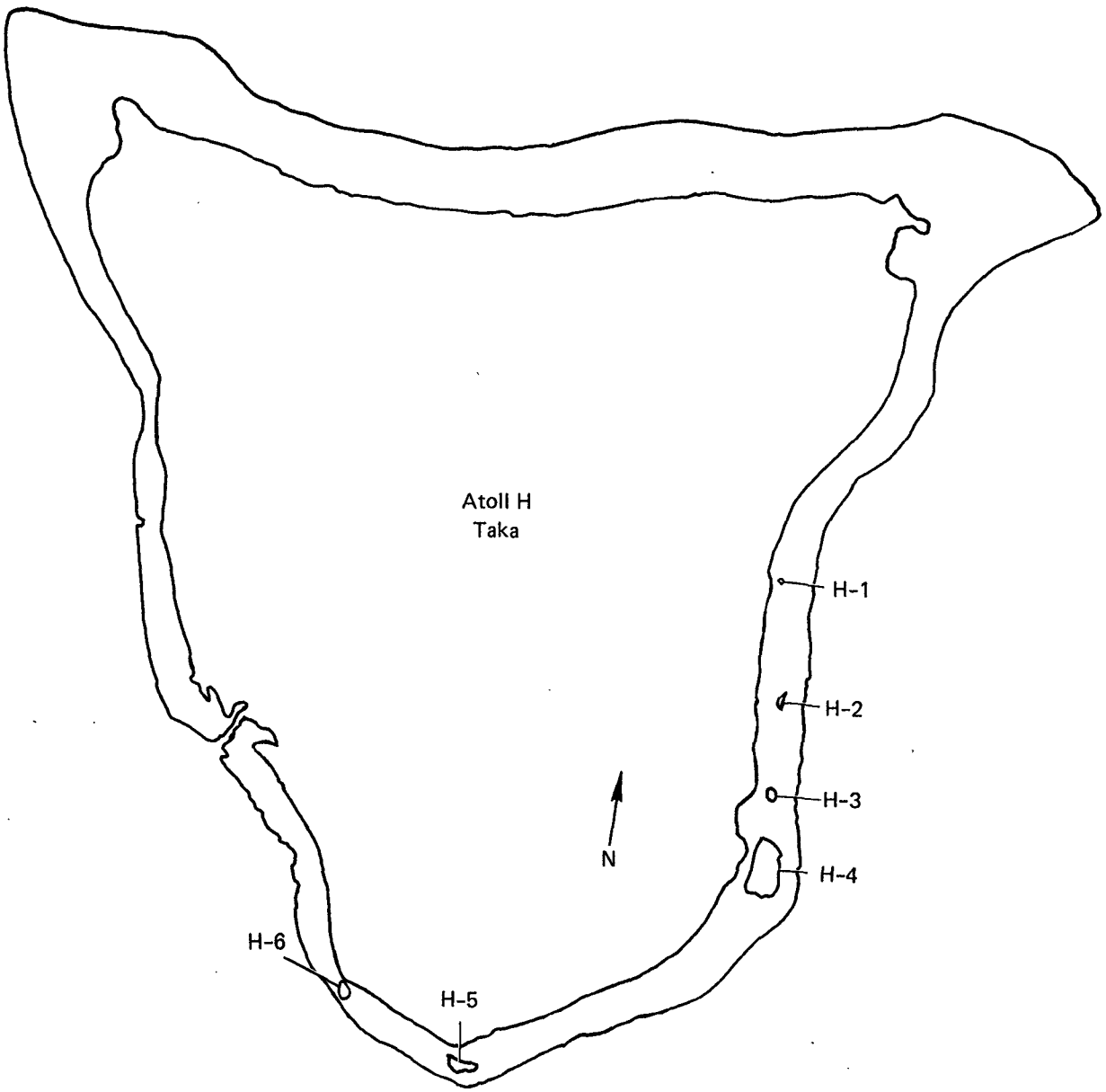

FIG. 3. Taka Atoll with code letter and numbers for the islands.

TABLE 12. Summary of soil and vegetation samples collected from Taka Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Taka Island (H-4)	
Soil	47	47
Coconut	5 (32)	10
Pandanus	3 (6)	6
TOTAL		
Soil	47	47
Vegetation	8	16
	Eluk Island (H-5)	
Soil	6	6
Coconut	1 (5)	1

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 13. Summary of fish samples collected from Taka Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
H-1	Mullet (B)	34	182±36	207±9	33	1
H-1	Snapper (pigfish)	2	2618±1040	542±48	--	2
H-4	Mullet (B)	20	161±38	204±26	11	9
H-4	Convict surgeonfish	33	108±27	132±10	20	13
H-5	Mullet (B)	16	153±45	187±56	16	--
H-5	Convict surgeonfish	26	39±16	93±12	24	2
Lagoon	Jack	1	5585	670 (*)	--	1
TOTAL		132	27.2 kg	--	104	28

NOTE: For explanation of table entries see footnotes, Table 11.

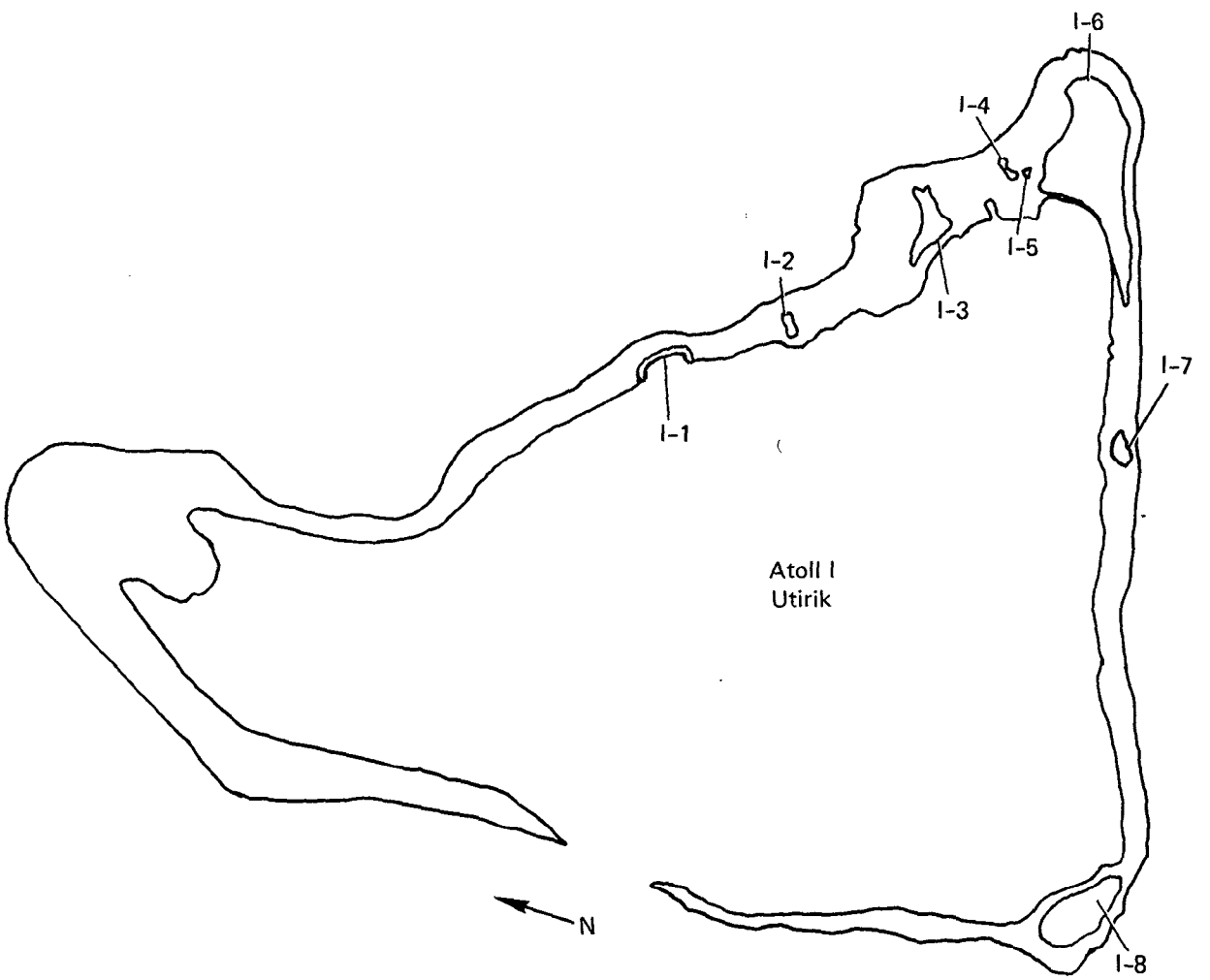

FIG. 4. Utirik Atoll with code letter and numbers for the islands.

TABLE 14. Summary of soil, vegetation, and animal samples collected from Utirik Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Pigrak Island (I-3)	
Soil	48	48
Coconut	6 (26)	12
Pandanus	5 (10)	10
TOTAL		
Soil	48	48
Vegetation	11	22
	Utirik Island (I-6)	
Soil	165	165
Coconut	18 (86)	39
Pandanus	9 (18)	18
Breadfruit	2 (9)	4
Papaya	1 (15)	3
Banana	1 (10*)	2
Pig	2	16
Chicken	1 (2)	6
TOTAL		
Soil	165	165
Vegetation	31	66
Animal	3	22

TABLE 14. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Aon Island (I-8)	
Soil	58	58
Coconut	10 (43)	19
Pandanus	3 (6)	4
Tacca	1 (5*)	2
Breadfruit	1 (4)	2
Breadfruit leaf	1	1
TOTAL		
Soil	58	58
Vegetation	16	28

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 15. Summary of fish samples collected from Utirik Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
I-1	Goatfish	76	85±24	164±17	73	3
I-2	Rudderfish	23	123±20	176±10	9	14
I-8	Convict surgeonfish	3	152±32	141±11	--	3
I-8	Threadfin	7	847±255	322±28	4	3
I-8	Parrotfish	1	680	270	1	--
I-8	Grouper	1	2549	480	--	1
Lagoon	Grouper	1	853	378	1	--
Lagoon	Jack	1	1363	400 (*)	1	--
TOTAL		113	21.1 kg	--	89	24

NOTE: For explanation of table entries see footnotes, Table 11.

