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Bikini Atoll Rehabilitation Committee

Report No. 1

Resettlement of Bikini Atoll: Feasibility and Estimated Cost of Meeting the Federal Radiation Protection Standards

Submitted to the U.S. Congress, House and Senate Committees on Interior
Appropriations, November 15, 1984, pursuant to Public Law No. 97-257
Department of Interior Account No. TT-1587X08,
Washington, D.C.

BIKINI ATOLL REHABILITATION COMMITTEE

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*Available on request, circa January 15, 1985, from: BARC, 1203 Shattuck Avenue, Berkeley, CA 94709.

ABSTRACT

The Bikini people wish to resettle Bikini Atoll, from which they were removed in 1946 to make way for a U. S. nuclear weapons testing program.

The hazard of resettlement stems almost entirely from cesium-137, a radionuclide in the soil which may contaminate the ground water and food crops. The waters of the lagoon and surrounding ocean are "clean". Strontium-90 plays a minor role, but some details are still under investigation.

Contamination aside, only two of the atoll's 23 islands are physically and historically suitable for permanent settlement, Bikini (2.4 km^2), the traditional site, and Eneu (1.2 km^2) which has been an ancillary one.

On the basis of the Federal radiation protection standards, all islands may be visited now. Eneu may be resettled, but depending on population size some food at least would have to be imported, especially during the initial years of resettlement. Bikini may be resettled with the proviso that no foods are to be grown nor ground water consumed for a period of 80 years, by which time spontaneous decay will have reduced cesium-137 to permissible levels.

The Bikini-Kili Council has informed the Committee (August 14, 1984) that the foregoing alternatives are unacceptable because Bikini Island would not be decontaminated. ?

The Committee has considered courses of action that attack the problem directly by removing the top 30 cm of Bikini's soil. The spoil would be disposed of either by the creation of a narrow, peripheral land strip on the seaward side of the island, or by dumping it into a crater in the lagoon. The execution of such plans would take 2-4 years and

cost $36-42 million. They would entail perhaps 10 years for the mature revegetation of the denuded island at an additional cost of some $6-8 million.

The Bikinians have requested that the spoil be used to build a causeway between Eneu and Bikini islands (September 21, 1984). Such construction would double the overall cost and has been questioned environmentally.

Some additional information will be required to assist the United States and the Bikinians to reach a final decision. A more refined estimate of external dose that specifically considers the beta-ray component should be made. The contribution to internal dose of strontium-90 in fish bone and in foliage should be examined further.

Pilot studies within the next two years are recommended to determine the following: (1) the cesium-137 content of plants grown in locations where 30 cm or more of topsoil have been removed; (2) if the loss of topsoil and the compacting effects of the excavation operation per se will materially impair the eventual productivity of Bikini soil; (3) the limitations of ground water supply on both Eneu and Bikini; (4) the possible loss of Bikini's seaward beach as a result of creating the peripheral landstrip; (5) the effectiveness of high-potassium fertilizer in blocking the uptake of cesium-137 by plants, a technique of potential ancillary use. However, preliminary civil engineering planning may begin now, as well as work on a proposed draft environmental impact statement.

Aside from the immediate problems of decontamination, the committee sees the need to initiate planning with the Bikinians for housing and community facilities, and for the eventual subsistence, agricultural and economic activities that will be essential for the maintenance of their community.

BIKINI ATOLL REHABILITATION COMMITTEE

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1. PROBLEM AND SOLUTIONS

The Bikini Atoll Rehabilitation Committee was authorized by Congress to report independently on the feasibility and cost of rehabilitating Bikini Atoll (1N)*. The Committee was initiated two years ago through the Office of Territorial and International Affairs, Department of the Interior, working with the Bikini people.

Planning for rehabilitation involves two separate tasks. The first one deals with how the contamination of the Atoll by radioactive fallout can be reduced or otherwise controlled to meet the Federal radiation protection standards, while at the same time respecting the atoll's biological and environmental integrity. The second task deals with the civilian needs of resettlement per se -- revegetation and agriculture, water supply, housing, community buildings, etc. The Bikinians should be given the opportunity to participate in such planning and in the actual work that follows.

In this report (No. 1), the Committee defines and evaluates the approaches and techniques for contamination control. The two major approaches are based on (1) the spontaneous decay of radioactivity or (2) the removal of contaminated soil.

1.1 Background

In 1946 the U. S. Government removed the 167 inhabitants of Bikini Atoll so that the atoll could be used for the testing of nuclear weapons. That program ended in 1958 after 23 tests which had rendered the atoll unsafe for human habitation (2).

The Bikini people were settled first on Rongerik Atoll (Figure 1), then briefly on Kwajalein, and finally in September 1948 on Kili Island, some 425 miles south of Bikini Atoll (3).

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*References with an N (e.g., 1N) contain a note as well as a citation.

In 1968, President Johnson was advised by the Atomic Energy Commission that the main islands of Bikini Atoll were safe (but should be monitored in the future), and permission for resettlement was given. In 1969, therefore, the Department of Defense and the Atomic Energy Commission cleared the atoll of brush, debris, and abandoned equipment, and during 1970-73, thousands of coconut trees and some breadfruit and pandanus were planted on Bikini and Eneu Islands with the help of a number of Bikini people who had begun the resettlement (3).

In 1978, however, an examination of the settlers on Bikini Island by a team from Brookhaven National Laboratory revealed significant body burdens of the radionuclide cesium-137 (4). As a result of these and additional findings by the Department of Energy (5), the 139 settlers were evacuated in August 1978, and settlement has not been allowed by the U. S. since that time.

Studies by the Lawrence Livermore National Laboratory team, especially during the past 6 years, have accumulated extensive information on the radioactivity of Bikini soil, plant products (6) and water (7). The validity of these data was questioned by the Bikini people on the basis that, coming from a government laboratory, the testing may have been biased. A review in 1982 by independent consultants selected by the Bikini people (Epidemiology Resources, Inc.) confirmed the Lawrence Livermore analytical findings (8).

The scarcity of land in the Marshall Islands and the cultural significance of land ownership make resettlement of Bikini Atoll a matter of overriding importance to the Bikini people. There are today approximately 1120 Bikinians, of whom some 500 dwell on Kili Island, about 200 on Ejit Island in Majuro Atoll, and the rest elsewhere in the Marshalls. The Committee estimates that more than 75 percent of the population is under 30 years of age, and the majority is well under 20, perhaps even under 16. The population has been increasing at a rapid rate.

1.2 Geography and Political Status

Bikini Atoll is located 4,000 km (2,500 miles) southwest of Hawaii, at 11°35'N, 165°25'E. It comprises a ring of 23 islands with a total land area of 8.8 km^2 (3.4 square miles), including 1.6 km^2 (0.6 sq. mi.) of intertidal area (Figure 2, Table 1). The lagoon of 630 km^2 (240 sq. mi.) has an average depth of 45 m (145 feet); the maximum depth is 58 m. Of the 23 islands, only Bikini (2.41 km^2) and, to a much lesser degree, nearby Eneu (1.22 km^2) have been inhabited. In fact, they are the only islands that are physically suited for permanent settlement; all the others are too small and too low to be safe from inundation during times of high wave and storm activity.

The geological structure of Bikini Atoll is that of a coral reef atoll resting on a submerged volcanic mass. The islands are made of reef debris, primarily of sand and gravel size, and reef organisms. The reef is continuously being built and eroded, but under present conditions the islands and the passes that connect lagoon and ocean are fairly stable (Appendix A).

The atoll is similar in appearance to others in the Marshall Islands. The principal islands of Bikini and Eneu, as well as many of the other smaller ones, are thickly covered with vegetation. The sandy soil supports a variety of plants, shrubby thickets along exposed coasts, and coconut plantations over most of the two larger islands. A variety of other food plants can be grown, but because of the long dry season, they are not likely to become staples (Appendix B).

Bikini Atoll is part of the Republic of the Marshall Islands, which has a total land area of about 170 km^2 (66 sq. mi.) scattered over roughly 700,000 km^2 of the central Pacific Ocean (Figure 1). The Marshall Islands, together with the Caroline and Northern Mariana Islands, comprise the Trust Territory of the Pacific Islands, which the United States has administered since 1947 under a Trusteeship Agreement with the United

Nations. On September 7, 1983, the voters of the Marshall Islands approved a Compact of Free Association which, if ratified by the U. S. Congress, will grant self-government to the Marshall Islands, while continuing United States financial and program aid for the next decade.

The population of the Marshalls numbers some 33,000 persons. The principal population centers are on Majuro Island, the capital (Majuro Atoll), and Ebeye Island in Kwajalein Atoll, which is a missile range under the jurisdiction of the U. S. Army.

On January 24, 1979, the U. S. conveyed Bikini Atoll back to the Bikinians. Thus as a legal matter, they possess all the rights of ownership. However, since the decontamination program for the atoll would be paid for by the U. S., it might be subject to U. S. environmental law and radiation protection standards (Appendix E).

1.3 Radiation Exposure and Control

Studies by the Lawrence Livermore National Laboratory group during recent years have shown that unrestricted settlement on Eneu would conform to Federal radiation protection standards (6). However, on the main island of Bikini this would not be the case, as the Brookhaven National Laboratory team demonstrated by direct measurements on settlers in 1978 (4).

The radiation dose from resettlement today would result primarily from eating locally grown food (6) (Appendix D), plus a much smaller contribution from radiation emanating from the ground. More than 90 percent of the dose would stem from the radionuclide cesium-137, and the rest from strontium-90. These radionuclides are concentrated in the uppermost layer of the soil. Coconut products would account for some 80 percent of the ingested dose.

In general, the following "rules" apply if the Federal radiation standards are to be met:

(a) Unrestricted use of Eneu and several other islands is now permissible. Any island may be visited.

(b) Bikini may be resettled only if all food is imported and only cistern (not ground) water is drunk. To permit unrestricted use of Bikini now would require a major program to render the contaminated soil innocuous.

(c) In 80 years, Bikini agricultural produce and ground water should become safe, owing to the spontaneous decay of cesium-137.

The direct approach to decontamination calls for the removal of the top 30 cm of Bikini soil (where cesium-137 and strontium-90 are concentrated) to expose a "safe" layer for planting. The resulting spoil (excavated soil) might be used to extend the island's seaward perimeter by 35-40 meters, or it might be dumped into the Bravo crater of the lagoon, caused by the 1954 test.

The Bikinians, however, notified the Committee (September 21, 1984) that they request the spoil be used to construct an 8 km-long causeway between Eneu and Bikini islands. The addition of this project would double the total cost.

The removal of the top 30 cm of soil from a coralloid island raises questions regarding the productivity of the remaining soil. To settle this and other questions (including the limitations of water-supply and the blockade of cesium-137 uptake by high-potassium fertilizer), we have requested support for pilot trials at the atoll.

On the other hand, there is the "wait-it-out" approach. That is to say, resettlement would be effected on Bikini and/or Eneu, but the consumption of local food (except fish) and ground water would b prohibited for 80 years. In effect, this would preclude any agricultura use of Bikini and could limit the agricultural use of Eneu under certai circumstances. It would also require a continuing radiation monitorin program of soil and plants and a large, reliable food-importation program.

As a scientific committee, we do not advocate any one of th feasible alternatives. Whether the direct approach or the wait-it-ou policy should be instituted is a decision involving value judgments tha are the responsibility of the Federal Government and the Bikinians. The Bikini-Kili Council has informed the Committee (August 14, 1984) that th "wait-it-out" approach is not acceptable to it.

In the following sections we set out the detailed information o the distribution of soil contamination (Section 2), the calculation o radiation dose and its dependence on diet (Section 3), and the variou specific plans for eliminating or countering soil contaminatio (Section 4). Section 4.5 compares the relative merits of such plans an notes some additional studies that are required to gauge their reliabilit and power. The general interrelationships of these factors are illustrate by the assessment model presented in Figure 3. Those desiring mor technical information are referred to the Appendices (see Table o Contents). Section 5, the final one, notes the importance of communit planning, which is not dealt with in this report.

2. CONTAMINATION

The 23 nuclear tests from 1946 to 1958, and in particular the Bravo H-bomb shot of 1954, deposited radioactive fallout unevenly throughout Bikini Atoll, including the lagoon. Over the past 26 years, contamination has diminished through spontaneous decay, and in the case of the lagoon, by exchange of water with the open sea. The most important remaining nuclide is cesium-137 (half-life, 30 years). Also present but much less important is strontium-90 (half-life, 29 years). Traces of the transuranic elements are also present (plutonium-239, -240; americium-241), but contribute very little to the total dose.

In the discussion that follows, the level of radioactivity (specific-activity) is expressed in picocuries per gram (pCi/g) of soil or other substance as of 1987, the earliest that resettlement might occur. One pCi/g signifies that in one gram of substance one atom disintegrates and emits a burst of radiation every 27 seconds. For comparison, naturally occurring potassium-40 in soil ranges between 0.5-0.8 pCi/g (9, p. 30); in sea water it is about .03 pCi/g.

2.1 Lagoon

The nuclear shots that occurred at Bikini (Appendix C) affected the floor, water and sediment of the lagoon.

2.1.1 Floor. Three shots in particular affected the floor of the lagoon. During Operation Crossroads in 1946, 11 ships sank to the bottom, five during the Able shot and six including the carrier Saratoga during the Baker shot (Figure 2, sunken ships). These ships carried fuel, loaded guns and stores of ammunition.

The remnants of several observation towers also lie on the bottom, near Lomilik Island (B4, Figure 2).

The ships themselves do not pose a significant radiation hazard, although the activity of the sediment in the immediate vicinity of some may be as high as 20 pCi/g (Appendix C). The sediment accumulating on the ships and a piece of one of the ships itself will be reported on in Appendix B.

Of more concern is conventional contamination from leaking fuel tanks or from exploding ammunition. However, at Truk Lagoon 26 sunken Japanese ships still rest on the bottom of a busy harbor and apparently are not dangerous if left undisturbed (Appendix C). The vessels are being covered with increasing amounts of sediment and coral and are the site of active marine life. Moderate chronic fuel leakage can be borne without difficulty by such ecosystems (10) owing to biodegradation. However, the Bikini site should be examined by divers to ascertain the current state of the sunken ships.

The third important event was the Bravo shot in 1954, creating the sizeable crater in the lagoon off Nam Island (Figure 2) which now might be used to store very low-level radioactive materials.

2.1.2 Water. Although the levels of contamination were high especially after the Bravo shot, by 1972 the specific-activity of lagoon water was low enough to meet the Federal standard for fresh drinking water (11 N).

2.1.3 Sediment. The specific-activity of the lagoon sediment (0-4 cm depth) is higher than lagoon water but still within permissible limits. Cesium-137 activity is generally below 10 pCi/g (Figure 2), and on the lagoon bottom within 15 km of Eneu and Bikini Islands it is 0.1-1 pCi/g (12). The levels of other radionuclides in the Bikini-Eneu area are: cobalt-60, 1; plutonium, 5; americium-241, $<$5 pCi/g.

Analyses of sediment from the northeast corner of the lagoon down to depths of 60 cm have shown that radionuclide levels fall off very appreciably with depth. The results of recent studies down to 100 cm off of Eneu and Bikini appear to be showing a similar result and will be fully reported on in Appendices A and B.

It is therefore anticipated that sediment dredged from the bottom of the lagoon offers a convenient source of backfill and landfill should plans require them. The sandy bottom is generally flat and thus suitable for dredging, but numerous coral heads emerge, some of which may exceed 1 km in diameter and stand more than 30 m high (Appendix A).

2.2 Islands

The islands of the atoll (Figure 2, Tables 1, 2) vary greatly in size and in contamination. Only two of them are larger than 1 km^2; Bikini (2.4 km^2) and Eneu (1.2 km^2).

2.2.1 Soil Composition. The major elements judged by their distribution in depth fall into two major classes. The concentrations of extractable potassium and of total phosphorus, nitrogen, and organic matter fall off with depth to become small below 50 cm (20 in.) as shown in Table 3. Cesium-137 follows this pattern (Tables 2 and 3) and is thought to be associated with the organic matter. On the other hand, the concentrations of nonradioactive strontium and calcium are practically constant, and that of magnesium rises with depth.

2.2.2 Radioactive Contamination. The transuranic elements plutonium-239, -240 and americium-241 contribute less than .08 percent to the 30-year cumulative dose because they are scarcely taken up by plants and their activity in the soil is low (6). Their combined surface activity on Bikini is about 17 pCi/g, on Eneu about 1.3 pCi/g, both well below the transuranic standard of 40 pCi/g employed at Enewetak (13N).

The two major radioactive contaminants today are cesium-137 and strontium-90, present in soil at roughly the same range of specific activities (Table 3). This is in spite of the fact that total cesium in the soil (radioactive plus nonradioactive) amounts to less than 1.3 parts per million whereas total strontium amounts to 2000-4000 parts per million owing to its very much greater natural abundance.

Unfortunately for cleanup purposes, cesium-137 is readily taken up by plants, moving in much the same way as potassium, an essential element with which it might compete for uptake. Its specific-activity varies in different foods, but in each case will rise and fall with the specific-activity of the soil. Plants, especially fruits, may concentrate cesium 3-6 times over the soil level (6). For strontium-90, the concentration ratio (plants/soil) in edible fruits ranges from .01 to .5 but in the leaves it may be as high as 10 (Appendix B).

The cesium-137 surface-zone activity (0-10 cm) for the individual islands of the Bikini Atoll, determined by a comprehensive aerial survey, is given in Table 1. In the case of Bikini and Eneu, the estimates were confirmed by terrestrial measurements. These measurements show that Bikini is among the most heavily contaminated islands, while Eneu is in the lower range.

In the soil, cesium-137 specific-activity (island distributed mean) fell exponentially with depth on both islands as illustrated in Figure 4, based on Table 2:

$$A_Z = A_o e^{-\mu Z} \quad ..... \quad (1)$$

where A_Z is specific activity (pCi/g) at depth Z (cm), and A_o is the activity at zero depth (Bikini, 80.5 pCi/g; Eneu, 5.5 pCi/g).

Although the surface activity of Bikini averaged more than 10 times that of Eneu, the fractional decline of activity per centimeter depth (μ) was about the same (-.065 per cm vs. -.052 per cm).

The means of these two factors (-.059 per cm) could be used to calculate the subsurface activity on islands where such data are lacking.

The mean specific-activity of the rooting zone $\overline{A}$ (0-40 cm depth) is:

$$\overline{A} = \frac{A_0}{40\mu}\left\{1 - e^{-40\mu}\right\} \quad ..... \quad (2)$$

For Bikini and Eneu, the mean rooting zone activities are 28.6 pCi/g and 2.31 pCi/g, respectively. The relation between these levels and human dosage is discussed in Sections 3.2 and 3.4.

Although the island-distributed mean activity fell smoothly with depth, the local activity at some sampling sites on Bikini and Eneu did not. These were locations where the ground had been disturbed mechanically during one or more previous trash cleanups or perhaps during the planting of trees. Often the bulk of the irregularity occurred within a layer that would be scheduled for excavation (if such decontamination were called for). Furthermore, such sites would be monitored during the course of excavation and could receive additional treatment if necessary.

2.3 Water Supply

2.3.1 Rain Water and Coconut Fluids. In the Marshall Islands fresh ground water is in short supply. At Bikini Atoll, although total annual rainfall is in the range 100-200 cm (40-80 inches), periods of drought and water scarcity are frequent. Cistern water therefore is the usual source of drinking water; it is uncontaminated and is much preferred to the more or less brackish ground water. Traditionally, coconut fluids also make an important contribution to fluid intake. More recently, imported canned soft drinks are being used throughout the Marshall Islands.

2.3.2 Ground Water. Ground water accumulates in the following way. Rain water drains through the permeable soil and accumulates in the underlying porous rock and sand matrix as a roughly lens-shaped body of fresh water, floating on the denser salt water. Most of the fresh water is rapidly mixed with the underlying salt water by wave and tidal activity, leaving only a very thin fresh layer, usually in the central portion of the island. The smaller the island, the more rapidly mixing occurs; hence the smaller the freshwater body. No potable ground water is thought to exist on the smaller islands. In the Marshall Islands, the chloride standard for potable water has been set at 400 mg/l compared to 250 mg/l in the U.S.

During the summer drought of 1984, four of seven wells on Bikini were dry and none had potable water. None of the wells has met the Federal standards for cesium-137 or strontium-90 (Table 4) (12, and Appendices A and B). Two of four wells on Eneu were functional and had potable water; the quantities observed could have met the needs of 200-250 persons with careful use (Appendix A). These wells were located close to the runway.

It is therefore recommended that detailed studies be initiated to estimate the potential for ground water development. The studies should include the aerial, vertical and seasonal changes in both salinity and radioactivity.

On Bikini, the removal of the uppermost, heavily contaminated layer of soil presumably would materially reduce the radioactivity in ground water. We note that the cesium-137 levels in the rooting zone and in ground water on Bikini are both more than 10 times those of Eneu.

On the other hand, potassium-fertilizer blockade treatment (Section 4.4) would not be expected to reduce the cesium-137 level in ground water. Whether or not it would increase the level would be checked in the pilot trials recommended for next year.

3. RADIATION EXPOSURE AND DOSE

At Bikini Atoll, the radiation dosage stems from two kinds of exposure: external from radiation emanating from the contaminated soil (Table 1), and internal from radiations emitted by contaminated food and water or inhaled as gas or dust (Appendix D). The decay of cesium-137 accounts for practically all external dosage (half-life 30 years; mean beta, .52 MeV; .66 MeV gamma). It also accounts for practically all internal dosage. Bone marrow, however, receives an additional 7 percent from the decay of strontium-90 (half-life 29 years; mean beta, .196 MeV and .93 MeV) (6).

The calculation of the external and internal doses depends directly on the levels of soil and food contamination, and on assumptions regarding the Bikini diet (Table 2, Figure 3) (Appendix D). Although the levels of contamination in the atoll (Table 1) may differ greatly, in no case will they lead directly or indirectly to an acute or subacute reaction (Annex J in Reference 14). The dangers of exposure, if any, would be registered as a late effect, namely, a small increase in the lifetime risk of cancer if sufficient contaminated food is eaten over an extended period and sufficient time elapses for the cancer to appear (15).

3.1 External Dosage

Calculated for 1987, the earliest that resettlement might occur, the annual external dose per person (above natural background) for both Eneu (.012 rem) and Bikini (.16 rem) is within the Federal radiation protection standard of .17 rem (Table 4) (6). For comparison, the annual dose (world average) from background terrestrial plus cosmic sources is approximately 0.2 rem, and in the Marshall Islands it is less than .03 rem (14, 16N, 17, 18).

The annual dose declines progressively with time owing to the spontaneous decay of cesium-137 (half-life, 30 years). Therefore, the

30-year cumulative dose (Eneu, .27 rem; Bikini, 3.5 rem) (6) is relatively further below the standard (5 rem) than the initial annual one.

Although the above external dose estimates are quite adequate for planning, it is to be noted that specific beta-ray exposure measurements at ground level (0-10 cm above surface) have not been published for Bikini. The Committee is therefore recommending that such measurements be made to make the estimates complete.

3.2 Internal Dosage: Food

Food consumption is the primary determinant of dose, but it is not clear what the Bikinians will eat when they resettle Bikini Atoll (Appendix D). The Lawrence Livermore Laboratory team has assumed that the dietary estimates made by a Micronesian Legal Services investigator in 1979 for the Enewetak people, then living on Ujelang Atoll, would apply to Bikini. The estimate were made for conditions under which imported foods might or might not be available. For practical reasons the committee uses a "planning diet" which assumes that local produce is always available and that imports are available 75 percent of the year. The local produce includes coconut, some pork and chicken, pandanus and breadfruit, and fish. Very important imports are rice, flour and sugar as well as canned meats and fish.

Knowing the composition of the diet and the average radionuclide content of the various foods in it, the daily intake of cesium-137 and strontium-90 can be estimated in pCi/day per person. Assuming the nature of the diet to remain constant, the 30-year dose in rem (whole-body) is calculated by multiplying the initial (e.g., 1987) daily intake of cesium-137 by the conversion factor .00045 rem/pCi (Appendix D). The dose to bone marrow will be about 7 percent greater owing to strontium-90 consumption.

All agree that coconut consumption has been the principal radionuclide source in the diet (e.g., 19, 20), and by Lawrence Livermore calculation it would account for more than 80 percent of the internal planning dose (6). Fish meat, an important staple, contributes practically nothing. The possible contribution from fish bone is under investigation.

Coconut consumption, however, has been declining in recent years, and imported foods have become increasingly important as Marshallese life-style has reacted to the influence of external cultures. On the other hand, resettlement with a planned agricultural program might very well increase the importance of local produce.

In view of the foregoing, judgment must be exercised in deciding on a likely "planning diet" for estimating daily radionuclide intake. To allow for possible errors of one sort or another, and especially for the possibility of increased use of local produce after resettlement in order to become more self-sufficient, we have decided to multiply the estimates employed by the Lawrence Livermore team by the factor of 1.75.

On this basis, the 30-year cumulative dose for Eneu of 4.2 rem would be within the 5-rem Federal standard, but the dose of 30.8 rem for Bikini would be far beyond it (Table 5).

3.3 Internal Dosage: Water

Cistern (rain) water is the chief source of drinking water and is practically uncontaminated (6). On the other hand, the radionuclide levels in ground water, though low, are notable because they exceed one of the two Federal standards (Table 4).

Drinking water is regulated by a "practical" Federal standard (21, 22) that sets specific-activity limits for cesium-137 at 200 pCi/l and for strontium-90 at 8 pCi/l (Table 4). When two or more nuclides are present, the standard for each is reduced proportionally. As stated in

Section 2.3, the Bikini wells do not meet the practical standard, whereas wells on Eneu do.

Ground-water consumption makes a small contribution to the whole body dose. If calculated on the unrealistically high consumption of 2 liters per day (6), it would amount to less than 5 percent of the total dose for Eneu or Bikini. However, the Lawrence Livermore team estimates ground-water consumption to average about 0.25 liter per day over the course of a year (6).

3.4 Permissible Soil Specific-Activity

For the very low concentrations of cesium in atoll soil, it may be assumed that uptake by food plants -- and thus subsequent human intake -- will be proportional to soil concentration (23N). Turning the problem around, we may say that having found the estimated dose to be six times too high (30.8 vs. 5 rem), the island's rooting-zone specific-activity (0-40 cm depth) should be reduced to one-sixth of the present level.

On this basis, the liminal specific-activity of the island's rooting zone -- that mean value (0-40 cm depth) not to be exceeded -- can be calculated for Bikini as follows:

$$(5 \text{ rem}/30.8 \text{ rem}) \times 28.6 \text{ pCi/g} = 4.6 \text{ pCi/g (liminal value)},$$

where 5 rem is the standard and 30.8 rem is the dose associated with the current mean specific-activity of the rooting zone, 28.6 pCi/g (island distributed mean).

Spontaneous decay of cesium-137 will reduce the mean specific-activity of Bikini's rooting zone to the liminal value in 80 years (79.1 exactly). Or the liminal value can be produced more quickly by removing 30 cm (28 cm, exactly) of the top layer of soil (Section 2.2, Figure 4).

The strontium-90 level of the rooting zone will fall by some 85 percent in 80 years. Removing 30 cm of topsoil will reduce the level by some 66 percent (Table 2).

It should be noted that dose does not fall in direct proportion to the depth of such excavation. Since dose is proportional to rooting-zone specific-activity, it falls exponentially with depth like the rooting-zone activity (Figure 4).

4. MEETING THE PROTECTION STANDARDS

Operationally, there are three ways to meet the radiation protection standards: (a) Delay resettlement so that spontaneous decay of radionuclides can reduce contamination; (b) Treat the soil to reduce the uptake of cesium-137 by food plants; (c) Remove the contaminated soil. In the following, we first note the options under each approach and then compare effectiveness, cost, and time required for execution.

The estimates of cost in 1984 dollars are based continental U.S. experience and especially on the experience of the Army Corps of Engineers in the Pacific. They assume that work on an isolated, uninhabited atoll without construction resources, employing imported U.S. personnel, will cost 2.4 times as much as on the continental U.S. Such costs might be materially reduced by the extent to which a Marshallese work force could be employed and locally available equipment from Kwajalein or Majuro (250-500 miles away) could be employed. The staging costs, nonetheless, would probably be relatively high.

Of the 13 islands that do not meet the federal standard and therefore are potentially in need of decontamination (Table 6), only three of them are them are larger than 25 hectares (1 hectare = 2.47 acres) -- Bikini (240 ha), Enedrik (96 ha), and Nam (54 ha). The levels of contamination on Bikini and Nam are relatively high, that on Enedrik appears marginal. Only Bikini, however, is physically suitable for settlement (Appendix A).

4.1 Delay Resettlement

The simplest technical approach is to wait until the spontaneous decay of cesium-137 (half-life, 30 years) and strontium-90 (half-life, 29 years) decontaminates the soil. In the case of Bikini Island, the objective can be achieved over a period of 80 years. The advantage of doing nothing is that it costs little or nothing directly. The disadvantage is that the Bikinians are deprived of the use of their home land for 80 years. There are two variations of this plan.

The first one is for the Bikinians to resettle Bikini Island with the proviso that no food be grown nor ground water consumed on that island during the decontamination waiting period. Fishing would be permissible.

The plan therefore entails large scale food imports; a substitute for ground water which is of great importance in times of drought; the control of agriculture and especially coconut production (nipping the flower buds 2-3 times a year, annual cost about $100,000); and soil and plant assays of radioactivity every 5 years (cost, about $500,000 per survey). Over an 80-year period, the food control and monitoring costs would total about $20 million. The cost to generate a substitute for the contaminated ground water would be less than $1 million, but a precise figure cannot be given now since the number of settlers is not known.

The second one involves resettling Eneu while declaring Bikini off-limits for agriculture. Since Eneu is one-half as large as Bikini ($2.4\ km^2$), it is practically certain that it could not support a population of 1100 living in traditional fashion (assuming that all Bikinians would in fact return). Its ground water supply appears to be good (Appendix A). Bikini, of course, would have to be monitored and food (coconut) production prevented.

4.2 Treatment of Soil

Four types of treatment have been considered -- leaching, biological extraction by cropping, topping with clean soil, and application of high-potassium fertilizer. The first three of these are regarded as ineffective, cumbersome or too expensive. Treatment with fertilizer shows promise where the level of contamination is low. Unit costs for some of these operations are given in Table 7.

4.2.1 Leaching. Thirty-five years of rain, averaging some 150 cm (60 inches) per year, have failed to wash the radionuclides from the soil. Large-scale leaching with sea water by the Lawrence Livermore group (Appendix B) has not yet proved effective (24). In most continental soils, cesium is very firmly fixed to clay minerals (25, 26). In the coralloid soils of the Marshall Islands, however, the fixation may be to organic matter, but the nature of the process is undefined (Appendix B).

4.2.2 Biological Extraction (Cropping). Since cesium may be concentrated in plants, the possibility exists of removing cesium from soil by cropping. The method does not seem practical. For example, assume that the plant specific-activity is three times that in soil, and that 1.5 kg/m^2 of plant material can be harvested annually. Then for Bikini's 2.4 km^2, some 3500 metric tons per year of plant material would have to be removed for 50 years to reduce rooting-zone cesium-137 activity from 29 pCi/g (the present level) down to 4.6 pCi/g (the liminal level).

4.2.3 Topping. A clean rooting zone may be created by topping contaminated soil with a fresh layer 50 cm or more thick, as might be needed. If the topping layer is thick enough and fertile, large numbers of roots of the edible plants will not penetrate from it into the contaminated layer below. Nor would the tightly bound cesium-137 of the contaminated layer be expected to diffuse upwards into it. The plan would involve removing and disposing of the vegetation currently in place (cost, $3 million), topping with 50 cm of dredged sediment from the lagoon, the only practical source (cost, $55 million), and conditioning and replanting the area thus treated (cost, $6-8 million), for a total cost of about $65 million. Two to four years would be required to complete the civil engineering, after which, with adequate planning and care, mature revegetation would develop over a period of 10 years.

Topping, however, would not decontaminate the ground water. Furthermore, the roots of such plants as Messerschmidia, Pisonia, and mature breadfruit would penetrate into the contaminated depth. As a result, the falling leaves of these plants would contaminate the surface soil.

4.2.4 Treatment with Potassium Fertilizer. Exploratory experiments have shown that potassium fertilizer at high levels will reduce the specific-activity of cesium-137 in plants (27N, 28, Appendix B). Such reduction presumably is the result of competitive blocking by potassium of the uptake of cesium-137. The extent to which such blockade would be effective against the cesium levels on Bikini Island is not known; to estimate this, support has been requested for pilot trials that would begin in the fall of 1984.

Although such treatment may not be powerful enough for the high levels of cesium-137 on Bikini Island, it maybe of use in marginal or moderate cases of contamination, for example, Enedrik, where 50 percent reduction in plant uptake would lead to a diet that meets the standard. Potassium treatment might also be used to truncate the end of the 80-year waiting period for Bikini if that island is allowed to go untreated.

The advantage of potassium treatment is that the topsoil is retained, and in fact, its productivity would be improved by the fertilizer treatment. The increased yields would partly compensate for the treatment cost. On the other hand, the treatment must be continued year after year until spontaneous decay of the cesium-137 reduces specific-activity to an acceptable level. Furthermore, the treatment does not decontaminate the ground water.

The cost of such a treatment would be of the order of \$500 per hectare (.01 km^2). The cost of radioactivity monitoring also must be allowed for. The annual and total costs, however, cannot be stated now with any precision because it is not yet known how frequently the individual treatments must be given.

4.3 Soil Removal

Removal is the direct way to deal with contaminated soil. After clearing of vegetation, the contaminated soil is excavated and disposed of by outright dumping or by using it as landfill. The method is feasible at Bikini Atoll because cesium-137 is largely concentrated in the upper layers of soil, falling off exponentially with depth (Figure 4). The depth of soil to be removed varies from about 30 cm on Bikini Island to estimates of a few centimeters on Enedrik (Tables 6, 8). The spoil (excavated soil) can be handled with impunity so that only monitoring, but not costly and complex precautions, would be necessary. Conventional masks might be required for certain kinds of work owing to the level of dust or smoke.

The disadvantages of direct removal are, first, relatively rich topsoil is lost; second, some 10 years will be required to revegetate the denuded island (shading and coconut production are the slowest to appear (Appendix B)); and third, substantial skills and costs ($6-8 million) will be required for the revegetation program and to provide for agricultural development.

Soil removal becomes more efficient when it is a large-scale operation. For Bikini Island, the time required would be 2 to 4 years. Based on the unit costs in Table 7, the total cost would range from $36 to $80 million, depending on how the spoil is disposed of, e.g., marine dumping, island extension, or causeway construction. Backfilling the excavated area with lagoon sediment is an additional option. The more important details for such soil-removal programs are as follows.

4.3.1 Clearing. The process involves clearing the land and burning the refuse or storing it on an unused island. Aside from the temporary loss of food supply and amenity, the destruction removes the shield that guards against excessive sunlight and the winds that blow almost constantly. Under favorably planned conditions, it is thought that vegetation can be reestablished in 8-10 years; shading and coconut production are the slowest to reappear. The estimated cost is $3 million for clearing.

In part on general grounds, in part owing to the variable results at Enewetak Atoll, a U.S. government operation in the Marshalls (1972-1980) (13), doubts have been expressed about the possibility of successful agriculture at Bikini after topsoil removal (Appendices A, B, and E).

We note, however, that the Majuro causeway built of lagoon sediment has spontaneously revegetated itself. Scrub revegetation of new sandbars and typhoon-eroded islands is commonplace. At Enewetak where in certain areas the land had been cleared and in some locations paved, the difficulties might stem from the compaction of the soil by previous heavy-duty usage and by the heavy clean-up earth moving machinery employed. In any case, we recommend that a pilot trial be executed on Bikini that will deal with the effects on productivity of soil compaction and exposure to wind.

4.3.2 Disposal of Spoil. Four locations for the disposal of spoil are the lagoon, an unoccupied island, the site of causeway construction, and the oceanward side of Bikini. Various laws, national and international, regulate disposal. With respect to ocean dumping, the situation is so complex and uncertain that the option is precluded. (29N).

(a) The lagoon-disposal alternative for Bikini Island would cost a total of $36 million. To immobilize the spoil by bagging it before disposal would increase the cost by about $12 million.

The best location in the lagoon would be the Bravo crater (73 m deep; volume, 16 million m^3). The ecological consequences are minimal because the crater is "dead", and the more or less monthly replacement of lagoon water tends to prevent the accumulation of turbidity and dissolved contaminants (Appendices A, E). From an engineering point of view, such dumping would be a simple operation.

The mean specific-activity of Bikini spoil totals less than 10^{-4} Ci/ton for all radionuclides and thus falls below the former so-called de minimis level of 10^{-3} Ci per metric ton, a non-official level now, but one that might well be considered acceptable scientifically. However, at present, there is no legal standard and the matter is under international study (29N).

(b) Disposal on an unoccupied island declared off-limits for food production would localize the spoil. We see no reason to incur the additional cost of unloading and other steps.

(c) The Bikinians have suggested that the spoil be used to build a causeway, 8 km long, connecting Eneu and Bikini Islands. Such a structure would facilitate transportation between the two islands. The specific-activity of the spoil would not be important because the causeway would not be used for food production. The total cost of the prototype diagrammed in Figure 5 (including items 1, 2, and 7, Table 7), would be some $80 million.

From the engineering and ecological points of view, the desirability of such a structure is open to question (30N, Appendices A, E). It would be built on a narrow reef, especially sensitive to wind, wave and tidal action. Even though supplied with a series of culverts to allow the free flow of water between reef and lagoon, the causeway would threaten fishing on the neighboring reef flats, the integrity of the shore line, and the lagoon's circulation. The maintenance of the causeway would be expensive, running into some millions of dollars over a period of 20 years. Especially important would be the requirement to provide continued month by month care.

(d) Instead of dumping the spoil off-island, it could be used as backfill to extend slightly the land mass of Bikini Island on the exceptionally broad reef flat that bounds its oceanward side (Figure 6). The total cost is estimated at about $42 million (Table 9). The narrow, elevated land strip thus formed would be planted with inedible vegetation and would serve as a screen against wind and exceptional high tides. However, the present beach would be covered, so that the formation of a new beach over a period of some years would have to be planned for. Significant movement of radionuclides from the strip back into the island's soil is most unlikely, since over the past 25 years cesium has not been washed out of the soil by rain. If necessary, a membrane would separate the strip from the island proper.

Psychologically, this alternative might be uncomfortable for the Bikinians. The contaminated soil which has prevented the resettlement of Bikini Island would be used to form its new seaward boundary.

The legal problems presented by this alternative are minimal. Since the reef is now awash, the strip would not affect the atoll's baseline, which in any case has not yet been drawn, nor would it affect navigation.

4.4 Soil Replacement

The removal of 30 cm of Bikini topsoil does not entail replacement (Appendices A, B, E) since the island would have sufficient elevation without it. If for some reason replacement is undertaken, the sediment dredged from the lagoon off of Eneu and Bikini could be used conveniently. The incremental cost would be some $25 million, which when added to the island-extension plan above, for example, would bring the total cost to about $67 million (Table 9). If only small quantities of backfill are needed, projecting sand spits could supply them.

The basic chemical nature of lagoon sediment and of island sand is similar to that of the island soils, but the upper layers of the soil have accumulated over the years considerable amounts of organic matter, nitrogen and sometimes phosphorus (Table 3), important substances for vigorous plant growth. In any case, the new land surfaces should be promptly seeded and fertilized to prevent wind erosion. Revegetation with desirable food or woody species could then be attempted, but the same reservations apply here as stated above in Section 4.3.1.

Dredging for backfill might cause some transient but significant ecological disturbances that will be reflected in diminished fish stocks and may also lead temporarily to rendering fish tissue toxic for human consumption (Appendix E).

4.5 Comment

In the Interim Report (Nov. 23, 1983), the cost of decontamination was estimated to be "of the order of" $100 million. The simpler plans that continue to merit major consideration cost far less. We have concentrated primarily on their applicability to Bikini and Eneu, since only these two islands are suitable for permanent resettlement (Appendix A). The other islands sooner or later will be washed over by the great storms of the region.

The cost estimates that we have used may be high; they are a factor of 2.4 higher than comparable continental costs in the U.S. to allow for the difficulties of staging in a remote, small, uninhabited area. To the extent that such difficulties can be overcome by the use of relatively nearby labor markets and available equipment, the total cost will drop, possibly dramatically.

All planning, of course, is contingent on the accuracy of the dosimetry, based on the work of the Lawrence Livermore National Laboratory, which may be subject to minor modification and refinement. We are recommending field measurements at Bikini, including beta-ray and gamma-ray components, but we do not anticipate findings that will materially affect the overall planning discussed here.

It also should be noted that the plans may be affected by environmental-impact review. At present, however, it is not clear who the responsible authority will be. After the Compact of Free Association with the Republic of the Marshall Islands becomes effective, presumably in 1985, EPA and/or U.S. Army Corps of Engineers regulations may no longer apply.

In summary, there are two basic approaches to decontamination.

The wait-it-out plan in which spontaneous decay solves the contamination problem is technically the simplest and ecologically the most benign, but has the major disadvantage of compelling the Bikinians to give up agricultural rights to Bikini Island for 80 years. The island would have to be monitored and otherwise controlled, at a total cost of about $25 million. If the Bikinians settled on the island during this period, a food import program would have to be established and a substitute for ground water provided. Or, resettlement could be initiated on Eneu, which is half the size of Bikini, and Bikini declared off bounds. In this case, Eneu-grown foods could be used. The Bikini-Kili Council, however, has rejected both of these alternatives.

The direct approach, on the other hand, removes the top 30 cm of the island's soil, where contamination is concentrated, to expose a new, acceptable layer for planting.

The disposal of the spoil generated by the direct approach requires a choice among three alternatives. The first one, lagoon dumping, would be the simplest and cheapest. The second one, using the spoil to extend the island's seaward perimeter, would provide protection, but would affect the beach for a period of several years, and might have other disadvantages as well. These alternatives would cost some $36-42 million and require 2-4 years for execution. (To achieve mature revegetation of the denuded surface would cost $6-8 million and would take about 10 years.)

The third alternative, requested by the Bikinians, uses the spoil to build a causeway, connecting Bikini and Eneu, a distance of some 8 km. The increment in cost for this alternative over the other two is estimated at about $40 million. As noted, our cost estimates may be on the high side, but in any event on a relative basis the causeway would be about twice as expensive as the land-extension or lagoon-dumping alternatives. Also, questions have been raised regarding the environmental impact of such a structure. Presumably these negative factors would have to be balanced against the assessed positive value to the Bikini community. Also decisive would be the U. S. government's perception of its obligation, if any, to go beyond restoring Bikini to a state functionally equivalent to that of 1946.

A major environmental impact of the excavation approach (whatever the disposal of the spoil may be) relates to Bikini Island itself. Excavation removes the "richest" layer of soil, and there is uncertainty regarding the productivity of the newly created rooting zone, even after application of fertilizer. The matter has not been tested.

To deal with this and related questions, the Committee has requested support for the following pilot trials at Bikini, to be completed within two years.

(a) After removing the top 30-60 cm of soil, productivity would be tested with and without fertilizer treatment (including high-potassium fertilizer which blocks cesium-137 uptake), and with and without the compaction that results from the use of heavy earth-moving or trucking vehicles. Cesium-137 and strontium-90 would be assayed in the crops as well as in the residual soil to insure that they are at anticipated levels.

(b) The spoil generated in these trials would be used to build a pilot segment of perimeter strip (including berm). Its stability would be observed, and the diffusion from it of cesium-137 and strontium-90, which might contaminate ground water, would be measured.

(c) The ground-water potentialities of Eneu and Bikini would be defined much more precisely to facilitate resettlement planning.

(d) The possibility of making land available for agriculture on contaminated islands that are physically unsuitable for habitation would be explored. The ability of high-potassium fertilizer to block the uptake of cesium-137 would be tested on Enedrik (where contamination is marginal) and compared to results on Bikini (where contamination is high). The effects on ground water would be observed. In the case of Nam (high contamination), the island's tolerance for the removal of 15-20 cm of soil would be considered.

The Committee believes that within two years of initiation, the results of these studies will provide an adequate basis for the United States and the Bikinians to decide on a final course of action. Meanwhile, various preliminary engineering studies should be initiated, which will also help to define the costs more precisely. As matters stand now, the costs for Bikini Island may be tabulated for comparison as follows:

A)	Delay resettlement for 80 years:	$25 million,
B)	Soil removal, lagoon dumping:	$36 million,
C)	Soil removal, land extension:	$42 million,
D)	Item C plus backfilling with lagoon sediment:	$67 million,
E)	Soil removal plus causeway:	$80 million.

To the engineering costs of plans B-E would be added $6-8 million for revegetating the denuded island and providing for agricultural development.

5. REHABILITATION: CIVILIAN REQUIREMENTS

Planning for decontamination constitutes the first phase of planning for rehabilitation. The second phase considers the civilian requirements such as revegetation including agriculture, water supply, housing, community buildings, docking facilities, etc. In doing so, it should be recalled that while 167 persons left Bikini in 1946, more than 1000 may now wish to return.

Such planning has not been the primary responsibility of this Committee, and in fact, until the major decisions regarding the decontamination program have been made, detailed community planning may not be efficient. The Committee, however, would like to note that such planning might at least be initiated by the Bikinians and their advisors so that by the time the recommended pilot studies, detailed in Section 4.5, are completed (within two years), the Bikinian needs would be defined, and where practical, steps to meet them could be coordinated with the decontamination work.

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16. A precise estimate for the Marshall Islanders is 0.04 rem/y, based on cosmic radiation, 22 mr/y (2, 14, 17); and internal radiation due to potassium-40, 18 mrem/y (14, Annex B, Table 17). The cosmic level is low owing to sea-level altitude. The external radiation level is about the same as in much of Florida. The value of .04 rem is well below the estimated world average of 0.2 rem (14).

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29. Any kind of ocean dumping requires an EPA permit (40 C.F.R. Part 220, et seq.), and this will continue to hold in the Marshall islands even after the signing of the Compact of Free Association. Presumably EPA would be reluctant to grant a permit now since the international

standard under the London Dumping Convention (26 U.S.T. 2403, T.I.A.S. 8165) has not been established. The Convention's advisor, the International Atomic Energy Agency, is studying the matter and has proposed that the standard be stated in terms of dose rather than of specific-activity of dumped material (IAEA-TECDOC-244, Vienna 1981). On this basis, the annual dose to the average Bikinian should not exceed 1 mrem as a result of dumping. The external dose would stem from boating or swimming, the internal dose from sea food. We note that this 30-year standard totals 30 mrem, compared to 5000 mrem for landborne exposure.

30. EPA regulations will apply if the work is done by an agency of the U.S. However, if the funds are given to the Bikini people directly or to an agency of the Marshall Islands government, who then assign the contracts, the regulation of environmental impact may be outside the jurisdiction of EPA, and therefore might be more or less confining.

TABLE 1

ISLANDS OF BIKINI ATOLL
AREA, EXPOSURE RATE, AND SOIL-SURFACE — ZONE ACTIVITY OF CESIUM-137 (AS OF 1987)

ISLAND	AREA (KM²)	EXPOSURE RATE[a] (R/y)		SOIL ACTIVITY, 0-10 cm DEPTH		
					TERRESTRIAL SURVEY[d]	
		AERIAL SURVEY[b]	TERRESTRIAL SURVEY[c]	AERIAL SURVEY[b] (pCi/g)	SAMPLES (NUMBER)	DISTRIBUTED MEAN (pCi/g)
B1 NAM	0.54	0.15	—	30	—	—
B2 IROIJ	0.20	0.048	—	9.7	—	—
B3 ODRIK	0.04	0.011	—	2.3	—	—
B4 LOMILIK	0.22	0.15	—	30	—	—
B5 AOMEN	0.17	0.033	—	6.6	—	—
B6 BIKINI	2.41	0.22	0.23	45	157	55
B7 BOKANTAUK	0.09	0.00085	—	0.13	—	—
B8 IOMELER	0.03	0.0053	—	0.81	—	—
B9 ENAELO	0.02	0.00085	—	.13	—	—
B10 ROJKERE	0.08	0.11	—	22	—	—
B11 EONJEBI	0.03	0.00085	—	0.13	—	—
B12 ENEU	1.22	0.016	0.02	3.3	133	4.4
B13 AEROKOJLOL	0.41	0.00085	—	0.13	—	—
B14 BIKDRIN	0.10	—	—	—	—	—
B15 LELE	0.23	0.0093	—	1.9	—	—
B16 ENEMAN	0.10	0.0093	—	1.9	—	—
B17 ENEDRIK	0.96	0.03	—	6.0	—	—
B18 LUKOJ	0.14	0.26	—	54	—	—
B19 JELETE	0.17	0.31	—	63	—	—
B21 OROKEN	0.05	0.078	—	16	—	—

a. The federal standard is less than .45 roentgens per year (R/y).

b. Tipton and Meibaum (2). The exposure rate and the specific activity calculated from it or measured in soil were due to cesium-137. The rate was estimated at 1 meter above the ground.

c. Gudiksen et al. (17).

d. Robison et al. (6), based on dry weight of soil (about 80 percent of fresh weight).

TABLE 2

BIKINI AND ENEU ISLANDS: CESIUM-137 IN SOIL (1987)[a]

ISLAND	NO. OF SITES	SPECIFIC ACTIVITY (pCi/g) AT SPECIFIED DEPTHS[b]						
		0-40 cm[c]	0-10 cm	10-15 cm	15-25 cm	25-40 cm	40-60 cm	60-100 cm
		(ROOTING ZONE)	(SURFACE ZONE)					
BIKINI								
MEDIAN (MEAN)[d]	145-157	25 (37.9)	55 (74)	27 (43)	10 (29)	4.2 (18)	1 (6.6)[f]	
DISTRIBUTED[e] MEAN	145-157	28.6	55	36	23.4	9.7	3.0	
ENEU								
MEDIAN (MEAN)[d]	126-133	1.93 (2.85)	3.6 (5.1)	2.4 (3.4)	1.6 (2.4)	.88 (1.5)	.25 (1.1)[g]	
DISTRIBUTED[e] MEAN	126-133	2.31	4.4	2.6	2.1	1.0	0.4	

a. 1987 is the earliest data of resettlement.

b. Robison et. al. (6), based on soil dry weight, which is about 80 percent of fresh weight.

c. Based on least squares fit of Figure 4 and Equation 2, Section 2.2. The values at other depths are the observed values.

d. The data for the entire island were pooled at each depth.

e. For the distributed mean, Eneu and Bikini were each divided into 6 areas, the median for each area (at each depth) determined, and the island mean of the 6 medians calculated.

f. 85 sites.

g. 63 sites.

TABLE 3

ANALYSIS OF SOIL FROM BIKINI AND ENEU ISLANDS[a]

ISLAND LOCATION AND DEPTH (cm)	pH[b]	Cs-137 (pCi/g)	Sr-90[c] (pCi/g)	TOTAL[d]						EXTRACTABLE K[g] (ppm)	PARTICLES SIZED < 0.5mm (%)
				Sr (%)	Ca (%)	Mg (%)	P[e] (%)	N (%)	ORGANIC MATTER[f] (%)		
BIKINI NO. 1											
0-5	7.7	282	64	0.38	30.4	.95	1.35	0.64	14.4	79	11.5
5-10	7.8	85	73	.39	30.8	.89	1.28	.62	13.2	26	
10-15	7.9	35	63	.39	30.9	.89	1.29	.63	12.3	20	9.5
15-25	7.9	22	39	.40	31.9	.86	1.17	.50	10.6	23	11.7
25-40	8.3	3.5	24	.39	34.3	1.28	.67	.19	4.5	4	6.3
40-60	8.4	1.1	—	.31	34.5	2.06	.16	.11	1.6	3	0.6
											79
BIKINI NO. 2											26
0-5	7.8	119	64	0.40	31.0	1.02	0.82	0.49	10.7	50	5.7
5-10	8.0	55	73	.40	32.4	1.09	.71	.46	8.5	24	3.7
10-15	7.9	21	63	.38	33.1	1.18	.56	.35	7.4	24	3.3
15-40	8.2	4.2	32	.38	34.7	1.79	.32	.11	1.6	6	1.1
ENEU NO. 1											
0-5	7.7	8	2.3	0.32	32.0	1.74	0.085	0.30	5.1	41	2.3
5-10	8.0	6.7	2.6	.34	32.6	1.76	.055	.35	5.6	20	1.6
10-15	8.0	2.5	2.7	.31	34.3	2.08	.037	.17	2.6	9	.8
15-25	8.4	.1	2.5	.28	34.0	2.40	.016	.06	0.9	1	.3
25-40	8.7	.1	2.4	.28	34.4	2.48	.014	.05	0.8	1	.2
40-60	8.9	.2		.30	33.3	2.37	.015	.03	0.6	< 1	.1

a. Samples collected in May 1982 by Lawrence Livermore National Laboratory team and analyzed by Nelson Laboratories, Stockton, CA. Particle size was 2 mm or less (99.8 percent-83.6 percent total). Based on dry weight (≈80 percent fresh weight).

b. pH in water.

c. The strontium-90 activities are the mean of 55-63 sites on Bikini and 37-40 on Eneu. The activity at locations 1 and 2 on Bikini and Eneu Islands was not determined.

d. Total cesium was below detection limit (1.3 ppm).

e. High phosphorus values indicate ancient guano deposition.

f. Organic matter by wet oxidation.

g. Extractable in N NH_4 acetate.

TABLE 4

FEDERAL RADIATION PROTECTION STANDARDS

1. WHOLE-BODY[a]	
POPULATION STANDARDS	
MEAN ANNUAL DOSE	**0.17 rem PER PERSON**
MAXIMUM ANNUAL DOSE	**0.50 rem PER PERSON**
MEAN 30-YEAR CUMULATIVE DOSE	**5.00 rem PER PERSON**
OCCUPATIONAL STANDARD	
ANNUAL DOSE	**5 rem PER WORKER (OVER 18 YEARS OLD)**
2. DRINKING WATER[b,c,d]	
CESIUM-137	**200 pCi/LITER**
STRONTIUM-90	**8 pCi/LITER**
ANNUAL TOTAL CONTRIBUTION TO WHOLE-BODY DOSE	**.004 rem**
30-YEAR TOTAL CONTRIBUTION	**.120 rem**

[a] Whole-body equivalent doses (18).

[b] References 19, 20.

[c] For one radionuclide. When more than one is present, the standards are reduced proportionally. The total contribution to the whole-body equivalent dose shall not be more than .004 rem, annually.

[d] In the Marshall Islands the chloride standard is 400 mg/l, in the U.S. it is 250 mg/l.

TABLE 5

RESETTLEMENT WITHOUT DECONTAMINATION
30-YEAR (FROM 1987) ADULT PLANNING DOSES FOR ENEU AND BIKINI

EXPOSURE		ADULT DOSE (rem)[a]	
		ENEU	BIKINI
CESIUM-137:	EXTERNAL[b]	.27	3.5
	INTERNAL (PLANNING DIET)[c]	3.9 (8700 pCi/d)[d]	27.3 (60,700 pCi/d)[d]
	TOTAL (PLANNING DOSE)	4.2	31
NATURAL BACKGROUND		<0.9	<0.9

a. Whole-body due to cesium-137. Dose to bone marrow about 7 percent greater due to strontium-90.

b. Does not allow for shielding by buildings or gravel spread around dwellings.

c. Local foods always available, imported foods available for the equivalent of nine out of twelve months.

d. Initial intake at the beginning of 30-year period on a constant diet. The intake declines due to spontaneous decay. The 30-year dose (rem) equals initial intake (pCi/d) x .00045. The 30-year dose (rem) to bone marrow due to strontium-90 equals initial intake (pCi/d) x .0031.

TABLE 6

EXCAVATION REQUIRED ON ISLANDS THAT DO NOT MEET THE CESIUM-137 STANDARD FOR THE ROOTING ZONE

ISLAND[a]	SURFACE-ZONE SPECIFIC ACTIVITY[b] (pCi/g)	AREA[c] (km^2)	EXCAVATION		
			DEPTH (m)	VOLUME[d] ($10^6 m^3$)	Cs^{137} ACTIVITY REMOVED (Ci)
B1 NAM	30	.54	.15	.083	2.6
B6 BIKINI	55 (45)	2.41	.30	.722	30.1
B17 ENEDRIK	6	.96	0	0	0
SMALL ISLANDS					
B2 IROIJ	9.7	.20	0	0	0
B4 LOMILIK	30	.22	.15	.034	1.1
B5 AOMEN	6.6	.17	0	0	0
B10 ROJKERE	22	.08	.10	.008	.2
B18 LUKOJ	54	.14	.25	.036	1.6
B19 JELETE	63	.17	.28	.048	2.4
TOTALS		4.89		0.93	38

a. Excludes four islands (B20-23) with areas of less than .02 km^2.

b. Mean for 0-10 cm depth, by aerial survey (2). For Bikini, the terrestrial measurement is given, with the aerial one in parentheses, and is based on dry weight.

c. 1 km^2 equals .386 square miles.

d. Bulk density about 1.2; 1.2 metric tons per m^3. There are 1.31 cubic yards per cubic meter.

TABLE 7

UNIT COSTS (1984) OF EXCAVATION PLANS FOR BIKINI ISLAND[a]

ITEM	UNIT COST $
1. VEGETATION[b]	
CLEARING AND DISPOSAL (BURNING)	$ 1.30/m²
2. EXCAVATION & HAULING SPOIL TO DOCK OR TO ISLAND'S SEAWARD PERIMETER	$ 6.30/m³
3. BAGGING SPOIL	$12.40/m³
4. CONSTRUCTION OF PERIPHERAL LAND-STRIP WITH BERM[c]	$90.00/m³
5. DUMPING SPOIL IN LAGOON/OCEAN	
LOADING AND UNLOADING BARGES FOR MARINE DUMPING (UP TO 60 KM ROUND TRIP)	$ 5.90/m³
6. BACKFILLING EXCAVATED SITE	
DREDGING LAGOON SEGIMENT	$12.60/m³
HAULING AND SPREADING	$ 5.40/m³
7. CONSTRUCTION CAUSEWAY	
HAUL SPOIL TO CAUSEWAY FROM ISLAND	$ 3.60/m³
ARMOR LAYER	$86.00/m³
CULVERTS (60; 1.52m DIA, CONCRETE)	$39,000/culvert
8. DISPOSAL ON NAM	
TRANSPORT TO NAM, UNLOAD AND SPREAD	$12.20/m³

a. In the Marshall Islands, costs are estimated at 2.4 times those in the continental U.S. (see references on following page). Unit costs will tend to be significantly greater (about 300 percent) on smaller islands owing to the relatively greater cost of landing equipment and supplies, and less efficient operations required for small volume excavation. The majority of these estimates are provided by The Pacific Division, U.S. Corps of Engineers (Ref 6, next page). See Table 8 for depth and volume of spoil to be dealt with.

b. The estimated cost range for replanting coconut trees is \$2 to \$4 per m^2.

c. Not including Items 1 and 2, but principally for building protective coral-rock armor layer.

REFERENCES FOR TABLE 7

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3. Engelsman, C. 1982 Heavy Construction Cost File. Van Nostrad Reinhold Co., New York, 1982.

4. Toekles, M. International Bridge Corporation, Guam. Personal communication to the Committee on construction costs in the Marshall Islands, May 1983.

5. US Air Force Headquarters, Directorate of Engineering and Services. HQ USAF annual construction pricing guide for FY85.

6. US Army Corps of Engineers, Pacific Ocean Division, Letters. Subject: Bikini-Eneu Causeway Designated Cost, dated Jan. 12 and 25, 1984, with follow-up memo, Feb. 8, 1984.

7. Holmes and Narver, Inc. Letter to Commander, Joint Task Force Eight, Subject: Bikini Cleanup Documentation, dated Sept. 5, 1969.

8. Hummer, C. W. US Army Corps of Engineers, Coastal Research Group, Fort Belvoir, VA. Personal communication to the Committee of dredging and barging operations, June 1983.

9. Defense Nuclear Agency. The Radiological Cleanup of Enewetak Atoll. AD 107997. Washington, DC, 1981.

TABLE 8

BIKINI ISLAND: DECONTAMINATION BY REMOVAL OF TOP SOIL (1987)

SOIL REMOVED (DEPTH IN cm)	SPECIFIC ACTIVITY OF ROOTING ZONE		ASSOCIATED 30-YEAR PLANNING DOSE[a,b] (rem)
	A_0 (0 cm) (pCi/g)	MEAN (0-40 cm) (pCi/g)	
0	80.5	28.6	30.8
20	21.8	7.73	8.3
30	11.4	4.04	4.35
40	5.91	2.10	2.26
50	3.08	1.09	1.17

a. Based on planning diet plus external exposure (Table 5).

b. For Eneu: Ao = 5.53 pCi/gm and Rooting Zone Mean = 2.31 pCi/gm (0-40 cm).

TABLE 9

TOTAL COST[a] OF ISLAND EXTENSION AND BERM
BIKINI ISLAND AREA = 2,400,000 m^2
VOLUME REMOVED/FILLED = 720,000 m^3[b]

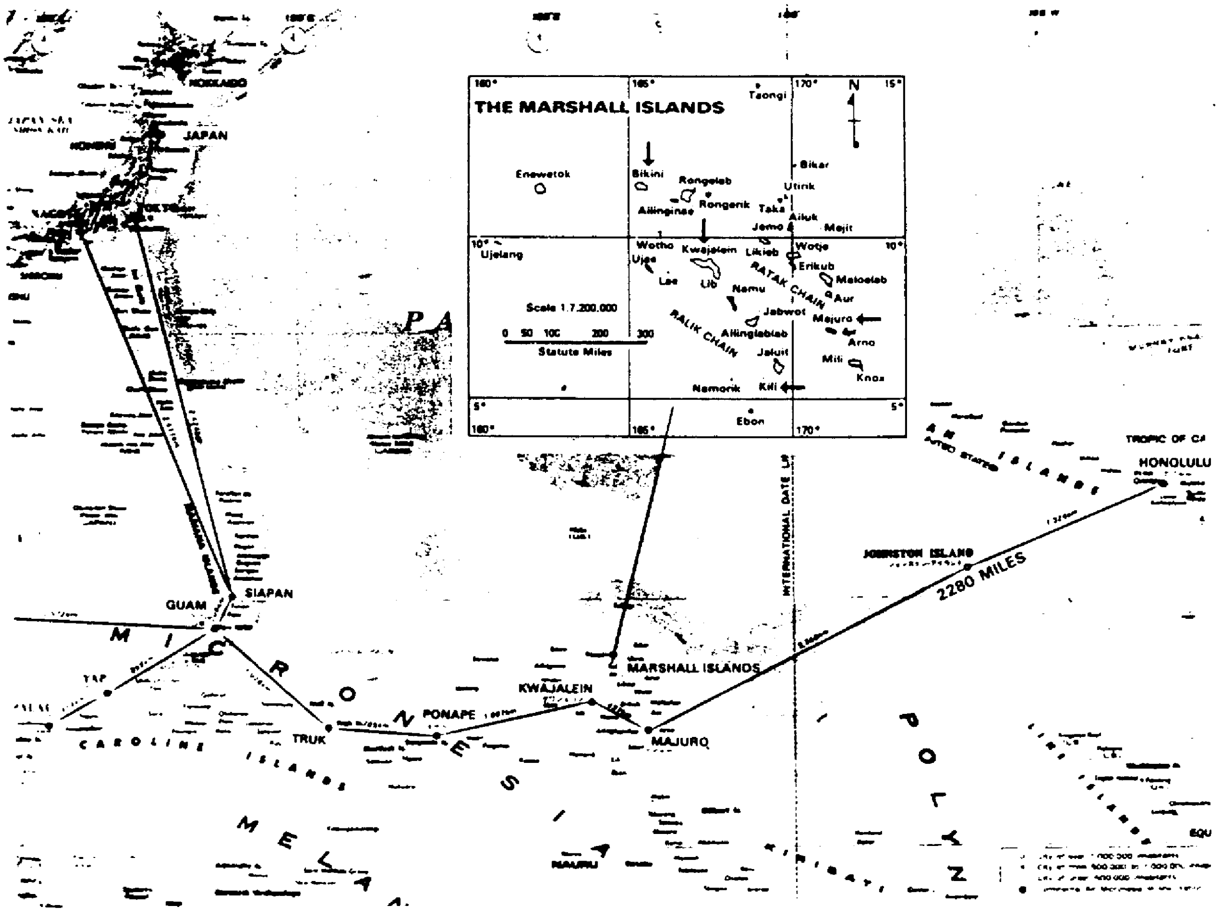
ITEM		TOTAL COST ($\$10^3$)
NO FILL		
1. MOBILIZATION AND DEMOBILIZATION COSTS		5,700
• BARGE HONOLULU TO BIKINI	700	
• PIERS BIKINI AND ENEU	3,500	
• BASE YARD	250	
• CHANNEL	750	
• EQUIPMENT AND LABOR	540	
2. SUBSISTENCE AND LODGING @ \$45/MAN DAY		1,700
3. VACATIONS @ \$6,260/MAN YEAR		660
4. SURVEY BIKINI ISLAND, TOPOGRAPHIC AND RADIOLOGICAL; QUALITY CONTROL		5,600
5. CLEAR AND BURN VEGETATION @ $\$1.30/\text{m}^2$		3,100
6. EXCAVATE FILL AND MOVE TO BERM @ $\$6.30/\text{m}^3$		4,600
7. QUARRY AND BUILD ARMORED BERM USING GEOTECHNIC FABRIC @ $\$90/\text{m}^3$ OF ARMOR ROCK		7,300
	SUBTOTAL	28,700
8. BURDEN @ 47.3%[c]		13,600
OVERHEAD HOME = 2%	BERM, NO FILL	42,000
OVERHEAD JOB = 5%		
PROFIT = 8%		
BOND = 0.6%		
CONTINGENCY = 20%		
SUPERVISION AND ADMINISTRATION = 5.5%		
FILL (ADDED TO NO FILL ABOVE)		
1. MOBILIZATION AND DEMOBILIZATION		
• FLOATING DREDGE EQUIPMENT		2,900
2. SUBSISTENCE @ \$45/MAN DAY		680
3. VACATIONS @ \$6,260/MAN YEAR		260
4. DREDGE AND TRANSPORT TO BIKINI DOCK @ $\$12.60/\text{m}^3$		9,100
5. HAUL AND SPREAD @ $\$5.40/\text{m}^3$		3,900
	SUBTOTAL	16,800
6. BURDEN @ 47.3%[c]		7,960
	SUBTOTAL	25,000
	BERM + FILL	67,000

---

a. Costs estimated to two significant figures, 1984 dollars.

b. Volume to be removed to achieve 4.64 pCi/gm average rooting zone specific activity.

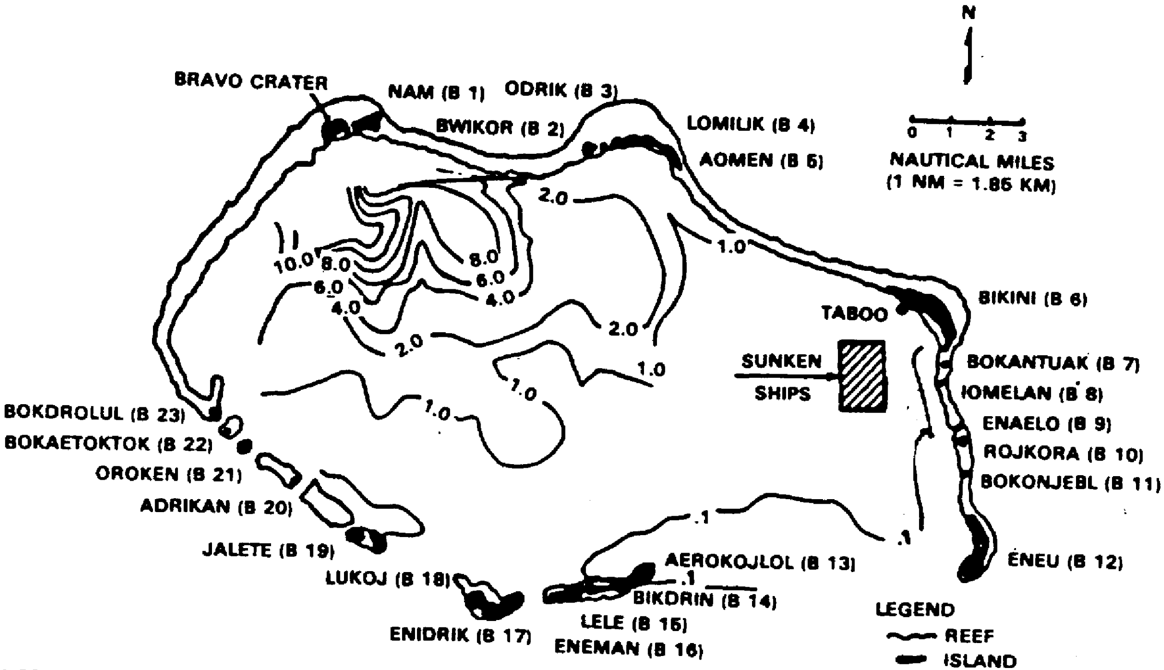
c. Overall burden computed by taking product of individual factors, e.g., (1.02) (1.05) (1.08) (1.20) (1.055) = 1.473 or 47.3%.



Copyright. 1982 by Continential Air Micronesia, Route Map, Actual Flight Path.

Figure 1. Location of the Marshall Islands.

BIKINI ATOLL



NOTE: THE ISOPLETHS (pCi/g), BASED ON SAMPLE STATIONS 2.6 km APART, ARE FOR 1979, AND WILL BE PUBLISHED BY V.E. NOSHKIN, LAWRENCE LIVERMORE NATIONAL LABORATORY, LIVERMORE, CA.

Figure 2. Bikini Atoll. Cesium-137 Isolpleths Are Shown for Lagoon Sediment (pCi/g, top 3 cm, fine fraction).

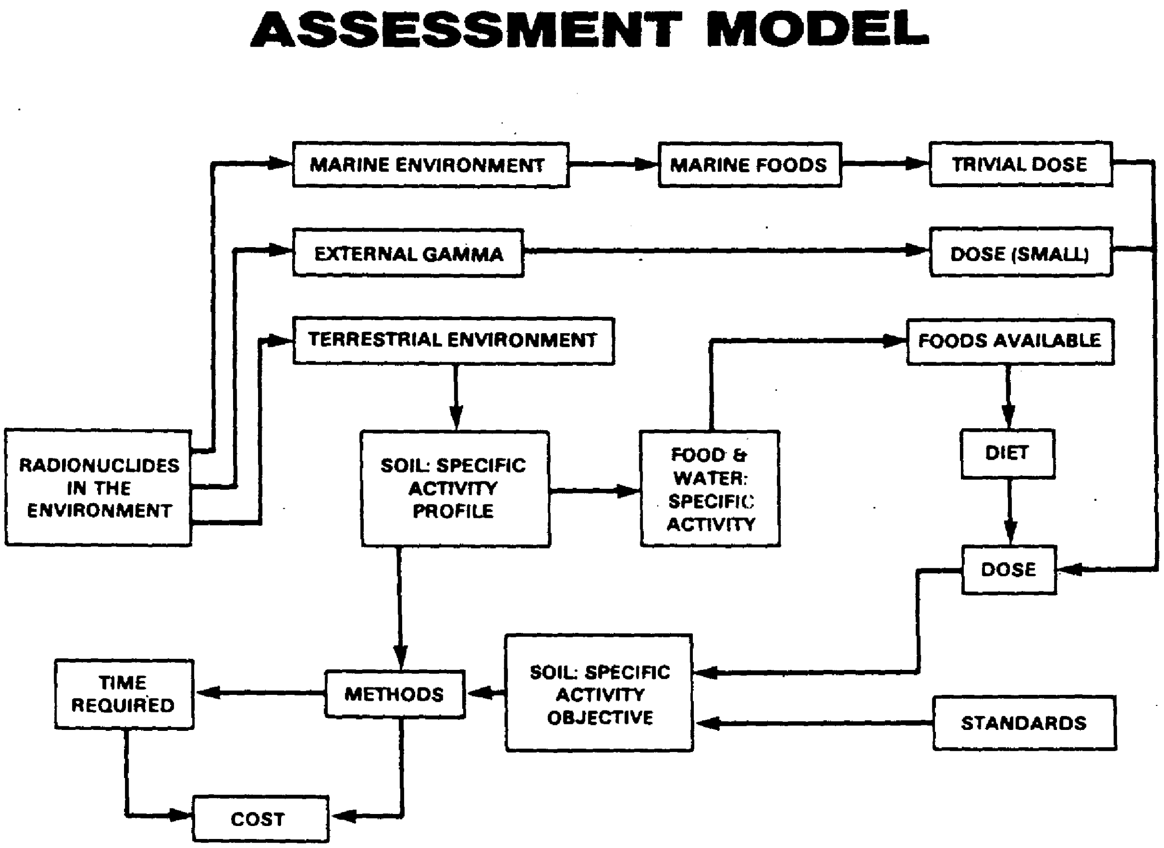


Figure 3. General Assessment Model.

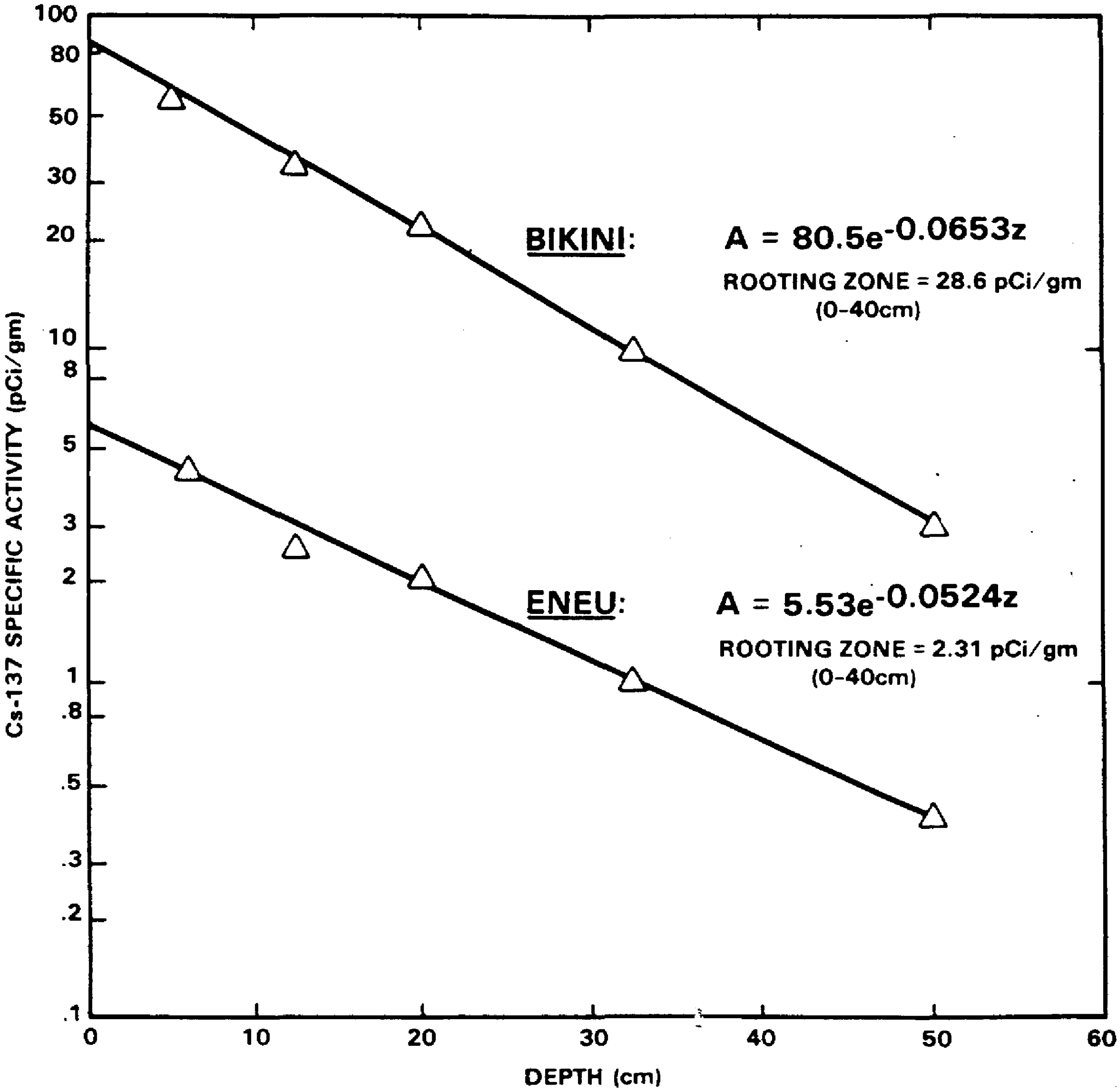
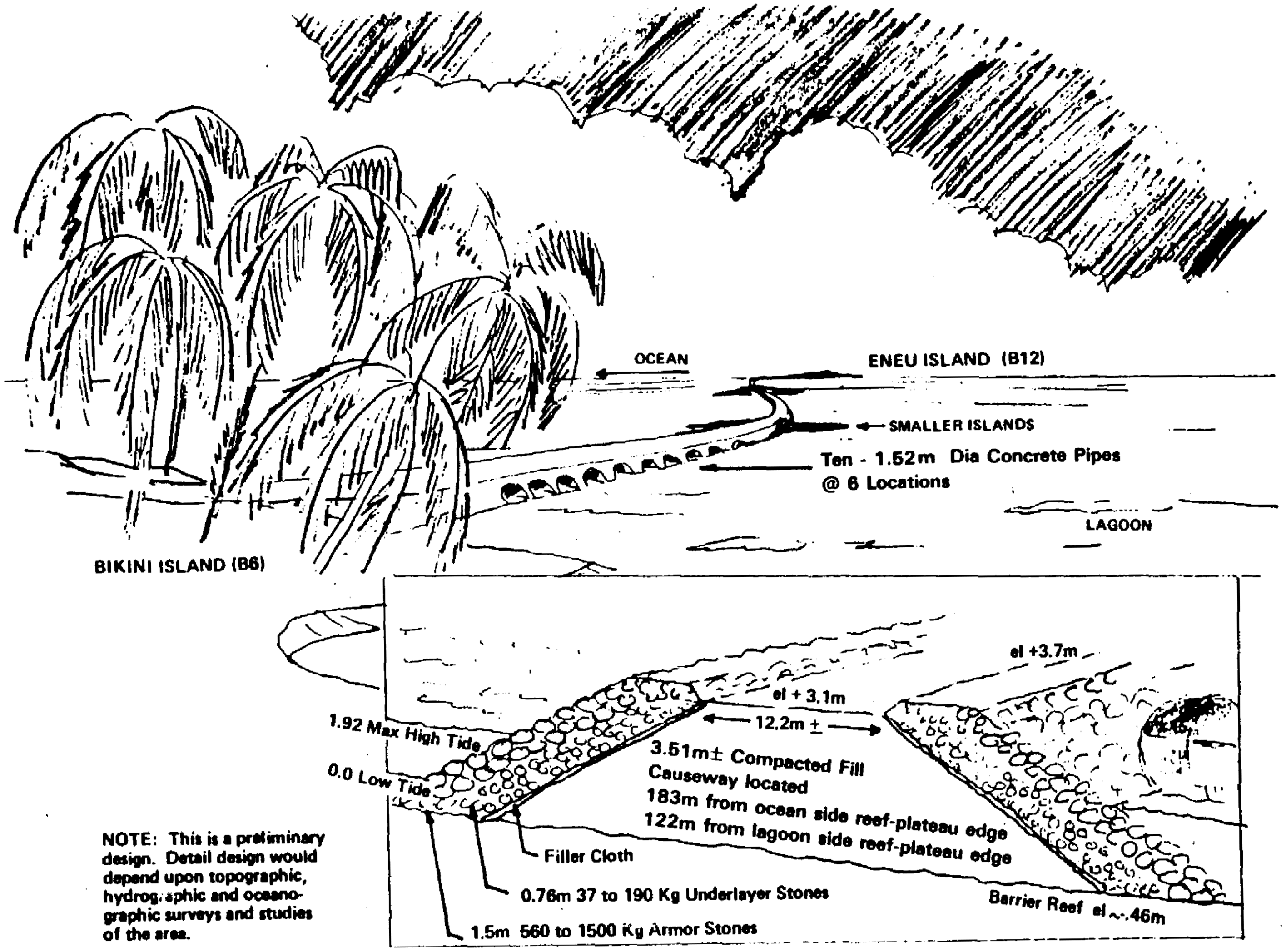


Figure 4. Cs-137 Specific Activity As A Function of Soil Depth (1987).