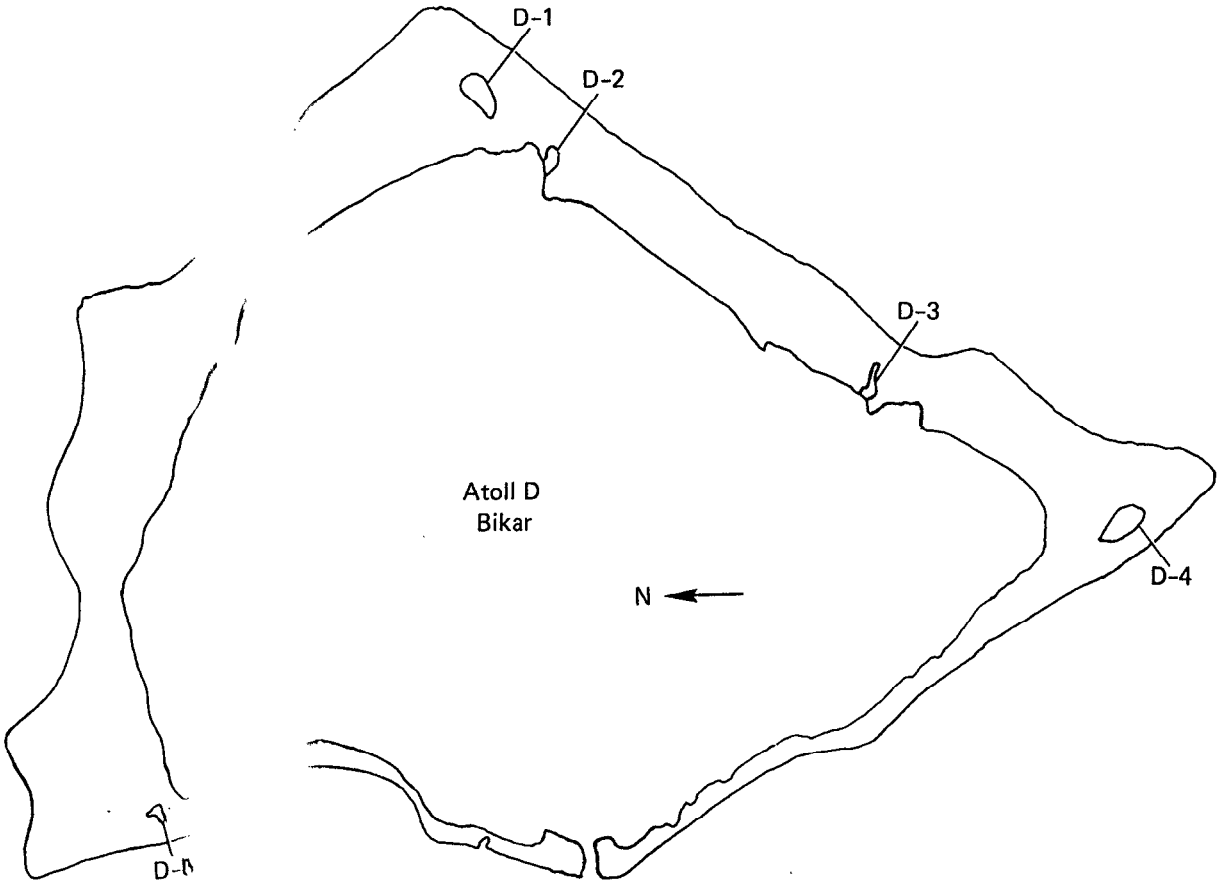

FIG. 5. Bikar Atoll with code letter and numbers for the islands.

TABLE 16. Summary of soil and vegetation samples collected from Bikar Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Namar Island (D-1)	
Soil	22	22
Pisonia leaf	4	4
	Namani Island (D-2)	
Soil	6	6
Pisonia leaf	1	1
	Bikar Island (D-4)	
Soil	13	13
Coconut	1 (3)	2
Pisonia leaf	1	1
TOTAL		
Soil	13	13
Vegetation	2	3

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 17. Summary of fish samples collected from Bikar Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
D-1	Mullet (A)	3	691±117	312±18	--	3
D-1	Mullet (B)	7	197±50	198±56	1	6
D-1	Convict surgeonfish	7	119±17	137±6	4	3
D-1	Parrotfish	2	578±216	260±30	1	1
D-4	Mullet (B)	60	75±16	150±12	52	8
D-4	Convict surgeonfish	55	57±11	103±10	34	21
D-4	Parrotfish	6	206±24	174±10	1	5
Lagoon	Jack	2	2105±435	485±42 (*)	1	1
Lagoon	Jack	2	1440±540	421±72 (*)	2	--
TOTAL		144	21.4 kg	--	96	48

NOTE: For explanation of table entries see footnotes, Table 11.

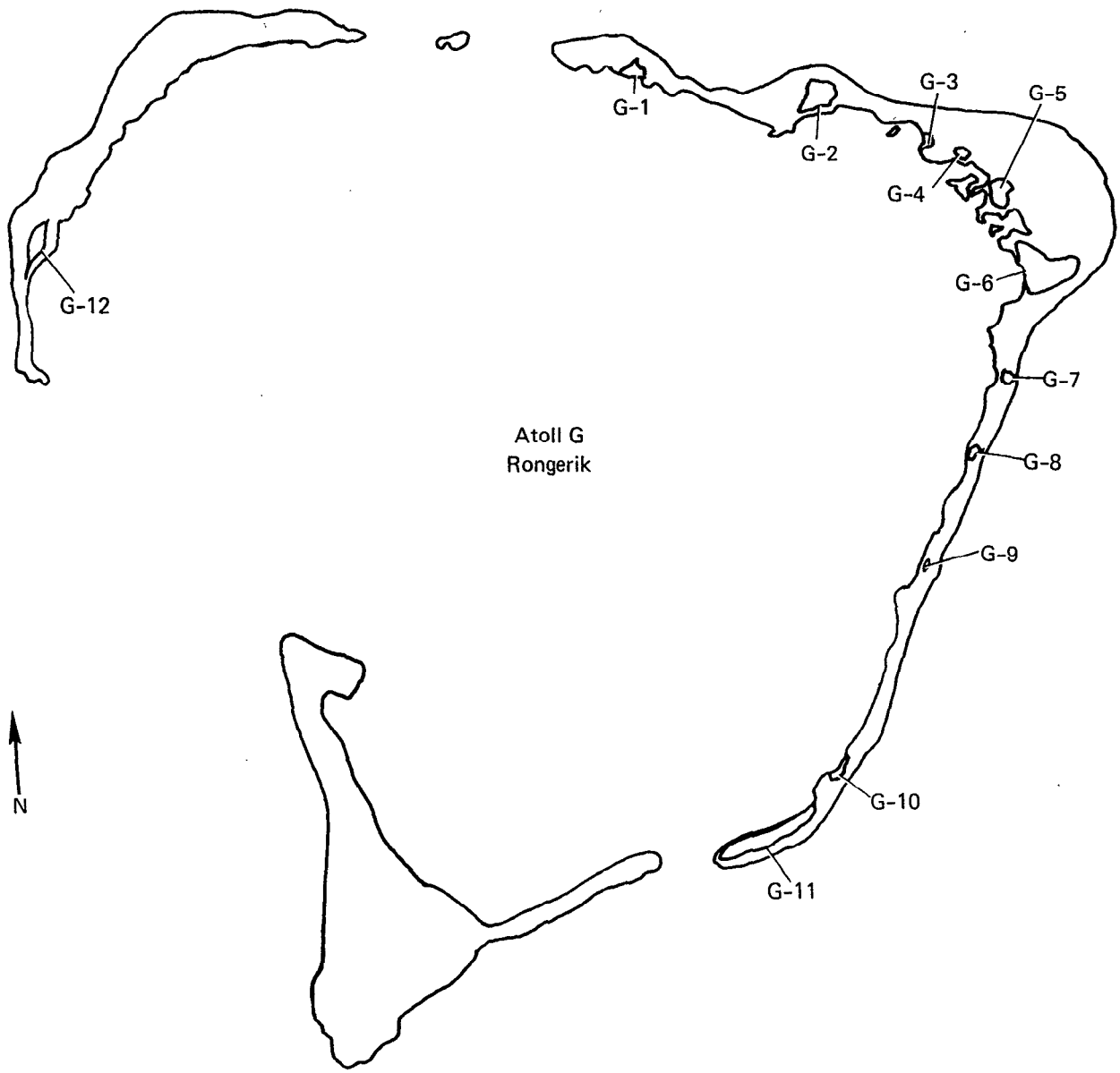

FIG. 6. Rongerik Atoll with code letter and numbers for the islands.

TABLE 18. Summary of soil, vegetation, and animal samples collected from Rongerik Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Jedibberbib Island (G-1)	
Soil	6	6
Coconut	1 (7)	4
Messerschmedia leaf	1	1
Messerschmedia litter	1	1
TOTAL		
Soil	6	6
Vegetation	3	6
	Latoback Island (G-2)	
Soil	25	25
Coconut	3 (12)	6
Pandanus	1 (2)	2
Coconut crab	1	1
TOTAL		
Soil	25	25
Vegetation	4	8
Animal	1	1
	Bigonattam Island (G-5)	
Soil	12	12
Coconut	2 (6)	2
	Rongerik Island (G-6)	
Soil	40	40
Coconut	4 (20)	8
Pandanus	2 (5)	4
Sprouted coconut	1 (8)	2
TOTAL		
Soil	40	40
Vegetation	7	14

TABLE 18. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Enewetak Island (G-11)	
Soil	66	66
Coconut	9 (47)	19
Pandanus	1 (5)	2
Sprouted coconut	1 (2)	2
Scaevola leaf	1	1
TOTAL		
Soil	66	66
Vegetation	12	24
	Bock Island (G-12)	
Soil	12	12
Coconut	2 (10)	4

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 19. Summary of fish samples collected from Rongerik Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
G-1	Mullet (B)	15	159±80	191±34	9	6
G-1	Convict surgeonfish	64	72±26	113±10	61	3
G-1	Threadfin	6	738±137	306±15	1	5
G-6	Convict surgeonfish	45	71±23.3	115±11	20	25
G-6	Goatfish	19	232±64	224±18	10	9
G-11	Mullet (B)	20	129±68	179±31	14	6
G-11	Convict surgeonfish	45	73±16	118±12	32	13
G-11	Parrotfish	2	493±134	239±13	2	--
G-12	Convict surgeonfish	67	64±22	111±10	63	4
Pass	Mackerel	1	891	453 (*)	--	1
Lagoon	Grouper	1	22.73	525	1	--
Lagoon	Jack	1	2434	495 (*)	--	1
Lagoon	Grey snapper	2	1914±499	505±35	1	1
Lagoon	Tuna	2	5773±198	750±20 (*)	--	2
TOTAL		290	51.1 kg	--	214	76

NOTE: For explanation of table entries see footnotes, Table 11.

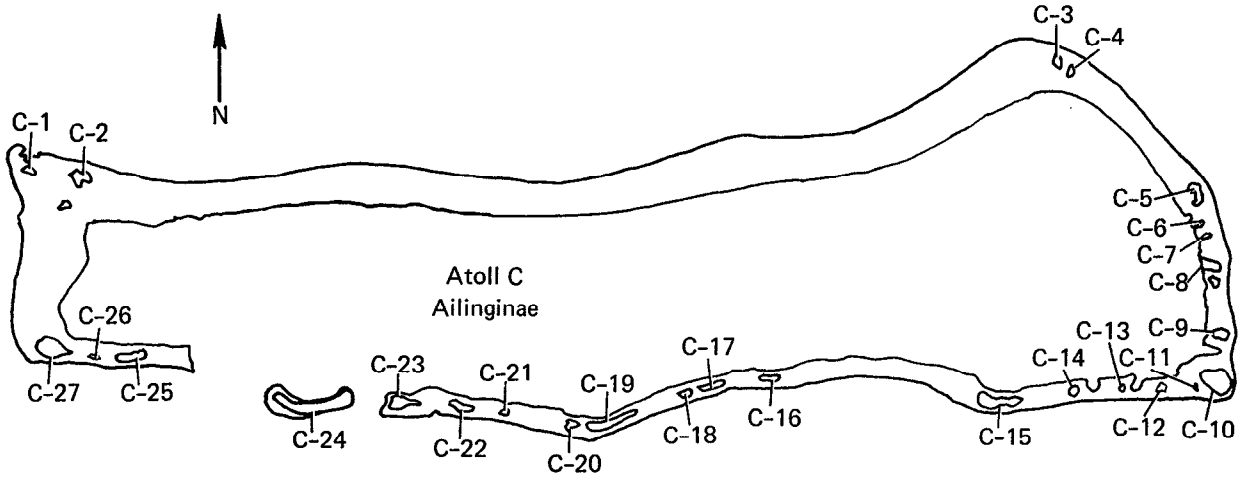

FIG. 7. Ailinginae Atoll with code letter and numbers for the islands.

TABLE 20. Summary of soil, vegetation, and animal samples collected from Ailinginae Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Majokoryaan Island (C-8)	
Soil	14	14
Messerschmedia leaf	1	1
Messerschmedia litter	1	1
Pisonia leaf	1	1
Pisonia litter	1	1
TOTAL		
Soil	14	14
Vegetation	4	4
	Knox Island (C-10)	
Soil	18	18
Coconut	3 (18)	6
	Ucchuwanen Island (C-15)	
Soil	12	12
Coconut	1 (6)	2
Pandanus	1 (2)	2
TOTAL		
Soil	12	12
Vegetation	2	4
	Kuobuen Island (C-18)	
Soil	18	18
Pisonia leaf	2	2
Coconut	1 (7)	2
TOTAL		
Soil	18	18
Vegetation	3	4

TABLE 20. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Ribinouri Island (C-19)	
Soil	23	23
Coconut	2 (10)	4
Messerschmedia leaf	1	1
Pisonia leaf	1	1
TOTAL		
Soil	23	23
Vegetation	4	6
	Enibuk Island (C-23)	
Soil	52	52
Coconut	6 (32)	13
Pandanus	5 (10)	10
Messerschmedia leaf	1	1
TOTAL		
Soil	52	52
Vegetation	12	24
	Mogiri Island (C-24)	
Soil	34	34
Pandanus	2 (5)	4
Pisonia leaf	2	2
Coconut	1 (5)	2
Tacca	1 (5*)	2
Morinda fruit	1 (20*)	1
Coconut crab	1	1
TOTAL		
Soil	34	34
Vegetation	7	11
Animal	1	1

TABLE 20. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Manchinikon Island (C-25)	
Soil	18	18
Coconut	2 (12)	4
Pandanus	2 (4)	4
TOTAL		
Soil	18	18
Vegetation	4	8
	Sifo Island (C-27)	
Soil	36	36
Coconut	4 (23)	8
Pandanus	1 (6)	2
Messerschmedia leaf	1	1
Pisonia leaf	1	1
Coconut crab	2	1
TOTAL		
Soil	36	36
Vegetation	7	12
Animal	2	1

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 21. Summary of fish samples collected from Ailinginae Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
C-5	Mullet (A)	5	257±41	410±175	3	2
C-5	Convict surgeonfish	16	75±20	118±12	8	8
C-5	Goatfish	28	163±51	199±18	21	7
C-15	Goatfish	64	66±12	145±15	43	21
C-19	Mullet (A)	14	395±132	257±35	9	5
C-19	Convict surgeonfish	26	33±11	90±13	21	5
C-24	Convict surgeonfish	26	47±23	97±17	18	8
C-24	Parrotfish	9	630±74	274±18	1	8
C-24	Grouper	1	1832	490	--	1
C-24	Snapper (pigfish)	2	2017±372	510±28	2	--
C-27	Mullet (A)	3	520±69	278±19	1	2
C-27	Mullet (B)	14	129±62	179±32	12	2
C-27	Convict surgeonfish	73	52±19	100±12	51	22
Lagoon	Rainbow runner	1	2642	615	1	--
Lagoon	Mackerel	1	1041	475 (*)	--	1
TOTAL		283	41.3 kg	--	191	92

NOTE: For explanation of table entries see footnotes, Table 11.

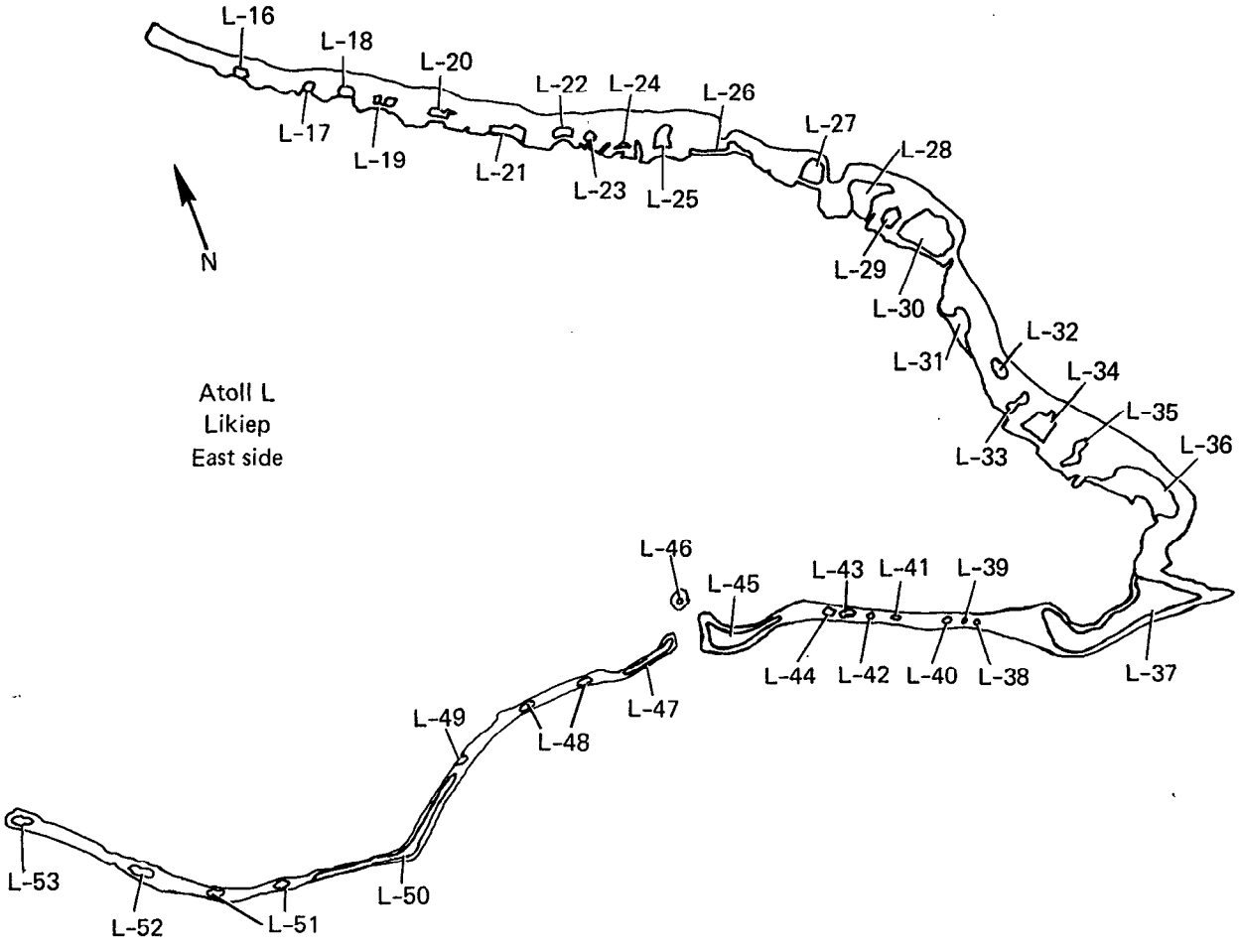

FIG. 8. East side of Likiep Atoll with code letter and numbers for the islands.