NOTE: This is a preliminary design. Detail design would depend upon topographic, hydrographic and oceanographic surveys and studies of the area.

Figure 5. Causeway to Connect Bikini and Eneu Islands.

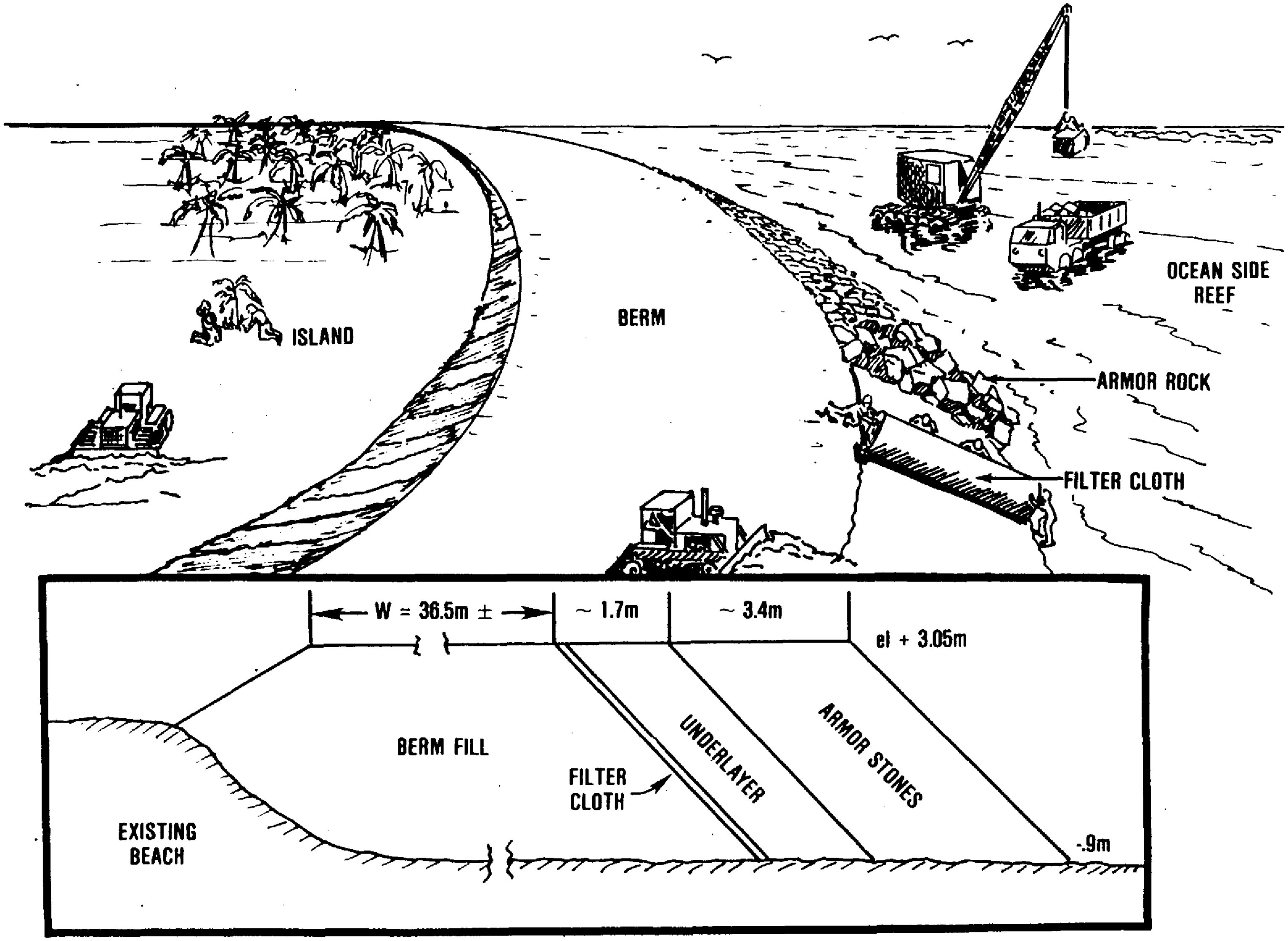


Figure 6. Construction of Island Extension and Berm.

APPENDIX A

GEOLOGY, OCEANOGRAPHY AND HYDROLOGY

By

F. L. Peterson, Ph.D. and J. E. Maragos, Ph.D.

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APPENDIX A

GEOLOGY, OCEANOGRAPHY, AND HYDROLOGY OF BIKINI ATOLL

Physical Setting and Climate

Bikini Atoll, located in the northwestern part of the Marshall Islands, is an oval-shaped coral reef atoll approximately 40 km long and 25 km wide (see Figure 1). It comprises 23 separate coral islands which have a total land area of 8.8 km^2. Bikini Island, the largest island in the atoll is approximately 4 km long and 0.8 km wide, and Eneu Island, the next largest is approximately 3 km long and 0.6 km wide. Together they comprise about half of the total land area in Bikini Atoll. These two main islands also are higher than the other islands, with an average elevation of about 3 m above msl, and a maximum on Bikini of about 5 m. The average elevation of the other 21 islands is only about 1-2 m above msl.

The climate of Bikini Atoll is tropical, and the mean monthly temperature is quite uniform throughout the year, ranging between 81° and 83°F. The prevailing winds are the northeast trades which blow most persistently during the winter months, from December through March, when they have an average velocity of nearly 20 knots. During the rest of the year the winds are somewhat lighter and more variable in direction. Hurricanes are infrequent, and usually occur during the summer and fall months and come from the southeast. Rainfall in the Bikini Atoll has been measured only since 1980 at Eneu Island by Lawrence Livermore Laboratory. During this time rainfall has averaged about 135 cm a year. Rainfall is heaviest during the months of August to November and lightest during the months of December to March. Over a long-term basis, intense tropical storms contribute much of the total rainfall.

Geology

The geology of Bikini Atoll was described extensively by Emery, Tracey, and Ladd (1954). The atoll is of geologic structure typical of deep oceanic atolls, and consists of a basaltic volcanic core overlain by approximately 800 m of essentially unconsolidated calcareous materials capped by a shallow wave resistant reef platform enclosing a slightly deeper oval-shaped lagoon. The atoll was formed when the original volcanic land mass subsided beneath the ocean surface, leaving exposed only a narrow band of a living reef which continued to grow upward to keep pace with subsidence.

The reef platform is very shallow (at approximately msl) and continuous around the perimeter of the atoll except where passes cut through and deepen the connection between the lagoon and ocean waters. Two deep passes cut through the reef rim or platform, one near Enidrik and the other near Adrikan Islands. Other narrow passes of intermediate depth occur off Bokdrolul, Bokaetoktok, Oroken, and Jalete Islands, and a wider shallow passage occurs between Lukoj and Enidrik Islands. By far the largest passage is the 16 km wide pass between Eneu and Aerokojlol Islands at the southeast corner of the atoll. Although the pass is relatively shallow (averaging some 15 m depth), it is the major connection between the waters of the ocean and lagoon.

The islands consist of reef debris (coral shingle and fragments) in lower strata, and primarily sands and gravels in upper strata deposited on the hard intertidal reef flat by waves and currents. Figure 2 shows geologic logs taken from three bore holes drilled on Bikini Island in 1947 (after Emery, Tracey and Ladd, 1954). It is expected that the shallow subsurface geology of the other islands in the atoll, while varying somewhat in detail, generally is consistent with the lower elevation strata of Bikini Island as shown in Figure 2.

Beach rock and occasionally reef conglomerates form most of the intertidal and supra-tidal shorelines of the islands, but sandy beaches are common along many depositional shorelines, including the ocean sides of Bikini and Eneu Islands the lagoon sides of most of the other islands. A soil layer with organics seems to be well developed only on the larger higher islands (Bikini and Eneu), and observations suggest soil is poorly developed or absent on the smaller islands (also see Stone and Robison, Appendix B).

Bikini Atoll is situated in a very dynamic oceanic environment, and hence reef materials are continuously being eroded, especially on the windward side. However, the erosion is more than balanced by rapid biological growth, and sand and other reef debris are constantly transported to the lagoon side of the reefs and washed into the lagoon. In their comprehensive study of the geology of the Bikini Atoll Emery, Tracey and Ladd (1954) observed the islands to be fairly stable under conditions which existed at the time, although there has been some recently observed minor losses and gains of land area.

During a site visit to Bikini in May 1984 two members of this Committee (Peterson and Maragos) made the following observations concerning general island stability and susceptibility to wave overwash:

(1) Bikini and Eneu, because of their relatively large size and elevation and wide expanse of ocean reef flat, appear relatively stable and show little evidence of recent shoreline erosion or wave overwash. Minor shoreline erosion is evident only on the southern end of Eneu Island.

(2) If anything, the northwest tip of Bikini and its northern and eastern ocean shoreline for the most part appear to be areas of net sand deposition. A sandspit over 1 km long off the northwestern tip of Bikini appears quite stable and a gently sloping beach averaging between 8 and 12 m wide along the ocean shoreline also appears stable. Undoubtedly these depositional features owe their stability to the very wide expanse of reef flat on the ocean side of Bikini Island. The reef flat, which averages 1 to 1.5 km wide here, is an excellent dissipator of wave energy and protects the island's shoreline.

(3) Conversely, the 12-km long stretch of reef flat separating Eneu and Bikini Islands is an area of high erosive energy. The several small islets on this reef flat are all narrow and low, and show extensive evidence of erosion and wave overwash. This reef flat is also an important area of ocean-lagoon water exchange and strong wave driven and tidal currents (estimated at 1-3 knots depending upon tide) usually flow across it from the ocean (eastern) side. Any structure built on this stretch of reef flat (such as a causeway) would be constantly exposed to very high energy erosive forces particularly during tropical storms and associated high waves during high tide. A causeway there would be exposed to lagoon wave action from the south and west and ocean wave action from the northeast to southeast.

(4) Except for Bikini and Eneu all the other islands comprising Bikini Atoll show evidence of some degree of shoreline erosion and wave overwash. Because of their low elevation, exposure to wave action and small size all would appear to be too hazardous for permanent habitation. All of the southern islands are situated very close to the outer edge of the ocean reef flat (in most cases 100-200 m), increasing their vulnerability to storm waves. Even the northern islands show recent evidence of shoreline erosion from the southern lagoon side, possibly the result of large waves entering the lagoon via the wide southeastern passage.

The reef platform that comprises the uppermost visible perimeter of the Bikini Atoll forms a shallow terrace to depths of 20 m to widths of 2-3 km. Seaward of the shallow terrace, however, the ocean bottom generally drops precipitously, and at a distance of 5 km from Bikini Island ocean depths are approximately 2000 m and within 8 km are as great as 3000 m (see Figure 3).

The Bikini lagoon, which covers some 632 km^2, has an average depth of 45 m and a maximum depth of 58 m. The lagoon floor generally is quite flat and consists mainly of loose sandy and silty carbonate sediments except for the occurrence of numerous coral pinnacles and patch reefs, some of which may exceed a km in diameter and stand several tens of meters high; very few, however, are located near Bikini and Eneu Islands.

The sediments that make up the lagoon bottom essentially are of 5 types: fine debris, corals, Foraminifera, Halimeda, and mollusk shells (Emery, Tracey, and Ladd, 1954). Generally the shallowest parts of the lagoon bottom near the reef flats are covered with fine debris with a particle size averaging less than about 0.5 mm in diameter, which consists primarily of skeletons of reef organisms. Throughout the rest of the lagoon, the calcareous remains of the alga Halimeda up to about a centimeter across are the most abundant constituent of the bottom sediments, except in a few deeper areas where Foraminifera are abundant. Figure 5 shows the distribution of bottom material near Bikini Island.

Of special interest for this Committee is the suitability of lagoon bottom sediments for use as topping material should existing soil be removed from one or more islands. In this regard several characteristics of the bottom material are of importance: (1) their ease of dredging, (2) their radioactivity, and (3) their fertility (with respect to plant growth).

As can be seen from Figure 4, large quantities of loose easily dredgeable sediments are available at shallow depths near Bikini and Eneu Islands. Studies on the radionuclides of the top layer of sediment (0-12 cm) have shown low levels of radioactivity in the entire area within 15 km of Bikini and Eneu Islands (Figure 5); however, the depth profile of specific activity is not well known for the lagoon sediment. Recent work by McMurtry, et al, (in press) in Enewetak Atoll shows no consistent decrease in activity within the upper 200 cm of lagoon sediment, and in fact, in some cases the radioactivity increases dramatically at depth. They attribute these results primarily to bioturbation from benthic invertebrates and possibly to constant natural sedimentation since the testing era, resulting in burial of the more radioactive layer. The results from bottom samples collected in November, 1983 in Bikini Lagoon should provide additional information when analyses are completed by Lawrence Livermore Laboratory.

The suitability of material dredged from the lagoon bottom for use as a soil growth medium is uncertain. Little data are available on the fertility of the lagoon bottom sediments, but what is known suggests this material will be high in salt content (at least until the salts are leached out) and extremely nutrient and organic poor (see Figure 6 and Table 1). It is probable that the nutrient and organic content of lagoon sediments are quantitatively similar to that which would occur in the island sediments after removal of the top 50 cm or so of contaminated soils. Thus, from a soil fertility standpoint there appears to be no advantage to be gained from topping with sediments dredged from the lagoon bottom.

Oceanography

Tidal exchange, wind driven currents, and wave action all contribute significantly to circulation and turnover of lagoon waters (Von Arx 1954).

The general circulation pattern in Bikini lagoon is produced primarily by the northeast tradewinds blowing across the lagoon water surface, and influenced secondarily by ocean waves, tides and the North Equatorial Current.

Throughout most of the year the ocean currents, waves and swell approach Bikini Atoll from an east-northeasterly direction, driven by the northeast tradewinds and break on the reefs primarily between Aomen Island (to the north and Eneu Island (to the east). Minor wave action also occurs along the southern atoll reef west of Lokoj Island and along the northern reefs between Aomen and Nam Islands. This persistent attack from the ocean generally subjects the northeastern windward shorelines of the atoll to strong erosive forces and constantly drives water across the windward reef flats into the lagoon during all stages of the tide during prevailing tradewind conditions. This flushing action is particularly significant and effective because the flow is unidirectional into the lagoon which maximizes turnover. As described previously, the stretch of reef flat between Eneu and Bikini Islands is especially susceptible to this flow pattern. During the summer and autumn months the tradewinds weaken and the ocean currents and swell become more variable.

Substantial tidal exchange also occurs at all other passages through the reef and over the shallow reef flats along the reef platform where islands are not situated. The deep passage at Enidrik probably has a major influence on deep lagoon circulation and water quality. Figures 7a and 7b show the generalized circulation of Bikini lagoon during the winter months when the tradewinds dominate. During the summer months when the trades weaken the lagoon circulation becomes more variable.

Hydrology

Since the water supply is limited and periods of drought are relatively frequent in the Marshall Islands, any large-scale rehabilitation program must plan for its water supply. Resettlement plans should specifically consider the catchment and storage of rainfall, as well as possible groundwater development and use during drought periods. Rainfall catchment techniques are straightforward and would most likely involve direct capture of water from rooftops with storage in cisterns as well as collection (and possible treatment) of water from the runway on Eneu.

In order to properly design rain catchment and storage systems, additional rainfall data, especially their time distribution, must be collected. To do this, the program of meteorological data collection presently underway on Eneu by the Lawrence Livermore Laboratory should be continued.

Rainfall produces only small amounts of fresh groundwater on the large islands of Bikini and Eneu, and probably no potable groundwater on the smaller islands. Rainfall drains quickly through the soil and accumulates in a roughly "lens-shaped" body of fresh water floating on the more dense salt water. Most of the fresh groundwater is very rapidly mixed with the underlying salt water by wave and tidal activity, leaving only a very thin fresh layer, generally in the central portion of the island (Figure 8).

Development of potable groundwater in Bikini Atoll is limited by two factors: chemical quality and radiological quality. In terms of chemical quality, salinity is most important, with chloride content normally being the limiting constituent. In the United States the standard for chloride content in drinking water is set at 250 mg/l (for Bikini groundwater this is approximately equivalent to 0.45 ppt total salinity), but a higher standard has been set by TTPI of 400 mg/l Cl for drinking water (for Bikini groundwater this is approximately equivalent to 0.75 ppt total salinity). In terms of radiological quality the most important constituents in Bikini groundwater are ^{90}Sr and ^{137}Cs. In the United States (presumably the same standards will be applied to Bikini) the limiting concentrations of ^{90}Sr and ^{137}Cs are 10 and 200 pCi/l, respectively. When both nuclides are present the standard for each is reduced proportionally.

Groundwater chemical and radiological quality data collected from wells on Bikini and Eneu Islands by Lawrence Livermore Laboratory since 1975 are summarized in Figure 9 and Table 2. As can be seen from these data, a very small body of marginally potable (from a salinity standpoint) groundwater exists in the south-central part of Bikini Island in the vicinity of wells HFH2 and HFH7. All Cl and total salinity data collected from these two wells during the period 1975-79 meet United States drinking water standards. However, salinity measurements made by two of the Committee members (Peterson and Robison) on May 10-11, 1984, after nearly two years of very low rainfall show Cl and total salinity levels of the freshest water sampled (well HFH7) to be approximately triple the limits set in the United States for potable water, and about double those of TTPI (see Table 2). Water salinity data collected by the United States Geological Survey in April and May 1972 generally confirm these 1984 results. These data raise a serious question about the availability of potable groundwater on Bikini Island during times when it would be needed most, that is during periods of drought. This question may be moot, however, because as can be seen in Table 2, the concentration of both ^{90}Sr and ^{137}Cs in Bikini groundwater exceed drinking water standards.

From both a chemical and a radiological standpoint the groundwater picture on Eneu looks much more promising than on Bikini. As can be seen in Table 2 and Figure 9 a moderately-sized body of potable groundwater exists in the central part of the island near the runway. All samples collected from wells FWR 4, 5, 6, and 7 during the period 1975-84 yielded water that meets TTPI standards for potability. In fact, groundwater collected from FWR 4 on May 12, 1984 contained only 23.2 mg/l Cl, an extremely low value considering the long period of drought conditions preceding this sampling. Furthermore, an 8-hour pump test run on well FWR 4 on May 13, 1984, during which time about 82,000 liters (21,500 gallons) of water were pumped from the well, produced virtually no increase in water salinity, thus further substantiating the existence of a significant fresh groundwater lens. The very freshness of this groundwater undoubtedly is due to extensive runoff from the runway, and hence this general region would be a good place for groundwater development.

From a radiological standpoint the Eneu groundwater also looks good, and ^{137}Cs is not a problem. Although initially ^{90}Sr limits were exceeded in several wells, by 1977 all wells except FWR 6 had acceptable ^{90}Sr levels. Samples were collected in May 1984 for ^{90}Sr analysis, and the results when available should provide an up-to-date picture of radioactivity levels in Eneu groundwater.

Groundwater data from Bikini and Eneu Islands are limited to only about the top meter of the groundwater body, and except for the most recent sampling period in May 1984, little data have been collected that define seasonal changes in the groundwater body. In order to make a reliable quantitative estimate of the groundwater development potential for these islands, additional data are required that better define the vertical, areal and seasonal distribution of groundwater.

The extent and quality of groundwater on the smaller islands in the Bikini Atoll is not known at all. However, based on experience elsewhere in the Marshall Islands, it seems unlikely that any significant quantity of potable groundwater persists on these islands for any length of time, especially through periods of drought, because of their small size and the moderate amounts of rainfall they receive.

To summarize, the amount of groundwater available for development on Bikini Atoll is not well known at this time, however, it most certainly would be limited. No potable groundwater is thought to exist on the small outer islands, and the salinity of groundwater on Bikini Island during periods of drought appears to be marginal for drinking purposes. From a radiological standpoint, Bikini Island groundwater does not meet drinking water standards. From both a salinity and radiological consideration, a potable groundwater body exists on Eneu Island. Its size is undetermined, but data collected to date suggest it may be capable of supplying the drinking water needs of a population of 200-250 during periods of drought when surface water supplies are not available.

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McMurtry, G.M., Colin, P.L., Schneider, R.C., Buddemeier, R.W., and Suchanek, T.H., in press, Redistribution of Fallout Radionuclides in Enewetak Lagoon Sediments by Callianassid Bioturbation.

Noshkin, V.E., Robison, W.L., Wong, K.M., and Eagle, R.J., Evaluation of the Radiological Quality of the Water on Bikini and Eneu Islands in 1975: Dose Assessment Based on Initial Sampling, Lawrence Livermore National Laboratory Rpt UCRL-51879, Part 4.

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Von Arx, W.S., 1954, Circulation Systems of Bikini and Rongelap Lagoons, U.S. Geological Survey Prof. Paper 260-B.

TABLES

FIGURES

Analyses 1, 2, 5, 6, 7, 9 by Charlotte M. Warshaw; analyses 3, 4, 10, 11, 12, 13 by A. C. Vlisidis. Final SrO determinations with flame photometer by W. W. Brannock. X-ray determinations by J. M. Axelrod)

	Foraminifera		*Halimeda*		Calcareous red algae			Corals	Sediments				
	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	0.20	0.12	0.50	0.14	0.18	0.24	0.10	0.06	0.12	0.16	0.20	0.20	0.20
$(Al, Fe)_2O_3$	.30	.22	.30	.34	.40	.46	.34	.06	.36	.28	.26	.28	.18
MgO	5.52	5.67	.32	.38	8.01	8.25	6.73	.24	4.95	1.32	2.26	.82	.54
CaO	46.90	47.86	54.51	53.25	42.20	41.85	42.91	53.08	47.78	52.28	50.31	52.84	52.64
SrO	.18	.16	.90	.87	.24	.24	.22	----------	.28	.72	.46	.82	.73
CO_2	42.64	43.16	42.66	41.46	41.08	40.43	39.75	41.68	42.36	41.57	41.65	41.60	41.28
Acid sol. SO_3	.32	.68	.16	.25	.70	.64	.70	(?)	.44	.34	.55	.29	.37
Acid insol. org	.26	.16	----------	.15	1.27	1.60	2.01		.28	.17	.21	.16	.32
Water sol. org	.45	.87	----------	----------	1.98	2.73	2.47	3.21	----------	----------	----------	----------	----------
Water	.40	.50	.20	.30	1.53	1.48	1.52		.48	.28	.28	.24	.44
Total	97.17	99.40	99.55	97.14	97.59	97.92	96.75	98.33	97.05	97.12	96.18	97.25	96.70
Acid insol. inorg	0.18	0.09	----------	0.38	0.35	0.38	0.36	----------	0.12	0.20	0.05	0.43	0.25
X-ray	Cal.	Cal.	Arag.	Arag. very little cal.	Cal.	Cal.	Cal	(Arag.)	Cal and little arag.	Arag. and little cal.	Arag. and cal.	Arag. and little cal.	Arag. and little cal.
SiO_2	0.21	0.12	0.50	0.14	0.19	0.28	0.11	0.06	0.12	0.16	0.21	0.20	0.21
$(Al,Fe)_2O_3$	.31	.22	.30	.35	.43	.53	.37	.06	.37	.29	.27	.29	.19
$MgCO_3$	12.03	12.12	.67	.82	18.00	18.54	15.41	.52	10.72	2.83	4.95	1.76	1.17
$CaCO_3$	87.18	87.30	97.25	97.42	81.02	80.28	83.77	99.38	88.38	95.66	93.89	96.55	97.35
$SrCO_3$	.27	.24	1.28	1.27	.36	.37	.34	----------	.41	1.06	.69	1.20	1.08
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	----------	100.00	100.00	100.00	100.00	100.00

1. Picked Foraminifera (*Calcarina spengleri*). Lagoon beach.
2. Picked Foraminifera (*Marginopora vertebralis*). Lagoon beach.
3. Picked unweathered *Halimeda* segments.
4. Picked weathered *Halimeda* segments.
5. *Lithophyllum* (*Porolithon*) *gardineri*.
6. *Lithophyllum craspedium*.
7. *Porolithon onkodes*.
8. Average of 15 analyses of madreporarian reef corals (Clarke and Wheeler, 1917).
9. Coarse foraminiferal beach sand (Bik. 3).
10. Fine beach sand (Bik. 5).
11. Medium sand—lagoon, 69 feet (Bik. 51).
12. Medium sand and *Halimeda* debris—lagoon, 108 feet, (Bik. 713).
13. *Halimeda* debris—lagoon, 156 feet (Bik. 548).

Table 1. Sediment analyses (percent) from Bikini Atoll (after Emery, Tracey and Ladd, 1954, p. 67).

Table 3. Groundwater quality data from Bikini and Eneu Islands (all data is from Lawrence Livermore Laboratory unless other noted).

1. average of 3 samples
2. collected by F. Peterson
3. located in middle of salwater flushing plot
4. average of 2 samples

Island	Well	Date Sampled	Depth Sampled	Salinity (ppt)	Chloride (mg/l)	^{90}Sr (pCi/l)	^{137}Cs (pCi/l)
Bikini	HFH1	6/21/75	surface	0.90[1]	475[1]	57[1]	601[1]
"	"	1/29/77	"	1.00	—	7.2	—
"	"	11/19/77	"	0.27	—	25.5	—
"	"	4/8/78	"	1.87	—	12.3	—
"	"	4/21/79	"	1.00	—	—	—
"	"	5/11/84	"	8.5[2]	5730[2]	—	—
Bikini	HFH2	6/19/75	"	0.06	6	77	244
"	"	1/23/77	"	0.16	—	7.3	—
"	"	11/19/77	"	0.24	—	77.5	—
"	"	11/9/78	"	0.45	—	13.0	—
"	"	4/24/79	"	0.50	—	—	—
"	"	5/11/84	"	20[2]	—	—	—
Bikini	HFH3	6/20/75	"	2.56	1390	227	335
"	"	1/24/77	"	8.28	—	4.0	—
"	"	11/20/77	"	4.27	—	73.6	—
"	"	11/9/78	"	3.24	—	—	—
"	"	4/24/79	"	2.27	—	—	—
"	"	5/11/84	"	22.5[2]	15300[2]	—	—
Bikini	HFH4	6/20/75	"	0.14	53.3	260	226
"	"	1/24/77	"	0.61	—	21.9	—
"	"	11/20/77	"	0.14	—	92.0	—
"	"	11/18/78	"	0.95	—	—	—
Bikini	HFH5	6/19/75	"	0.67	344	180	530
"	"	1/23/77	"	2.23	—	4.2	—
"	"	11/20/77	"	2.67	—	4.0	—
"	"	11/9/78	"	1.87	—	—	—
"	"	4/24/79	"	4.55	—	—	—
"	"	5/10/84	"	35.1[3]	—	—	—
Bikini	HFH7	6/20/75	"	0.61	315	1.0	250
"	"	1/24/77	"	0.22	—	9.2	—
"	"	11/20/77	"	0.28	—	6.4	—
"	"	11/9/78	"	0.40	—	—	—
"	"	4/21/79	"	0.23	—	—	—
"	"	5/11/84	"	1.5[2]	756[2]	—	—
Bikini	HFH8	5/11/84	"	6.5[2]	—	—	—
Eneu	FWA1	6/24/75	"	1.07[4]	559[4]	58.3[4]	72.7[4]
"	"	1/27/77	"	1.63	—	9.9	—
"	"	11/17/77	"	1.23	—	8.2	—
"	"	11/6/78	"	1.10	—	—	—
"	"	4/21/79	"	2.27	—	—	—
"	"	5/12/84	"	4.1[2]	2060[2]	—	—

Table 2. continued

Island	Well	Date Sampled	Depth Sampled	Salinity (ppt)	Chloride (mg/l)	^{90}Sr (pCi/l)	^{137}Cs (pCi/l)
Eneu	FWR 2	6/24/75	Surface	3.33	1820	66	69
"	"	1/27/77	"	5.75	—	3.9	—
"	"	11/7/77	"	7.34	—	1.3	—
"	"	11/6/78	"	—	—	—	—
"	"	4/21/79	"	11.37	—	—	—
Eneu	FWR3	6/22/75	"	2.61	1420	1.3	32
"	"	1/27/77	"	2.79	—	42	—
"	"	4/22/79	"	6.71	—	—	—
Eneu	FWR4	6/22/75	"	0.10	30.9	3.4	1.1
"	"	1/27/77	"	0.07	—	9.5	—
"	"	11/7/77	"	0.07	—	2.8	—
"	"	11/17/78	"	—	—	—	—
"	"	4/21/79	"	0.07	—	—	—
"	"	5/12/84	"	0.20[2]	23.2[2]	—	—
Eneu	FWL5	1/28/77	"	0.24	—	32.6	—
"	"	11/19/77	"	0.33	—	10.7	—
"	"	11/7/78	"	0.67	—	7.7	—
"	"	4/21/79	"	0.37	—	—	—
"	"	5/12/84	"	0.25[2]	—	—	—
Eneu	FWL6	1/29/77	"	0.26	—	3.4	—
"	"	11/17/77	"	0.58	—	21.2	—
"	"	11/7/78	"	—	—	17.0	—
"	"	4/20/79	"	0.50	—	—	—
"	"	5/12/84	"	0.70[2]	—	—	—
Eneu	FWR7	5/12/84	"	0.40[2]	167	—	—

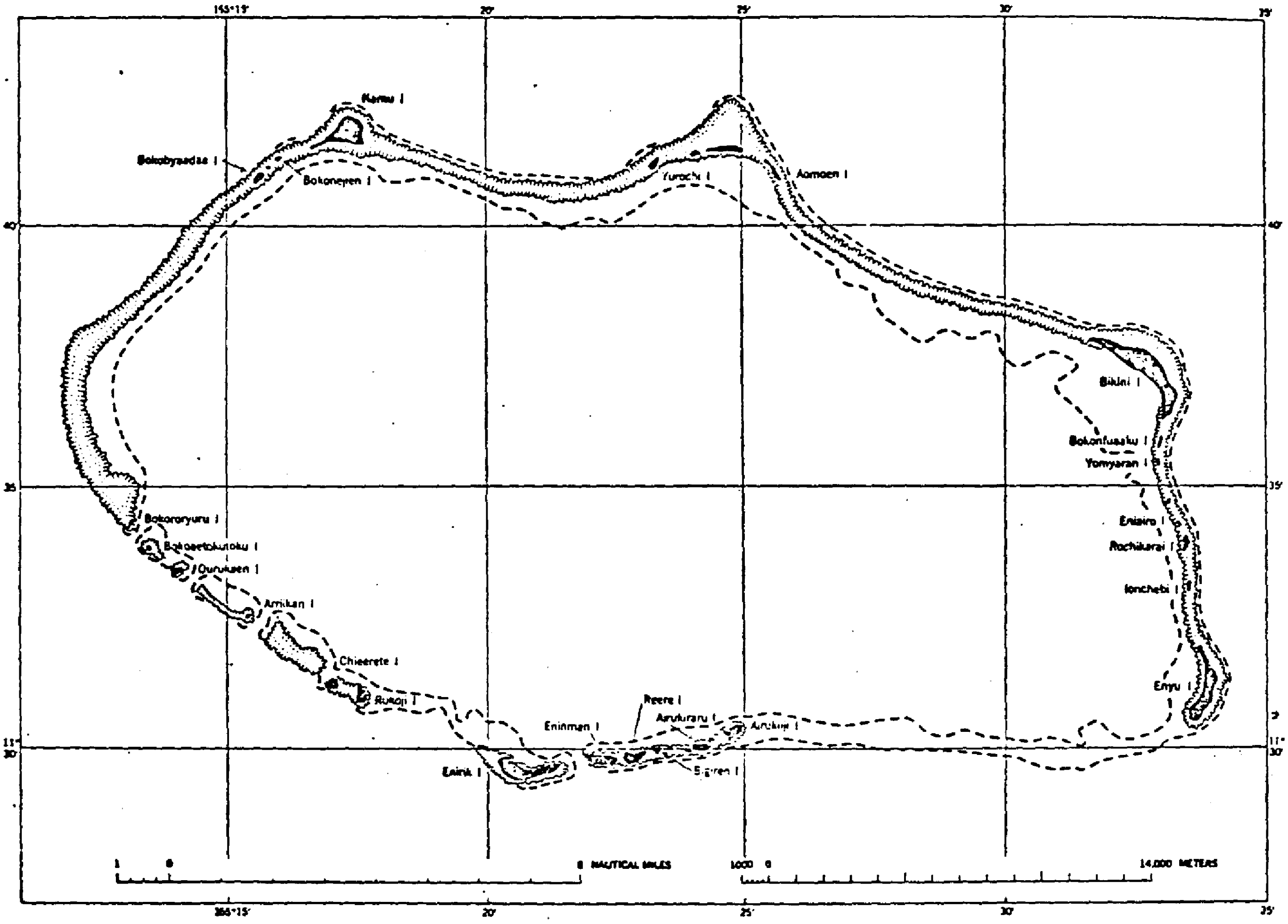


Figure 1. Location map of Bikini Atoll (after Emery, Tracey and Ladd, 1954, p. 51).

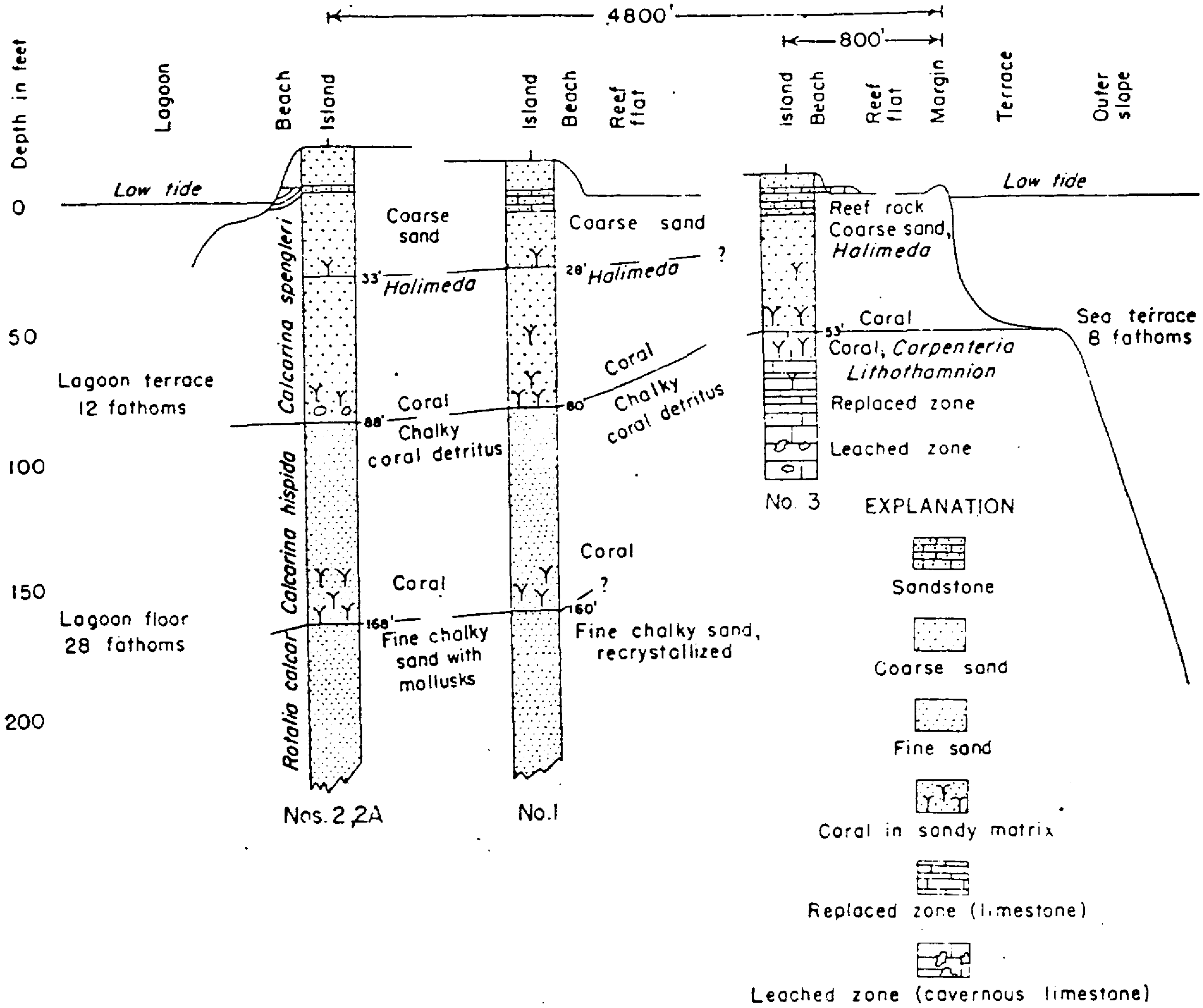


Figure 2a. Geologic logs from Bikini Island boreholes (after Emery, Tracey and Ladd, 1954, p. 75).