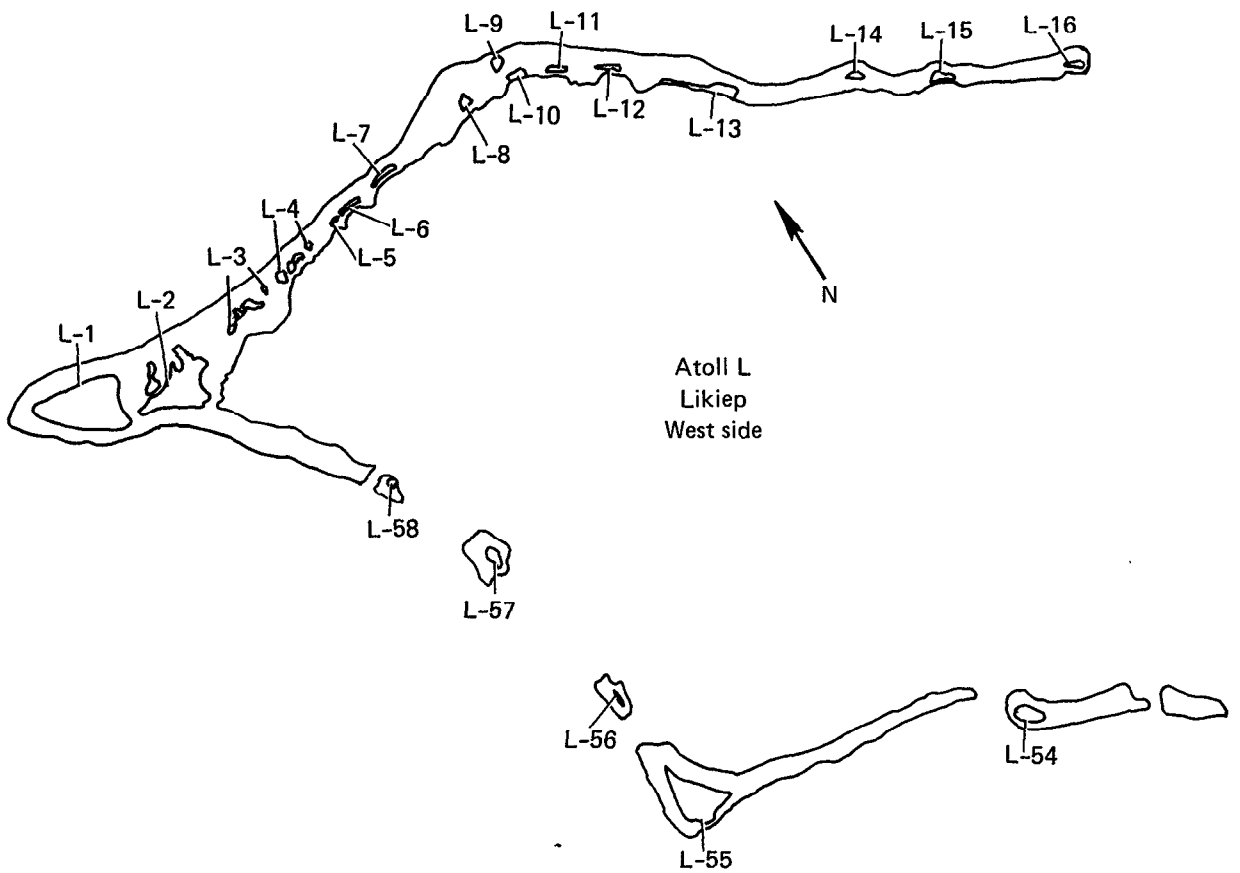

FIG. 9. West side of Likiep Atoll with code letter and numbers for the islands.

TABLE 22. Summary of soil, vegetation, and animal samples collected from Likiep Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Rikuraru Island (L-2)	
Soil	72	72
Coconut	9 (44)	20
Pandanus	2 (5)	4
Breadfruit	1 (5*)	2
TOTAL		
Soil	72	72
Vegetation	12	26
	Jeltonet Island (L-13)	
Soil	18	18
Pandanus	2 (4)	4
Coconut	1 (4)	3
TOTAL		
Soil	18	18
Vegetation	3	7
	Jiebaru Island (L-30)	
Soil	33	33
Coconut	2 (12)	4
Taro	2 (10*)	2
Banana	1 (10*)	2
Tacca	1 (5*)	2
Breadfruit	1 (2)	2
Pandanus	1 (2)	2
TOTAL		
Soil	33	33
Vegetation	8	14

TABLE 22. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Likiep Island (L-37)	
Soil	71	71
Coconut	5 (25)	11
Pandanus	3 (6)	6
Breadfruit	2 (9)	4
Tacca	1 (5*)	2
Scaevola leaf	1	1
Pig	2	17
Chicken	2	7
TOTAL		
Soil	71	71
Vegetation	12	24
Animal	4	24
	Agony Island (L-45)	
Soil	18	18
Coconut	3 (13)	6
Tacca	1 (5*)	2
Pandanus	1 (2)	2
TOTAL		
Soil	18	18
Vegetation	5	10
	Etoile Island (L-47)	
Soil	18	18
Coconut	2 (9)	4
Pandanus	2 (4)	4
TOTAL		
Soil	18	18
Vegetation	4	8

TABLE 22. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Kapenor Island (L-55)	
Soil	36	36
Coconut	4 (22)	10
Pandanus	2 (4)	4
TOTAL		
Soil	36	36
Vegetation	6	14

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 23. Summary of fish samples collected from Likiep Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
L-3	Rabbitfish	13	388±66	251±14	11	2
L-37	Mullet (A)	8	590±80	301±14	8	--
L-37	Goatfish	28	71±31	147±18	22	6
L-50	Mullet (A)	11	463±115	274±23	11	--
L-50	Convict surgeonfish	36	56±13	105±13	32	4
L-50	Goatfish	25	148±38	189±30	16	9
L-55	Mullet (A)	7[a]	406±326	243±71	5	--
L-55	Convict surgeonfish	4	48±10	96±7	1	3
L-55	Convict surgeonfish	10	82±48	113±24	6	4
L-55	Rudderfish	25	264±30	187±9	24	1
L-55	Parrotfish	1	723.2	275	--	1
L-58	Convict surgeonfish	48[a]	100±48	125±14	21	25
L-58	Goatfish	56	145±30	190±18	8	48
L-58	Parrotfish	22	565±155	256±15	19	3
TOTAL		294[b]	59.1 kg	--	184	106

NOTE: For explanation of table entries see footnotes, Table 11.

[a]Including two immature individuals of undeterminable sex.

[b]Including four immature individuals of undeterminable sex.

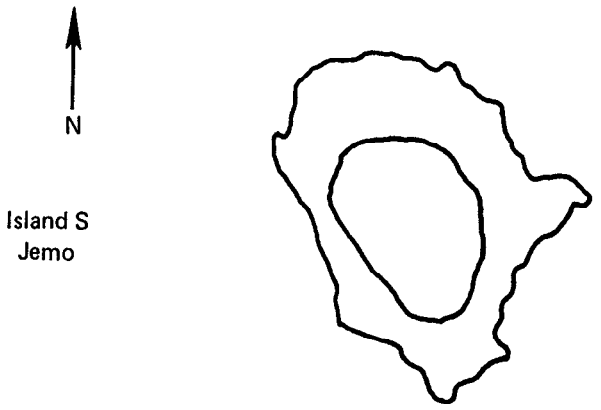

FIG. 10. Jemo Island.

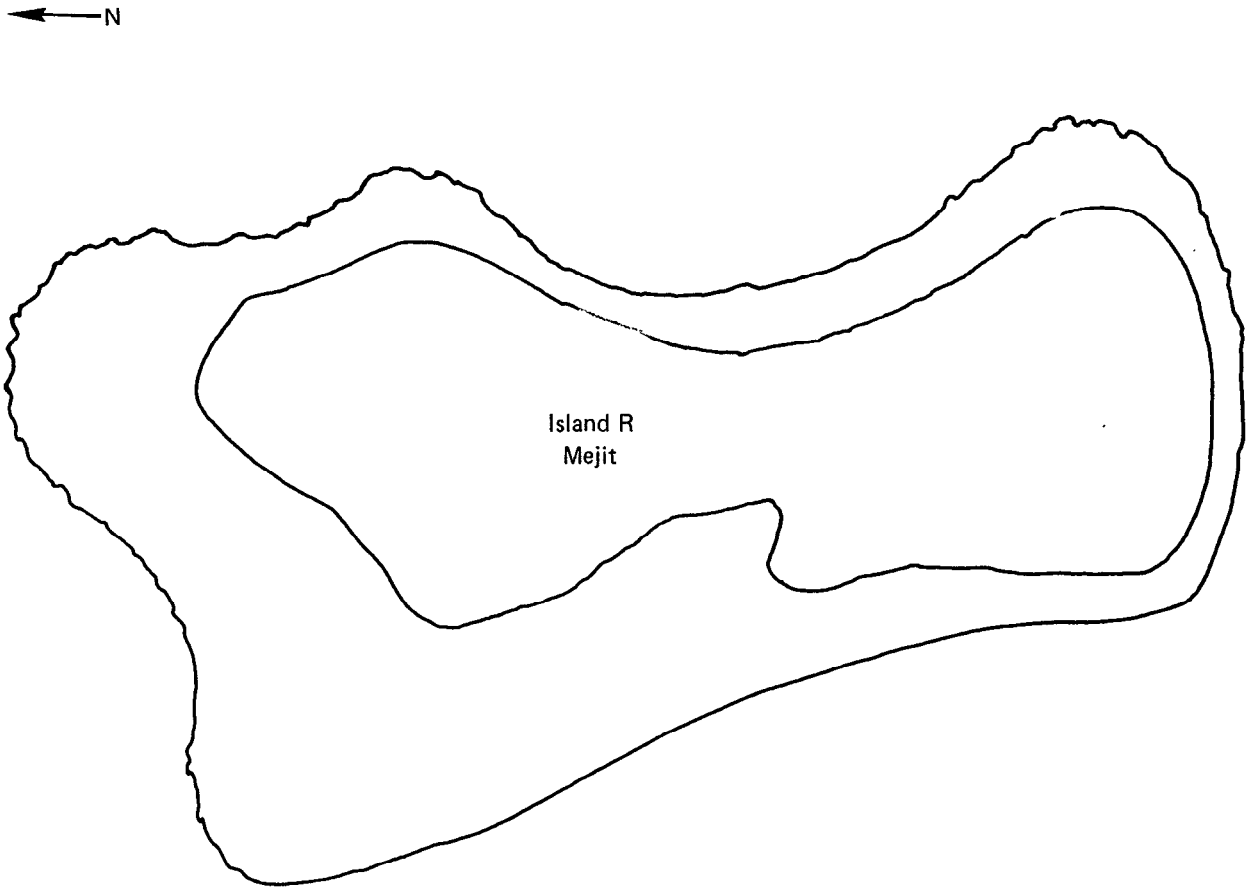

FIG. 11. Mejit Island.

TABLE 24. Summary of soil, vegetation, and animal samples collected from Jemo and Mejit Islands; arranged by sample types.

Sample	Number of composite samples	Number of analytical samples
	Jemo Island (S-1)	
Soil	18	18
Coconut	3 (15)	6
	Mejit Island (R-1)	
Soil	48	48
Coconut	5 (28)	9
Breadfruit	3 (13)	6
Pandanus	3 (7)	6
Papaya	1 (2)	3
Tacca	1 (5)	2
Pig	2	16
Chicken	2	7
TOTAL		
Soil	48	48
Vegetation	13	26
Animal	4	23

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 25. Summary of fish samples collected from Jemo Island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
S-1	Convict surgeonfish	2	266±11	160±14	2	--
S-1	Convict surgeonfish	69	98±29	125±13	33	36
S-1	Unicornfish	12	264±64	193±18	7	5
S-1	Threadfin	28	444±49	268±11	13	15
TOTAL		111	22.9 kg	--	55	56

NOTE: For explanation of table entries see footnotes, Table 11.

TABLE 26. Summary of fish samples collected from Mejit Island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
R-1	Rudderfish	70	96±17	166±10	20	50
TOTAL		70	6.7 kg	--	20	50

NOTE: For explanation of table entries see footnotes, Table 11.

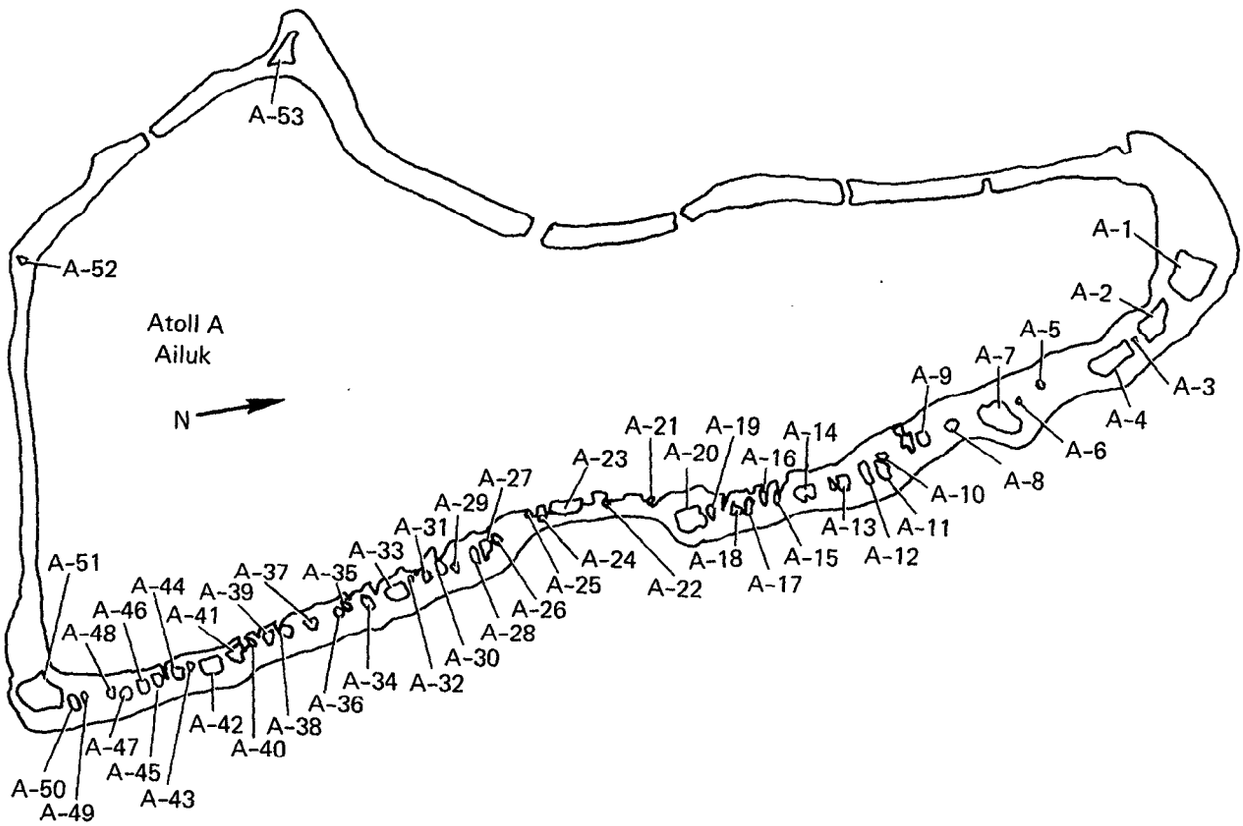

FIG. 12. Ailuk Atoll with code letter and numbers for the islands.

TABLE 27. Summary of soil, vegetation, and animal samples collected from Ailuk Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Kapen Island (A-1)	
Soil	24	24
Coconut	3 (15)	6
Pandanus	1 (2)	2
TOTAL		
Soil	24	24
Vegetation	4	8
	Enijabro Island (A-2)	
Soil	24	24
Coconut	3 (15)	6
Pandanus	1 (2)	2
TOTAL		
Soil	24	24
Vegetation	4	8
	Enejelar Island (A-4)	
Soil	28	28
Coconut	3 (17)	6
Breadfruit	1 (5)	2
Pandanus	1 (2)	2
TOTAL		
Soil	28	28
Vegetation	5	10

TABLE 27. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Bigen Island (A-7)	
Soil	22	22
Coconut	3 (19)	6
Pandanus	2 (4)	4
TOTAL		
Soil	22	22
Vegetation	5	10
	Aliet Island (A-20)	
Soil	23	23
Coconut	3 (16)	6
Pandanus	2 (4)	4
TOTAL		
Soil	23	23
Vegetation	5	10
	Bererjan Island (A-33)	
Soil	22	22
Coconut	3 (17)	6
Pandanus	1 (2)	2
TOTAL		
Soil	22	22
Vegetation	4	8

TABLE 27. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Ailuk Island (A-51)	
Soil	77	77
Coconut	9 (45)	16
Breadfruit	3 (11)	6
Pandanus	2 (4)	4
Squash	1	3
Banana	1 (10*)	2
Papaya	1 (8)	2
Pig	2	17
Chicken	1	7
TOTAL		
Soil	77	77
Vegetation	17	33
Animal	3	24
	Agulve Island (A-53)	
Soil	42	42
Coconut	5 (27)	11
Pandanus	2 (7)	4
TOTAL		
Soil	42	42
Vegetation	7	15

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 28. Summary of fish samples collected from Ailuk Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
A-1	Mullet (A)	7	164±91	186±29	5	2
A-1	Convict surgeonfish	17	38±10	95±7	14	3
A-11	Mullet (A)	18	434±80	272±20	2	16
A-11	Convict surgeonfish	24	40±9	95±13	9	15
A-11	Goatfish	45	171±37	202±20	30	15
A-20	Goatfish	31	45±5	133±15	23	8
A-53	Mullet (A)	7	266±270	198±86	5	2
A-53	Goatfish	23	189±43	206±10	17	6
Lagoon	Mackerel	1	629	400 (*)	--	1
TOTAL		173	26.5 kg	--	105	68

NOTE: For explanation of table entries see footnotes, Table 11.