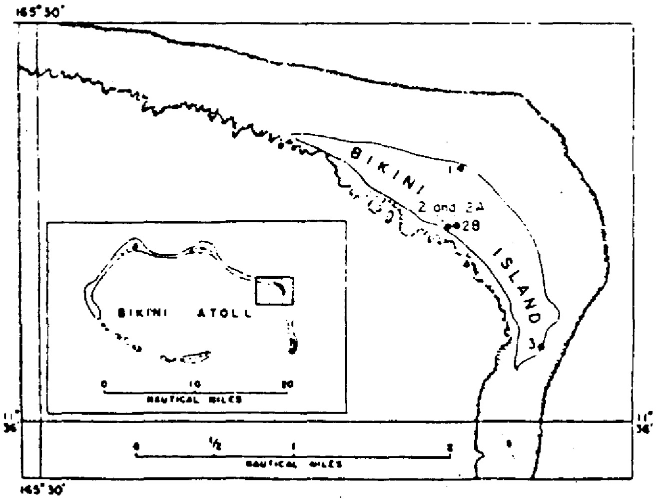
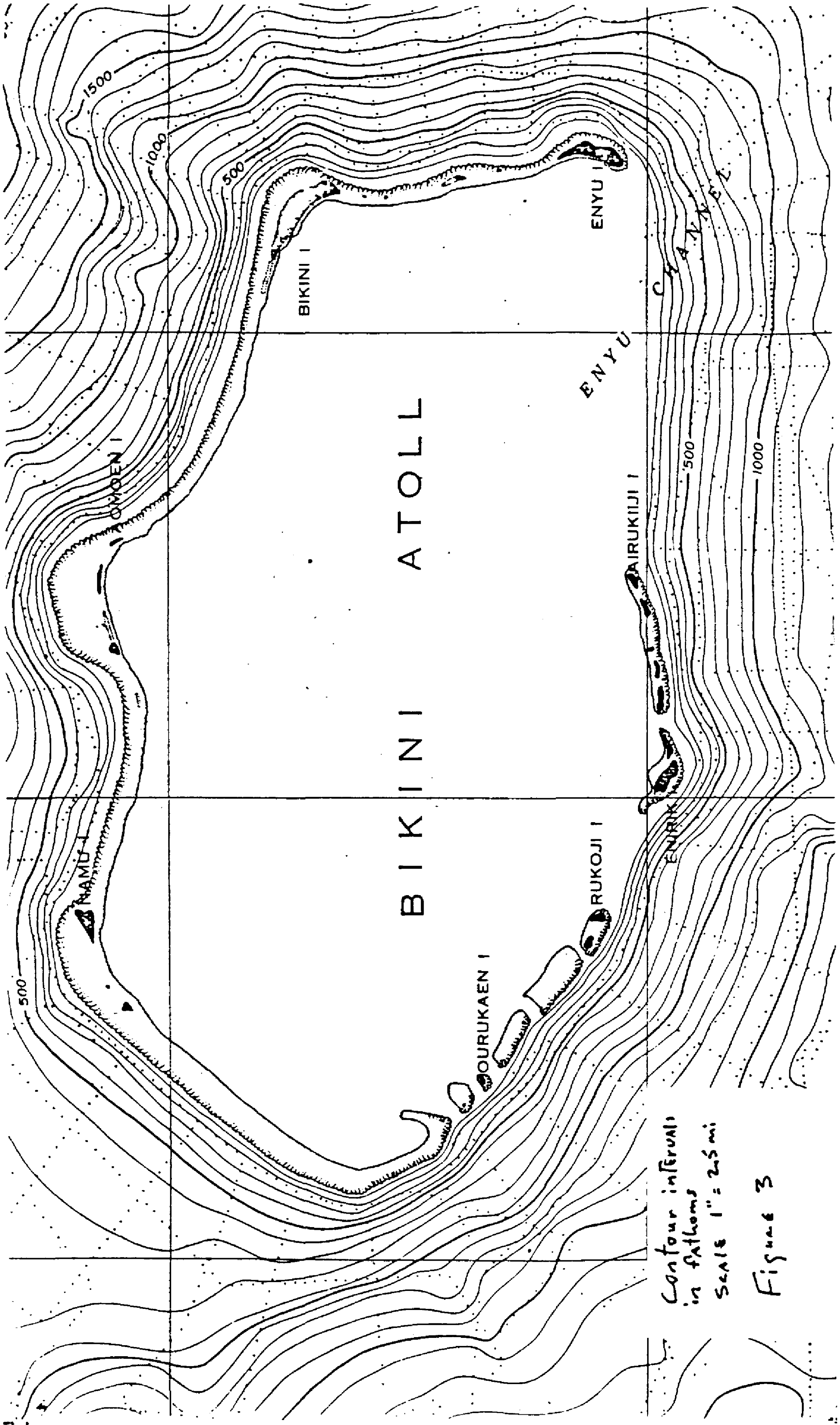


Figure 2b. Location of drill holes on Bikini Island (after Emery, Tracey and Ladd, 1954, p. 74).



Contour intervals
in fathoms
Scale 1" = 2.5 mi

Figure 3

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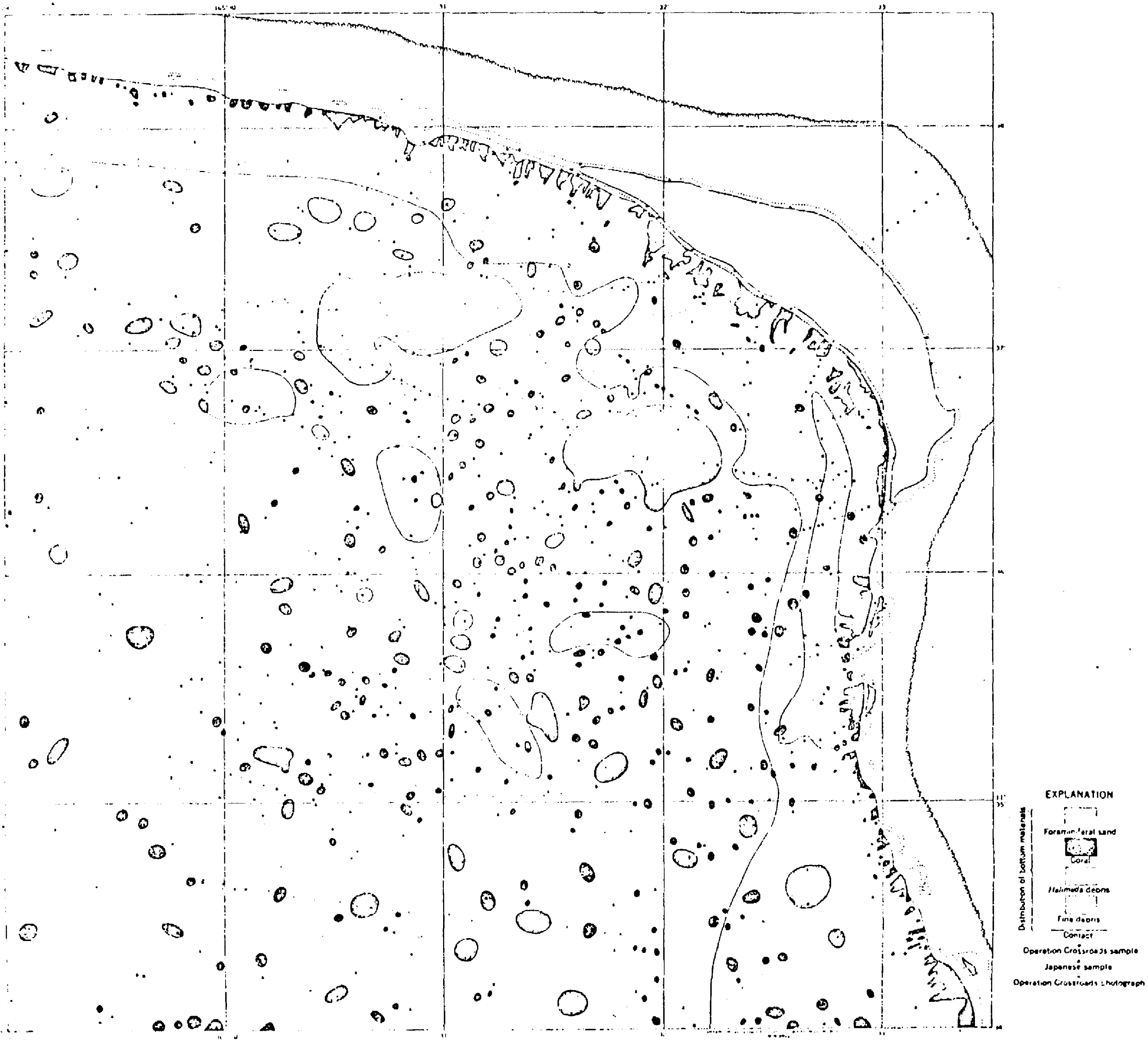


DISTRIBUTION OF BOTTOM MATERIAL NEAR BIKINI ISLAND

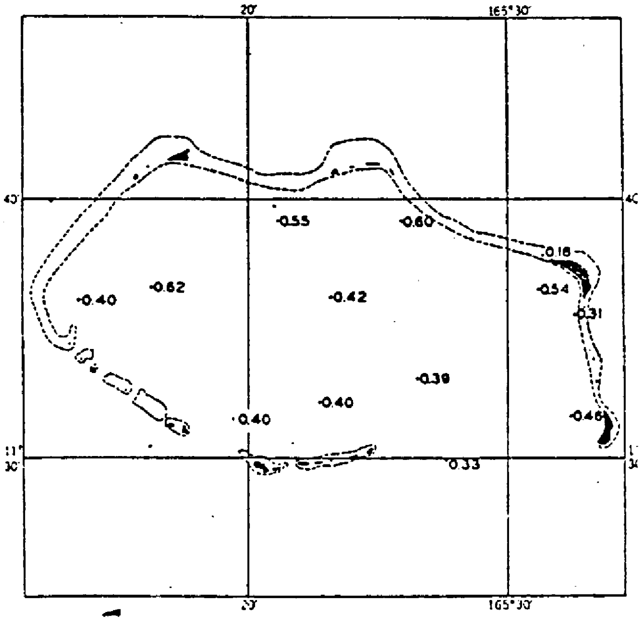
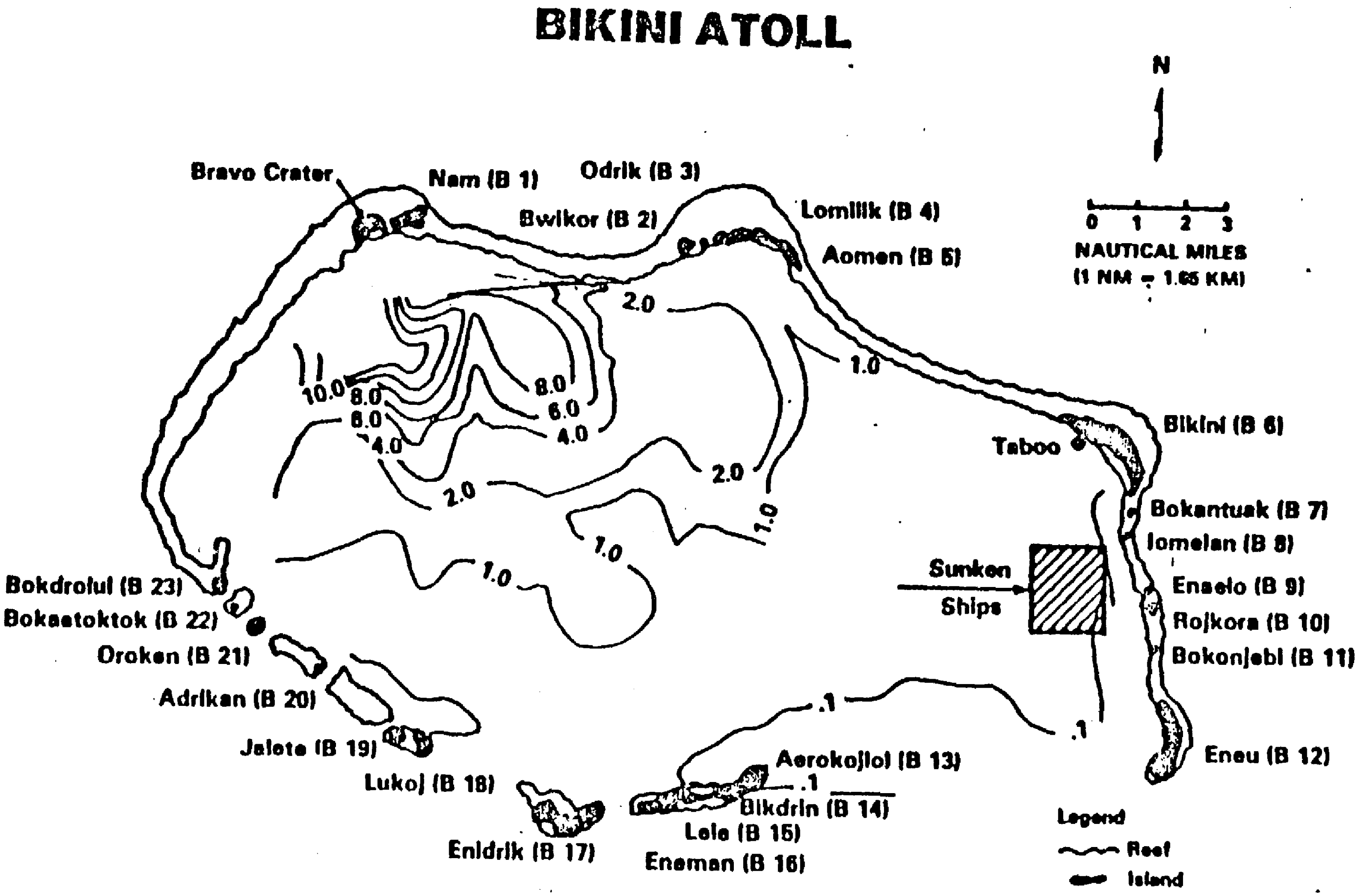


Figure 5. Percentage of organic carbon in sediments of Bikini Lagoon (after Emery, Tracey and Ladd, 1954, p. 63).



Note: The isopleths (pCi/g), based on sample stations 2.6 km apart, are for 1979, and will be published by V. E. Noshkin, Lawrence Livermore National Laboratory, Livermore, CA.

Figure 8. Bikini Atoll. Cesium-137 isolpleths are shown for lagoon sediment (pCi/g, top 3 cm, fine fraction).

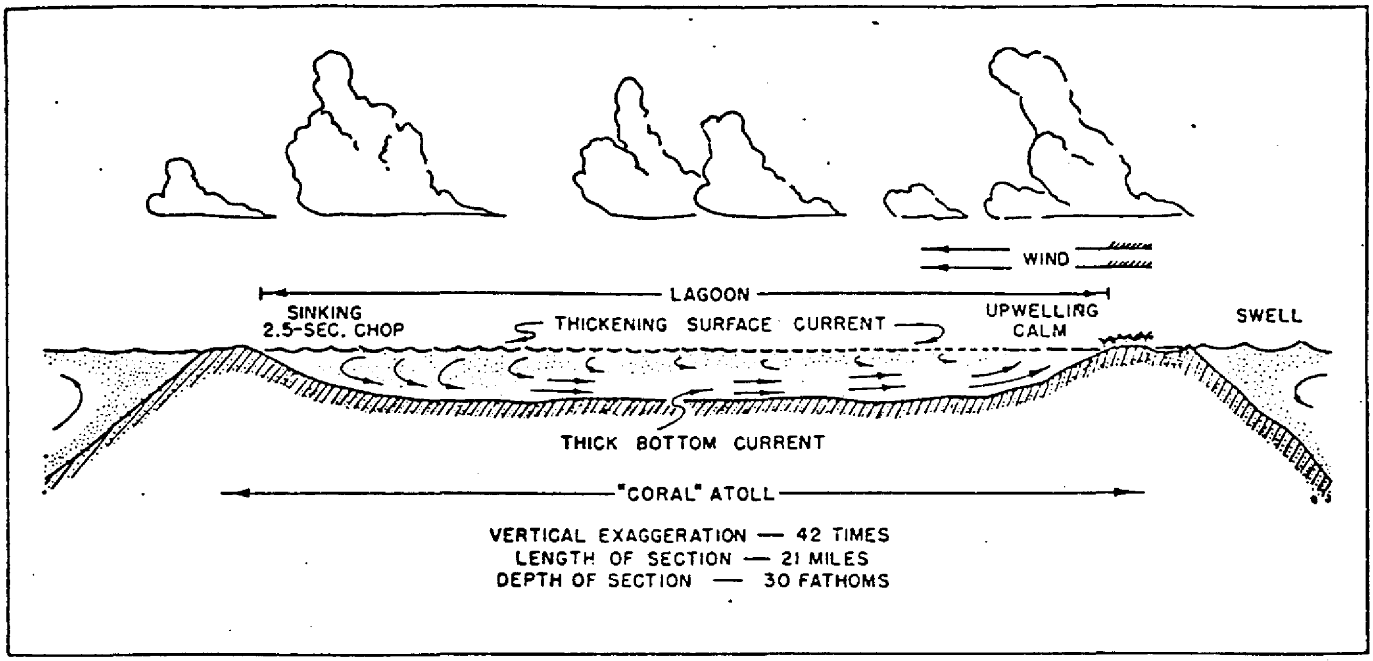


FIGURE 7a.—Nature of wind-driven overturning circulation (schematic).

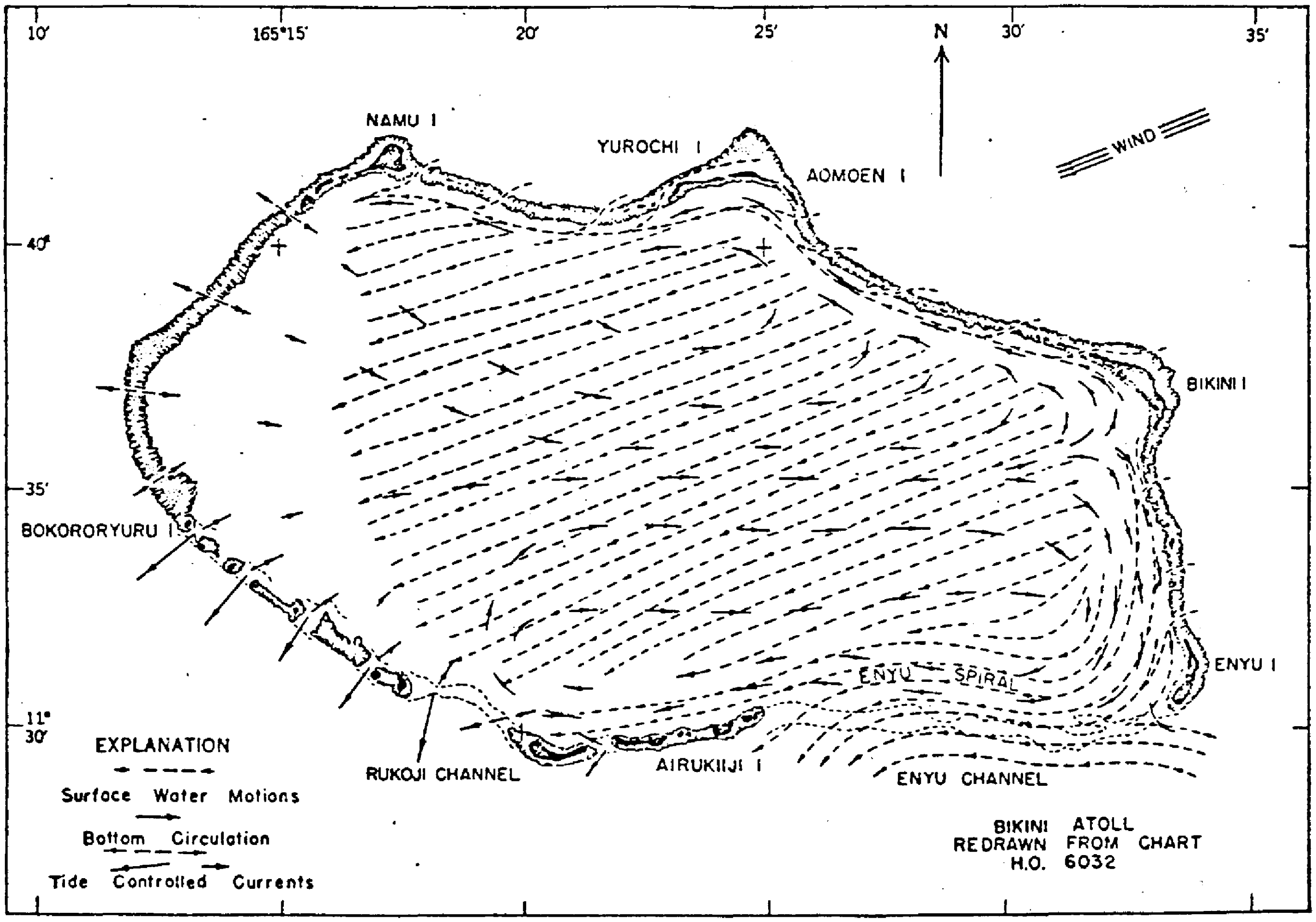


FIGURE 7b.—Generalized circulation of Bikini Lagoon in winter.

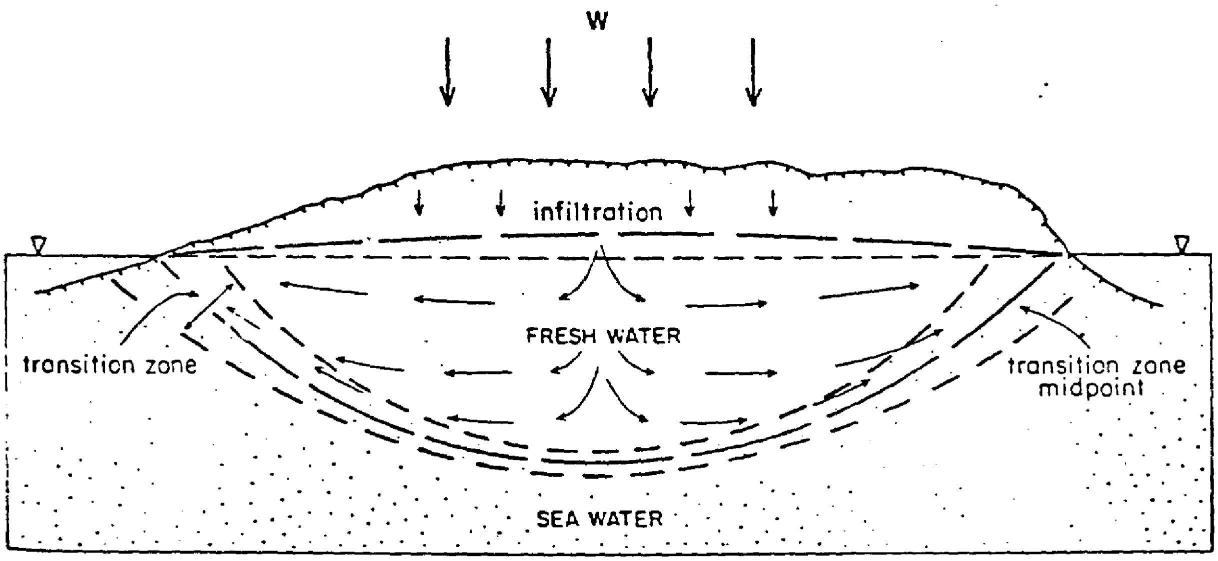


Figure 8. Fresh groundwater occurrence on small island.

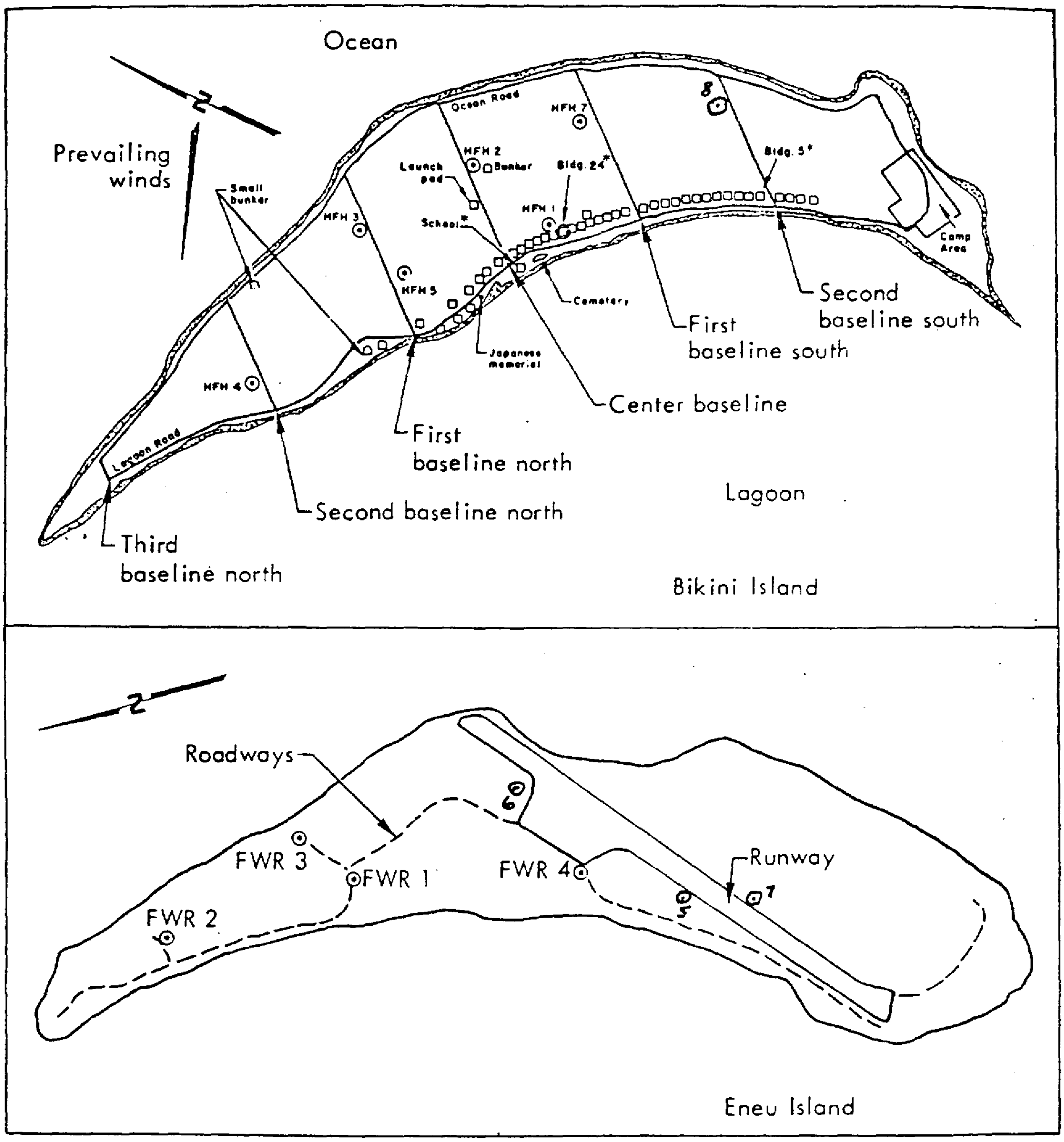


Figure 9. Locations of wells on Bikini (top) and Eneu (bottom) Islands (after Noshkin _et al_, 1975).

APPENDIX C

SUNKEN SHIPS AND OBSTACLES IN THE LAGOON

By

A. S. Kubo, Ph.D.

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APPENDIX C
SUNKEN SHIPS AND OBSTACLES IN THE LAGOON

1. INTRODUCTION

There were 23 announced nuclear tests at the Bikini Atoll. For the Operation and Event Names and date of test, see Table C-1. The approximate locations for these tests are shown on Figure C-1. During Operations Crossroads and Castle a series of tests particularly affected the floor of the Lagoon.

1.1 Operation Crossroads (see Figure C-1, Site A) consisted of two nuclear weapons tests, ABLE and BAKER, to assess the effects of nuclear weapons against naval warships. The tests were conducted in the spring and summer of 1946 at a site approximately 5000 yards southwest of Bikini Island. ABLE was an above-water detonation. The ground zero (GZ) of ABLE was not reported. It was an air burst and did not cause permanent disturbance of the lagoon bottom. BAKER was an underwater burst. Approximate GZ of the BAKER shot is longitude 165° 30' 40" East and latitude 11° 35' 5" North.

Eleven ships were sunk in the lagoon (See Table C-1) during Operation Crossroads. The ships were reported to be in battle-ready condition at the time of the tests, i.e., loaded with fuel and ammunition. At present, the sunken ships remain on the lagoon bottom. The area surrounding BAKER's GZ was disturbed and contaminated by radioactive material (see Figure C-1). The fuel oil and ammunition remain on the warships, and it has been reported that the "Saratoga" (one of the sunken ships) can be located by sighting a small surface oil slick above her.

1.2 Operation Castle consisted of 5 nuclear weapons tests. The most significant of these tests is the BRAVO shot (Figure C-1, Site B) which caused a 6000-foot diameter, 240-foot deep crater in the lagoon off Nam Island. BRAVO, a surface burst H-bomb shot, deposited radioactive fallout unevenly throughout Bikini Atoll causing the contamination of Bikini Island in particular. In addition to BRAVO, the testing of Union and Yankee (Site D) and Cherokee (Site E) caused numerous obstructions (test towers, etc.) that lie on the bottom near Lomilik Island (Figure C-1, B-4). The BRAVO crater was recently visited and cursorily inspected by a diving team (reference Appendix E, Environment, this Report). Very little regeneration has occured. The remnants of the Union, Yankee and Cherokee tests have not been reinspected recently.

2. RESURVEY OF THE BAKER SITE AND SUNKEN SHIPS

2.1 General

The 11 sunken ships of Operation Crossroads present a potential problem. They are an attractive nuisance and they sank carrying fuel, loaded guns and stores of ammunition. Because of their potential as a long-term problem, a brief summary of their status as of 1947 is presented here.

The Bikini Scientific Resurvey (reference C-1) originated by the Joint Chiefs of Staff in May 1947 with the general purpose of completing... "studies and projects begun in 1946 in connection with operations Crossroads." The Navy Department was supported by the U.S. Geological Survey, the Department of Interior, and the National Museum in accomplishing the resurvey.

> ...The Bikini Scientific Resurvey "...would entail the collection of biological specimens; diving on target ships to recover specific instruments and to make certain structural examinations; the taking of water and bottom samples and cores; and radiological studies of the lagoon, the surrounding islands, and organisms,

with particular reference to analysis of hazards from alpha radiation and from possibly contaminated food organisms."

...The following items were listed for specific investigation:

A. The amount and nature of radioactivity remaining in the lagoon water and on the reef and land structures of the atoll, wherever it exceeded normal levels of radioactivity and cosmic rays. Particular attention to be given to that portion of the reef between Amon and Bikini Islands; at a stage of tide as nearly as possible that which existed 15 minutes after Test B, to chart the exposed portion of the reef by use of aerial photography.

B. The concentration and kind of radioactive materials in plants and animals of the area, and the effects of radioactivity upon such organisms.

C. Physiological, geological, and oceanographic studies of organisms and reef-building processes, including the drilling of cores down to 1,000 and perhaps 2,500 feet.

D. Detailed observations (including photographic recording) of ships sunk as a result of Test B, with special attention to Saratoga, Nagato, Pilotfish, and Apogon, and perhaps Arkansas and Gilliam, time permitting. Detailed structural inspection of the sunken vessels, to determine the exact cause of sinking; and to reveal minor structural failures such as bent, warped, or ruptured plating and scantlings.

E. Recovery of four instruments from Nagato, as follows: one ionization gage, two linear time pressure recorders and one diaphragm type damage gage. These instruments, being watertight, were believed to be in good condition, and it was thought that their recordings might be of considerable value.

F. Time permitting, to attempt to locate a section of LSM-60, believed to have been identified in photographs, and to inspect this section thoroughly for type of rupture, heat effects, and radioactivity.

2.2 The Lagoon Bottom Around BAKER GZ

The following is an excerpt from Reference C-2 that describes the lagoon bottom surrounding the BAKER target area.

> The characteristic sediment in the target area, prior to Test B, consisted chiefly of remains of the calcareous alga Halimeda. This alga, green when living consists of flat oval plates, 2mm. to 5mm. in diameter, joined together in series like a string of beads. When the plant dies, the green tissue decomposes and the plates fall apart, leaving a residue of small white or pale brown plates resembling uncooked rolled oats. With this Halimeda debris there usually is admixed a variable amount of mud (silt and clay-sized particles), sand, and shells.
>
> Five cores taken in the vicinity of the explosion point two weeks after Test B in the summer of 1946 showed that this sediment no longer occurred in the target area. Instead, a layer of mud covered the bottom, with coarser material below. However, the 33 cores taken during the 1947 resurvey show that the typical sequence in the target area now is as follows:
>
> A. A top layer of "target area" mud (see Figure C-3), grading through a thin transition zone into -
>
> B. A layer of silt and fine to coarse silty sand, the coarseness increasing with depth. This in turn grades into -
>
> C. A layer of clean, white Halimeda debris, with occasional fragments of green Halimeda. This rests, usually with a sharp contact, on -
>
> D. Pale tan or brownish Halimeda debris with admixed mud and sand.
>
> The bottom layer (D) of this sequence appears to be the original sediment of the target area prior to the Baker explosion. It usually is not radioactive. The three top layers (A, B, D {sic}) apparently represent material that was stirred up by the explosion and subsequently settled out roughly in a sequence

based upon settling rates, though there is considerable mixing of sizes. Most of the Halimeda fragments settled first to form layer C, with some living green Halimeda included; the latter has not yet decomposed and still retaining its green color. Coarse sand, followed by progressively finer sand and silt-sized particles settled later, followed by the silt and clay-sized particles composing the mud. The latter is quite fine (about 40% of the particles by weight are less than two microns in diameter, and 35% between 20 and two microns), cream colored, and with a typical fetid odor. The mud contains the only evident non-calcareous material in the sediments -- dark streaks and occasional small, crumbly, dark-brown lumps which chemical tests indicate to be nearly pure carbon. The latter may represent the tissues of fish, or possibly oil, carbonized by the intense heat of the explosion. This carbonized material makes up less than 1% of the sediment. The mud also contains about 0.1% by weight of iron, presumably from the target ships.

...The mud is pitted by the borings of marine animals. Holothurians (sea cucumbers) are living on the bottom in abundance....

The thickness of the three top layers of sediment in the target area varies greatly, as shown in Figure C-2* and in the cross-sections of Figure C-3. In Figure C-3, the thicknesses of the various layers of sediment are plotted against distance from the position of LSM-60, with no attempt made to show the topography of the bottom. Two sections are shown; one running NE-SW, the other E-W. Note that the layer is 5 ft. 3 in. thick below the LSM-60 location, and reaches a maximum of 8 ft. in thickness 125 yd. to the southwest in core No. 33. Also, the longest core taken (No. 4: 10 ft. in length) failed to penetrate the second layer (silt and sand) near the center of the target area. Near the edge of the mud area, on the other hand, the second and third layers frequently are missing (as in core No. 5), and a very thin layer of mud, a fraction of an inch in thickness, rests directly on the original bottom sediment (Halimeda debris).

Although the bottom was stirred up by the explosion to a distance of 1,000 to 1,500 yd. (Figure C-3), the intense disturbance was limited to a radius of about 300 yd. Moreover, the center of intensity is

> about 100 yds. to 150 yds. southwest of the position of LSM-60.... Both Figures C-2 and C-3 of the present report and Figure 27 of Enclosure F of the Crossroads Report, (which shows the increase in depth of water after Baker day) are comparable, however, and in essential agreement. The thickness of the mud layer (Figure C-2 and Figure C-3), of the other layers of disturbed and redeposited sediment (Figure C-3), and the increase in depth of water as measured last summer, all show a symmetrical distribution, elongated to the southwest.
>
> The radioactivity of the bottom material in the target area is concentrated in the top (mud) layer of re-deposited sediment. Though the second and third layers show some radioactivity, and even the superficial layer of normal sediment outside the mud area is weakly radioactive in many places, over 90% of the plutonium and fission products are in the mud. Therefore, an attempt has been made to estimate the volume and weight of this material. Owing to the difficulty in penetrating the coarse Halimeda debris with the coring instrument, and the restrictions imposed on the location of cores by sunken ships and by diving operations from COUGLA (ASR-S), the distribution and number of cores was not ideal for this purpose. With the additional information furnished by small bottom samples, however, a rough approximation is possible.

*Appendix Figure Numbers replace original report.

Shown on Table C-3 are the calculated radioisotope relative activities one year following the BAKER Test. If these calculated data represent the relative radioisotopic presence in the cored mud samples (see Table C-4) taken from the BAKER test area one year following the test, then one can project the current level of specific activity in 1984 as shown in Table C-3 based on half-life calculations. This assessment assumes that the radioisotopes remain fixed in the mud although there was some speculation by researchers during the resurvey that Sr^{90} and Cs^{137} would be leached out because of their solubility in sea water. We believe that very little has been leached (see Appendix B); however, there should be a diminished gradient.

2.3 The Condition of the Vessels

As part of the resurvey of the BAKER test site, the following vessels were inspected:

A. <u>Saratoga</u>

B. <u>Pilotfish</u>

C. <u>Apogon</u>

D. <u>Nagato</u>

The following is an excerpt from Reference C-3.

> Very detailed inspections were made on A, B, and C, but sufficient time was available for only a cursory inspection of <u>Nagato</u>.
>
> Much more serious damage to <u>Saratoga</u> occurred than had been reported originally. She is presumed to be beyond economical repair, even if she chould have been kept afloat. The hull girder appears to have been twisted, and the flight deck is broken at about frame No. 192 and has about a 4-foot step in it. At frame No. 192 port and starboard, a crack was reported in each sheer strake as well as heavy buckling. The flight deck appears to bend up forward of the elevator, and the elevator is destroyed. Bottom damage included rupture of both starboard struts and misalignment of both No. 1 and No. 3 shafts as well as cracks in both starboard stern tubes. Forward from about frame No. 10 aft the garboard and B strakes were deeply indented as far as could be seen (frame No. 48-49). A crack was found in the starboard blister at about frame No. 76.

Shown on Figure C-3 is the "Saratoga" as it lies on the lagoon bottom. The exact location of the "Saratoga" is uncertain. Reference C-4 reports her location as Longitude 165° 30' East and Latitude 34° 50° (sic) North in 27-34 fathoms heading 270°T. Clearly this is in error. If the actual latitude is 11° 34' 50" North, then the "Saratoga" is located at the "X" shown on Figure C-2 and lies on contaminated mud.

> Pilotfish was found a complete loss with major failures in pressure and tank plating, scantlings, closures, piping, and miscellaneous fittings. Damage was so thorough throughout the boat that no one section or piece of damage can be considered the most serious. Pilotfish was destroyed.
>
> Apogon was in considerable better condition than Pilotfish, and if it had been salvaged immediately, probably could have been put back in operable condition after considerable time. Main failures in Apogon occurred in the forward torpedo room, where there is a hole 18 in. by 30 in., in the top at about frame No. 30, another hole between main ballast tanks 6B and 6D, and a leak in the top of 6B. Because of passage of air from aft to forward, it is believed that bulkhead flappers, stuffing tubes or other fittings, failed. Vent risers to No. 1 main ballast tank and No. 7 failed at the valves, and it is presumed that others did also. Time required for salvaging Apogon is estimated at being between 3 and 4 weeks.

The divers who inspected the ships reported that there was no evidence that the munitions on-board the "Saratoga" detonated as a result of the tests (Reference C-4), thus inferring that the on-board explosives remain neither salvaged nor safed. The divers reported (Reference C-3) that fogs of mud and sand were easily stirred up while investigating the ships confirming that they are located in the proximity of BAKER GZ. Additionally, it was reported that the "Saratoga" is radioactively contaminated, especially the wood, manila line, fire hoses and foamite (Reference C-4). Finally, both the "Saratoga" and "Pilotfish" were reported as closest to the BAKER GZ (Reference C-3).

3. POTENTIAL SALVAGE OF THE VESSELS AND EXPLOSIVES

In 1973, S. A. Farle investigated the sunken Japanese fleet at Truk Lagoon approximately Longitude 152° East and Latitude 7° North (Reference C-8). Approximately 60 Japanese cargo and combat vessels were sunk in the lagoon during World War II by American aircraft. The ships sank with battle stores and fuel oil. Approximately 40 years following their sinking, S. A. Earle after completing an on-site survey of the sunken ships observed significant coral growth on and about the sunken ships, observed no evidence of environment degradation though fuel oils were slowly seeping from the ships and ammunition casings were corroding, and concluded that

> the best course of action concerning her cargo is **no** action. The gradual dispersion of fuel over the years should have little or no damaging consequences, but releasing massive amounts all at once would without question be detrimental to the marine life.
>
> That evening Al (Giddings, Earle's diving partner) and I discussed the fate of the munitions ship "San Francisco Maru" with Kimiuo, and we all concurred: Her cargo is not dangerous if left untouched. The picric acid now locked in the unexploded mines will seep into the sea harmlessly through gradual corrosion, but detonation of those mines would have severe impact on the lagoon. Salvage techniques are dangerous, expensive --and in this case, unnecessary.

Based on the resurvey reports of the extremely damaged conditions of the sunken ships (loss of structural and water tight integrity), the contaminated bottom condition that surrounds the BAKER test site, the apparent benign affect on the environment that the ships and test site have on the Bikini Lagoon over the past 40 years replicating the Truk experience, and the relatively secureness of the test site from outside intrusion approximately 25 fathoms (150 feet -- see Figure C-1), it appears inadvisable to attempt salvage. However, no recent on-site resurvey has been accomplished.

4. RECOMMENDATIONS

4.1 The numerous obstructions located near Lomilik Island and sited on the Bikini Atoll map (Reference C-9) should be detailed to assess potential hazards to navigation if rehabilitation and resettlement of the Atoll is undertaken.

4.2 A detailed survey and assessment of the sunken ships and the radioactive contaminated lagoon bottom should be undertaken to determine whether salvage or other safing activities are necessary or desirable.

REFERENCES

C-1 through C-7 Bikini Scientific Resurvey, Armed Forces Special Weapons Project, December, 1947. (The following documents have the same title and publication date as the major reference.)

- C-1. Operations, Volume I, AD077489
- C-2. Report of The Technical Director, Volume II, AD077490
- C-3. Report of the Director of Ship Material, Volume III, AD077491
- C-4. Saratoga, Annex I, Volume III, AD077492
- C-5. Pilotfish, Annex II, Volume III, AD077493
- C-6. Apogon and Nagato, Annex III, Volume III, AD077494
- C-7. Supplement to Volume II of the Cikini Scientific Resurvey Report of the Technical Director, Annex IV, AD077495

C-8. S. A. Earle, "Life Springs from Death in Truk Lagoon", National Geographic, May 1976, pp. 578-603.

C-9. Map, "North Pacific Ocean Marshall Islands - Northern Part Bikini Atoll", Defense Mapping Agency Hydrographic Center, Washington, D. C. 20390

C-10. W. R. Schell, F. G. Lowman, and R. P. Marshall, "Geochemistry of Transuranic Elements at Bikini Atoll", Transuranic Elements in the Environment, W. C. Hanson, Ed., DOE, DOE/TIC-22800, 1980.

C-11. "Announced United States Nuclear Test Statistics Through December 31, 1977, Nevada Operations Office, DOE, Las Vegas, NV.

C-12. L. J. Circeo, Jr. and M. D. Nordyke, Nuclear Cratering Experience at the Pacific Proving Grounds, Lawrence Radiation Laboratory, UCRL-12172, November 10, 1984.

C-13. M. W. Carter and A. A. Moghissi, "Three Decades of Nuclear Testing", Health Physics, Vol. 33, July 1977, pp. 55-71.

TABLE C-1. ANNOUNCED NUCLEAR DETONATIONS AT BIKINI ATOLL [a, b, c]

NO.	OPERATION AND EVENT	DATE (GCT)	TYPE	PURPOSE[b]	YIELD RANGE	MAP REF
CROSSROADS						
1	ABLE	06/30/46	AIRDROP	WEAPONS RELATED	23 KT[b, e]	A
2	BAKER	07/24/46	UNDERWATER	WEAPONS RELATED	23 KT[b, e]	A
CASTLE						
3	BRAVO	02/28/54	SURFACE	WEAPONS RELATED	15 MT	B
	EXPERIMENTAL THERMONUCLEAR DEVICE					
4	ROMEO	03/26/54	BARGE	WEAPONS RELATED		B
5	KOON	04/06/54	SURFACE	WEAPONS RELATED	110 KT	C
6	UNION	04/25/54	BARGE	WEAPONS RELATED		D
7	YANKEE	05/04/54	BARGE	WEAPONS RELATED		D
REDWING						
8	CHEROKEE	05/20/56	AIRDROP	WEAPONS RELATED	SEVERAL MT	E
	FIRST AIRDROP BY U.S. OF A THERMONUCLEAR WEAPON					
9	ZUNI	05/27/56	SURFACE	WEAPONS RELATED	3.5 MT	C
10	FLATHEAD	06/11/56	BARGE	WEAPONS RELATED		F
11	DAKOTA	06/25/56	BARGE	WEAPONS RELATED		F
12	NAVAJO	07/10/56	BARGE	WEAPONS RELATED		D
13	TEWA	07/20/56	BARGE	WEAPONS RELATED	5 MT	G
HARDTACK PHASE I						
14	FIR	05/11/58	BARGE	WEAPONS RELATED		B
15	NUTMEG	05/21/58	BARGE	WEAPONS RELATED		H
16	SYCAMORE	05/31/58	BARGE	WEAPONS RELATED		B
17	MAPLE	06/10/58	BARGE	WEAPONS RELATED		I
18	ASPEN	06/11/58[d]	BARGE	WEAPONS RELATED		B
19	REDWOOD	06/27/58	BARGE	WEAPONS RELATED		I
20	HICKORY	06/29/58	BARGE	WEAPONS RELATED		H
21	CEDAR	07/02/58	BARGE	WEAPONS RELATED		B
22	POPLAR	07/12/58	BARGE	WEAPONS RELATED		J
23	JUNIPER	07/22/58	BARGE	WEAPONS RELATED		H

[a] The basic data for this table was obtained from W. R. Schell, F. G. Lowman, and R. P. Marshall, "Geochemistry of Transuranic Elements at Bikini Atoll", Transuranic Elements in the Environment, W. C. Hanson, Ed., DOE, DOE/TIC-22800, 1980.

[b] _________, Announced United States Nuclear Test Statistics through December 31, 1977, Nevada Operations Office, DOE, Las Vegas, NV.

[c] M. W. Carter and A. A. Moghissi, "Three Decades of Nuclear Testing", Health Physics, Vol. 33, July 1977, pp. 55-71.

[d] Reference b reports this date as 06/14/58.

[e] Reference c reports these as < 20 KT.

TABLE C-2 (Reference C-3)

The ships which were sunk incident to Operation CROSSROADS:

SHIP	TEST
SARATOGA	B
PILOTFISH	B
APOGON	B
NAGATO	B
ARKANSAS	B
YO 160	B
GILLIAM	A
CARLISLE	A
ANDERSON	A
LAMSON	A
SAKAWA	A

TABLE C-3. CALCULATED FISSION-PRODUCT ACTIVITIES AT BAKER TEST SITE (Reference C-7)

	Relative Fission Product Activity at BAKER Day Plus One Year			Calculated Fission Product Activity[d] In Core 4 (pCi/gm)	
	Percentage of Total Activity	Radiation Energy (Mev)			
Radioisotope		Beta	Gamma	1947	1984
53d Sr^{89}	1.20	1.5	None	26	None[e]
25y Sr^{90}	1.07	0.6	None	23	8.2
65h Y^{90}	1.07[a]	2.2	None	23	None
57d Y^{91}	2.50	1.6	None	54	None
65d Zr^{95}	7.38	0.4	0.8	160	None
35d Cb^{95}	7.38[a]	0.15	0.8	160	None
42d Ru^{103}	1.36	0.2	0.56	30	None
1.0y Ru^{106}	----[b]	----[b]	None	---	None
30s Rh^{106}	33.8[b]	3.9	0.3,0.8[c]	734	None
33y Cs^{137}	1.90	0.5,0.8	0.75	41	19
275d Cd^{144}	20.6	0.35	None	447	None
17.5m Pr^{144}	20.6[b]	3.1	0.2,1.25[c]	447	None
3.7y 61^{147}	6.04	0.2	None	131	1.3
2y Eu^{155}	0.81	0.2	0.084	18	None

[a] Supported by the longer-lived parent

[b] The beta rays of Ru^{106} are so soft that they are practically undetectable and are not included in the calculations

[c] Low intensity

[d] Based on the average activity of Core 4 down to 5 feet (2170 pCi/gm)

[e] Negligible activity

TABLE C-4 (Reference C-7)

DISTRIBUTION OF TOTAL FISSION PRODUCT ACTIVITY IN BOTTOM DEPOSITS TAKEN NEAR BAKER GROUND ZERO (See Figure C-2a for Core Locations)

Core No.	Sample Number	Position Relative To Target Center	Depth Below Top of Core	c/min/gm	Curies/gm($\times10^9$)[a]	Description of Material
2	1,216	Target Center	0 ft. - 6 in.	7,230	3.25	Soft mud (sandy, silty clay)
	1,217		½ ft. - 1 ft.	3,900	1.75	"
	1,218		1 ft. - 2 ft.	3,570	1.61	"
	1,219		2 ft. - 3 ft.	3,170	1.43	"
	1,220		3 ft. - 4 ft.	4,070	1.83	"
	1,221		4 ft. - 5 ft.	3,940	1.77	"
						(Break at 5 ft. 3 in.)
	1,222		5 ft. - 7 ft.	2,380	1.07	Sandy silt, coarser with depth
	1,223		7 ft. - 9 ft.	346	0.16	"
4	1,224	Target Center	0 ft. - 6 in.	6,500	2.92	Soft mud
	1,225		½ ft. - 1 ft.	5,600	2.52	"
	1,226		1 ft. - 2 ft.	5,500	2.47	"
	1,227		2 ft. - 3 ft.	4,300	1.93	"
	1,228		3 ft. - 4 ft.	4,350	1.96	"
	1,229		4 ft. - 5 ft.	3,900	1.75	"
						(Break at 5 ft. 3 in. to:)
	1,230		5 ft. - 6 ft.	670	0.30	Sandy silt, coarser with depth
	1,231		6 ft. - 7 ft.	450	0.20	"
	1,232		7 ft. - 8 ft.	177	0.08	"
	1,233		8 ft. - 9 ft.	300	0.14	Muddy sand
	1,234		9 ft. - 10 ft.	230	0.10	"
5	1,235	3,700 yd SW	0 in. - 2 in.	161	0.07	*Halimada* debris; green *H.*, shells
	1,236		2 in. - 4 in.	0	0	Finer *H.* debris
	1,237		4 in. - 10 in.	0	0	*H.* debris, with mud
	1,238		10 in. - 16 in.	0	0	"
	1,239		16 in. - 24 in.	0	0	"

[a] Reference C-7 lists the activity in this column as curies/gm ($\times10^8$) which is 10x's too large if the counts/min/gm is reported correctly.

TABLE C-4 (Continued)

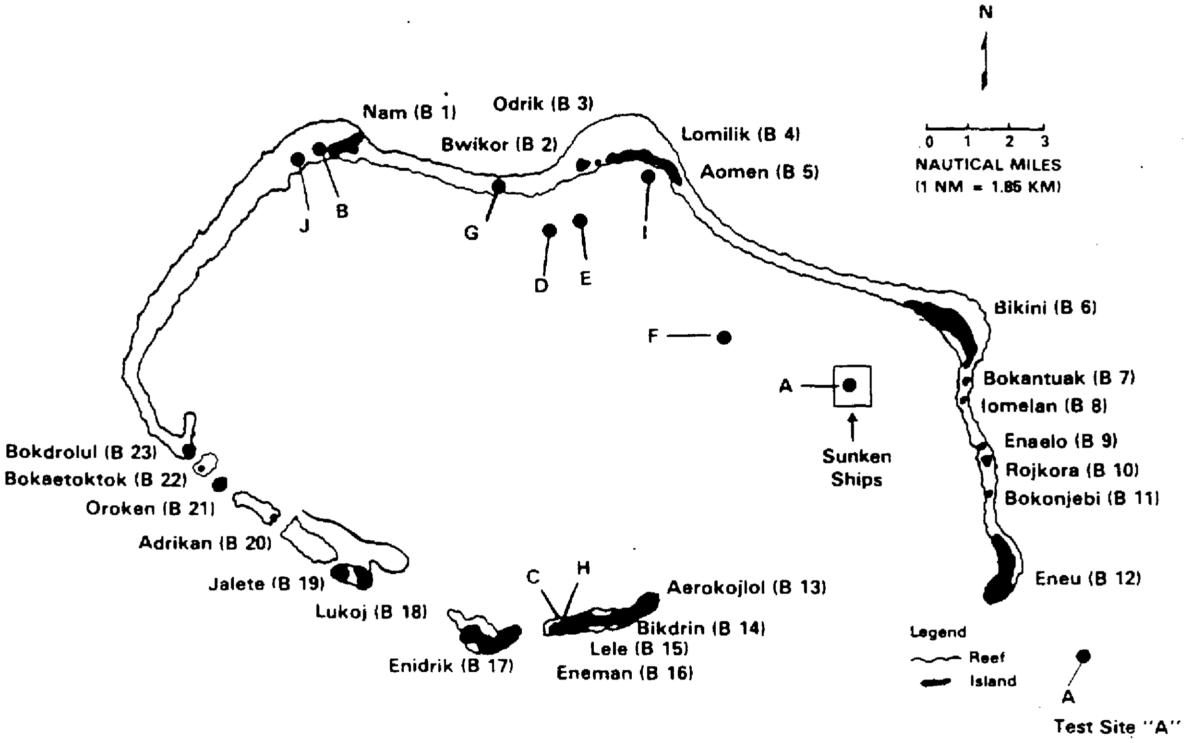
Core No.	Sample Number	Position Relative To Target Center	Depth Below Top of Core	c/min/gm	Curies/ gm(x10^{9})	Description of Material
6	1,082	2,000 yd SW	0 in. - 1 in.	722	0.32	Silty mud
	1,083		1 in. - 3 in.	326	0.15	*H.* debris
	1,084		3 in. - 11 in.	0	0	*H.* debris, with mud
7	1,085	1,000 yd SW	0 in. - 1 in.	29,700	13.40	Silty mud
	1,086		1 in. - 7 in.	3,380	1.52	*H.* debris
8	1,203	600 yd SW	0 in. - 5 in.	42,000	18.90	Soft mud
	1,204		5 in. - 10 in.	43,000	19.30	Soft silty mud
	1,205		10 in. - 15½ in.	1,500	0.68	Fine to coarse sand
	1,206		15½ in. - 21 in.	530	0.24	*H.* debris
9	1,207	300 yd SW	0 in. - 10 in.	5,300	2.39	Silty mud
	1,208		10 in. - 15 in.	2,300	1.07	"
	1,209		15 in. - 20 in.	1,190	0.54	"
	1,210		20 in. - 23 in.	755	0.34	Silt and fine sand
10	1,212	1,000 yd NE	0 in. - 1 in.	73,000	32.80	Mud
	1,213		1 in. - 6 in.	5,200	2.34	*H.* debris
	1,214		6 in. - 12 in.	440	0.20	"
11	1,215	300 yd NNE	0 in. - 6 in.	1,350	0.61	Thin layer mud; rest *H.* debris and sand
12	1,256	300 yd NW	0 in. - 4 in.	17,200	7.74	Mud
	1,257		4½ in. - 10½ in.	504	0.23	Coarse *H.* debris
	1,258		11 in. - 14½ in.	690	0.31	Finer *H.* debris, coarse sand
	1,259		14½ in. - 18½ in.	415	0.19	*H.* debris, mud, sand
	1,260		18½ in. - 22½ in.	73	0.03	"
13	1,261	300 yd WSW	0 in. - 1 in.	23,000	10.70	Mud
	1,262		1 in. - 2 in.	29,500	13.30	Mud, dark streaks
	1,263		2 in. - 6 in.	20,700	9.30	"
	1,244		6 in. - 12 in.	14,400	6.48	"

TABLE C-4 (Continued)

Core No.	Sample Number	Position Relative To Target Center	Depth Below Top of Core	c/min/gm	Curies/ gm(x10^{9})	Description of Material
13	1,245	300 yd WSW	12 in. - 16 in.	16,800	7.56	Mud, dark streaks
	1,248		16 in. - 20 in.	13,200	5.99	"
	1,252		21 in. - 24 in.	600	0.27	Coarse H. debris
	1,253		24 in. - 25½ in.	750	0.34	H. debris, coral fragments, sand
14	1,544	200 yd SE	0 in. - 6 in.	6,270	2.82	Mud, dark streaks
	1,545		6 in. - 12 in.	5,760	2.59	Mud
	1,546		1 ft. - 2 ft.	6,300	2.84	"
	1,547		2 ft. - 3 ft.	5,860	2.64	"
	1,548		3 ft. - 4 ft.	6,220	2.80	"
	1,549		4 ft. - 5 ft.	6,570	2.96	"
	1,550		5 ft. - 5 ft. 3 in.	4,750	2.14	"
	1,551		5 ft. 3 in. - 5 ft. 9 in.	1,520	0.68	Silt
	1,552		5 ft. 9 in. - 6 ft. 5 in.	890	0.40	Silt and fine sand
15	1,553	400 yd ESE	0 in. - 6 in.	2,440	1.10	Trace of mud, remainder silty sand
	1,544		6 in. - 12 in.	1,350	0.61	Silty sand
	1,555		12 in. - 20 in.	1,050	0.47	"
	1,556		20 in. - 21 in.	--	--	H. debris
16	1,557	490 yd SSE	0 in. - 1/8 in.	38,600	17.40	Mud
	1,558		1/8 in. - 6 in.	7,270	3.27	Silty sand
	1,559		7½ in. - 13 in.	480	0.22	Sandy H. debris
17	1,560	480 yd S by W	0 in. - 1½ in.	46,100	20.80	Mud, dark streaks
	1,561		1½ in. - 4 in.	38,300	17.20	Mud
	1,562		4 in. - 12 in.	690	0.31	Silty sand
	1,563		12 in. - 18 in.	180	0.08	"
	1,564		18 in. - 22 in.	23	0.01	"
	1,565		23 in. - 31 in.	179	0.08	H. debris, some green H.
	1,566		31 in. - 42 in.	1,470	0.66	"
	1,567		42½ in. - 44½ in.	0	0.00	Muddy H. debris (original materials)

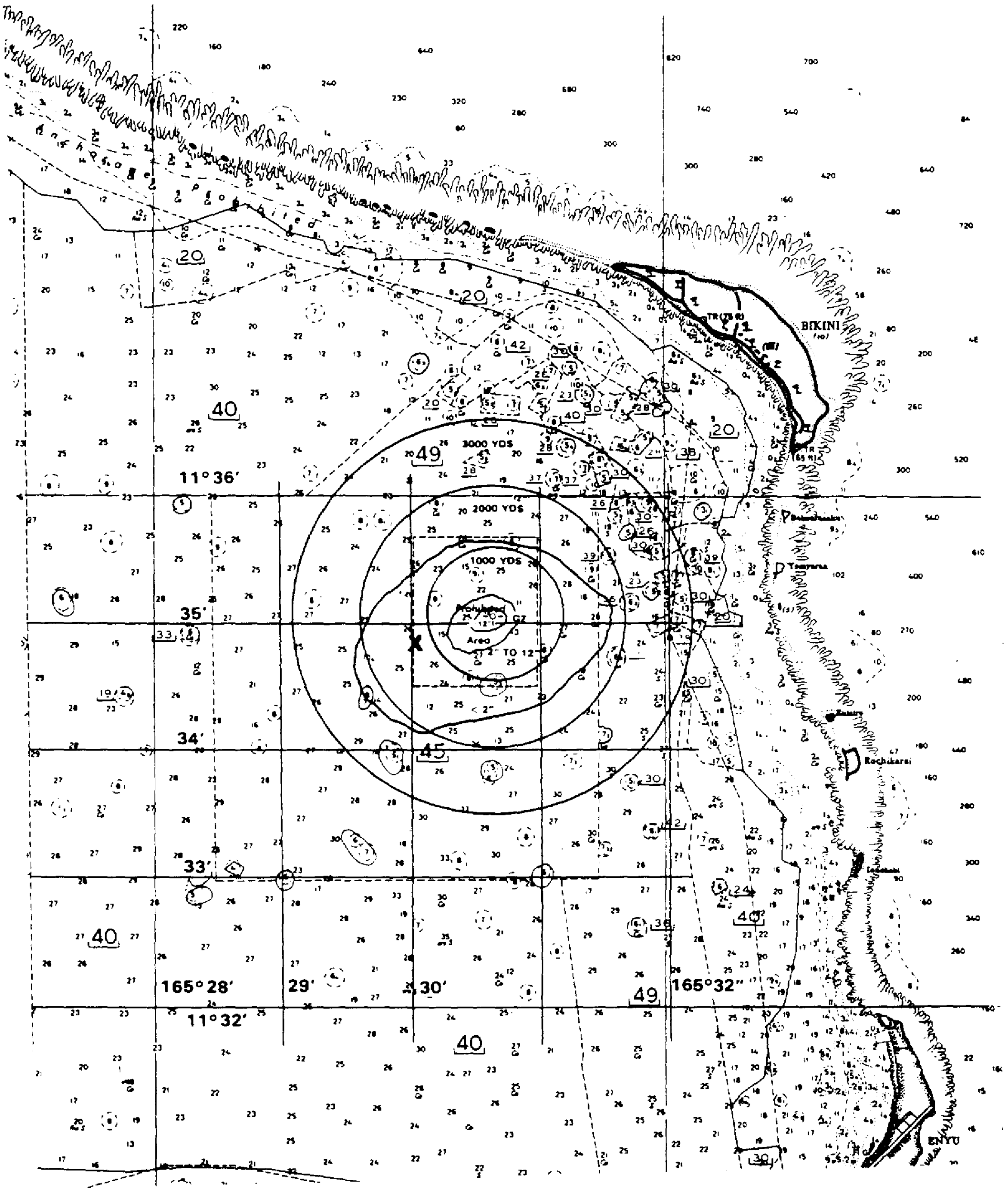
TABLE C-4 (Continued)

Core No.	Sample Number	Position Relative To Target Center	Depth Below Top of Core	c/min/gm	Curies/ gm($\times 10^{9}$)	Description of Material
18	1,568	475 yd SE by E	0 in. - 1 in..	45,300	20.40	Mud, dark streaks
	1,569		1 in. - 4 in.	1,560	0.70	Silty sand
	1,570		5 in. - 11 in.	610	0.27	*H.* debris and sand
	1,571		11 in. - 16½ in.	335	0.15	*H.* debris, green *H.*
	1,572		17 in. - 24 in.	0	0	Muddy *H.* debris (original material)
	1,573		24 in. - 33 in.	--	--	"
19	1,574	400 yd ENE	0 in. - ½ in.	60,000	27.00	Mud, dark streaks
	1,575		½ in. - 1½ in.	4,380	1.97	Silty sand
	1,576		2 in. - 10 in.	657	0.30	*H.* debris, green *H.*
	1,577		10 in. - 17 in.	1,440	0.65	"
20	1,578	250 yd NE by E	0 in. - 1½ in.	46,500	20.90	Mud, dark streaks
	1,579		1½ in. - 6 in.	10,200	4.59	Muddy silt
	1,580		6 in. - 12 in.	820	0.37	Silt and fine sand
	1,581		12 in. - 20 in.	206	0.09	Coarser silty sand
	1,582		20 in. - 22 in.	538	0.24	*H.* debris, green *H.*
	1,583		22 in. - 26 in.	1,010	0.45	*H.* debris
	1,584		26 in. - 33 in.	--	--	"



a. W. R. Schell, F. G. Lowman, and R. P. Marshall, "Geochemistry of Transuranic Elements at Bikini Atoll." Transuranic Elements In the Environment, W. C. Hanson, Ed., DOE, DOE/TIC-22800, 1980.

Figure C-1. Approximate Locations of Nuclear Tests at Bikini Atoll[a]



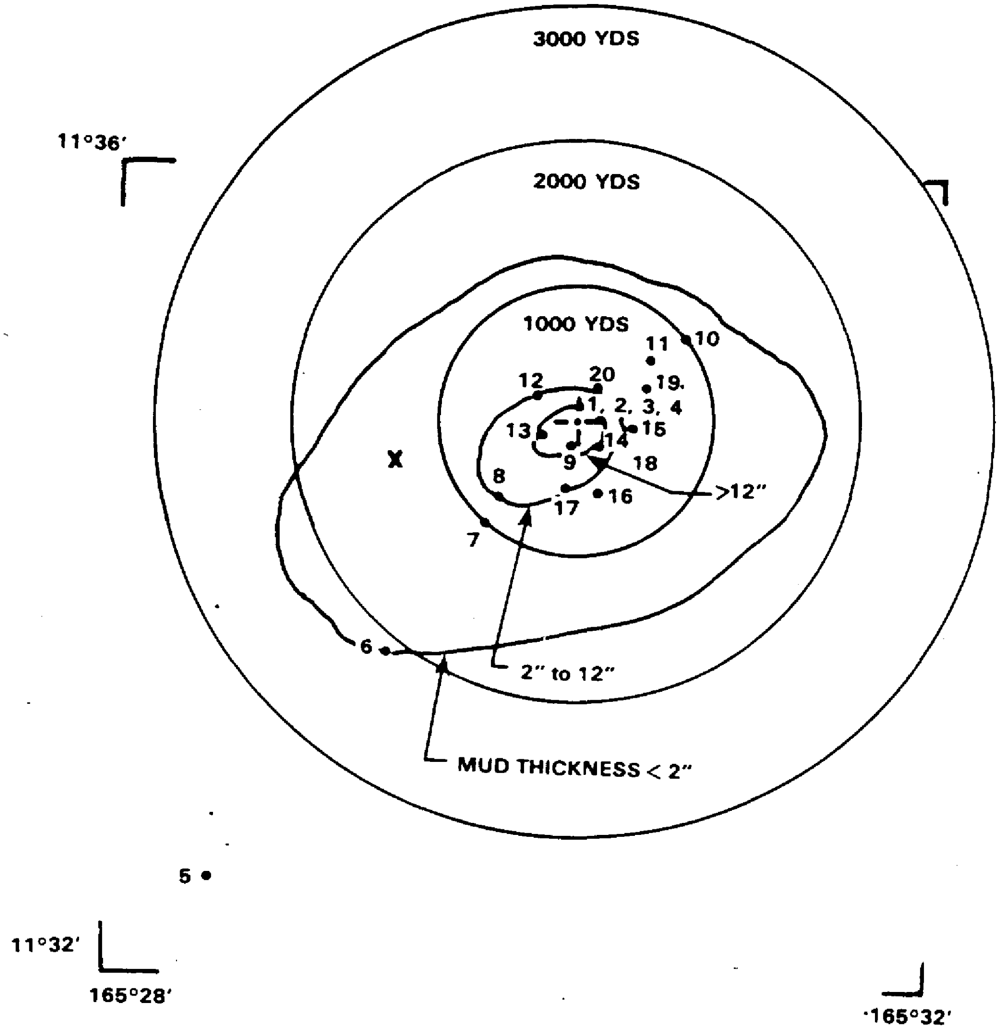
X Possible location for the "Saratoga"

BAKER Ground Zero (LSM-60)

Isopleths for mud thickness shown for > 12", 2" to 12", and <2".

See Figure C-2a for enlargement of site details.

Figure C-2. Thickness of Contaminated Mud Around BAKER Ground Zero (Reference C-7 and C-9).



Legend:

5° Location of Core 5

X Possible Location of "Saratoga"

-¦- BAKER Ground Zero

Figure C-2a. Location of Cores.

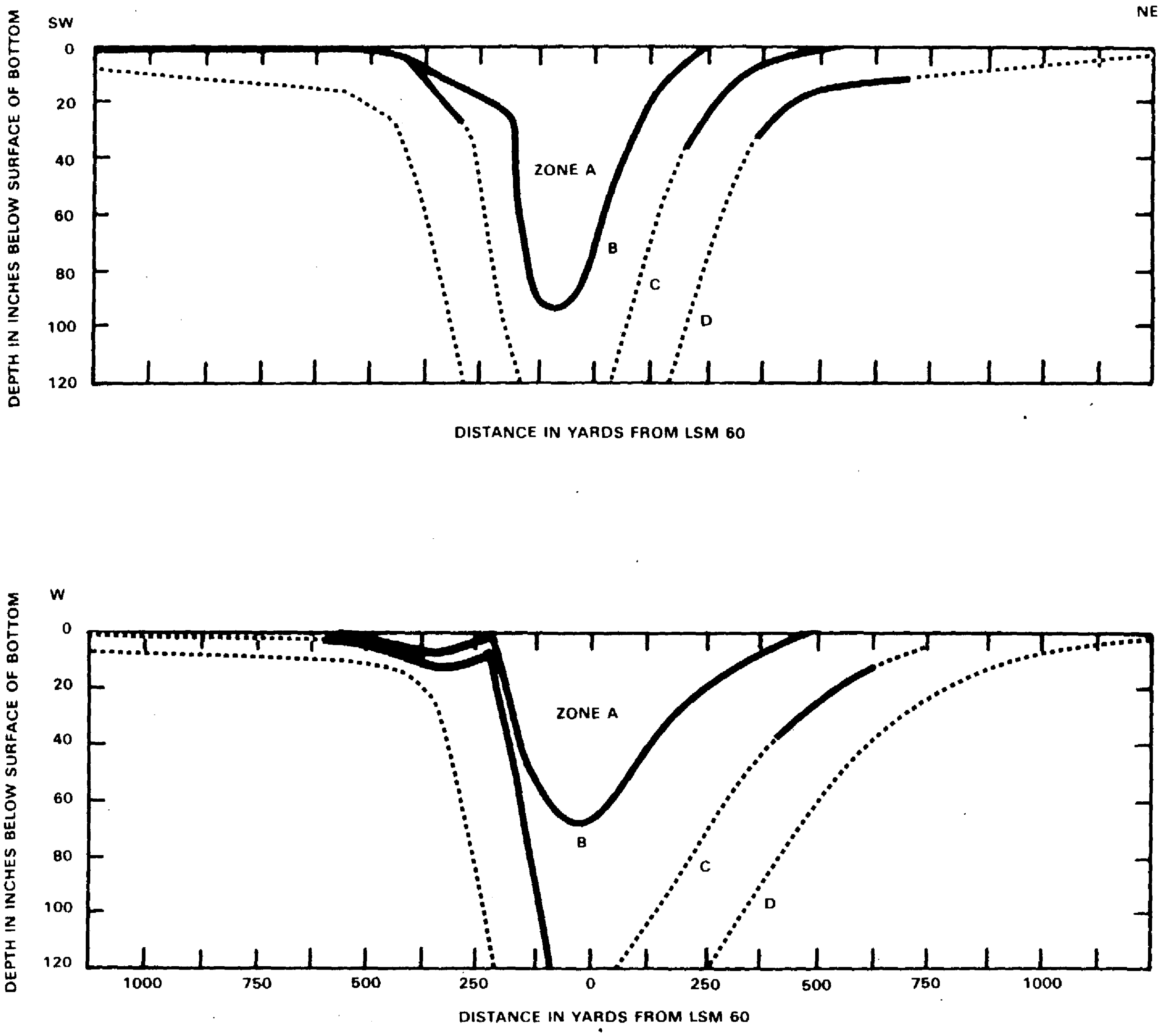
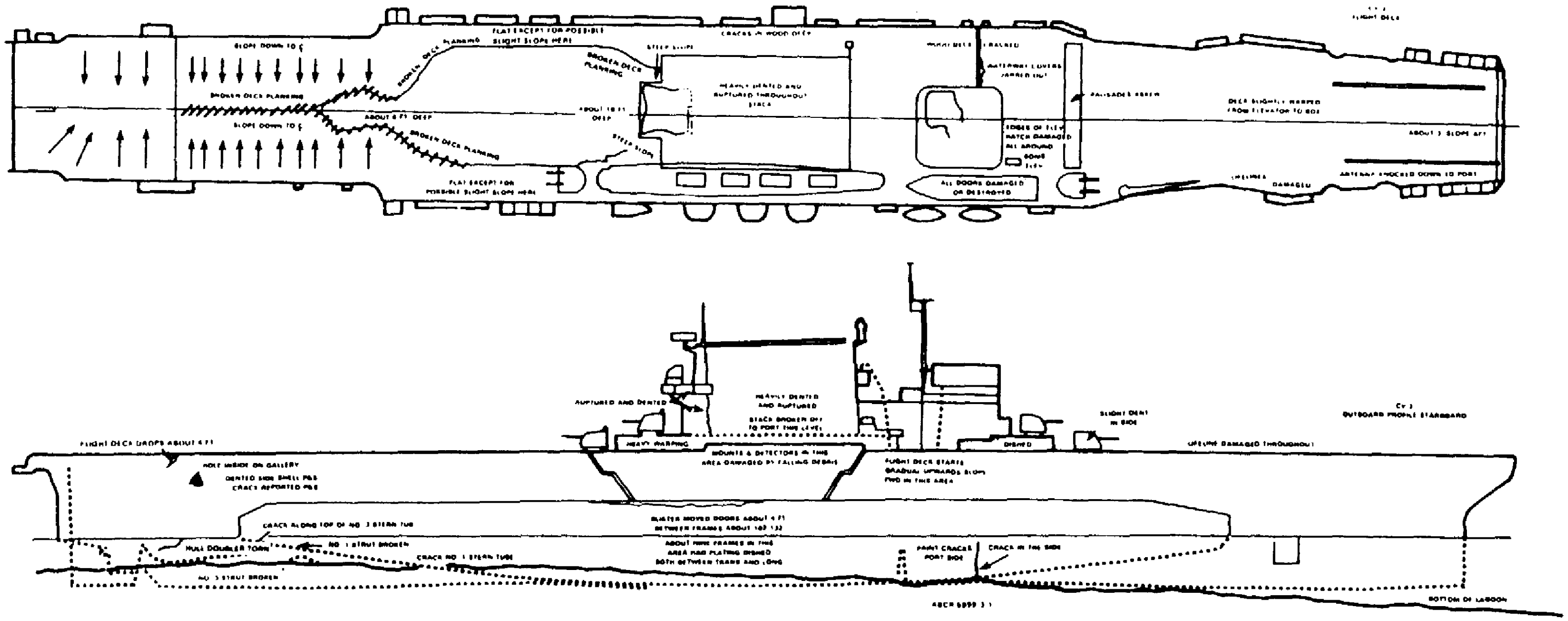


Figure C-3. Cross Sections of Bottom in the Target Area. (Reference B-7).



NOTE: THE DOCUMENT FROM WHICH THIS DIAGRAM WAS PRODUCED WAS ILLEGIBLE. THEREFORE MANY DESCRIPTORS ARE MISSING OR HAVE BEEN RECONSTRUCTED

Figure C-4. Damage of the Saratoga.

APPENDIX D

DOSIMETRY

By

W. L. Robison, Ph.D.

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APPENDIX D. DOSIMETRY

1. Introduction

Settlers of Bikini Atoll will be exposed to both external and internal man-made sources of radiation as a result of contamination of soil by cesium-137, and to a lesser degree be other radionuclides (1,2) (Table 1). Internal exposure accounts for about 80% of the estimated radiological dose at Bikini and Eneu Islands. Most of the internal exposure results from radionuclides ingested via consumption of terrestrial foods, particularly coconut meat and fluid. For the two principal islands, the general conclusion is that Eneu meets the Federal radiation standards but Bikini does not.

In the following we discuss various parameters that affect estimated doses and compare estimated body burdens to those measured by wholebody counting. We also briefly describe the dose calculation methodology.

2. External Exposure

External exposure to the gamma rays of cesium-137 was measured in a detailed terrestrial survey of Bikini and Eneu Islands in 1975 (1) and by aerial survey of the entire atoll in 1978 (2). Both were in good agreement (Report, Table 1); the calculated 30-year doses (1987-2016) based on them are 0.27 rem for Eneu and 3.5 rem for Bikini Island. These estimates do not include the reduction by a factor of two or so, from shielding by the house and by crushed coral which is customarily spread around the housing area, due to spending a large part of each day indoors and around the family dwelling.

External exposure from boating or swimming in the lagoon is trivial.

The beta radiation contribution to the external dose was evaluated at Enewetak Atoll(3). The median beta dose contribution to the skin (i.e. "shallow dose" in keeping with the concepts set forth in ICRU 25(4)) and eyes, in excess of the measured external gamma dose, is about 29% at 1 meter height above the ground surface. The range of values was 16% to 50% depending on the ground cover. Thus, the dose calculated from external gamma measurements should be multiplied by 1.29 to estimate the shallow dose at Enewetak. Other than the increase in dose to the top few millimeters of skin, the rest of the wholebody and bone marrow dose would be unchanged from the external gamma estimate.

The ratio of Sr to Cs in the soil is considerably higher at Enewetak then at Bikini. Thus, the contribution of beta radiation in excess of the measured external gamma dose would be less at Bikini than at Enewetak. Based on measurements made at Enewetak and the relative ratios of Sr to Cs in the top 5cm of soil at the two atolls, the total external exposure at Bikini at 1 meter due to external gamma plus beta radiation would be about 15% greater than the external gamma measurement. The total unattenuated external exposure dose to the skin (i.e. shallow dose) at the ground surface could be 50 to 100% greater than the external gamma dose at 1 meter.

The external gamma dose listed in reference 3 and this report are based on open field external gamma measurements. They do not include reductions which can be as much as a factor of 2 or more which occur as a result of the considerable time spent in and around the houses from shielding due to the houses and crushed coral which is customarily spread around the houses(1). The reductions in the beta dose could be even greater because clothing, shoes, sandals and <u>Pandanus</u> mats on which people commonly sit or lie would absorb most of the beta radiation and people only spend part of their time with the wholebody on the ground surface level.

The net effect is that the external dose to the wholebody, bone marrow, eyes and skin would most likely be less than those listed in these reports for most living patterns and lifestyles.

3. Internal Exposure

3.1 Role of Diet Estimates

As discussed previously (5,6,7), the diet of the Bikinians is not known precisely. This is not surprising; nutritionists in the United States have remarked on the difficulty of finding out accurately what people eat (8). The Lawrence Livermore group has assumed that the Micronesian Legal Service (MLSC) dietary estimates for the Enewetak people, when they were living on Ujelang Atoll in 1979, will apply to the resettlement of Bikini. The estimates were made by a staff member of MLSC (M. Pritchard) during a 2 1/2 week visit to Ujelang.

The MLSC diets are open to some question since they are based on a short period of data collection by an "outsider", although he was aided by the local school teacher. An inconsistency of the Pritchard diet is that it predicts that women eat more than men and thus should have a cesium-137 body burden that is 60% higher. The Brookhaven team (9) found in 1978 that the male settlers had a mean body-burden 40% higher than the female. The LLNL group uses the higher intake of the females from the MLSC diet as a reasonable estimate of our adult intake at the atolls. In this report, we have averaged the male and female estimates to obtain a dietary estimate for the adult population. However, recent comparison of predicted body burdens (and, therefore, dose) using different diet models with measured body burdens at Bikini, Rongelap and Utirik Atolls indicate that the MLSC adult diet used by LLNL best predicts the observed body burdens (10,11).

As mentioned previously the largest fraction of the predicted dose at the atolls comes from potential consumption of coconuts. Thus, determining a reasonable average intake of coconuts by people living on the outer atolls is very important in estimating the radiation dose.

The MLSC diets (Tables D.2, D.3) assume the use of 1-2 coconuts per person per day averaged over a year. Other estimates based on previous experience ranged from 0.5 to upwards of 5 per day. The important points also have been made that the number of coconuts used in preparing a meal is not necessarily the number eaten; that many nuts are used primarily for drinking, especially during work in the groves, so that much if not all of the meat may be discarded; and that local and external factors significantly affect consumption (5,6).

It is clear to all who have been visiting the Marshall Islands that the Marshallese diet has been changing significantly during the past 10 years. For example, canned drinks and canned foods are now commonplace in many communities, in part due to the food assistance program. Coconut consumption has certainly diminished.

Ralph Waltz, a consultant to this Committee who resides on Majuro and is a member of the Bikini family, made a small diet survey during the fall of 1983. The 88 individual members of 14 Bikini families were reported on daily for six days. The data given to the Committee by Mr. Waltz show that references to fish and chicken (imported) averaged 0.7 per day per person. The overall average for coconuts was less than 1 per person per week. In fact, coconut consumption was limited to 4 of the 14 families; in these four, there were 3-4 references per person per week, equivalent to about one-third of the Pritchard estimate of 7-10 coconuts per person per week.

Two senior Marshallese officials independently have made the following estimates from their experience on the outer atolls where there are no major food distribution programs: less than one coconut per day per person; from 0.5 to one coconut per day per person (12,13).

The Bikini Council was asked to estimate coconut usage after resettlement but has not been heard from.