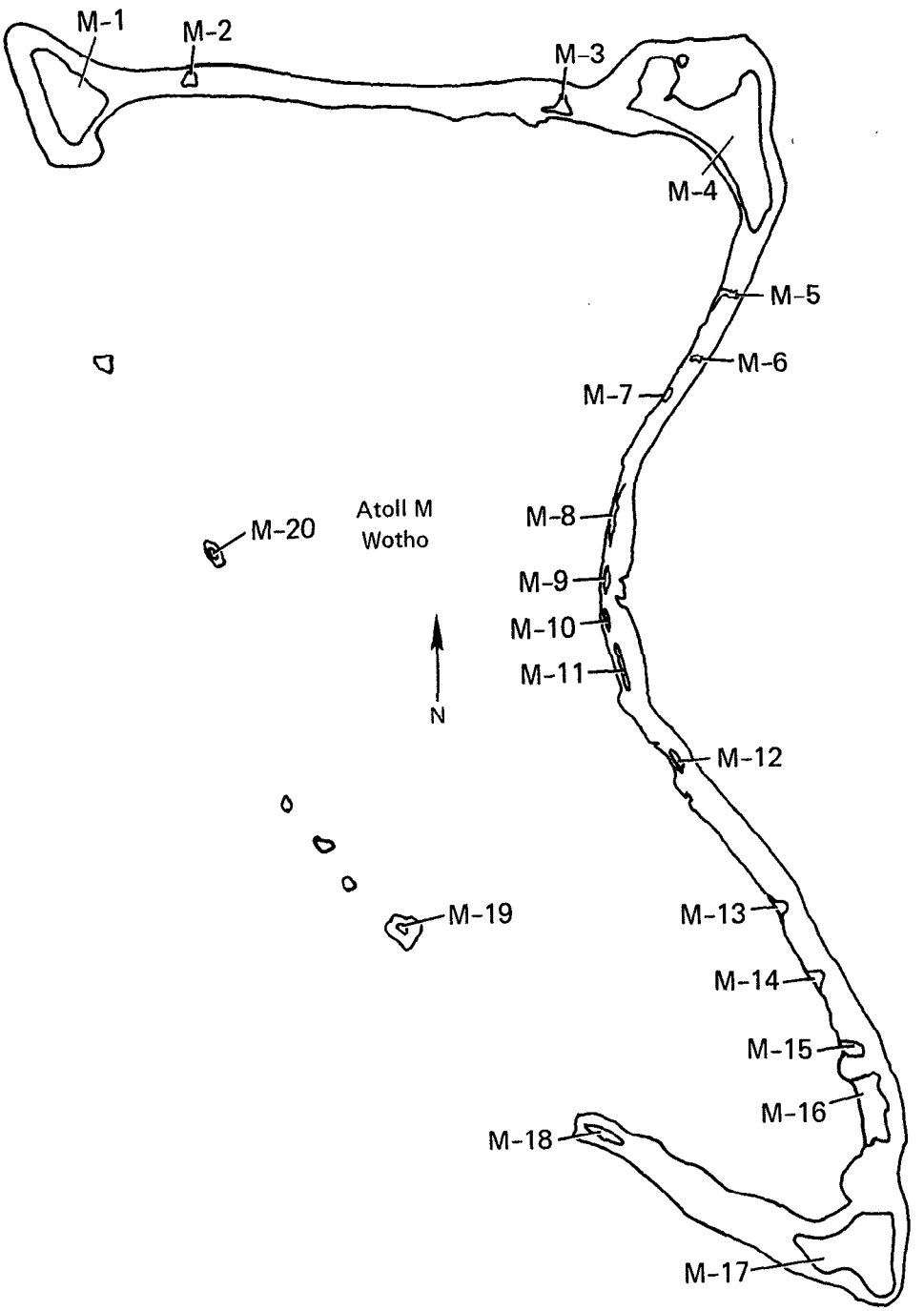

FIG. 13. Wotho Atoll with code letter and numbers for the islands.

TABLE 29. Summary of soil, vegetation, and animal samples collected from Wotho Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Medyeron Island (M-1)	
Soil	48	48
Coconut	3 (15)	6
	Wotho Island (M-4)	
Soil	90	90
Coconut	9 (45)	18
Pandanus	3 (6)	6
Breadfruit	2 (10)	4
Papaya	1 (5)	3
Pig	1	8
Chicken	1 (2)	7
TOTAL		
Soil	90	90
Vegetation	15	31
Animal	2	15
	Kabben Island (M-17)	
Soil	36	36
Coconut	6 (31)	11

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 30. Summary of fish samples collected from Wotho Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
M-1	Mullet (B)	55	130±40	184±16	43	12
M-1	Goatfish	22	145±22	188±19	19	3
M-1	Parrotfish	4	552±218	242±33	--	4
M-12	Mullet (B)	37	209±45	195±30	25	12
M-12	Convict surgeonfish	41	61±11	103±10	12	29
M-12	Parrotfish	4	494±111	238±15	2	2
M-17	Mullet (A)	3	591±66	290±15	1	2
M-17	Convict surgeonfish	89	59±14	104±10	49	40
M-17	Goatfish	43	181±37	196	9	34
Lagoon	Rainbow runner	1	3006	635 (*)	--	1
Lagoon	Grey snapper	1	2113	497	1	--
TOTAL		300	44.7 kg	--	161	139

NOTE: For explanation of table entries see footnotes, Table 11.

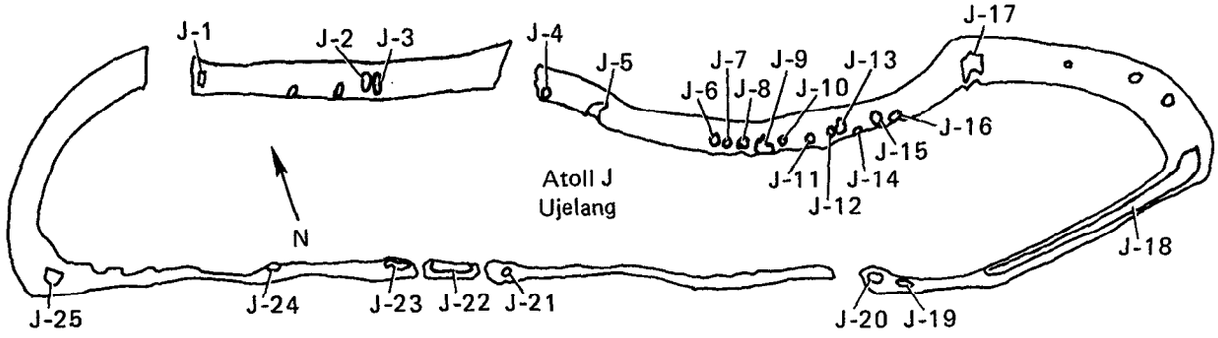

FIG. 14. Ujelang Atoll with code letter and numbers for the islands.

TABLE 31. Summary of soil, vegetation, and animal samples collected from Ujelang Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Pokon Island (J-5)	
Soil	18	18
Coconut	2 (10)	3
Pandanus	1 (2)	2
TOTAL		
Soil	18	18
Vegetation	3	5
	J-13	
Soil	12	12
Coconut	1 (5)	2
Pandanus	1 (2)	2
TOTAL		
Soil	12	12
Vegetation	2	4
	Daisu Island (J-17)	
Soil	35	35
Pandanus	4 (7)	8
Coconut	2 (10)	4
Tacca	1 (5*)	2
TOTAL		
Soil	35	35
Vegetation	7	14

TABLE 31. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Ujelang Island (J-18)	
Soil	129	129
Coconut	14 (70)	28
Pandanus	6 (11)	12
Breadfruit	3 (15*)	9
Papaya	1 (20*)	3
Banana	1 (20*)	2
Melon	1 (2*)	3
Squash	1	3
Tacca	1 (5*)	2
Pig	2	14
TOTAL		
Soil	129	129
Vegetation	28	62
Animal	2	14
	Burle Island (J-20)	
Soil	13	13
Pandanus	2 (5)	3
Banana	1 (10*)	2
TOTAL		
Soil	13	13
Vegetation	3	5
	Eimnlapp Island (J-22)	
Soil	24	22
Coconut	1 (5)	2
Pandanus	1 (3)	2
TOTAL		
Soil	24	22
Vegetation	2	4

TABLE 31. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Ennimenetto Island (J-23)	
Soil	20	20
Coconut	2 (10)	3
Papaya	1 (20*)	3
Tacca	1 (5*)	2
Pandanus	1 (2)	2
TOTAL		
Soil	20	20
Vegetation	5	10
	Kalo Island (J-25)	
Soil	30	30
Pandanus	2 (4)	4
Coconut	2 (10)	3
Papaya	1 (6)	3
TOTAL		
Soil	30	30
Vegetation	5	10

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 32. Summary of fish samples collected from Ujelang Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
J-5	Goatfish	26	169±44	198±17	10	16
J-5	Jack	14	345±51	265±13 (*)	14	--
J-18	Goatfish	31	163±35	195±15	10	21
J-18	Jack	73	91±12	181 (*)	47	26
J-22	Mullet (B)	17	49±8	127±7	17	--
J-22	Convict surgeonfish	20	31±7	84±4	13	7
Lagoon	Jack	1	1699	430 (*)	--	1
TOTAL		182	24 kg	--	111	71

NOTE: For explanation of table entries see footnotes, Table 11.

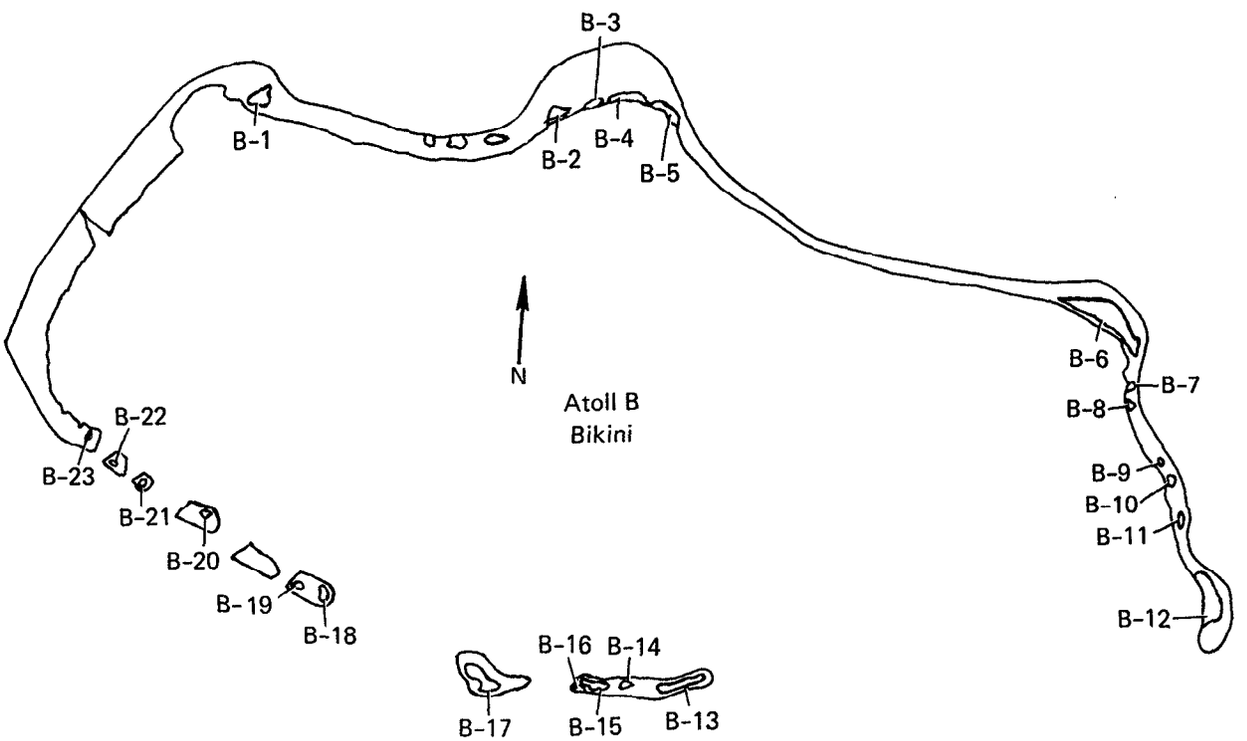

FIG. 15. Bikini Atoll with code letter and numbers for the islands.