In view of the foregoing, some judgement must be exercised in deciding on a likely "resettlement diet" for dose calculations. Since the trend of coconut consumption now is downward, and most estimates are no greater than the MLSC diet, this committee arbitrarily has decided to include a safety factor and use a "planning dose" that is 1.75 times the MLSC based dose used by the Lawrence Livermore group.

3.2 Dose Estimates

The 5 major radionuclides of Bikini Atoll are ^{137}Cs, ^{90}Sr, $^{239+240}Pu$ and ^{241}Am. The internal dose, which is about 10 times the external one, is determined by the ingestion of these radionuclides via the diet or by inhalation, the fraction of the radionuclide intake absorbed from the gut and/or lungs, the location and duration of their stay in the body, the fraction of atoms decaying per unit time (i.e. radiological half-life), and the energy of the emitted radiations (Table D.1, D.4). Inhalation doses are very low; the major exposure is via the food chain(5).

Thus the amount of locally grown foods in the diet and the radionuclide concentrations in these foods determines the quantities of radionuclides ingested. The amount of locally grown foods in the diet depends on whether or not imported foods are available (Tables D.3 and D.4). In current diet models some 80% of the predicted dose is the result of coconut consumption.

For this report, the planning diet is considered as the case where local foods are always available and imported foods are available for 9 months of the year.

A review of the LLNL sample collection, analytical results and dose assessment was conducted by an independent group of scientists. Their report confirmed the validity of the LLNL data of radionuclide concentrations in soil and foods and the estimated doses (7).

As discussed in Section 3.1, the precise diet of the Bikinians after resettlement, especially the coconut consumption, can only be approximated. Therefore, to provide a significant measure of conservatism, we have arbitrarily multiplied by 1.75 the radionuclide intakes estimated from the MLSC diets used by the Lawrence Livermore Laboratory group (5), and set out in Tables D.3 and D.4, to calculate the "planning doses" used in this report. For Eneu, the 1987 daily intake of ^{137}Cs would be 8700 pCi/d, for Bikini it would be 64,800 pCi/d. The intake of strontium would be less than 1.5 per cent of these figures, and that of plutonium and americium less than 0.01%.

The Federal daily and annual limits on intake of the pertinent radionuclides are given in Table D.5. The projected intake for Eneu is permissible, but not that for Bikini.

Thirty-year-dose factors are given in Table D.6, i.e., the constant by which to multiply the initial daily radionuclide intake (pCi/d) to obtain the 30-year cumulative dose (rem) given in Table D.7. Eneu at 4 rem falls within the 5-rem Federal standard, but Bikini at 30.8 rem does not. In these calculations, it is assumed that the diet remains constant, and that the loss of radioactivity in the diet is by radiological decay only.

The 30-year cumulative doses of Table D.7 apply to the period 1987-2016. In the next 30-year period the doses from cesium-137 and strontium-90 would be no more than half of these. The transuranic dose continues to increase with time but the dose due to the transuranics would be less than 3% of the total dose over 50 y.

Of the principal contaminating radionuclides, cesium-137 is, therefore, the most important (Table D.8). It accounts for 93 per cent of the 30-y integral bone marrow dose and practically 100 per cent of the dose to most other tissues. Strontium-90 contributes 7 per cent of the 30-y integral bone marrow dose while the contributions of the plutonium and americium are less than 1%.

Of the foods, coconut products supply some 83% of the cesium intake (Tables D.3, D.4) and Pandanus fruit and local meat (but not fish) supply about 12%. Coconut, therefore, is responsible for about 83% of the whole-body dose.

The preponderance of cesium-137 in determining the dose is the result of a much larger intake of ^{137}Cs than of other radionuclides, amplified by much greater absorption from the gut, so that the cesium-137 entering the circulation is about 300 times that of strontium-90, and more than one million times that of the transuranics combined.

4. Leeway

An additional margin of safety (in addition to the factor of 1.75 already applied) is implicit in these calculations, which optimistically take 1987 as the year of resettlement and assume that coconut and other crops will be immediately available. A more realistic timetable, allowing for plans to be drawn and approved by all concerned, contracts let, a work force assembled, and the Congressional appropriation of funds, would forsee 1987-88 as a very early date for starting the work, and 1990 as an early date for resettlement of Bikini Island. To this must be added 8 years for the coconut plantations to become significantly productive, i.e., in 1998. This 10-year delay will ensure an additional loss of 20% in cesium-137 and strontium-90 by spontaneous decay. There may also be a continual, albeit small, loss of radionuclides into the groundwater and thence into the lagoon.

In addition, the doses reported here are calculated using the average value for all of the parameters in the dose model. We have shown that the data for almost all of the parameters are log-normally distributed and, therefore, so is the final distribution of estimated doses(5). The doses calculated using the average value for the model parameters then fall between the 65-70th percentile so that about 70% of a returning population would be expected to have a dose less than or equal to the listed doses. The doses calcualated using the median value for all model parameters would fall at the midpoint of the distribution, that is 50% would be expected to have doses less than and 50% doses more than those listed. These "median" doses would be about 40% less than the doses listed here and in the LLNL report (5).

5. Dose and Soil Specific Activity

The internal dose is calculated from the amount of radionuclide ingested in food; it is thus directly proportional to radionuclide intake. How, then, does the magnitude of dose change when the specific activity of the soil changes; for example, when decontamination is carried out or when one goes from island to island?

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It is reasonable to assume for the very low levels of specific activity dealt with at Bikini Atoll that plant uptake will be directly proportional to soil concentration, and therefore, in turn, so will dietary intake and internal dose. This is substantiated by concentration ratios (pCi/g in plant/pCi/g in soil) developed by measuring the ^{137}Cs concentration in the soil in the root zone of the sampled tree. The same concentration ratio was observed on both Bikini and Eneu Islands where soil radionuclide concentrations differ by a factor of 10(5).

In planning for decontamination by removing top soil, the assumption is made that plant specific activity will be directly proportional to soil specific activity regardless of soil radionuclide concentration and soil condition. Although, there may be little reason to doubt this assumption when applied to one island, this report is recommending that the assumption be tested in the course of pilot excavation trials at Bikini during the next two years.

6. Body Burden

The best way to determine the internal dose is by calculation from a direct measurement of the body burden. When Bikini Atoll is resettled, body burden measurements will provide the most convincing and accurate estimates for public health control.

Cesium-137 body burden measurements were made on Bikini settlers in 1974, 1977, 1978, 1979 and 1980. Unfortunately, practically no dietary information accompanied them. The average body burden of cesium-137 rose quickly in 1977-78 to about 2.4 μCi in April of 1978 when coconut production became significant, and fell quickly to less than 10% of that value by May 1979(9) after the settlers left the atoll in August of 1978. The maximum permissible burden is 3 μCi, and some settlers had already exceeded it.

Theoretically, it is possible to calculate the body burden at anytime from an exact knowledge of the daily intake of cesium-137. Conversely, knowing the body burden, one can calculate the daily intake if a cesium steady-state in the body is assumed. With constant intake of ^{137}Cs, other than for reduction due to natural radiocactive decay, a steady state is reached in about 1.5 years.

If people were actually consuming less local food than assumed in the predictive model, then the predicted body burden at any time would be greater than that which is measured. This appears to be the case at Bikini Atoll in 1978 where the average adult body burden predicted by the model was 5.5 μCi and the average measured body burden was 2.4 μCi (10). This is actually a reasonable agreement because the full diet was used in the predictive model and we know the people were not on a full local diet; only coconuts were available in limited supply but other terrestrial foods such as breadfruit and Pandanus were unavailable.

At Rongelap and Utirik, where resettlement has been continuous since 1957 and 1954 respectively, where steady-state conditions are more likely, and where all local food products are available if the people choose to use them, the comparison between the model predictions and measurements of ^{137} body burden are very good indeed. At Rongelap, using the MLSC adult diet developed by LLNL, the model predictions for ^{137}Cs body burden were 0.19 μCi assuming imported foods are available and 0.42 μCi if imported foods are unavailable and the total diet consists of local foods. The average measured adult body burdens on Rongelap were 0.17 μCi(10). At Utirik Atoll the average predicted ^{137}Cs adult body burdens were 0.043 μCi when imported foods are available and 0.098 μCi when only local foods are available. The average measured body burdens for the adults was 0.053μCi(10).

Imported foods are almost always available at Rongelap and Utirik and it is hard to say what fraction of the year the people might be only on a local food diet. It can only be said that it is not very often.

The relatively good agreement between model predictions and measured body burdens indicates that the observed body burdens are predicted better by the MLSC diet, assuming imported foods are available, than by other diet models.(10,13)

7. Dose Calculation Methodology

7.1 The ^{137}Cs and ^{60}Co Methodology

Ingestion

For ^{137}Cs and ^{60}Co, the methods of the ICRP(14,15) and the National Council on Radiation Protection and Measurements (NCRP)(16) as developed by Killough and Rohwer in the INDOS code(17) are used for the dose calculations. This code is used as published; however, the output is modified to show the body burdens for each year.

The amount of ^{137}Cs ingested that is transferred to the wholebody is referred to as the gut transfer coefficient. The gut transfer coefficient for ^{137}Cs is taken to be 1.

The ^{137}Cs dose model for adults consists of two compartments with removal half-times of 2 and 110 d, with 10% of the intake going to the 2-d compartment and 90% to the 110-d compartment. These data are consistent with preliminary data obtained by BNL on the half-time of the long-term compartment in the Marshallese (18). The average results for ten Marshallese males showed a mean of 114 d (range: 76 to 178 d).

Childrens doses from ^{137}Cs are always less than those for the adults. The half-time in days of ^{137}Cs in children is determined using the relationship, $T_{1/2}$ = 1.63M, where M is the body mass in kilograms (19). The M as a function of age is determined using equations given by Spiers(20). When the Snyder and Spiers equations are combined, the physiological half-time of ^{137}Cs as a function of age can be determined. The average half-time using the above approach for ages 5 through 10 is about 42d. Data from BNL whole-body counting for 14 Marshallese children in this age bracket is 43 d. For ages 11 to 15, the Snyder-Spiers method gives an average half-time of about 70 d, while the BNL data for nine adolescents in this age bracket is 69 d (21).

Combining a constant dietary intake with radionuclide reduction only by radiological decay, a gut transfer factor of 1 for the intake of ^{137}Cs, a distribution of 90% of the intake in the 110d compartment and 10% in the 2d compartment, an exponential decay from these compartments and an effective energy of 0.59 Mev, leads to the 30-y integral dose conversion constant of 0.00045 listed in Table 6.

The relationship of these factors is given in the following equation.

$$\frac{D = E f_1 W Q(t) F}{M}$$

Where E = the effective energy of ^{137}Cs beta = 0.59 Mev.
f_1 = the gut transfer coefficient for ^{137}Cs = 1.0.
M = the body mass = 70,000 g.
W = the constant to convert pCi to g-rem/Mev=d = 51.2×10^{-6}.
Q(t) = the term for the time integration over the exponential functions representing the retention time of ^{137}Cs in the body with the parameters listed in the above text. The value for Q(t) for 30 years is = 1.04×10^{6} pCi-d/(pCi/d) intake.
F = the quality factor for beta radiation = 1.0 rem/rad

Thus

$$\frac{D = 51.2\times10^{-6} \times 0.59 \times 1.0 \times 1.04 \times 10^{6} \times 1.0 = 0.000\ 45\ \text{rem}}{7 \times 10^{4}}$$

Not only is the physiological half-time for children for ^{137}Cs shorter than that of adults but the dietary intake of ^{137}Cs is usually less (5). The net result of the more rapid turnover of ^{137}Cs in the body and the lower intake of ^{137}Cs via the diet makes the dose from ingested ^{137}Cs less for children than adults.

External Gamma

The primary external gamma exposure is from ^{137}Cs, with a very small contribution from ^{60}Co. To convert external gamma measurements in μr/h to an absorbed dose in tissue, we chose the conversion factor from exposure dose in air to absorbed dose in tissue given in the UNSCEAR report(22) that is (0.87) (0.82) = 0.71. The value of 0.87 is the conversion from exposure to absorbed dose in air and 0.82 is the conversion from absorbed dose in air to the mean absorbed dose in the body.

In ICRP Publication 21, the conversion factor for ^{137}Cs gamma rays (0.66 MeV) is 0.65 and it is 0.7 for ^{60}Co (1.17 MeV) (23). The value for the conversion factor for total body given by O'Brien and Sanna for 0.5-MeV gamma rays is 0.52; for 1 MeV the value is 0.56 (24). For the skeleton, the conversion factors are 0.49 and 0.54 for 0.5 and 1.0 MeV, respectively.

The range of possible living patterns and lifestyle scenarios can lead to a reduction by as much as a factor of 2 in the open field external gamma dose calculated as described above. Thus, a refinement for beta exposure for "shallow dose" and eyes of some 10 to 50% is not included because reductions in open field gamma doses to wholebody and bone marrow listed in this report and reference 5, 10 and 11 would generally be reduced by 50% or more depending on the scenario developed for lifestyle and living pattern.

7.2 The ^{90}Sr Methodology

The conversion factors to convert the concentration of ^{90}Sr in bone to dose to bone cells are quoted by the United Nations Scientific Committee on the Effects of Atomic Radiation[25] and are equivalent to a bone-marrow dose rate of 1.4 mrad/y per pCi ^{90}Sr/g calcium in bone and an endosteal cell dose rate of 1.8 mrad/y per pCi ^{90}Sr/g calcium in bone. They are based upon the intake of ^{90}Sr relative to the intake of calcium, the residence time of ^{90}Sr in bone and the mean effective energy of the ^{90}Sr-^{90}Y beta particles.

These conversion factors for endosteal cell and bone-marrow doses and dose rates are calculated in two steps. First, the model of Bennett(25-27) is used to correlate the ^{90}Sr concentrations in diet with that in mineral bone. Second, the dosimetric model developed by Spiers(20) is used to calculate the bone-marrow dose rate from the concentration in mineral bone.

Bennett's empirical model is developed from ^{90}Sr concentrations from world-wide fallout found in foods and autopsy bone samples from New York and San Francisco. It also includes age-dependent variations that allow us to make dose estimates for children as well as adults. An estimate of the calcium content of the normal Marshallese diet is over 0.8 g/d, which is very similar to the 0.9 g/d estimated for U.S. diets(5). Thus, the ^{90}Sr uptake and retention would be essentially the same as those developed by Bennett.

Using Spiers' model the dose rate D_o to a small, tissue- filled cavity in bone is calculated from the ^{90}Sr concentration in mineral bone. Then from geometrical considerations, the dose rates to the bone marrow D_m and endosteal cells D_s are calculated using conversion factors $D_m/D_o = 0.31$ and $D_s/D_o = 0.62$ respectively. This is equivalent to a bone marrow dose rate of 1.4 mrad/pCi-y/g Ca and an endosteal dose rate of 1.8 mrad/pCi-y/g Ca.

The above models and conversion factors are used to calculate the dose conversion constant for ^{90}Sr in Table 6.

The dose equation relating the various factors is similar to that for ^{137}Cs but it is more difficult to determine the integrated pCi-d because the ^{90}Sr model requires a numerical integration. The base parameters are:

E = the average effective energy of ^{90}Sr -^{90}Y beta particles = 1.13 Mev and is included in the W term defined below.

f_1 = the gut transfer factor = 0.3 for 30 years.

W = the conversion factor from pCi of ^{90}Sr in bone to the rad dose in bone marrow $= 1.4 \dfrac{\text{mrad}}{\frac{\text{pCi-y}}{\text{g Ca}}} = 1.4 \times 10^{-3} \dfrac{\text{rad}}{\frac{\text{pCi-y}}{\text{g Ca}}}$

Z = the ratio of bone mass to calcium mass = 5g bone/g Ca.

Q = the term for the time integration representing the retention of ^{90}Sr in the bone $= 7.9 \times 10^3 \dfrac{\text{pCi-y}}{(\text{pCi/d})\text{ Intake}}$

M = the mass of mineral bone = 5000 g

F = the quality factor for beta particles $= 1.0 \dfrac{\text{rem}}{\text{rad}}$

Thus $D = \frac{f_1 WZQF}{M}$

$$D = \frac{0.3 \times 1.4 \times 10^{-3} \times 5 \times 7.9 \times 10^{3} \times 1.0}{5000}$$

$$D = 3.3 \times 10^{-3} \text{ rem} = 0.003 \frac{\text{rem}}{(\text{pCi/d}) \text{ Intake}}$$

The ^{90}Sr dose calculated for children from 1 thru 30 years of age is very similiar to, but a bit less than, the integral 30 year dose calcualted for adults. Because bone marrow is considered a blood-forming organ (annual dose limit equals 500 mrem/y) and endosteal cells are in the other organ category (annual dose limit equals 1500 mrem/y), the bone marrow is the more sensitive organ in bone for ^{90}Sr(29).

7.3 Transuranic Radionuclides Methodology

The inhalation model used for the various isotopes of plutonium and for ^{241}Am is that of the ICRP Task Group(29,30). Parameters for the lung model are also those of the ICRP. Both ^{241}Am and plutonium are assumed to be class-W compounds.

For the ingestion pathway, the gut transfer coefficients are 10^{-4} for plutonium and 5×10^{-4} for ^{241}Am(31). The critical organs are bone and liver with a biological half-life of 100 y in bone and 40 y in liver. Of the plutonium and ^{241}Am transferred to blood, 45% is assumed to reach the bone and 45% is assumed to reach the liver. The remaining 10% is distributed among other organs. A quality factor of 20 is used for both Am and Pu in all dose calculations.

The $^{239+240}$Pu dose to bone marrow and endosteal cells is calculated by Spiers' method in a manner analagous to ^{90}Sr(20,32,33). First, a dose to bone mass D_B is determined based on the concentration in pCi/g. Second, the ratios D_m/D_B and D_S/D_B are applied to find the specific doses to the tissues of interest. The D_B is related to D_o by

$$D_B = \frac{D_o}{(S_T/S_B)},$$

where S_T and S_B are the stopping powers for tissue and bone respectively.

S_T/S_B = 1.225
D_B = 0.2636 (mrad/d • pCi • g)
D_m/D_B = 0.26
D_S/D_B = 3.11

Thus, the ratio for endosteal cell dose to bone marrow dose is 3.11/0.26 = 12. The conversion for red marrow for Pu from Spiers approach is 338 rem/μCi-y where the Pu is distributed in a 5Kg bone mass and the quality factor is 20. Thus the conversion for endosteal cells (surface cells) is 4056 rem/μCi-y. The integral 30-y dose conversion factor listed in Table 6 is developed from the above models, parameters and conversion factors.

The conversion from intake to dose is essentially the same relationship described for ^{137}Cs. The differences are in the parameters and these are:

F_1 = the gut transfer factor for $^{239+240}$Pu $= 10^{-4}$ and for ^{241}Am $= 5 \times 10^{-4}$.
F_2 = the fraction transferred across the gut that goes to bone = 0.45 for Pu and Am.
W = the constant to convert pCi in bone to the rad dose in bone marrow = $4.63 \times 10^{-8} \frac{\text{rad}}{(\text{pCi-d})}$ for Pu and 4.80×10^{-8} rad/pCi-d for Am. This number is converted from Spiers conversion factor of 16.9 $\frac{\text{rad}}{\text{uCi-Y}}$ which is based on 5000 g of mineral bone and alpha energies for $^{239+240}$Pu and ^{241}Am of 5.4 Mev and 5.6 Mev respectively.
Q(t) = the term for the time integration over the exponential function representing the retention time of Pu and Am in bone with the parameters listed in the above text. The values for Q(t) for 30 years for $^{239+240}$Pu $= 5.61 \times 10^7$ (pCi/d)/(pCi/d) Intake and for

^{241}Am $= 5.52 \times 10^7 \frac{(\text{pCi-d})}{(\text{pCi/d})}$ Intake.
F = the quality factor for alpha radiation = 20 $\frac{\text{rem}}{\text{rad}}$

Thus for Pu,
$D = f_1 f_2 WQF$
$D = 10^{-4} \times 0.45 \times 4.63 \times 10^{-8} \times 5.61 \times 10^7 \times 20 = 0.0024 \frac{\text{rem}}{(\text{pCi/d})}$ Intake

and for Am,
$D = 5 \times 10^4 \times 0.45 \times 4.80 \times 10^{-8} \times 5.52 \times 10^7 \times 20 = 0.012 \frac{\text{rem}}{(\text{pCi/d})}$ Intake

Table D.2.A

BIKINI (HOW)

SEX: MALE AGE RANGE: 18-80 DIET CONDITIONS: IMPORTS AVAILABLE

ALL LOCAL FOODS FROM BIKINI (HOW)

INITIAL DIET RADIONUCLIDE INTAKE

YEAR 1

	FOOD ITEM	INTAKE (G/DAY)	CS137 (PCI/DAY)	SR90 (PCI/DAY)	PU239+240 (PCI/DAY)	AM241 (PCI/DAY)	PCT	ISLAND
1	REEF FISH	20.60	3.296E+00	4.120E-02	7.828E-03	3.914E-03	100	LAGOON
2	TUNA	15.76	2.206E+00	3.152E-02	5.989E-03	2.994E-03	100	LAGOON
3	MAHI MAHI	5.13	7.179E-01	1.026E-02	1.949E-03	9.743E-04	100	LAGOON
11	MARINE CRABS	1.01	5.050E-03	5.050E-03	1.717E-03	8.585E-04	100	LAGOON
12	LOBSTER	4.85	2.621E-01	2.427E-02	8.250E-03	4.125E-03	100	LAGOON
21	CLAMS	4.66	5.127E-02	2.797E-02	6.525E-03	3.263E-03	100	LAGOON
22	TROCHUS	0.48	5.247E-03	2.862E-03	6.678E-04	3.339E-04	100	LAGOON
23	TRIDACNA MUSCLE	1.76	1.932E-02	1.054E-02	2.458E-03	1.229E-03	100	LAGOON
25	JEDRUL	1.68	1.849E-02	1.009E-02	2.353E-03	1.177E-03	100	LAGOON
31	COCONUT CRABS	3.10	1.490E+02	2.735E+01	2.111E-02	1.055E-02	100	BIKINI (HOW)
32	LAND CRABS	0.25	1.207E+01	2.215E+00	1.710E-03	8.548E-04	100	BIKINI (HOW)
40	OCTOPUS	2.56	2.254E-01	1.280E-02	1.024E-03	5.122E-04	100	LAGOON
50	TURTLE	3.67	9.539E-02	2.788E-01	4.770E-04	2.385E-03	100	LAGOON
61	CHICKEN MUSCLE	5.03	3.471E+01	2.868E-01	0.	0.	100	BIKINI (HOW)
62	CHICKEN LIVER	1.77	1.223E+01	1.010E-01	0.	0.	100	BIKINI (HOW)
64	PORK MUSCLE	7.76	1.800E+03	1.342E+01	0.	0.	100	BIKINI (HOW)
66	PORK LIVER	4.14	3.892E+02	2.774E+00	0.	0.	100	BIKINI (HOW)
71	BIRD MUSCLE	6.07	3.337E-01	2.427E-01	7.888E-04	3.944E-04	100	BIKINI (HOW)
72	BIRD VISCERA	2.71	1.085E+00	1.085E-01	0.	0.	100	BIKINI (HOW)
81	BIRD EGGS	3.74	1.235E-01	6.734E-02	4.863E-04	2.432E-04	100	BIKINI (HOW)
82	CHICKEN EGGS	3.17	2.186E+01	1.806E-01	0.	0.	100	BIKINI (HOW)
83	TURTLE EGGS	2.15	7.082E-02	3.863E-02	2.790E-04	1.395E-04	100	LAGOON
91	PANDANUS FRUIT	2.53	5.035E+02	2.404E+01	3.795E-04	5.313E-04	100	BIKINI (HOW)
92	PANDANUS NUTS	0.16	3.132E+01	1.495E+00	2.361E-05	3.305E-05	100	BIKINI (HOW)
100	BREADFRUIT	12.80	2.765E+02	5.555E+01	1.037E-03	7.296E-04	100	BIKINI (HOW)
111	COCONUT FLUID	63.65	5.410E+03	1.241E+00	3.883E-04	3.437E-04	100	BIKINI (HOW)
112	COCONUT MILK	35.22	8.382E+03	7.746E+00	3.874E-03	8.453E-04	100	BIKINI (HOW)
113	TUBA/JEKERO	0.71	1.194E+02	1.555E-01	7.774E-05	1.696E-05	100	BIKINI (HOW)
121	DRINKING COCO MEAT	9.98	1.927E+03	2.196E+00	1.098E-03	2.396E-04	100	BIKINI (HOW)
122	COPRA MEAT	6.31	1.501E+03	1.387E+00	6.935E-04	1.513E-04	100	BIKINI (HOW)
123	SPROUTING COCONUT	2.99	7.782E+02	6.585E-01	3.292E-04	7.183E-05	100	BIKINI (HOW)
124	MARSHALLESE CAKE	13.22	3.146E+03	2.908E+00	1.454E-03	3.173E-04	100	BIKINI (HOW)
130	PAPAYA	1.63	1.600E+02	3.103E+00	1.257E-04	1.600E-04	100	BIKINI (HOW)
150	PUMPKIN	0.17	3.874E+01	3.191E-01	2.268E-05	1.725E-05	100	BIKINI (HOW)
201	RAINWATER	358.90	6.819E-01	2.189E-01	2.261E-03	1.148E-03	100	BIKINI (HOW)
202	WELLWATER	213.20	9.168E+01	2.558E+01	9.594E-03	4.690E-03	100	BIKINI (HOW)
203	MALOLO	132.20	2.512E-01	8.064E-02	8.329E-04	4.230E-04	100	BIKINI (HOW)
204	COFFEE/TEA	275.40	5.233E-01	1.680E-01	1.735E-03	8.813E-04	100	BIKINI (HOW)
	TOTAL =	1231.11	2.479E+04	1.741E+02	8.754E-02	4.455E-02		

TABLE D.2.B

BIKINI (HOW)

SEX: MALE AGE RANGE: 18-80 DIET CONDITIONS: IMPORTS UNAVAILABLE

ALL LOCAL FOODS FROM BIKINI (HOW)

INITIAL DIET RADIONUCLIDE INTAKE

YEAR 1

FOOD ITEM	INTAKE (G/DAY)	CS137 (PCI/DAY)	SR90 (PCI/DAY)	PU239+240 (PCI/DAY)	AM241 (PCI/DAY)	PCT	ISLAND
1 REEF FISH	40.95	6.552E+00	8.190E-02	1.556E-02	7.781E-03	100	LAGOON
2 TUNA	34.73	4.862E+00	6.946E-02	1.320E-02	6.599E-03	100	LAGOON
3 MAHI MAHI	13.62	1.907E+00	2.724E-02	5.176E-03	2.588E-03	100	LAGOON
11 MARINE CRABS	2.59	1.293E-02	1.293E-02	4.396E-03	2.198E-03	100	LAGOON
12 LOBSTER	25.06	1.354E+00	1.254E-01	4.264E-02	2.132E-02	100	LAGOON
21 CLAMS	32.94	3.623E-01	1.976E-01	4.612E-02	2.306E-02	100	LAGOON
22 TROCHUS	1.00	1.102E-02	6.012E-03	1.403E-03	7.014E-04	100	LAGOON
23 TRIDACNA MUSCLE	8.59	9.448E-02	5.153E-02	1.202E-02	6.012E-03	100	LAGOON
25 JEDRUL	8.53	9.383E-02	5.118E-02	1.194E-02	5.971E-03	100	LAGOON
31 COCONUT CRABS	8.42	4.040E+02	7.414E+01	5.723E-02	2.861E-02	100	BIKINI (HOW)
32 LAND CRABS	5.64	2.708E+02	4.970E+01	3.836E-02	1.916E-02	100	BIKINI (HOW)
40 OCTOPUS	12.10	1.065E+00	6.050E-02	4.840E-03	2.420E-03	100	LAGOON
50 TURTLE	7.58	1.972E-01	5.764E-01	9.859E-04	4.930E-03	100	LAGOON
61 CHICKEN MUSCLE	9.94	6.861E+01	5.668E-01	0.	0.	100	BIKINI (HOW)
62 CHICKEN LIVER	3.90	2.690E+01	2.222E-01	0.	0.	100	BIKINI (HOW)
63 CHICKEN GIZZARD	10.58	7.300E+01	6.031E-01	0.	0.	100	BIKINI (HOW)
64 PORK MUSCLE	12.37	2.870E+03	2.140E+01	0.	0.	100	BIKINI (HOW)
66 PORK LIVER	5.63	5.291E+02	3.771E+00	0.	0.	100	BIKINI (HOW)
71 BIRD MUSCLE	17.18	9.449E-01	6.872E-01	2.233E-03	1.117E-03	100	BIKINI (HOW)
72 BIRD VISCERA	8.25	3.299E+00	3.299E-01	0.	0.	100	BIKINI (HOW)
81 BIRD EGGS	8.26	2.726E-01	1.487E-01	1.074E-03	5.370E-04	100	BIKINI (HOW)
32 CHICKEN EGGS	6.06	4.183E+01	3.456E-01	0.	0.	100	BIKINI (HOW)
83 TURTLE EGGS	2.24	7.395E-02	4.034E-02	2.913E-04	1.457E-04	100	LAGOON
91 PANDANUS FRUIT	27.21	5.415E+03	2.585E+02	4.032E-03	5.714E-03	100	BIKINI (HOW)
92 PANDANUS NUTS	0.64	1.278E+02	6.101E+00	9.633E-05	1.349E-04	100	BIKINI (HOW)
100 BREADFRUIT	57.57	1.244E+03	2.499E+02	4.663E-03	3.281E-03	100	BIKINI (HOW)
111 COCONUT FLUID	130.80	1.112E+04	2.551E+00	7.979E-04	7.063E-04	100	BIKINI (HOW)
112 COCONUT MILK	37.18	8.849E+03	8.180E+00	4.090E-03	8.923E-04	100	BIKINI (HOW)
113 TUBA/JEKERO	0.71	1.194E+02	1.555E-01	7.774E-05	1.696E-05	100	BIKINI (HOW)
121 DRINKING COCO MEAT	59.31	1.145E+04	1.305E+01	6.524E-03	1.423E-03	100	BIKINI (HOW)
122 COPRA MEAT	33.35	7.937E+03	7.337E+00	3.669E-03	8.004E-04	100	BIKINI (HOW)
123 SPROUTING COCONUT	32.44	8.434E+03	7.137E+00	3.568E-03	7.786E-04	100	BIKINI (HOW)
130 PAPAYA	6.78	6.641E+02	1.288E+01	5.218E-04	6.641E-04	100	BIKINI (HOW)
150 PUMPKIN	0.70	1.612E+02	1.327E+00	9.435E-05	7.176E-05	100	BIKINI (HOW)
201 RAINWATER	347.90	6.610E-01	2.122E-01	2.192E-03	1.113E-03	100	BIKINI (HOW)
202 WELLWATER	217.50	9.353E+01	2.610E+01	9.788E-03	4.785E-03	100	BIKINI (HOW)
204 COFFEE/TEA	5.07	9.635E-03	3.093E-03	3.195E-05	1.623E-05	100	BIKINI (HOW)
TOTAL =	1243.34	5.992E+04	7.466E+02	2.977E-01	1.536E-01		

TABLE D.2.C.

BIKINI (HOW)

SEX: FEMALE   AGE RANGE: 18-78   DIET CONDITIONS: IMPORTS AVAILABLE

ALL LOCAL FOODS FROM BIKINI (HOW)

INITIAL DIET RADIONUCLIDE INTAKE

YEAR 1

	FOOD ITEM	INTAKE (G/DAY)	CS137 (PCI/DAY)	SR90 (PCI/DAY)	PU239+240 (PCI/DAY)	AM241 (PCI/DAY)	PCT	ISLAND
1	REEF FISH	24.17	3.867E+00	4.834E-02	9.185E-03	4.592E-03	100	LAGOON
2	TUNA	13.85	1.939E+00	2.770E-02	5.263E-03	2.632E-03	100	LAGOON
3	MAHI MAHI	3.56	4.985E-01	7.122E-03	1.353E-03	6.766E-04	100	LAGOON
11	MARINE CRABS	1.68	8.420E-03	8.420E-03	2.863E-03	1.431E-03	100	LAGOON
12	LOBSTER	3.88	2.094E-01	1.938E-02	6.591E-03	3.295E-03	100	LAGOON
21	CLAMS	4.56	5.018E-02	2.737E-02	6.387E-03	3.193E-03	100	LAGOON
22	TROCHUS	0.10	1.151E-03	6.276E-04	1.464E-04	7.322E-05	100	LAGOON
23	TRIDACNA MUSCLE	1.67	1.833E-02	9.996E-03	2.332E-03	1.166E-03	100	LAGOON
25	JEDRUL	3.08	3.388E-02	1.848E-02	4.312E-03	2.156E-03	100	LAGOON
31	COCONUT CRABS	3.13	1.503E+02	2.759E+01	2.130E-02	1.065E-02	100	BIKINI (HOW)
40	OCTOPUS	4.51	3.968E-01	2.255E-02	1.804E-03	9.018E-04	100	LAGOON
50	TURTLE	4.34	1.128E-01	3.296E-01	5.638E-04	2.819E-03	100	LAGOON
61	CHICKEN MUSCLE	8.36	5.766E+01	4.763E-01	0.	0.	100	BIKINI (HOW)
62	CHICKEN LIVER	4.50	3.102E+01	2.562E-01	0.	0.	100	BIKINI (HOW)
63	CHICKEN GIZZARD	1.66	1.146E+01	9.468E-02	0.	0.	100	BIKINI (HOW)
64	PORK MUSCLE	5.67	1.316E+03	9.811E+00	0.	0.	100	BIKINI (HOW)
66	PORK LIVER	2.60	2.447E+02	1.744E+00	0.	0.	100	BIKINI (HOW)
67	PORK HEART	10.58	1.301E+03	1.100E+01	0.	0.	100	BIKINI (HOW)
71	BIRD MUSCLE	2.71	1.488E-01	1.082E-01	3.518E-04	1.759E-04	100	BIKINI (HOW)
72	BIRD VISCERA	1.56	6.236E-01	6.236E-02	0.	0.	100	BIKINI (HOW)
81	BIRD EGGS	1.54	5.065E-02	2.763E-02	1.996E-04	9.978E-05	100	BIKINI (HOW)
82	CHICKEN EGGS	7.25	5.003E+01	4.133E-01	0.	0.	100	BIKINI (HOW)
83	TURTLE EGGS	9.36	3.069E-01	1.685E-01	1.217E-03	6.084E-04	100	LAGOON
91	PANDANUS FRUIT	8.66	1.724E+03	8.229E+01	1.299E-03	1.819E-03	100	BIKINI (HOW)
92	PANDANUS NUTS	0.50	9.884E+01	4.719E+00	7.451E-05	1.043E-04	100	BIKINI (HOW)
100	BREADFRUIT	27.16	5.867E+02	1.179E+02	2.200E-03	1.548E-03	100	BIKINI (HOW)
111	COCONUT FLUID	99.05	8.419E+03	1.931E+00	6.042E-04	5.349E-04	100	BIKINI (HOW)
112	COCONUT MILK	51.86	1.234E+04	1.141E+01	5.705E-03	1.245E-03	100	BIKINI (HOW)
121	DRINKING COCO MEAT	31.70	6.118E+03	6.974E+00	3.487E-03	7.608E-04	100	BIKINI (HOW)
122	COPRA MEAT	12.15	2.892E+03	2.673E+00	1.337E-03	2.916E-04	100	BIKINI (HOW)
123	SPROUTING COCONUT	7.79	2.025E+03	1.713E+00	8.566E-04	1.869E-04	100	BIKINI (HOW)
124	MARSHALLESE CAKE	11.66	2.775E+03	2.565E+00	1.283E-03	2.798E-04	100	BIKINI (HOW)
130	PAPAYA	6.59	6.458E+02	1.252E+01	5.074E-04	6.458E-04	100	BIKINI (HOW)
150	PUMPKIN	1.24	2.851E+02	2.348E+00	1.669E-04	1.269E-04	100	BIKINI (HOW)
160	BANANA	0.02	1.695E-01	1.385E-02	3.367E-06	1.280E-06	100	BIKINI (HOW)
201	RAINWATER	313.20	5.951E-01	1.911E-01	1.973E-03	1.002E-03	100	BIKINI (HOW)
202	WELLWATER	206.70	8.888E+01	2.480E+01	9.302E-03	4.547E-03	100	BIKINI (HOW)
203	MALOLO	199.30	3.787E-01	1.216E-01	1.256E-03	6.378E-04	100	BIKINI (HOW)
204	COFFEE/TEA	227.90	4.330E-01	1.390E-01	1.436E-03	7.293E-04	100	BIKINI (HOW)
	TOTAL =	1329.78	4.117E+04	3.246E+02	9.535E-02	4.893E-02		

TABLE D.2.D.

BIKINI (HOW)

SEX: FEMALE AGE RANGE: 18-78 DIET CONDITIONS: IMPORTS UNAVAILABLE

ALL LOCAL FOODS FROM BIKINI (HOW)

INITIAL DIET RADIONUCLIDE INTAKE

YEAR 1

	FOOD ITEM	INTAKE (G/DAY)	CS137 (PCI/DAY)	SR90 (PCI/DAY)	PU239+240 (PCI/DAY)	AM241 (PCI/DAY)	PCT	ISLAND
1	REEF FISH	43.39	6.942E+00	8.678E-02	1.649E-02	8.244E-03	100	LAGOON
2	TUNA	36.02	5.043E+00	7.204E-02	1.369E-02	6.844E-03	100	LAGOON
3	MAHI MAHI	10.70	1.498E+00	2.140E-02	4.066E-03	2.033E-03	100	LAGOON
11	MARINE CRABS	9.75	4.873E-02	4.873E-02	1.657E-02	8.284E-03	100	LAGOON
12	LOBSTER	17.61	9.509E-01	8.805E-02	2.994E-02	1.497E-02	100	LAGOON
21	CLAMS	29.05	3.196E-01	1.743E-01	4.067E-02	2.033E-02	100	LAGOON
22	TROCHUS	0.12	1.305E-03	7.116E-04	1.630E-04	8.302E-05	100	LAGOON
23	TRIDACNA MUSCLE	5.72	6.290E-02	3.431E-02	8.005E-03	4.003E-03	100	LAGOON
25	JEDRUL	9.69	1.066E-01	5.815E-02	1.357E-02	6.764E-03	100	LAGOON
31	COCONUT CRABS	12.47	5.986E+02	1.099E+02	8.480E-02	4.240E-02	100	BIKINI (HOW)
40	OCTOPUS	24.51	2.157E+00	1.225E-01	9.804E-03	4.902E-03	100	LAGOON
50	TURTLE	8.88	2.309E-01	6.750E-01	1.155E-03	5.773E-03	100	LAGOON
61	CHICKEN MUSCLE	15.59	1.076E+02	8.886E-01	0.	0.	100	BIKINI (HOW)
62	CHICKEN LIVER	8.84	6.100E+01	5.039E-01	0.	0.	100	BIKINI (HOW)
63	CHICKEN GIZZARD	1.66	1.146E+01	9.468E-02	0.	0.	100	BIKINI (HOW)
64	PORK MUSCLE	6.96	1.615E+03	1.204E+01	0.	0.	100	BIKINI (HOW)
66	PORK LIVER	3.35	3.150E+02	2.245E+00	0.	0.	100	BIKINI (HOW)
67	PORK HEART	10.58	1.301E+03	1.100E+01	0.	0.	100	BIKINI (HOW)
71	BIRD MUSCLE	13.19	7.255E-01	5.276E-01	1.715E-03	8.573E-04	100	BIKINI (HOW)
72	BIRD VISCERA	4.65	1.860E+00	1.860E-01	0.	0.	100	BIKINI (HOW)
81	BIRD EGGS	11.38	3.755E-01	2.048E-01	1.479E-03	7.397E-04	100	BIKINI (HOW)
82	CHICKEN EGGS	20.60	1.421E+02	1.174E+00	0.	0.	100	BIKINI (HOW)
83	TURTLE EGGS	117.40	3.874E+00	2.113E+00	1.526E-02	7.631E-03	100	LAGOON
91	PANDANUS FRUIT	31.48	6.265E+03	2.991E+02	4.722E-03	6.611E-03	100	BIKINI (HOW)
92	PANDANUS NUTS	1.00	1.990E+02	9.500E+00	1.500E-04	2.100E-04	100	BIKINI (HOW)
100	BREADFRUIT	93.06	2.010E+03	4.039E+02	7.538E-03	5.304E-03	100	BIKINI (HOW)
111	COCONUT FLUID	166.50	1.415E+04	3.247E+00	1.016E-03	8.991E-04	100	BIKINI (HOW)
112	COCONUT MILK	60.91	1.450E+04	1.340E+01	6.700E-03	1.462E-03	100	BIKINI (HOW)
121	DRINKING COCO MEAT	90.36	1.744E+04	1.980E+01	9.940E-03	2.169E-03	100	BIKINI (HOW)
122	COPRA MEAT	35.65	8.485E+03	7.843E+00	3.922E-03	8.556E-04	100	BIKINI (HOW)
123	SPROUTING COCONUT	61.15	1.590E+04	1.345E+01	6.727E-03	1.468E-03	100	BIKINI (HOW)
130	PAPAYA	13.48	1.321E+03	2.561E+01	1.038E-03	1.321E-03	100	BIKINI (HOW)
150	PUMPKIN	2.72	6.269E+02	5.163E+00	3.669E-04	2.791E-04	100	BIKINI (HOW)
160	BANANA	0.29	2.458E+00	2.008E-01	4.884E-05	1.857E-05	100	BIKINI (HOW)
201	RAINWATER	314.70	5.979E-01	1.920E-01	1.983E-03	1.007E-03	100	BIKINI (HOW)
202	WELLWATER	215.20	9.254E+01	2.582E+01	9.684E-03	4.734E-03	100	BIKINI (HOW)
	TOTAL =	1508.61	8.517E+04	9.695E+02	3.112E-01	1.602E-01		

TABLE D.3.A.

ENEU (NAN)

SEX: MALE AGE RANGE: 18-80 DIET CONDITIONS: IMPORTS AVAILABLE

ALL LOCAL FOODS FROM ENEU (NAN)

INITIAL DIET RADIONUCLIDE INTAKE

YEAR 1

	FOOD ITEM	INTAKE (G/DAY)	CS137 (PCI/DAY)	SR90 (PCI/DAY)	PU239+240 (PCI/DAY)	AM241 (PCI/DAY)	PCT	ISLAND
1	REEF FISH	20.60	3.296E+00	4.120E-02	7.828E-03	3.914E-03	100	LAGOON
2	TUNA	15.76	2.206E+00	3.152E-02	5.989E-03	2.994E-03	100	LAGOON
3	MAHI MAHI	5.13	7.179E-01	1.026E-02	1.949E-03	9.743E-04	100	LAGOON
11	MARINE CRABS	1.01	5.050E-03	5.050E-03	1.717E-03	8.585E-04	100	LAGOON
12	LOBSTER	4.85	2.621E-01	2.427E-02	8.250E-03	4.125E-03	100	LAGOON
21	CLAMS	4.66	5.127E-02	2.797E-02	6.525E-03	3.263E-03	100	LAGOON
22	TROCHUS	0.48	5.247E-03	2.862E-03	6.678E-04	3.339E-04	100	LAGOON
23	TRIDACNA MUSCLE	1.76	1.932E-02	1.054E-02	2.458E-03	1.229E-03	100	LAGOON
25	JEDRUL	1.68	1.849E-02	1.009E-02	2.353E-03	1.177E-03	100	LAGOON
31	COCONUT CRABS	3.10	1.490E+02	2.735E+01	2.111E-02	1.055E-02	100	ENEU (NAN)
32	LAND CRABS	0.25	1.207E+01	2.215E+00	1.710E-03	8.548E-04	100	ENEU (NAN)
40	OCTOPUS	2.56	2.254E-01	1.280E-02	1.024E-03	5.122E-04	100	LAGOON
50	TURTLE	3.67	9.539E-02	2.788E-01	4.770E-04	2.385E-03	100	LAGOON
61	CHICKEN MUSCLE	5.03	8.553E+00	7.043E-02	0.	0.	100	ENEU (NAN)
62	CHICKEN LIVER	1.77	3.012E+00	2.481E-02	0.	0.	100	ENEU (NAN)
64	PORK MUSCLE	7.76	4.034E+02	3.336E+00	0.	0.	100	ENEU (NAN)
66	PORK LIVER	4.14	1.035E+02	8.694E-01	0.	0.	100	ENEU (NAN)
71	BIRD MUSCLE	6.07	3.337E-01	2.427E-01	2.306E-03	1.153E-03	100	ENEU (NAN)
72	BIRD VISCERA	2.71	1.085E+00	1.085E-01	0.	0.	100	ENEU (NAN)
81	BIRD EGGS	3.74	1.235E-01	6.734E-02	1.422E-03	7.108E-04	100	ENEU (NAN)
82	CHICKEN EGGS	3.17	5.386E+00	4.435E-02	0.	0.	100	ENEU (NAN)
83	TURTLE EGGS	2.15	7.082E-02	3.863E-02	2.790E-04	1.395E-04	100	LAGOON
91	PANDANUS FRUIT	2.53	3.157E+01	2.677E+00	8.268E-05	1.518E-04	100	ENEU (NAN)
92	PANDANUS NUTS	0.16	1.964E+00	1.665E-01	5.144E-06	9.444E-06	100	ENEU (NAN)
100	BREADFRUIT	12.80	2.212E+01	2.061E+00	1.459E-04	1.088E-04	100	ENEU (NAN)
111	COCONUT FLUID	63.65	6.238E+02	3.246E-01	1.069E-03	7.320E-04	100	ENEU (NAN)
112	COCONUT MILK	35.22	1.303E+03	2.219E+00	4.931E-03	3.874E-03	100	ENEU (NAN)
113	TUBA/JEKERO	0.71	1.484E+01	4.452E-02	9.894E-05	7.774E-05	100	ENEU (NAN)
121	DRINKING COCO MEAT	9.98	1.897E+02	6.289E-01	1.398E-03	1.098E-03	100	ENEU (NAN)
122	COPRA MEAT	6.31	2.333E+02	3.972E-01	8.827E-04	6.935E-04	100	ENEU (NAN)
123	SPROUTING COCONUT	2.99	1.197E+02	1.886E-01	4.130E-04	3.292E-04	100	ENEU (NAN)
124	MARSHALLESE CAKE	13.22	4.691E+02	8.329E-01	1.851E-03	1.454E-03	100	ENEU (NAN)
130	PAPAYA	1.63	2.286E+01	3.266E-01	1.404E-05	9.308E-05	100	ENEU (NAN)
150	PUMPKIN	0.17	1.429E+00	1.076E-02	1.345E-06	6.724E-07	100	ENEU (NAN)
180	ARROWROOT	2.29	2.133E+00	0.	0.	0.	100	ENEU (NAN)
201	RAINWATER	358.90	1.113E-01	8.614E-02	1.615E-03	8.255E-04	100	ENEU (NAN)
202	WELLWATER	213.20	6.609E+00	6.609E+00	1.961E-03	9.807E-04	100	ENEU (NAN)
203	MALOLO	132.20	4.098E-02	3.173E-02	5.949E-04	3.041E-04	100	ENEU (NAN)
204	COFFEE/TEA	275.40	8.537E-02	6.610E-02	1.239E-03	6.334E-04	100	ENEU (NAN)
	TOTAL =	1233.41	3.756E+03	5.149E+01	8.237E-02	4.654E-02		

TABLE D.3.B.

ENEU (NAN)

SEX: MALE AGE RANGE: 18-80 DIET CONDITIONS: IMPORTS UNAVAILABLE

ALL LOCAL FOODS FROM ENEU (NAN)

INITIAL DIET RADIONUCLIDE INTAKE

YEAR 1

	FOOD ITEM	INTAKE (G/DAY)	CS137 (PCI/DAY)	SR90 (PCI/DAY)	PU239+240 (PCI/DAY)	AM241 (PCI/DAY)	PCT	ISLAND
1	REEF FISH	40.95	6.552E+00	8.190E-02	1.556E-02	7.781E-03	100	LAGOON
2	TUNA	34.73	4.862E+00	6.946E-02	1.320E-02	6.599E-03	100	LAGOON
3	MAHI MAHI	13.62	1.907E+00	2.724E-02	5.176E-03	2.588E-03	100	LAGOON
11	MARINE CRABS	2.59	1.293E-02	1.293E-02	4.396E-03	2.198E-03	100	LAGOON
12	LOBSTER	25.08	1.354E+00	1.254E-01	4.264E-02	2.132E-02	100	LAGOON
21	CLAMS	32.94	3.623E-01	1.976E-01	4.612E-02	2.306E-02	100	LAGOON
22	TROCHUS	1.00	1.102E-02	6.012E-03	1.403E-03	7.014E-04	100	LAGOON
23	TRIDACNA MUSCLE	8.59	9.448E-02	5.153E-02	1.202E-02	6.012E-03	100	LAGOON
25	JEDRUL	8.53	9.383E-02	5.118E-02	1.194E-02	5.971E-03	100	LAGOON
31	COCONUT CRABS	8.42	4.040E+02	7.414E+01	5.723E-02	2.861E-02	100	ENEU (NAN)
32	LAND CRABS	5.64	2.708E+02	4.970E+01	3.836E-02	1.918E-02	100	ENEU (NAN)
40	OCTOPUS	12.10	1.065E+00	6.050E-02	4.840E-03	2.420E-03	100	LAGOON
50	TURTLE	7.58	1.972E-01	5.764E-01	9.859E-04	4.930E-03	100	LAGOON
61	CHICKEN MUSCLE	9.94	1.690E+01	1.392E-01	0.	0.	100	ENEU (NAN)
62	CHICKEN LIVER	3.90	6.628E+00	5.459E-02	0.	0.	100	ENEU (NAN)
63	CHICKEN GIZZARD	10.58	1.799E+01	1.481E-01	0.	0.	100	ENEU (NAN)
64	PORK MUSCLE	12.37	6.432E+02	5.319E+00	0.	0.	100	ENEU (NAN)
66	PORK LIVER	5.63	1.407E+02	1.182E+00	0.	0.	100	ENEU (NAN)
71	BIRD MUSCLE	17.18	9.449E-01	6.872E-01	6.528E-03	3.264E-03	100	ENEU (NAN)
72	BIRD VISCERA	8.25	3.299E+00	3.299E-01	0.	0.	100	ENEU (NAN)
81	BIRD EGGS	8.26	2.726E-01	1.487E-01	3.139E-03	1.570E-03	100	ENEU (NAN)
82	CHICKEN EGGS	6.06	1.031E+01	8.488E-02	0.	0.	100	ENEU (NAN)
83	TURTLE EGGS	2.24	7.395E-02	4.034E-02	2.913E-04	1.457E-04	100	LAGOON
91	PANDANUS FRUIT	27.21	3.396E+02	2.879E+01	8.892E-04	1.633E-03	100	ENEU (NAN)
92	PANDANUS NUTS	0.64	8.015E+00	6.794E-01	2.099E-05	3.853E-05	100	ENEU (NAN)
100	BREADFRUIT	57.57	9.948E+01	9.269E+00	6.563E-04	4.893E-04	100	ENEU (NAN)
111	COCONUT FLUID	130.80	1.282E+03	6.671E-01	2.197E-03	1.504E-03	100	ENEU (NAN)
112	COCONUT MILK	37.18	1.376E+03	2.342E+00	5.205E-03	4.090E-03	100	ENEU (NAN)
113	TUBA/JEKERO	0.71	1.484E+01	4.452E-02	9.894E-05	7.774E-05	100	ENEU (NAN)
121	DRINKING COCO MEAT	59.31	1.127E+03	3.737E+00	8.303E-03	6.524E-03	100	ENEU (NAN)
122	COPRA MEAT	33.35	1.234E+03	2.101E+00	4.669E-03	3.669E-03	100	ENEU (NAN)
123	SPROUTING COCONUT	32.44	1.298E+03	2.044E+00	4.542E-03	3.568E-03	100	ENEU (NAN)
130	PAPAYA	6.78	9.488E+01	1.355E+00	5.828E-05	3.863E-04	100	ENEU (NAN)
150	PUMPKIN	0.70	5.945E+00	4.476E-02	5.595E-06	2.798E-06	100	ENEU (NAN)
180	ARROWROOT	64.82	6.028E+01	0.	0.	0.	100	ENEU (NAN)
201	RAINWATER	347.90	1.078E-01	8.350E-02	1.566E-03	8.002E-04	100	ENEU (NAN)
202	WELLWATER	217.50	6.743E+00	6.743E+00	2.001E-03	1.001E-03	100	ENEU (NAN)
204	COFFEE/TEA	5.07	1.572E-03	1.217E-03	2.232E-05	1.166E-05	100	ENEU (NAN)
	TOTAL =	1308.16	8.477E+03	1.911E+02	2.941E-01	1.601E-01		

TABLE D.3.C.

ENEU (NAN)

SEX: FEMALE AGE RANGE: 18-78 DIET CONDITIONS: IMPORTS AVAILABLE

ALL LOCAL FOODS FROM ENEU (NAN)

INITIAL DIET RADIONUCLIDE INTAKE

YEAR 1

FOOD ITEM	INTAKE (G/DAY)	CS137 (PCI/DAY)	SR90 (PCI/DAY)	PU239+240 (PCI/DAY)	AM241 (PCI/DAY)	PCT	ISLAND
1 REEF FISH	24.17	3.867E+00	4.834E-02	9.185E-03	4.592E-03	100	LAGOON
2 TUNA	13.85	1.939E+00	2.770E-02	5.263E-03	2.632E-03	100	LAGOON
3 MAHI MAHI	3.56	4.985E-01	7.122E-03	1.353E-03	6.766E-04	100	LAGOON
11 MARINE CRABS	1.68	8.420E-03	8.420E-03	2.863E-03	1.431E-03	100	LAGOON
12 LOBSTER	3.88	2.094E-01	1.938E-02	6.591E-03	3.295E-03	100	LAGOON
21 CLAMS	4.56	5.018E-02	2.737E-02	6.387E-03	3.193E-03	100	LAGOON
22 TROCHUS	0.10	1.151E-03	6.276E-04	1.464E-04	7.322E-05	100	LAGOON
23 TRIDACNA MUSCLE	1.67	1.833E-02	9.996E-03	2.332E-03	1.166E-03	100	LAGOON
25 JEDRUL	3.08	3.388E-02	1.848E-02	4.312E-03	2.156E-03	100	LAGOON
31 COCONUT CRABS	3.13	1.503E+02	2.759E+01	2.130E-02	1.065E-02	100	ENEU (NAN)
40 OCTOPUS	4.51	3.968E-01	2.255E-02	1.804E-03	9.018E-04	100	LAGOON
50 TURTLE	4.34	1.128E-01	3.296E-01	5.638E-04	2.819E-03	100	LAGOON
61 CHICKEN MUSCLE	3.36	1.421E+01	1.170E-01	0.	0.	100	ENEU (NAN)
62 CHICKEN LIVER	4.50	7.642E+00	6.293E-02	0.	0.	100	ENEU (NAN)
63 CHICKEN GIZZARD	1.66	2.824E+00	2.325E-02	0.	0.	100	ENEU (NAN)
64 PORK MUSCLE	5.67	2.949E+02	2.439E+00	0.	0.	100	ENEU (NAN)
66 PORK LIVER	2.60	6.508E+01	5.466E-01	0.	0.	100	ENEU (NAN)
67 PORK HEART	10.58	3.280E+02	2.645E+00	0.	0.	100	ENEU (NAN)
71 BIRD MUSCLE	2.71	1.488E-01	1.082E-01	1.028E-03	5.141E-04	100	ENEU (NAN)
72 BIRD VISCERA	1.56	6.236E-01	6.236E-02	0.	0.	100	ENEU (NAN)
81 BIRD EGGS	1.54	5.065E-02	2.763E-02	5.833E-04	2.917E-04	100	ENEU (NAN)
82 CHICKEN EGGS	7.25	1.233E+01	1.015E-01	0.	0.	100	ENEU (NAN)
83 TURTLE EGGS	9.36	3.089E-01	1.685E-01	1.217E-03	6.084E-04	100	LAGOON
91 PANDANUS FRUIT	8.66	1.081E+02	9.164E+00	2.831E-04	5.197E-04	100	ENEU (NAN)
92 PANDANUS NUTS	0.50	6.199E+00	5.255E-01	1.623E-05	2.980E-05	100	ENEU (NAN)
100 BREADFRUIT	27.16	4.693E+01	4.373E+00	3.096E-04	2.309E-04	100	ENEU (NAN)
111 COCONUT FLUID	99.05	9.707E+02	5.052E-01	1.664E-03	1.139E-03	100	ENEU (NAN)
112 COCONUT MILK	51.86	1.919E+03	3.267E+00	7.260E-03	5.705E-03	100	ENEU (NAN)
121 DRINKING COCO MEAT	31.70	6.023E+02	1.997E+00	4.438E-03	3.437E-03	100	ENEU (NAN)
122 COPRA MEAT	12.15	4.496E+02	7.655E-01	1.701E-03	1.337E-03	100	ENEU (NAN)
123 SPROUTING COCONUT	7.79	3.115E+02	4.906E-01	1.090E-03	8.566E-04	100	ENEU (NAN)
124 MARSHALLESE CAKE	11.66	4.314E+02	7.346E-01	1.632E-03	1.283E-03	100	ENEU (NAN)
130 PAPAYA	6.59	9.226E+01	1.318E+00	5.667E-05	3.756E-04	100	ENEU (NAN)
150 PUMPKIN	1.24	1.051E+01	7.917E-02	9.896E-06	4.948E-06	100	ENEU (NAN)
160 BANANA	0.02	1.699E-02	4.363E-04	3.604E-07	1.186E-07	100	ENEU (NAN)
180 ARROWROOT	3.93	3.659E+00	0.	0.	0.	100	ENEU (NAN)
201 RAINWATER	313.20	9.709E-02	7.517E-02	1.409E-03	7.204E-04	100	ENEU (NAN)
202 WELLWATER	206.70	6.408E+00	6.408E+00	1.902E-03	9.508E-04	100	ENEU (NAN)
203 MALOLO	199.30	6.178E-02	4.783E-02	8.968E-04	4.584E-04	100	ENEU (NAN)
204 COFFEE/TEA	227.90	7.065E-02	5.470E-02	1.026E-03	5.242E-04	100	ENEU (NAN)
TOTAL =	1333.72	5.842E+03	6.422E+01	8.862E-02	5.262E-02		

TABLE D.3.D.

ENEU (NAN)

SEX: FEMALE AGE RANGE: 18-78 DIET CONDITIONS: IMPORTS UNAVAILABLE

ALL LOCAL FOODS FROM ENEU (NAN)

INITIAL DIET RADIONUCLIDE INTAKE

YEAR 1

	FOOD ITEM	INTAKE (G/DAY)	CS137 (PCI/DAY)	SR90 (PCI/DAY)	PU239+240 (PCI/DAY)	AM241 (PCI/DAY)	PCT	ISLAND
1	REEF FISH	43.39	6.942E+00	8.678E-02	1.649E-02	8.244E-03	100	LAGOON
2	TUNA	36.02	5.043E+00	7.204E-02	1.369E-02	6.844E-03	100	LAGOON
3	MAHI MAHI	10.70	1.498E+00	2.140E-02	4.066E-03	2.033E-03	100	LAGOON
11	MARINE CRABS	9.75	4.873E-02	4.873E-02	1.657E-02	8.284E-03	100	LAGOON
12	LOBSTER	17.61	9.509E-01	8.805E-02	2.994E-02	1.497E-02	100	LAGOON
21	CLAMS	29.05	3.196E-01	1.743E-01	4.067E-02	2.033E-02	100	LAGOON
22	TROCHUS	0.12	1.305E-03	7.116E-04	1.660E-04	8.302E-05	100	LAGOON
23	TRIDACNA MUSCLE	5.72	6.290E-02	3.431E-02	8.005E-03	4.003E-03	100	LAGOON
25	JEDRUL	9.69	1.066E-01	5.815E-02	1.357E-02	6.784E-03	100	LAGOON
31	COCONUT CRABS	12.47	5.986E+02	1.099E+02	8.480E-02	4.240E-02	100	ENEU (NAN)
40	OCTOPUS	24.51	2.157E+00	1.225E-01	9.804E-03	4.902E-03	100	LAGOON
50	TURTLE	8.88	2.309E-01	6.750E-01	1.155E-03	5.773E-03	100	LAGOON
61	CHICKEN MUSCLE	15.59	2.650E+01	2.183E-01	0.	0.	100	ENEU (NAN)
62	CHICKEN LIVER	8.84	1.503E+01	1.238E-01	0.	0.	100	ENEU (NAN)
63	CHICKEN GIZZARD	1.66	2.824E+00	2.325E-02	0.	0.	100	ENEU (NAN)
64	PORK MUSCLE	6.96	3.620E+02	2.994E+00	0.	0.	100	ENEU (NAN)
66	PORK LIVER	3.35	8.378E+01	7.037E-01	0.	0.	100	ENEU (NAN)
67	PORK HEART	10.58	3.260E+02	2.645E+00	0.	0.	100	ENEU (NAN)
71	BIRD MUSCLE	13.19	7.255E-01	5.276E-01	5.012E-03	2.506E-03	100	ENEU (NAN)
72	BIRD VISCERA	4.65	1.860E+00	1.860E-01	0.	0.	100	ENEU (NAN)
81	BIRD EGGS	11.38	3.755E-01	2.048E-01	4.324E-03	2.162E-03	100	ENEU (NAN)
82	CHICKEN EGGS	20.60	3.502E+01	2.884E-01	0.	0.	100	ENEU (NAN)
83	TURTLE EGGS	117.40	3.874E+00	2.113E+00	1.526E-02	7.631E-03	100	LAGOON
91	PANDANUS FRUIT	31.48	3.929E+02	3.331E+01	1.029E-03	1.889E-03	100	ENEU (NAN)
92	PANDANUS NUTS	1.00	1.248E+01	1.058E+00	3.268E-05	6.000E-05	100	ENEU (NAN)
100	BREADFRUIT	93.06	1.608E+02	1.498E+01	1.061E-03	7.910E-04	100	ENEU (NAN)
111	COCONUT FLUID	166.50	1.632E+03	8.491E-01	2.797E-03	1.915E-03	100	ENEU (NAN)
112	COCONUT MILK	60.91	2.254E+03	3.837E+00	8.527E-03	6.700E-03	100	ENEU (NAN)
121	DRINKING COCO MEAT	90.36	1.717E+03	5.693E+00	1.265E-02	9.940E-03	100	ENEU (NAN)
122	COPRA MEAT	35.65	1.319E+03	2.246E+00	4.991E-03	3.922E-03	100	ENEU (NAN)
123	SPROUTING COCONUT	61.15	2.446E+03	3.852E+00	8.561E-03	6.727E-03	100	ENEU (NAN)
130	PAPAYA	13.48	1.887E+02	2.696E+00	1.159E-04	7.684E-04	100	ENEU (NAN)
150	PUMPKIN	2.72	2.312E+01	1.741E-01	2.176E-05	1.038E-05	100	ENEU (NAN)
160	BANANA	0.29	2.465E-01	6.328E-03	5.228E-06	1.720E-06	100	ENEU (NAN)
180	ARROWROOT	47.44	4.412E+01	0.	0.	0.	100	ENEU (NAN)
201	RAINWATER	314.70	9.756E-02	7.553E-02	1.416E-03	7.238E-04	100	ENEU (NAN)
202	WELLWATER	215.20	6.671E+00	6.671E+00	1.960E-03	9.899E-04	100	ENEU (NAN)
	TOTAL =	1556.05	1.167E+04	1.967E+02	3.067E-01	1.714E-01		

Table D.4 Physiological Factors in Dosimetry

	Factor (adult)			
		Physiological half-life[a]		
Radionuclide	Fraction absorbed from gut	whole-body (days)	bone (years)	liver (years)
Cesium-137[b]	1	110 (90%)[c] 2 (10%)	--	--
Strontium-90[d]	0.3	--	3.2	--
Plutonium-239,240[d]	0.0001	--	100	40
Americium-241[d]	0.0005	--	100	40

[a] Time for 50% of the element to be gone as a result of excretion.

[b] Reference 16.

[c] For men 90% of the intake is in the compartment with a 110 day half-life and 10% in the compartment with a 2 day half-life. For women the long term compartment has an average half-life of 87 days.

[d] Reference 31. For children the physiological half-life is about 1/3 of this value.

Table D.5 Daily and Annual Limits on Radionuclide Oral Intake[a]

Radionuclide	Occupational Exposure		General Population
	pCi/d	Bq/y[a]	pCi/d
Cesium-137	296,000	4×10^6	9870
Strontium-90	73,000	1×10^6	2460
Americium-241	3700	5×10^4	123
Plutonium-239 Plutonium-240	14800	2×10^5	490

[a] Ref. 31 which gives the annual limit of intake (ALI) (Bq) for workers. We use 1/30th of this value for the general population average. ALI (Bq) x .074 = daily limit of intake (pCi).

Table D.6 Factors to convert initial daily intake (pCi/d) to 30-year dose (rem).[a/]

	Ingestion			Inhalation[c]		
Radionuclide	Wholebody	Bone Marrow	Liver	Lung	Bone Marrow	Liver
^{137}Cs	0.00045	0.00045	0.00045	-	-	-
^{90}Sr[d]	-	0.0031	-	-	-	-
$^{239+240}$Pu	-	0.0025[b]	0.0073[b]	17	1.4	4.1
^{241}Am	-	0.013[b]	0.039[b]	1.9	2	5.7

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[a] For adult males; when females differ significantly their factor is given in parentheses. The factors, based on Tables 1 and 4, and used by the Lawrence Livermore group, were supplied by W.L. Robison of that Laboratory. They assume a constant diet, and that the daily intake of radionuclide declines exponentially according to its half-life over the 30-year period.

[b] Based on a gut transfer coefficient of 10^{-4} for Pu and 5×10^{-4} for Am and a quality factor QF = 20(31).

[c] Based on pCi inhaled.

[d] Rem per pCi/d intake of ^{90}Sr per 0.9 g/d intake of Ca.

Table 7. ^{137}Cs daily intake based on the average of the male and female diets from the MLSC survey and the radionuclide concentrations decayed to the assumed resettlement date of 1987.[a]

	^{137}Cs Daily Intake pCi/d[b]		
	Imported and local food available	Only local food available	Planning diet
Eneu	6,802	14,280	8,700
Bikini	46,748	102,833	61,000

[a] Results are based on Tables 2A, 2B, 3A and 3B and are derived from the main report and Appendix A of reference 5.

[b] The daily intake of radionuclides was multiplied by 1.75 to obtain the numbers in this table. As described in the text the factor of 1.75 was arbitrarily applied to obtain a measure of conservatism.

Table 8. 30-year cumulative planning doses for resettlement (1987-2016).[a]

Island	Internal Dose (cesium-137)[b] Imported and local food available (rem)	Only local food (rem)	Planning diet[c] (rem)	External dose (rem)	Total planning dose[d] (rem)
Eneu	3.0	6.8	3.9	0.27	4.2
Bikini	20.4	48	27	3.5	31

[a] The internal doses are 1.75 times (see text) those used by the Lawrence Livermore group(5) because the daily intake of radionuclides listed in tables are based on Tables 2A, 2B, 3A, and 3B were multiplied by 1.75 to generate the numbers in Table 7 (corrected to 1987 from 1978). They are equal to 0.000787 times the pCi/d in Tables D.3 and D.4.

[b] The additional dose to bone marrow from strontium-90 amounts to about 7 per cent of the cesium-137 dose.

[c] Based on local food always being available and imported food being available for 9 months per year.

[d] Internal plus external dose.

APPENDIX E

ENVIRONMENTAL REPORT
FOR THE
REHABILITATION OF SOIL AT BIKINI ATOLL

by
James E. Maragos, PhD

OCTOBER 1984

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SUMMARY

This document provides a preliminary environmental evaluation of various proposed alternatives to rehabilitate soils at Bikini Atoll contaminated by nuclear weapons testing in 1946-1958. All alternatives and components of alternatives were evaluated by the Bikini Atoll Rehabilitation Committee, but three approaches are pursued in greater detail: delay of resettlement; chemical treatment of soil with potassium fertilizer; and excavation and disposal of contaminated soil. Some alternatives are still under active investigation. The main report discusses the technical feasibility, cost, advantages, and disadvantages for each of the three major approaches. This report will focus on the comparative environmental evaluation of all alternatives and incorporates the main report by reference. Table 1 lists the set of alternatives considered in detail for each major approach. The asterisks indicate those alternatives that the Committee will pursue in greater detail.

TABLE 1

MAJOR APPROACH	ALTERNATIVES
No action to rehabilitate soil (spontaneous decay of unstable cesium)	no action (of any kind) delayed resettlement resettlement with controlled diet phased or partial resettlement
No excavation of soil	chemical treatment of soil* biological extraction washing of soil topping of existing soil with new soil
Excavation and disposal of soil	extension of Bikini Island* disposal on Nam or another island disposal in a lagoon crater* open lagoon disposal open ocean disposal causeway construction soil replacement options*

At this time (Oct 1984), the combination of alternatives that will minimize environmental effects is initial early resettlement of Eneu Island (which requires no major soil cleanup) with soil cleanup actions taken later. The initial resettlement action could also lead to a more accurate estimate on the total number of Bikinians willing to resettle on Bikini Atoll. If cleanup of Bikini Island soil is required or desired at a later date, then the cleanup option with the least adverse environmental effects would be any feasible alternative not involving excavation and disposal of soil. However, these may be less desirable to the Bikinians or less effective and result in delays of several decades or more to permit subsistence use of atoll crops. If excavation and disposal of Bikini Island soil is still required or desired, then lagoon crater, Bikini Island expansion, or disposal on Nam island are

preferred over other soil disposal options. The replanting programs needed for excavation and topping alternatives would require up to a decade before all subsistence crops could be reestablished for use by the returning islanders. Addition of soil fertilizers, conditioners, or off-atoll sources of soil are preferred over dredging of lagoon sediments for a source of replacement soil. Table 2 contains a summary and checklist of the enviromental effects associated with each of the alternatives and their components plus a list of potential mitigation measures to reduce or avoid adverse effects.

THE POSSIBLE ROLE OF EXISTING FEDERAL ENVIRONMENTAL STATUTES IN THE REHABILITATION AND RESETTLEMENT OF BIKINI ATOLL.

At the present time (Oct 1984), Bikini Atoll is a part of the Trust Territory of the Pacific Islands and probably falls within the jurisdiction of many of the federal environmental laws and their associated regulations and the presidential executive orders discussed below. However, if the Compact of Free Association is ratified by Congress in its present form before or during the cleanup of the Atoll, at least some of the environmental statutes may no longer apply to the new Republic of the Marshall Islands. Furthermore, additional modification of the Compact, if any, prior to ratification may also affect additional statutes. Thus, the brief evaluation below is offered for information purposes only, and must be read in light of the above and any other uncertainties pertaining to the situation. It is not an official legal opinion.

NATIONAL ENVIRONMENTAL POLICY ACT (NEPA)

If the cleanup is accomplished by a federal agency and/or is subject to federal regulatory approval, the responsibility for preparation and coordination of environmental documentation, probably an Environmental Impact Statement (EIS), will rest with the lead federal agency. Coordination is accomplished during the active planning phase of the project. The EIS process normally requires coordination with other agencies, public notices, public meetings and hearings, supporting studies, and the preparation and revision of documents subject to public review, and responses to public concerns and comments, prior to approval of the final details of the cleanup. The EIS process usually takes a year or more to complete and the documents also contain information on the status of compliance with all other applicable environmental statutes. The lead agency then decides whether to go forward with the project and which alternative and mitigation measures to implement in a written document, the record of decision. The possibility also exists that the NEPA documentation for the Bikini cleanup would be handled as a legislative EIS (see 40 CFR 1506.8), and the "detailed statement" prepared in this manner might involve slightly different procedures during EIS coordination.

CLEAN WATER ACT

Section 402 of the Act requires an EPA permit for the discharge of pollutants into "waters of the United States," which is interpreted to include all lagoon waters and territorial waters up to the 3-mile limit as measured from the territorial baseline which is interpreted to be the outer edge of the atoll reef rim. Section 404 requires a Corps of Engineers permit for the discharge of dredged or fill materials into the same water body. Soil removed from islands may be categorized as fill material. The processing of both types of permits normally involves an evaluation of the environmental consequences of the discharges and possibly the institution of conditions or measures to reduce water quality and related ecological impacts.

TABLE 2. ALTERNATIVE METHODS TO REHABILITATE SOIL ON BIKINI ATOLL: CHECK-LIST OF THE ENVIRONMENTAL EFFECTS AND THEIR MITIGATION

A comparison and summary of the principal environmental effects of the major cleanup approaches (assigned roman numerals) and their alternate components (arabic numerals) and subcomponents (alpha characters). The effects are divided into two categories: unavoidable and avoidable, and measures to reduce or avoid adverse effects are listed afterwards. The alternatives and components are presented in descending order of environmental preference after the no-action alternative.

TYPE OF ACTION	UNAVOIDABLE ADVERSE EFFECTS	AVOIDABLE ADVERSE EFFECTS	MEASURES TO AVOID OR REDUCE ADVERSE EFFECTS
I. NO ACTION (SPONTANEOUS DECAY OF UNSTABLE CESIUM)			
1. No action (of any kind)	° Continued social, cultural and economic effects indefinitely ° this alternative is unacceptable to the Bikinians	° Lack of access to Bikini Atoll for resettlement ° Continued decentralized occupation of islanders on Kili and other less desirable sites	Assumption is made that none would be accomplished.
2. Delay resettlement	° Continued social and cultural impacts until resettlement accomplished (80 years) ° this alternative would be unacceptable to the Bikinians	Same as above	° Monetary compensation for the islanders' inconvenience ° Islanders resettle in a more desirable and centralized location in the interim
3. Allow resettlement but only control diet	° Delayed consumption of locally grown food for 80 years ° this alternative would be unpopular or unacceptable to the Bikinians	Restrictive diet and activities	Ship or fly in fresh foods on a regular basis. Enforce and monitor dietary restrictions on locally grown food
4. Phased or partial resettlement (beginning with Eneu Is.)	° May be unacceptable to the Bikinians unless the early cleanup of Bikini Island is included.	Restrictive diet and activities	Ship or fly in some fresh foods on a regular basis. Enforce and monitor dietary restrictions on locally grown food
II. NON SOIL EXCAVATION ALTERNATIVES			
5. Chemical treatment using potassium fertilizer (assumes no removal of ground cover)	Delayed consumption of locally grown food for an unspecified time period (less than 80 years)	Restrictive diet and activities Minor localized increases in marine productivity for potassium fertilizers containing nutrients	° Ship or fly in fresh foods on a regular basis. Enforce and monitor dietary restrictions on locally grown food ° Use potassium additives with reduced levels of phosphate, nitrite, nitrate or ammonium, if warranted
6. Biological Extraction	° Destroy and burn at least some vegetation ° Delayed consumption of locally grown crops for a time period not substantially less than 80 years	° Air and dust emissions from harvesting and burning of old and new vegetation that may be excessive ° Restrictive diet and activities	° Air emission controls, if warranted ° Save important existing plants or trees, if feasible ° Ship or fly in fresh food
7. Washing soil with seawater	° Temporary disruption of groundwater ° Delayed consumption of locally grown foods for a time period not substantially less than 80 years	° Destroy some vegetation ° Restrictive diet and activities	° Revegetate with desirable plants as soon as soil salinity is decreased ° Minimize removal of vegetation, especially valuable plants and trees ° Proper disposal of ash residues ° Ship or fly in fresh food

TABLE 2 - cont.

TYPE OF ACTION	UNAVOIDABLE ADVERSE EFFECTS	AVOIDABLE ADVERSE EFFECTS	MEASURES TO AVOID OR REDUCE ADVERSE EFFECTS
8. Topping existing soil with new soil (off atoll)	° Destroy and burn at least some vegetation ° Possible burial of archaeological sites ° Impacts at the site where new soil is collected	° Air emissions from burning vegetation that may be excessive ° Possible damage to unrecorded archaeological sites from heavy equipment operation ° Dredging for sources of soil (same as listed under 9.B_2)	° Air emission controls, if warranted ° Conduct archaeological study to locate and flaq sites that should be protected or relocated before topping ° Save or relocate important plants an trees ° Same as listed for dredging under 9.B_2
III. SOIL EXCAVATION ALTERNATIVES			
9. Excavation of soil (excluding disposal of excavated soil and its replacement)	° Destroy vegetation ° Destroy some archaeological and historic sites (including buildings)	° Air and dust emissions from burning and landclearing that may be excessive ° Possible destruction of valuable historic and archaeological sites	° Air emission controls, if necessar ° Replant vegetation quickly ° Study and salvage, protection or relocation of important historic and archaeological sites ° Preferential consideration of othe alternatives on islands where it feasible.
9.A. Disposal			
9.A_1. Place soil on another island (such as Nam Is.)	° Destroy or damage vegetation on recipient island ° Burial of archaeological sites, if any, on recipient island	° Dust from earthmoving and possible air emissions from burning vegetation that may be excessive ° Possible damage to significant archaeological sites ° Damage to reefs from dredging channels or accessways to recipient island (such as Nam) Shoreline erosion and washout of excess fill	° Air and dust emission controls, if necessary ° Save or relocate important trees c plants ° Replant vegetation quickly ° Survey and flaq or relocate impor archaeological sites ° Pick islands and access routes th avoid or minimizes dredging ° Proper design of fill areas using setbacks and protective berms
9.A_2. Extend seaward side of Bikini Island by filling nearshore reef flat with excavated soil protected by armor rock	° Permanent but minor loss of fish habitat from filling and remote risk of fish poisoning ° Permanent but minor loss of coral and subsistence habitat under the new landfill ° Disturbance and modification of reef flat at quarry site	° Sedimentation and turbidity on the reef flat next to ° Aquatic ecosystem damage ° Shoreline erosion and instability ° Turbidity sedimentation and ecological damage at quarry sites ° Dust and air emissions that may be excessive ° Ecological and water quality disturbance during construction ° Possible lateral migration of radionuclides causing possible contamination and restricted use of Bikini Island groundwater ° loss of a part of sandy beach	° Place armor rock and filter cloth prior to landfilling ° Locate fill land to avoid valuable habitat ° Monitor toxic algae and fish and warn islanders ° Locate fill land where wide reefs will protect it from wave action and currents ° Use armor rock of sufficient size filter cloth ° Design and locate quarries to enh fisheries ° Air and dust emission controls if needed ° Replant vegetation quickly on new land ° Impermeable liners if warranted t block migration of radionuclides ° reestablish sandy beach along se face of fill land.
9.A.3. Ocean disposal of soil	° Temporary impacts to pelagic ecosystems (primarily fish and plankton ° Disturbance or burial of deep sea benthic ecosystems ° Temporary water quality effects ° Loss of control of material	° Turbidity and sedimentation carried from disposal site to coral reefs at Bikini causing adverse effects to reefs ° Significant impact to benthic ecosystems ° Exposing food chain to additional radioactivity	° Locate disposal site away from where currents will not carry disposal plumes back to the re ° Locate disposal sites away from productive benthic ecosystems ° Bag, solidify or otherwise immo soil prior to disposal

TABLE 2 - cont.