TABLE 33. Summary of soil, vegetation, and animal samples collected from Bikini Atoll; arranged by sample types and island.

Sample	Number of composite samples	Number of analytical samples
	Nam Island (B-1)	
Soil	196	196
	Iroij Island (B-2)	
Soil	59	59
	Odrik Island (B-3)	
Soil	29	29
	Lomilik Island (B-4)	
Soil	94	94
	Aomen Island (B-5)	
Soil	50	50
	Bikini Island (B-6)	
Soil	78	78
Papaya	5 (100*)	15
Coconut	5 (25)	11
Pandanus	3 (6)	6
TOTAL		
Soil	78	78
Vegetation	13	32
	Rojkere Island (B-10)	
Soil	18	18
	Eneu Island (B-12)	
Soil	21	21
Coconut	37 (186)	77
Sprouted coconut	3 (17)	6
Papaya	2 (40*)	6
TOTAL		
Soil	21	21
Vegetation	42	89

TABLE 33. (Continued.)

Sample	Number of composite samples	Number of analytical samples
	Aerokoj Island (B-13)	
Soil	71	71
Coconut	2	4
	Lele Island (B-15)	
Soil	22	22
	Eneman Island (B-16)	
Soil	36	36
	Enidrik Island (B-17)	
Soil	188	188
	Lukoj Island (B-18)	
Soil	17	17
	Jelete Island (B-19)	
Soil	12	12
Coconut	1 (6)	2

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 34. Summary of fish samples collected from Bikini Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
B-1	Mullet (A)	12	641±71	298±13	11	1
B-1	Mullet (B)	18	183±67	208±23	13	5
B-1	Convict surgeonfish	4	62±16	109±10	--	4
B-1	Goatfish	33	91±32	162±18	25	8
B-5	Mullet (A)	8	712±143	303±19	5	3
B-5	Mullet (B)	24	181±45	202±19	12	12
B-5	Convict surgeonfish	20	65±12	108±9	12	8
B-5	Goatfish	22	147±34	187±15	11	11
B-6	Convict surgeonfish	55	64±26	103±14	31	24
B-6	Goatfish	39	127±39	180±19	26	13
B-10	Convict surgeonfish	46	68±24	108±14	30	16
B-10	Goatfish	42	111±35	173±18	32	10
B-12	Mullet (B)	21	209±57	212±22	13	8
B-12	Convict surgeonfish	64	64±21	110±13	45	19
B-12	Goatfish	42	91±32	166±20	38	4
B-13	Mullet (A)	8	493±116	275±26	3	5
B-13	Convict surgeonfish	31	88±28	115±15	8	23
B-13	Goatfish	37	103±28	167±16	20	17
B-17	Mullet (A)	9	545±86	297±18	--	9
B-17	Mullet (B)	18	177±71	204±27	9	9
B-17	Goatfish	37	93±28	171±17	11	26
B-17	Parrotfish	5	840±174	293±26	--	5
B-23	Mullet (B)	35	151±52	193±24	23	12
B-23	Goatfish	47	86±25	160±15	36	11

TABLE 34. (Continued.)

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
Lagoon	Jack	1	1125	490 (*)	--	1
Lagoon	Grey snapper	2	2270±511	520±14	1	1
Lagoon	Red snapper	1	2971	530	1	--
Lagoon	Red snapper	1	2214	480	--	1
Lagoon	Mackerel	1	1879	565 (*)	1	--
TOTAL		683	104.7 kg	--	417	266

NOTE: For explanation of table entries see footnotes, Table 11.

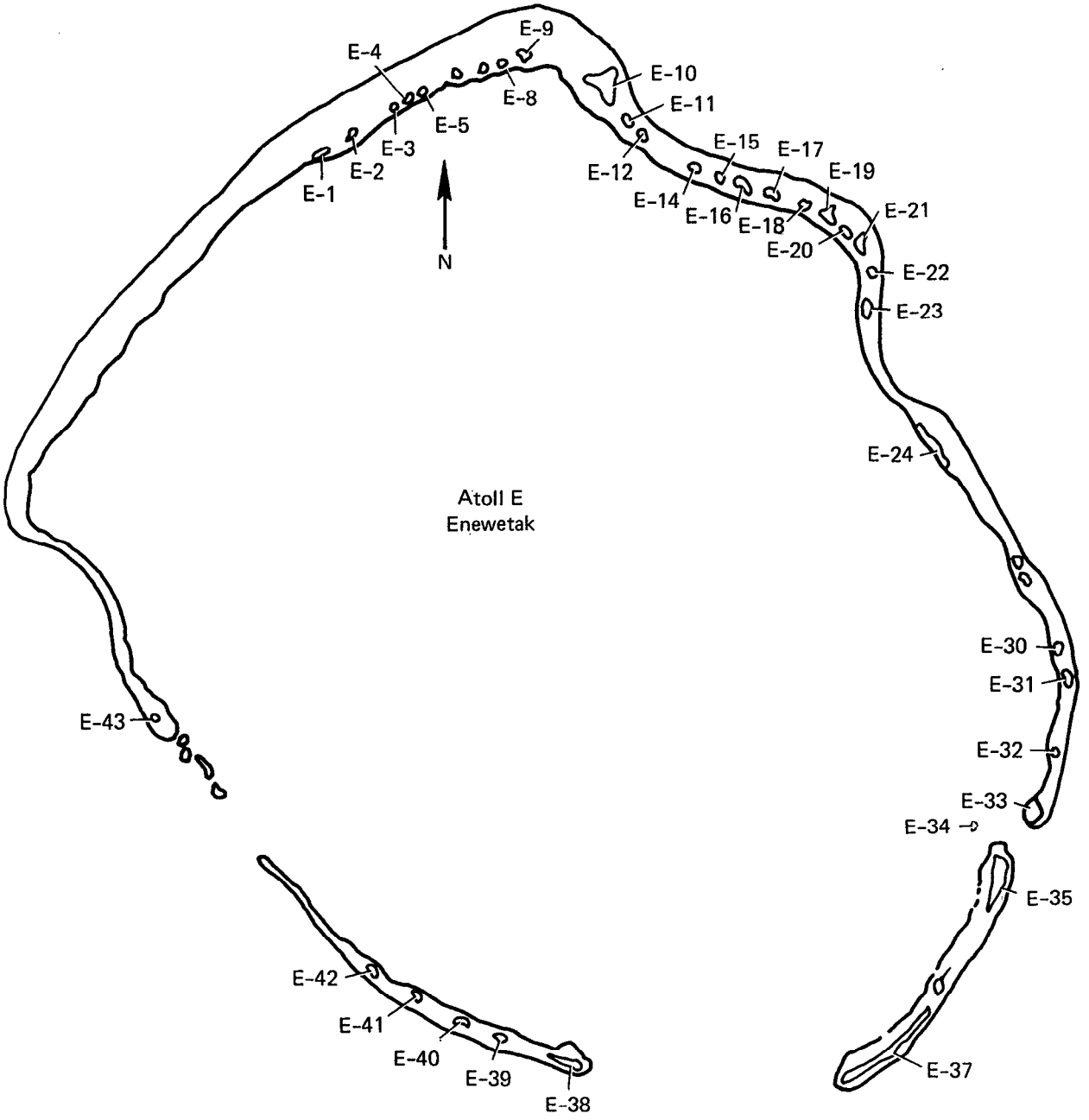

FIG. 16. Enewetak Atoll with code letter and numbers for the islands.

TABLE 35. Summary of soil and vegetation samples collected from Enewetak Atoll; arranged by sample type and island.

Sample	Number of composite samples	Number of analytical samples
	Belle Island (E-2)	
Soil	6	6
Pandanus	1 (2)	2
	Engebi Island (E-10)	
Papaya	4 (97)	12

NOTE: For explanation of table entries see footnotes, Table 10.

TABLE 36. Summary of fish samples collected from Enewetak Atoll; arranged by island.

Location	Common name	Number of fish collected	Average whole-body wet weight, g	Average standard length, mm	Number of males	Number of females
E-2	Mullet (B)	17	231±77	223±25	9	8
E-2	Convict surgeonfish	22	64±19	105±11	13	9
E-2	Goatfish	22	161±55	194±27	17	5
E-10	Convict surgeonfish	54	58±17	104±10	26	28
E-10	Goatfish	26	145±79	180±37	12	14
E-19	Convict surgeonfish	46	46±21	94±13	27	19
E-24	Mullet (A)	22	322±401	196±94	18	4
E-24	Convict surgeonfish	51	77±22	118±14	15	36
E-37	Convict surgeonfish	8	78±19	122±13	3	5
E-37	Unicornfish	3	173±45	162±23	2	1
TOTAL		271	30 kg	--	142	129

NOTE: For explanation of table entries see footnotes, Table 11.

TABLE 37. Average radionuclide detection limits by gamma-ray spectrometry for 1000 min count.

Marine sample type	Average sample weight, g	Average radionuclide detetection limit (pCi/g dry wt)							
		^{60}Co	^{101}Rh	^{102m}Rh	^{125}Sb	^{137}Cs	^{155}Eu	^{207}Bi	^{241}Am
Muscle	400	0.008	0.003	0.004	0.01	0.004	0.008	0.004	0.013
Skin	300	0.008	0.003	0.005	0.013	0.005	0.01	0.005	0.017
Viscera	150	0.015	0.007	0.01	0.027	0.011	0.02	0.01	0.033
Bone	150	0.015	0.007	0.01	0.027	0.011	0.02	0.02	0.033
Stomach contents	15	0.15	0.07	0.1	0.27	0.11	0.2	0.1	0.33
Liver	10	0.23	0.1	0.15	0.4	0.16	0.3	0.15	0.5

TABLE 38. Summary of gamma spectroscopy analyses; arranged by sample category and atoll or island.

Atoll or island	Soil	Vegetation	Animal	Fish	Clam	Lagoon sediment	TOTAL
Rongelap	398	143	29	137	11	11	729
Taka	53	17	--	40	9	5	124
Utirik	271	116	22	24	12	5	450
Bikar	41	8	--	49	6	3	107
Rongerik	161	58	2	74	10	6	311
Ailinginae	225	79	2	89	11	9	415
Likiep	266	103	24	75	11	9	488
Jemo	18	6	--	20	--	4	48
Ailuk	262	100	24	52	5	8	451
Mejit	48	26	23	6	--	3	106
Wotho	174	48	15	61	7	6	311
Ujelang	279	114	16	31	8	6	454
Bikini	891	127	--	154	8	11	1191
Enewetak	6	14	--	--	--	--	20
TOTAL	3093	959	157	812	98	86	5205

TABLE 39. Summary of wet chemistry analyses; arranged by sample category, atoll or island, and radionuclide.

Sample	^{90}Sr	^{137}Cs	^{238}Pu	^{239}Pu	^{240}Pu	$^{239+240}Pu$	^{241}Pu	^{241}Am
				Rongelap Atoll				
Soil	438	159	6	29	29	409	77	296
Vegetation	137	110	--	--	--	137	15	137
Animal	27	5	--	--	--	27	--	27
Fish	99	20	103	--	--	103	--	95
Clam	11	4	11	--	--	11	--	11
Water (lagoon)	5	6	10	--	--	10	--	10
Water[a]	5	5	7	--	--	7	--	7
Lagoon sediment	10	--	9	--	--	9	--	11
TOTAL	732	309	146	29	29	713	92	594
				Taka Atoll				
Soil	48	3	--	--	--	48	--	42
Vegetation	4	1	--	--	--	4	--	4
Fish	27	5	33	--	--	33	--	28
Clam	9	4	9	--	--	9	--	9
Water (lagoon)	1	2	4	--	--	4	--	2
Lagoon sediment	4	--	4	--	--	4	--	4
TOTAL	93	15	50	--	--	102	--	89
				Utirik Atoll				
Soil	300	115	--	6	6	294	18	300
Vegetation	100	47	--	--	--	100	--	100
Animal	23	4	--	--	--	23	--	23
Fish	23	6	28	--	--	28	--	24
Clam	11	5	11	--	--	11	--	10
Water (lagoon)	2	3	5	--	--	5	--	5
Water[a]	2	2	3	--	--	3	--	3
Lagoon sediment	6	--	6	--	--	6	--	6
TOTAL	467	182	53	6	6	470	18	471

TABLE 39. (Continued.)

Sample	^{90}Sr	^{137}Cs	^{238}Pu	^{239}Pu	^{240}Pu	$^{239+240}Pu$	^{241}Pu	^{241}Am
				Bikar Atoll				
Soil	28	--	--	--	--	28	--	18
Vegetation	6	1	--	--	--	6	--	6
Fish	28	7	38	--	--	38	--	30
Clam	6	3	6	--	--	6	--	6
Water (lagoon)	1	2	4	--	--	4	--	2
Lagoon sediment	3	--	3	--	--	3	--	3
TOTAL	72	13	51	--	--	85	--	65
				Rongerik Atoll				
Soil	137	15	--	--	--	137	--	98
Vegetation	40	21	--	--	--	40	--	40
Animal	2	--	--	--	--	2	--	2
Fish	56	12	61	--	--	61	--	57
Clam	10	5	10	--	--	10	--	10
Water (lagoon)	3	4	7	--	--	7	--	5
Lagoon Sediment	6	--	6	--	--	6	--	6
TOTAL	254	57	84	--	--	263	--	218
				Ailinginae Atoll				
Soil	124	28	--	--	--	124	--	69
Vegetation	37	3	--	--	--	37	--	37
Animal	2	1	--	--	--	2	--	102
Fish	52	14	60	--	--	60	--	56
Clam	11	6	11	--	--	11	--	11
Water (lagoon)	4	5	9	--	--	9	--	8
Water[a]	1	1	1	--	--	1	--	1
Lagoon sediment	9	--	9	--	--	9	--	8
TOTAL	240	58	90	--	--	253	--	292

TABLE 39. (Continued.)

Sample	^{90}Sr	^{137}Cs	^{238}Pu	^{239}Pu	^{240}Pu	$^{239+240}Pu$	^{241}Pu	^{241}Am
				Likiep Atoll				
Soil	163	56	--	--	--	163	--	94
Vegetation	50	21	--	--	--	50	--	50
Animal	24	3	--	--	--	24	--	24
Fish	54	12	59	--	--	59	--	54
Clam	8	--	8	--	--	8	--	8
Water (lagoon)	3	4	8	--	--	8	--	7
Water[a]	6	6	11	--	--	11	--	11
Lagoon sediment	8	--	9	--	--	9	--	9
TOTAL	316	102	95	--	--	332	--	257
				Jemo Island				
Soil	14	8	--	--	--	14	--	10
Fish	14	2	20	--	--	20	--	14
Water (lagoon)	--	1	2	--	--	2	--	2
Lagoon sediment	3	--	3	--	--	3	--	3
TOTAL	31	11	25	--	--	39	--	29
				Ailuk Atoll				
Soil	272	64	--	--	--	272	--	239
Vegetation	38	3	--	--	--	38	--	38
Animal	25	4	--	--	--	25	--	25
Fish	27	6	37	--	--	37	--	29
Clam	6	3	6	--	--	6	--	6
Water (lagoon)	3	3	8	--	--	8	--	7
Water[a]	6	6	9	--	--	9	--	8
Lagoon sediment	8	--	9	--	--	9	--	9
TOTAL	385	89	69	--	--	404	--	361
				Mejit Island				
Soil	50	10	--	--	--	50	--	43
Vegetation	7	2	--	--	--	7	--	7
Animal	24	--	--	--	--	24	--	24
Fish	2	--	--	--	--	2	--	2
Water (lagoon)	1	--	--	--	--	1	--	1
Water[a]	2	--	--	--	--	2	--	2
TOTAL	84							

TABLE 39. (Continued.)

Sample	^{90}Sr	^{137}Cs	^{238}Pu	^{239}Pu	^{240}Pu	$^{239+240}Pu$	^{241}Pu	^{241}Am
				Wotho Atoll				
Soil	184	53	--	--	--	184	--	114
Vegetation	34	18	--	--	--	34	--	34
Animal	15	3	--	--	--	15	--	15
Fish	32	6	40	--	--	40	--	30
Clam	7	2	7	--	--	7	--	7
Water (lagoon)	4	4	8	--	--	8	--	8
Water[a]	2	2	3	--	--	3	--	3
Lagoon sediment	7	--	7	--	--	7	--	7
TOTAL	285	88	65	--	--	298	--	218
				Ujelang Atoll				
Soil	163	34	--	--	--	163	--	111
Vegetation	46	10	--	--	--	46	--	46
Animal	16	8	--	--	--	16	--	16
Fish	20	6	26	--	--	26	--	20
Clam	6	2	6	--	--	6	--	5
Water (lagoon)	3	4	8	--	--	8	--	4
Water[a]	2	2	3	--	--	3	--	3
Lagoon sediment	5	--	5	--	--	5	--	5
TOTAL	261	66	48	--	--	273	--	210
				Bikini Atoll				
Soil	1012	298	225	79	79	946	155	536
Vegetation	120	42	--	--	--	120	4	120
Fish	54	--	97	--	--	97	--	65
Clam	3	--	10	--	--	10	--	4
Water (lagoon)	--	8	12	--	--	12	--	5
Water[a]	4	--	4	--	--	4	--	2
Lagoon sediment	11	--	11	--	--	11	--	11
TOTAL	1204	348	359	79	79	1200	159	743
				Enewetak Atoll				
Soil	6	6	--	--	--	6	--	6
Vegetation	1	--	--	--	--	1	--	1
TOTAL	7	6	--	--	--	7	--	7

[a]Cistern water and groundwater.

TABLE 40. Summary of analyses for major dose-contributing radionuclides; arranged by atoll or island.

Atoll or island	^{90}Sr	^{137}Cs	^{238}Pu	^{239}Pu	^{240}Pu	$^{239+240}Pu$	^{241}Pu	^{241}Am
Rongelap	732	1038	146	29	29	713	92	1323
Taka	93	139	50	--	--	102	--	213
Utirik	467	632	53	6	6	470	18	921
Bikar	72	120	51	--	--	85	--	172
Rongerik	254	368	84	--	--	267	--	529
Ailinginae	240	473	90	--	--	253	--	707
Likiep	316	590	95	--	--	332	--	745
Jemo	31	59	25	--	--	39	--	77
Ailuk	385	540	69	--	--	404	--	812
Mejit	84	126	11	--	--	92	--	187
Wotho	285	399	65	--	--	298	--	529
Ujelang	261	520	48	--	--	273	--	664
Bikini	1204	1539	359	79	79	1200	159	1934
Enewetak	7	26	--	--	--	7	--	27
TOTAL[a]	4431	6569	1146	114	114	4535	269	8840

[a]Total analyses performed for all radionuclides was 26,018. This includes analyses of duplicates but not standards. There were 120 standards that add 480 analyses to the total.

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