TYPE OF ACTION	UNAVOIDABLE ADVERSE EFFECTS	AVOIDABLE ADVERSE EFFECTS	MEASURES TO AVOID OR REDUCE ADVERSE EFFECTS
9.A$_4$. Lagoon disposal of soil	° Temporary impacts to water column and benthic ecosystems ° Temporary water quality impacts and sedimentation	° Migration of turbidity and suspended sediments toward valuable ecological areas ° Disturbance or destruction of important coral and fish habitat ° Dredging access ways to potential soil disposal sites ° Exposing food chain to additional radioactivity	° Locate disposal site where currents will not carry plumes toward valuable ecosystems ° Disposal in semi-confined craters such as Bravo ° Use turbidity curtains during disposal operations ° Bag, solidify or otherwise immobilize soil prior to disposal ° Locate disposal sites away from valuable coral and fish habitat, preferably over radioactive "hot spots" ° Choose sites where dredging and filling for access is not required
9.A$_5$. Construct a causeway between Bikini & Eneu Islands	° Permanent loss of coral and subsistence fishery habitat under the causeway ° Loss and potential poisoning of fish ° Disturbance to additional reef habitat from circulation changes ° Ecological and water quality disturbance from heavy equipment operation and other construction activity ° Decreased circulation and degraded water quality in eastern Bikini lagoon ° Reduced migration of shellfish and finfish between ocean and lagoon side of causeway ° Due to high volume of armor rock requirements, loss and disturbance of reef flat habitat at quarry sites ° Causeway instability during major storms, causing additional sedimentation	° Aggravated shoreline erosion near island approaches and along causeway ° Ciguatera fish poisoning outbreaks at sites of causeway construction and quarrying ° Major turbidity and sedimentation during filling operations ° Significant blockage of circulation and stagnation in the eastern lagoon ° Significant blockage of migratory routes of aquatic species ° Loss of valuable habitat at quarry sites	° Minimize causeway width and length ° Proper design of shoreline of causeway to prevent erosion from currents (armor rock, filter cloth) ° Monitor toxic algae and fish and warn islanders if and when fish poisoning is imminent ° Place armor rock and filter cloth prior to filling operations ° Use heavy equipment that minimizes disturbance ° Select construction corridors and access points to minimize impacts ° Conduct current and model studies to estimate magnitude of impact and need for culverts and bridges ° Install many culverts and large bridge openings at regular intervals along the causeway ° Locate quarry sites away from sandy areas and valuable coral areas ° Design quarry holes to enhance fishery populations
9.B. Replacement of Soil 9.B$_1$. Off-atoll sources of soil conditioners or fertilizers	Unspecified impacts at the site where replacement soil is obtained (sites not yet identified)	° Dust emissions during tilling, mixing or placement of soil, fertilizers, or conditioners, that may be excessive ° Unspecified impacts at site where soil obtained	° Dust control measures, as needed ° Measures may be needed to control impacts once the site and techniques to collect replacement soil are identified
9.B.$_2$. Dredging lagoon sediments as a source of soil	° Turbidity and sedimentation at cutterhead end of hydraulic dredge or at clamshell/bucket dredge site ° Damage and destruction of reef or lagoon floor habitat at dredge sites ° Loss and poisoning of fish	° Turbidity and sedimentation causing significant ecological damage at discharge end of hydraulic dredge ° Significant damage or destruction of coral, fish and shellfish habitat at dredging sites ° Ciguatera fish poisoning outbreaks at dredge and discharge sites	° Convey discharge slurry into sedimentation basins on land to prevent overflow and damage to aquatic resources ° Use silt curtains at dredging site ° Locate dredging sites away from valuable coral and fish areas ° Locate dredging sites where currents will not carry plumes to valuable areas ° Monitor toxic algae and fish and warn islanders if and when fish poisoning is imminent ° Minimize replacement fill and associated dredging requirements
9.B.$_2$. Dredging lagoon sediments as a source of soil	° Turbidity and sedimentation at cutterhead end of hydraulic dredge or at clamshell/bucket dredge site ° Damage and destruction of reef or lagoon floor habitat at dredge sites ° Loss and poisoning of fish	° Turbidity and sedimentation causing significant ecological damage at discharge end of hydraulic dredge ° Significant damage or destruction of coral, fish and shellfish habitat at dredging sites ° Ciguatera fish poisoning outbreaks at dredge and discharge sites	° Convey discharge slurry into sedimentation basins on land to prevent overflow and damage to aquatic resources ° Use silt curtains at dredging site ° Locate dredging sites away from valuable coral and fish areas ° Locate dredging sites where currents will not carry plumes to valuable areas ° Monitor toxic algae and fish and warn islanders if and when fish poisoning is imminent ° Minimize replacement fill and associated dredging requirements

MARINE PROTECTION RESEARCH AND SANCTUARIES ACT (OCEAN DUMPING ACT)

Sections 102 and 103 require permits from either the EPA or the Corps for the deep ocean disposal of pollutants beyond the 3-mile limit. The Corps issues the permit for the transportation and discharge of dredged or fill materials while EPA issues permits for the discharge of other substances. EPA also must approve of the suitability of the material for disposal, usually demonstrated through laboratory bioassay toxicity tests unless the material is "clean" enough to be exempted from testing. EPA must also designate the disposal sites, a process which usually involves oceanographic baseline studies and analysis of the consequences of disposal at the proposed site.

NATIONAL HISTORIC PRESERVATION ACT

Federal actions or those subject to federal permits that may affect historic resources listed or eligible to the National Register of Historic Places require coordination with federal and territorial historic preservation agencies (Department of the Interior, Advisory Council of Historic Preservation, Trust Territory Historic Preservation Office). Sites at Bikini that may be eligible for listing include: the Atoll as a whole because of its historic role in nuclear testing, shipwrecks in the lagoon, the cemetery, sacred sites or reef areas, and unrecorded archaeological sites on the inhabited islands. If the cleanup is to affect eligible sites, usually an archaeological/historic study is performed which includes recommendations to salvage data or protect resources of significance. These recommendations are then coordinated with the preservation agencies for their views and recommendations.

ARCHAEOLOGICAL AND HISTORIC DATA PRESERVATION ACT

This act requires a federal agency to finance the recovery, protection, and preservation of significant archaeological and historic data when it determine that its construction project may cause irreparable loss or destruction of such data.

ENDANGERED SPECIES ACT

Section 7 requires that federal agencies consult with the U.S. Fish and Wildlife Service (FWS) or National Marine Fisheries Service (NMFS) for federal undertakings that may affect any listed threatened or endangered species in order to consider conservation measures to avoid jeopardy to those species. Populations of the Green Sea Turtle, a threatened species, occur at Bikini and actions that affect the nesting and feeding habitat of this species must be evaluated and coordinated with the Services. Other listed sea turtles may occur at Bikini as well, but no other listed plants or animals are likely to be found there.

FISH AND WILDLIFE COORDINATION ACT

Section 2b of the Act requires federal agencies to coordinate with the FWS and the NMFS for federal projects requiring Congressional authorization that would affect fish and wildlife resources. This also applies to projects requiring certain federal permits. Usually, the Services prepare letters or reports which evaluate the consequences of the project on fish and wildlife resources and recommend measures to mitigate the impacts.

PRESIDENTIAL EXECUTIVE ORDER 12088, FEDERAL COMPLIANCE WITH POLLUTION CONTROL STANDARDS (1978)

This order requires the head of each executive agency to take actions for the prevention, control, and abatement of environmental pollution with respect to federal facilities and activities. This directive covers toxic substances, water pollution, drinking water, air emissions, noise, solid waste, radiation, ocean dumping, pesticides, and other biocides.

MIGRATORY BIRD TREATY ACT AND MARINE MAMMAL PROTECTION ACT

Although these acts may presently apply to Bikini, none of the cleanup options will probably affect marine mammals covered by the Acts. Some alternatives (topping, excavation, transfer of soil to another islet) will result in removal of trees and shrubs and could affect some seabird nesting habitat. Coordination with the US Fish and Wildlife Service will identify measures, if any, to comply with migratory bird treaties and acts.

PRESIDENTIAL EXECUTIVE ORDER 12114, ENVIRONMENTAL EFFECTS ABROAD OF MAJOR FEDERAL ACTIONS (1979)

This order does not presently apply to Bikini which is a part of the U.S. administered Trust Territory of the Pacific Islands. However, ratification of the Compact may render the order applicable to federal actions in the Republic of the Marshall Islands. If applicable, this executive order would require the federal (executive branch) agency to comply with applicable US <u>or</u> host country environmental laws and regulations, whichever are more stringent.

CLEAN AIR ACT

Bikini Atoll (and the Trust Territory of the Pacific Islands) is not a "State" as technically defined in the Act and is therefore outside the jurisdiction of the Clean Air Act.

RESOURCE CONSERVATION AND RECOVERY ACT

Although the Act applies to the Trust Territory, none of the proposed rehabilitation options will involve the handling of hazardous wastes as defined and listed in the Act. However, any actions to remove or dispose of oil and explosives contained in the lagoon shipwrecks may require coordination with EPA and/or permits in accordance with the Act.

3. ENVIRONMENTAL SETTING AT BIKINI ATOLL

A. INTRODUCTION.

The main Committee report (1984), Appendix "A" on geology, oceanography and hydrology by Peterson and Maragos, Appendix "B" on soil and vegetation by Stone and Robison, Appendix "C" on the shipwrecks by Kubo, and Appendix "D" on dosimetry by Kohn and Robison contain considerable information on the history, geography, physiography, geology, hydrology, oceanography, soils, vegetation, and dosimetry of Bikini Atoll. Rather than duplicate most of this information, it is incorporated by reference into this environmental report, and description of the existing environment at Bikini is limited only to a brief description of the resources that would be affected by one or more of the proposed alternatives.

B. TERRESTRIAL ECOLOGY.

Birds and Sea Turtles. A number of nesting and migratory seabirds were reported on all islands, especially on the outer smaller islets in May 1984. Breeding populations of the Brown Noddy and White Tern were reported commonly on all islands. Less common were breeding populations of the Greater Frigate, seen on the larger of the outer islets with nests in taller shrubs and trees. The least common nesting seabirds included a few Red-footed Boobies principally on the larger southern islets, Brown Boobies on Enidrik, Lukoj, and Nam Islets, Red-tailed Tropic Birds on Nam, and Reef Herons in bunkers and abandoned houses on Nam and Eneu. A few migratory ducks of unknown species were seen from a distance on the freshwater lake in the center of Lomilik Islet. The most common migratory shorebirds observed were the Ruddy Turnstone and the Bristle-thighed Curlew. The composition and population size of seabirds and shorebirds at Bikini will vary according to season, and many species not reported during the May 1984 field trip occupy the atoll at other times.

Both the Hawksbill Sea Turtle (Eretmochelys imbricata) a Federal endangered species, and the Green Sea Turtle (Chelonia mydas) Federal threatened species were reported during the field survey. Although only a few Hawksbills were seen, a great number of Green Turtles were seen, nearly in all lagoon waters surveyed. In addition, recent turtle tracks were seen on expansive white sand beaches off the west side of Enidrik and Bikini Islands, which may be evidence of turtle nesting activity. A number of the lagoon shorelines of many of the atoll islands, especially the outer islets, have thick gently sloping white sand beaches and berms potentially suitable as nesting sites. Many of the turtles in the lagoon were probably feeding on green algae. Recent evidence of turtle predation by a tiger shark off Bikini Island was reported by several of the crew of the Liktanur, a research vessel.

Vegetation. The vegetation of the islands of the atoll is dominated by indigenous species typical of many semi-arid coral islands and atolls of the Western Pacific. The degree of present vegetational development on each island is a product of recent disturbance (or its absence) from natural and man-made factors and prevailing climate. Except for Bikini, Eneu, and the southwest islets of the atoll (west of Lukoj), the abundance, diversity and vigor of the atoll's vegetation seems reduced, possibly due to recent droughts, recent damage from storm wave overwash and winds, and the residual effect of previous weapons testing and construction activity.

The small islets on the southwest side of the atoll (Lukoj, Jalete, Adrikan, Oroken, Bokaetoktok, and Bokdrolul) appear undisturbed and covered with mature healthy forests characterized by Pisonia, Messerschmidia, Pandanus, Pemphis, Cordia and Cocos. The vegetation of the islets on the southeast sector (Aerokojlol, Bikdrin, Lele, Eneman, and Enidrik) appears more disturbed and less developed. There was still residual evidence of previous construction or weapons testing there, and of recent wave and typhoon damage. The ocean reefs of these islets are also very narrow, affording these low islets little protection from storms approaching the atoll from the south. The most common species there included the shrubs Scaevola and Messerschmidia, the vine Ipomoea, and the grass Lepturus.

In contrast the vegetation of Bikini and Eneu is presently very well developed, healthy, and dominated by coconut (Cocos) groves planted during the Japanese era or the earlier atoll cleanup effort. Since the evacuation of the islanders from the islands in 1978, shrubs (especially Scaevola), vines, and weeds are beginning to take over much of the open space on both islands, including the spaces between adjacent coconut trees. A number of ornamental and cultivated species also occur primarily on Bikini Island, and the exotic legume tree (Leucaena) has spread rapidly over much of the southern half of the Bikini Island. Vegetation on the small islets between Bikini and Eneu Islands (Eonjebi, Enaelo, Iomeler, and Bokantauk) is very poorly developed or lacking altogether due to the probable instability and low elevations of these islets.

The northern islets (Aomen, Lomilik, Odrik, Iroij, and Nam) are larger and have greater vegetational development, but diversity is low (dominated by Scaevola and Messerschmidia), and mature stands of forest trees are rare and confined to Nam. The elevation of the northern islets is low and periodic inundation by waves may keep vegetation development at a low level. Two small islets referred to in the 1954 U.S. Geological Survey chart on Bikini as Bokonejien and Bokobyaadaa were destroyed, and it appears that the western end of Nam islet was also destroyed by nuclear weapons testing in the early 1950's based upon a comparison of the old chart to recent aerial photographs. The destruction of course prevented recovery of vegetation and probably postponed vegetational recovery on the rest of Nam and perhaps other islets to the north.

C. MARINE BIOLOGY.

The lagoon reefs of the atoll have been disturbed by past weapons testing and recent storm activity. No ocean reefs were surveyed due to logistical constraints and the presence of many aggressive sharks, primarily grey reef sharks. However, considerable historical information on the corals and reefs of Bikini are described in Wells (1954). The lagoon reefs and nearshore marine areas off the southern islands exhibited healthy coral and reef fish populations, except the lagoon sides of intact causeways which block water circulation from the ocean side and the sites of craters created during weapons testing. Some coral and fish recolonization has occurred in the smaller craters, but little marine life was observed in the fringes of larger craters. Thick sediment deposits and beaches have formed on the sides of some causeways built many years ago, displacing previously existing reef life.

The reefs and large craters in the vicinity of Eneman, Nam, and Aomen Islets have been heavily disturbed and show little sign of recovery or recolonization; much of the disturbance was obviously attributed to nuclear tests in the area (the George - Fox Series near the northern islets and other tests near the southern islets). Reef flats both upstream and downstream of "BRAVO" Crater and adjacent to other craters near the Aomen - Bwikor Islets show only partial coral recovery (10% coverage by Acropora, Pavona, Pocillopora and Porites), a few giant clams (Tridacna), and reduced populations of reef fishes. Furthermore, the zone of impact extends at least a mile or more on the downstream side of BRAVO Crater (to the outer ocean reef edge and limit of the survey), and no recovery of any consequence has occurred within 400 m of the craters. Some recovery of the reefs off the west side of Aomen was observed, but little healthy reef habitat was observed near Nam.

The observations made in "BRAVO" and other large bomb craters indicate virtually no coral or reef fish recovery. Coral colonization is obviously inhibited by the abundance of fine sediment and the steep unstable slopes of the crater walls (45-60°). The bottom of the craters could not be observed but were deeper than 100 feet to 150 feet. Recent observations in the lagoons of Bikini and Enewetak Atolls (Colin *et al* in press) suggest that callianassid Shrimp may be common in the bottom of the deeper Bikini craters. Reef fish populations were very reduced due to lack of food or shelter, and the few fish seen were aggregated near a few small ramose corals (*Acropora*) and beyond the upper lip of the craters. The most common alga was *Halimeda* beyond the upper lip of the craters.

The lagoon shorelines of all islands and reefs between Aomen and Bikini seemed disturbed, possibly by shifting sands or by recent high wave activity from the south. To a lesser extent the lagoon sorelines between the southern end of Bikini and southern Eneu were also disturbed, and large piles of coral rubble and shingle were noted just off the lagoon edge of the interisland reef flats between the two islands; these deposits may be accumulating from periodic heavy wave action, either from the lagoon or ocean side. Coral abundance was low except on the side of pinnacles and patch reefs offshore from the atoll reef rim or islands. Fish populations, however, were large, especially edible species of snappers, groupers, jacks, squirrelfish, and surgeonfish.

The ocean reef flats opposite Bikini and Eneu Islands and the reefs between the islands appeared to be healthy and representative of similar reefs reported at Bikini by Wells (1954) and elsewhere in the Marshalls. All these reefs show a predictable sequence of zonation; starting from the ocean reef edge the following major ecological zones were reported along all sites observed: 1) coralline algal ridge; 2) a highly productive filamentous/turf algal zone on the outer reef; 3) a mixed coral and filamentous algal zone at midreef; 4) a dead coral and thin sediment (or a scoured reef) zone at the back reef, and a thick sediment or rubble zone beyond the back edge of the reef flat. Many major groups of reef fishes were seen on the reef flats including parrotfish and surgeonfish in the front side and goatfish, rabbitfish, and mullet near the backside. In addition, subtidal beachrock formations around all the islets and islands (including Bikini and Eneu) were primarily sites for schools of surgeonfish, goatfish, rabbitfish, mullet, and sea perch, and suitable for easy capture by thrownet at low tide. Giant clams and oysters were also common on some of the interisland reef flats. The most common reef corals on the flats included *Palythoa*, *Pocillopora*, *Montipora*, and *Acropora* in the front wave washed zones, and the brain coral *Favia* and microatolls of *Porites* and *Heliopora* in tne back reef zones.

Greater development of live coral lagoonward from the lagoon edge of the reef flat was inhibited by sand and rubble deposits. Large growths of the filamentous blue green algae *Lyngbya* were reported along many lagoon reef slopes and reef flats between Aomen and Bikini Islands. This algae is probably seasonal and may be a good indicator of disturbed environments, possibly caused by periodic heavy wave action from the south (lagoon), shifting sand, or reduced water clarity near the shoreline or lagoon reef edge.

D. CULTURAL RESOURCES.

Cultural Resources and Miscellaneous Facilities. A lack of time and proper training did not permit more than a cursory look at some cultural resources on the islands of the atoll. The Bikini cemetery and Japanese shrine were noted on Bikini Island along with many homesites and a school abandoned during the 1978 evacuation. The ruins of a church (probably built in the 1950's) was noted on Eneu. Several reinforced concrete bunkers were also seen on Eneu, including a very large building centrally located on the island. Other bunkers may also occur on Bikini Island but were not seen. Many bunkers, built on the outer islands, to facilitate photography and other documentation during nuclear tests, can still be observed. The shipwrecks in the central eastern lagoon, sunk during the nuclear test "Baker" also exist and constitute a historic resource. (See Kubo, Appendix C for further information.) The aircraft carrier Saratoga is particularly noteworthy due to its age and the role it played during World War II and the early development of US aircraft carriers. A sacred reef is said to exist near the lagoon shore of Bikini Island.

The author could not document the existence of any previous archaeological or historical resource studies at Bikini Atoll. Previous extensive ground disturbance on the islands could have destroyed at least some sites, if they existed. Any cleanup alternatives involving removal of soil or vegetation will probably require an archaeological survey to locate cultural resources, if any, worthy of in-place protection relocation or additional study prior to earthmoving and grubbing.

E. SOCIOECONOMIC RESOURCES.

The Bikini islanders were evacuated from the atoll in 1978, and presently the atoll and its islands are uninhabited except during the brief visits of scientists involved in monitoring studies and experiments conducted by Lawrence Livermore Laboratory, Brookhaven, and other federally sponsored programs. All lands on the atoll are owned by the Bikini islanders. Bikini Island has been the traditional main island of occupation on the atoll, and many of the landowners on Bikini apparently also own land on Eneu Island, the only other large inhabitable island. The size of the land parcels may vary considerably among the different owners. The land ownership issue will be important for any options involving settlement on Eneu prior to settlement on Bikini Island.

The only navigational facility at Bikini is the ruins of the deep draft sheet pile dock at Eneu which appears beyond salvage; it serves now only as a convenient temporary mooring for small skiffs. Only some of the concrete supports for older landings or docks on Eneu are still standing and the structures are no longer functional or repairable. No docking facilities of any kind are located on Bikini Island. Concrete reinforced seawall groins placed at the southern lagoon shoreline of Eneu have been only partially effective in arresting shoreline erosion and are being undercut by wave surge. A large storage warehouse at the south end of Eneu Island appears salvageable but is in need of repair.

A considerable amount of heavy equipment (crane, backhoe, dozer, tractor, forklift, cherry picker, portable generators, etc.) were left out in the open in the aftermath of the 1978 evacuation, and are now rusting unsalvageable hulks. The approximately 40 residential structures built on Bikini Island in the early 1970's have not been maintained since the 1978 evacuation and were heavily damaged during subsequent storms. A major investment would be required to restore the dwellings, if restoration is possible.

The Lawrence Livermore Laboratory personnel, however, managed to repair some of the equipment several years ago (including the D-6 bulldozer) and it is still in operation. The laboratory also maintains power, water, air conditioned rooms, buildings, trucks, boats, backhoe, laboratory equipment, etc., in support of their ongoing studies.

The sheetpile road causeways on the outer islets constructed during the nuclear testing era have failed or have rusted beyond function in most areas including the causeways connecting some of the southern islands (Aerokojlol, Bikdrin). Sandy beaches have piled up against some of the causeways and are, therefore, still functioning to an extent, especially the causeway connecting Aomen and Lomilik Islets. The approximately 4,000-foot long runway on Eneu Island is in suprisingly good condition and is adequately crowned to avoid drainage problems. The paved parking apron adjacent to the west central side of the runway is in excellent condition and free of vegetation. This could serve as an excellent site for a large freshwater catchment system.

As noted earlier, most of the roads on both Bikini and Eneu Islands are no longer maintained and are rapidly being overgrown by indigenous and exotic vegetation.

4. REVIEW OF SPECIFIC ALTERNATIVES

A. MORE DESIRABLE PLANS. The Committee feels that alternatives involving (1) delayed resettlement (spontaneous decay of unstable cesium), (2) chemical treatment of soil with potassium fertilizer, and (3) excavation and disposal of soil are the three major areas worthy of continued examination and analysis. With regard to the first plan, the Bikinians expressed to the Committee by a letter dated 14 August 1984 their lack of support for alternatives that do not allow the early resettlement of Bikini Island. The latter two alternatives are described below:

CHEMICAL TREATMENT USING POTASSIUM FERTILIZER

This alternative involves the addition of potassium fertilizer to contaminated soils that result in reduced or blocked uptake of unstable cesium by food crops. Existings groundcover would not need to be removed. Preliminary studies indicate that the application of potassium rich fertilizers does somewhat reduce cesium uptake by plants at moderately low soil levels, but more systematic studies are needed prior to a final determination on effectiveness, especially at the higher cesium levels prevailing on Bikini Island. (See Robison and Stone Appendix B.) If feasible, potassium treatment would have the advantage of reducing or eliminating the need for soil excavation and possibly removal of vegetation on the lesser contaminated islands, say those within a factor of 2 or 3 from the liminal rooting zone specific activity. Certainly for Bikini Island it can help to the extent of truncating the waiting period, but it would still be inadequate as the sole strategy to allow early consumption of locally grown crops.

EXCAVATION AND DISPOSAL OF SOIL

This alternative involves the removal of vegetation and soil layers from contaminated islands to a depth that eliminates most of unstable cesium from the soil, thereby preventing its uptake by subsequently cultivated food crops. Although this approach would be considered the only certain way to eliminate cesium uptake, it is also the most expensive from both the environmental and economic standpoints. This alternative would also require disposal of contaminated soil. Feasible disposal options include using the excavated soil to expand Bikini Island along specific shoreline sectors (where food crops would not be grown), disposal of soil on another islet (such as Nam which is large enough to handle the entire stockpile), and disposal in BRAVO crater or another large crater in the lagoon. Excavation will probably require replacement soil, fertilizers or additives to stimulate the growth of new plantings and crops and reduce the time needed to develop all the subsistence crops for the returning islanders. Groundwater itself would not be cleaned up directly by excavation, but contamination levels would be expected to decline significantly once overlying contaminated soils are removed and leaching of residual contaminants occur. Use of contaminated soil to expand the size of Bikini Island may also result in back contamination of the groundwater of the island, unless the fill area is isolated using some sort of barrier (impermeable liners, etc.), if warranted.

B. LESS DESIRABLE PLANS. The Committee is still investigating the feasibility of all available alternatives and thus, none have been completely eliminated at this time. However, some (below) appear to be less desirable or feasible based upon existing information.

Biological Extraction. This is a technique to reduce radioactive cesium levels in the soil involving the cultivation and growth of plants, the uptake of the radionuclides by the plants, and the periodic harvesting and disposal of the plant crop. This alternative does not seem feasible because the plant growth needed to tender this approach effective does not seem possible without heavy irrigation and fertilization. Even under a most favorable scenario, biological extraction might not reduce significantly the time required to reduce radioactive cesium levels in the soil to safe and acceptable levels for crop production.

Washing Soil with Seawater. This alternative involves the washing down of unstable cesium layers from the upper soil horizon (within the root zone of crops) using large volumes of seawater pumped inland from the shoreline. Removal of most vegetation would not be needed. If this technique is feasible, plant uptake of radioactive cesium within the root zone of the plants would be reduced to safe levels without the need to excavate and dispose of the contaminated soil. However, studies to date have not provided evidence that this approach would be effective. Additional studies on washing are planned to acquire an ultimate determination of its effectiveness.

Topping Old Soil with New Soil. This alternative involves the dredging for a source of replacement soil or importation of suitable soil to Bikini and its placement over existing contaminated soils to a sufficient thickness to preclude plant uptake of unstable cesium from the lower contaminated layers. This alternative would also require removal, grubbing, and destruction of existing vegetation. Although this alternative would preclude the need for soil excavation, it would still require large quantities of topping soils, either from dredging sites at Bikini or from off-atoll sources of soil. Also, groundwater on Bikini Island would continue to be contaminated beyond drinking water standards for many years.

Ocean Disposal. Disposal of excavated soil into open ocean waters is technically feasible and could be accomplished at a site away from the atoll to eliminate sedimentation impact to Bikini's coral reef ecosystems. However, there may be institutional or legal constraints against this approach, and the proposal would be extremely controversial, particularly within the international community. Ocean disposal also may not be a politically feasible or acceptable alternative.

Open Lagoon Disposal. Disposal of excavated soil in open lagoon waters can lead to the risk of sediment or turbidity damage to lagoon reefs or fisheries within or downcurrent of the disposal areas. A more feasible approach would be lagoon disposal in one or more of several large craters created during nuclear weapons testing between 1946-1958, including BRAVO crater. Crater disposal has the advantage of confining turbidity and sedimentation to environments chronically disturbed by previous weapons testing. Thus open lagoon disposal appears less desirable from an environmental perspective. Since other lagoon alternatives (crater disposal) are more feasible and desirable, it may be pointless to pursue open lagoon disposal much further.

Causeway Construction. The Bikinians have expressed support for a causeway alternative, most recently in September 1984. Use of excavated material for the construction of a 8 km long road causeway over the reef between Eneu and Bikini Islands was earlier proposed as one "disposal" alternative that could also improve transportation and communication links between the two large inhabitable islands of the atoll. However, this option would cost roughly $40 million more than the cost of the next most expensive disposal alternatives. In addition, the causeway and its construction would be expected to destroy reef and subsistence fishery habitats, disrupt water circulation on either side of the causeway, reduce the migratory routes for reef biota, cause major changes to the water circulation of the eastern lagoon, and perhaps render lagoon circulation more sluggish as a whole. In addition the causeway would be vulnerable to damage from storm waves and would require a program of regular maintenance. There are likely cheaper alternatives for improving transportation and communication links between Eneu and Bikini Island including the construction of protected harbor basins on the lagoon side of both islands, from which shuttle boats could operate. The harbors would also provide additional benefits for improved cargo handling and commerce, fishery development, emergency evacuation of the atoll by ship, etc. Detailed discussion of harbor and other transportation needs, however, are beyond the scope of the committee's present work.

Lagoon Dredging of Sediment. Dredging of lagoon sediments as a source of replacement soil for both topping and excavation alternatives is less desirable for several reasons. The dredging operations themselves could lead to major ecological damage and outbreaks of fish poisoning. Dredging would be expensive and the sediments themselves would not be particularly valuable as a soil because of low nutrient and high salinity levels. Thus, the sediment would have to be leached of seawater, fertilized, and conditioned. Furthermore, there was some question whether the potential sources of lagoon sediments themselves would be clean and relatively free of radionuclides. At this time, it appears that dredging offers no clear advantages over other alternatives and the high elevations of the two main islands seem to preclude the need for replacement sediment to maintain the present geological stability of the islands (See Peterson, Appendix A).

COMPARISON OF ALL ALTERNATIVES

A comparison of the enviromental effects of all alternatives is presented in Table 2 (See Summary) and includes a ranking of alternative from "best" to "worst" from an environmental perspective and a list of potential measures to reduce or avoid adverse impacts. In general the nonstructural alternatives would have the least environmental effects, but are not as effective as other alternatives in avoiding the risk of soil contamination.

Excavation alternatives would be the most effective in eliminating soil contamination but the environmental effects are greater than for other alternatives. However, the effects of some of the excavation/disposal alternatives should still be acceptable and feasible including: lagoon crater disposal, disposal on Nam Island, and expansion of Bikini Island. If feasible and sufficiently effective, chemical treatment, washing, and topping would be environmentally preferred over excavation alternatives.

5. ENVIRONMENTAL CONSEQUENCES OF PROPOSED ALTERNATIVES TO REHABILITATE SOILS AT BIKINI ATOLL.

A. GENERAL.

The environmental consequences of all alternatives are summarized and listed in Table 2. The impacts are divided into two categories: unavoidable and avoidable. For the latter, a list of potential measures to reduce or avoid impacts is also included. The analysis of possible impacts is confined to actions directly or indirectly required for the rehabilitation of the soils. Other actions required for a successful resettlement program, such as housing, transportation, utilities, etc., are not being addressed by the Committee at this time. Hence, there is no discussion of the impacts of these other activities in this environmental assessment. However, all aspects of a proposed Bikini resettlement program should eventually be addressed in an Environmental Impact Statement when and if the decision is made to proceed with the cleanup and resettlement of Bikini Atoll. In light of the above, the alternatives not involving soil rehabilitation: (delay resettlement; allow resettlement but only control diet; or allow the first stage of phased resettlement) will not result in major adverse environmental impacts. If phased resettlement is implemented which eventually leads to the rehabilitation of soils on Bikini or other islands, then this subsequent phase would result in environmental impacts, depending upon the soil rehabilitation alternative selected. The impacts of these alternatives are highlighted in the remainder of this section.

B. AIR QUALITY.

Alternatives involving the removal of soil will require the grubbing, stockpiling, and burning of existing vegetation. In addition, the alternatives of topping and transfer of soil to another island could require destruction and burning of vegetation. Collectively actions that remove or relocate soil and destroy vegetation will generate dust and smoke emissions. These emissions may also contain radionuclides. If these emissions constitute a hazard to workers and residents of the affected islands, then emission control measures may be required.

C. GEOLOGY AND SOILS.

Alternatives involving topping or the removal of soil from Bikini Island, and its disposal on other islands or elsewhere on Bikini Island, will result in the loss of a relatively thick and rich soil layer of value for crop cultivation and vegetation. The loss of Bikini Island's existing soil horizon would seriously impede the future recovery of some vegetation and cultivation of some crops on the land areas denuded of soil unless organic additives, fertilizers or other treatment measures are applied. At best, the crops would require one to 10 years to reach maturity and support the subsistence needs of the returning islanders. The application of untreated dredged lagoon sediments may not accelerate, improve, or stimulate crop development because of high salt and low nutrient concentrations.

D. TERRESTRIAL ECOLOGY.

All alternatives involving excavation, topping, transfer of soil to another island or removal of vegetation will result in the destruction of vegetation on the affected islands. The impact of this can be reduced somewhat by flagging important trees or other vegetation for transplantation or protection prior to grubbing and excavation. The natural recovery of vegetation and the establishment of new crops will require one to 10 years. No proposed or existing threatened or endangered species of plants occur or are expected to be affected by a Bikini cleanup project.

The nesting activity of seabirds at Bikini Atoll could be affected by alternatives involving removal or relocation of soil and vegetation unless such actions are timed or located to avoid the breeding seasons of the seabirds. No threatened or endangered species of seabirds are thought to nest or reside at Bikini Atoll.

Coconut crabs and other edible species of land crabs may occur naturally on the islands of Bikini Atoll. Alternative actions involving disturbance to soil or groundcover, especially in established coconut groves, could reduce the available habitat for these species. Consumption of coconut crabs may also be subject to some dietary restrictions due to bioaccumulation of unstable cesium.

E. SEA TURTLES.

Cleanup programs and involving disturbance to potential turtle nesting beaches could adversely affect threatened and endangered species of sea turtles through disturbance or destruction of nesting habitat. In addition, the returning islanders would be expected to resume subsistence take of sea turtles as presently authorized in Federal regulations.

F. OCEANOGRAPHY.

The causeway alternative would block wave and wind driven circulation on the eastern reefs and lagoon and modify tidal circulation between the ocean and lagoon. The addition of culverts and bridge openings through the causeway could reduce but not eliminate these effects. In the absence of an adequate causeway maintenance and repair program, the failure of the causeway from storm wave damage could also disrupt water quality and circulation.

Water quality effects from aquatic disposal of excavated soil could result in extensive turbidity and sediment plumes. The extent of these impacts can be reduced or eliminated by confined aquatic disposal in one of the lagoon bomb craters (such as BRAVO crater), land disposal on another island (such as Nam), or reef flat expansion of Bikini Island by disposal of excavated soil behind protective berms. Bagging of excavated soil prior to aquatic disposal would be another technique to reduce the effect of turbidity and sedimentation.

Filling operations during causeway construction could also result in excessive production of turbidity and suspended sediments. Finally, cutterhead dredging operations to obtain sources of replacement soil could also generate excessive turbidity and sedimentaton; this can be reduced considerably by establishing settling basins on land to contain discharge slurry waters from the dredging operation. Quarrying operations on the reef flats to obtain armor rock and other stone for revetments should not result in major adverse effects on water quality, if done properly.

G. MARINE BIOLOGY.

Any alternatives involving construction in the water (such as for a causeway), aquatic disposal of soil, dredging, or other discharges could have an adverse effect on coral reef and subsistence fishery habitat. The causeway alternative in particular would be destructive to subsistence fishery and reef habitat from the direct effects of heavy equipment operation on the reefs and the discharge of fill materials and from the indirect effects of circulation and water quality changes as mentioned earlier. In addition, causeway construction and dredging could result in the outbreak of ciguatera fish poisoning which would further reduce the availability of fresh protein food resources to the islanders and increase public health risks. The latter effect could be mitigated by a monitoring program for the toxic algae and fish but most of the remaining adverse ecological effects would be unavoidable.

The migrations of fish, shellfish, and other invertebrates between the lagoon and ocean side of the reef could also be inhibited by the causeway, but this effect can be reduced considerably by adequate numbers and sized culverts and bridge openings. Quarrying operations for protective structures including the causeway revetment can also destroy existing marine biological habitat, but quarry sites and operations can be designed and located in a manner to reduce adverse effects and promote recruitment and colonization by fish and corals (based upon evidence from existing quarries at Kwajalein and Enewetak).

Open lagoon or open ocean disposal of excavated soils can also affect the ecology of pelagic and coral reef ecosystems via smothering, burial, loss of light and other factors. Furthermore, the sediment plumes from disposal operations can move down current and disrupt adjacent productive ecosystems. As noted previously, bagging of soil prior to disposal or disposal into confined bomb craters offers ways to reduce or eliminate significant impacts. Preliminary observations at Bravo and other large craters indicate coral reef and fish recovery has been very low since the cessation of testing nearly 30 years ago. Thus, disposal of soil in these craters has the advantage of confining impacts to reef environments heavily degraded and unrecovered from previous stresses. The elimination of dredging and causeway construction as part of the cleanup options would reduce considerably the overall effect of the entire program on marine ecosystems.

H. ARCHAEOLOGICAL AND HISTORICAL RESOURCES.

Although Bikini and Eneu Islands were extensively disturbed in the past, it is possible that archaeological sites may still exist there, in the absence of previous archaeological study at the atoll. Alternatives involving disturbance of soil or groundcover has the potential to affect significant unrecorded archaeological sites. Known important cultural sites such as the cemetery should be flagged and fenced during construction to avoid any damage. Historically significant bunkers, buildings, monuments, etc., can also be identified and protected. Since little information on the archaeology of Bikini exists in the literature, surveys would be required for Bikini and other islands where beach, soil, and vegetation removal or disturbance are contemplated. Impacts to historically significant shipwrecks and the sacred patch reef in Bikini lagoon are not expected from the cleanup operations as contemplated at this time.

I. SOCIOECONOMIC IMPACTS.

Evaluation of the socioeconomic consequences of the cleanup can only be superficially examined at this time. The major beneficial social effect of the rehabilitation of Bikini soils would be facilitating the safe and earlier resettlement of the atoll by the Bikini islanders. However, there would also be other socioeconomic effects, depending upon which alternative cleanup option is pursued. Implementation of resettlement with dietary controls or phased resettlement would allow an earlier return of the islanders compared to the other alternatives. Delayed resettlement, on the other hand, would place Bikini Island off limits to the islanders for 80 years. Phased resettlement involving an initial resettlement of islanders to Eneu Island may require leases, real estate agreements, or other arrangements to allow Bikini islanders to live on Eneu who do not own land on Eneu. Alternatives that do not hasten the return of the islanders to Bikini Island will be unpopular or unacceptable to them. Since they will be the beneficiaries of a cleanup program, it is logical that the views of the islanders be given great weight prior to the decision on the scope of the cleanup.

The alternative involving extension of Bikini Island along the seaward side would destroy a large section of a sandy beach that may be important to the Bikinians. If the beach is of recreational, cultural, or aesthetic value, a new beach can be designed and reestablished on the seaward side, as a part of the Bikini Island extension plan.

The major socioeconomic effect of the alternatives involving excavation of soils will be the ability of the islanders to resettle Bikini, but only after a delay of one to ten years (depending on the type of crop) before the subsistence crops of value to the islanders are fully reestablished. After soil excavation, fertilizing and conditioning of soil and planting programs will be required. Although some crops (melons, sweet corn) can be established quickly, the replanting of coconuts and breadfruit will require more time for the trees to reach maturity and bear fruit. However, the islanders could still be allowed to return to Bikini earlier if some crops are established quickly and if fresh foods are shipped or flown in from off-atoll during the replanting and regrowth of the longer maturing subsistence crops.

The excavation alternatives will also result in a loss of much of the historic vegetation, some cultural sites, and some of the natural features as remembered by the islanders prior to their evacuation from the atoll in 1946 and after extensive cleanup operations in the early 1970's.

6. RECOMMENDATIONS.

Additional environmental studies, as noted earlier, a more comprehensive review of the available literature, and direct communication and extensive dialogue with the Bikini islanders should also be accomplished prior to preparation of an EIS for the rehabilitation and resettlement of Bikini. The studies should include limited field studies on archaeology, botany, circulation, marine biology, and vegetation; and analysis of air quality, water quality, and health physics requirements. Funds have been requested by the Committee to support the preparation of a draft EIS and environmental supporting studies.

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