401188

SWRHL-111r

REPORT OF THE RADIOLOGICAL CLEAN-UP OF BIKINI ATOLL

by
Allan E. Smith and William E. Moore
Office of Dose Assessment & Systems Analysis
Western Environmental Research Laboratory

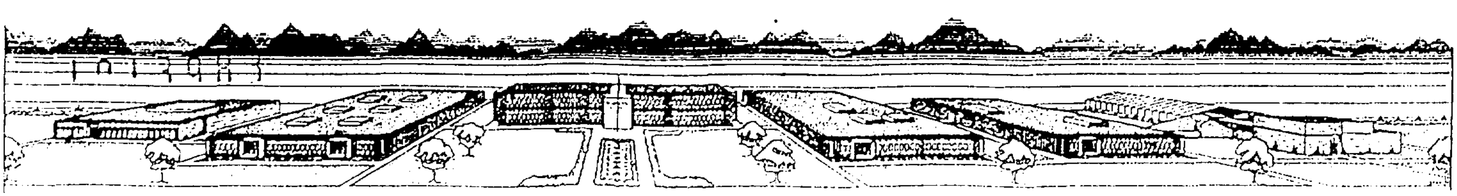
ENVIRONMENTAL PROTECTION AGENCY

Published January 1972

This study performed under a Memorandum of Understanding (No. SF 54 373) for the U.S. ATOMIC ENERGY COMMISSION

[redacted]

Box 6, Part 1
9/1978 - 5/1979



Available from the National Technical Information Service,
U. S. Department of Commerce
Springfield, Va. 22151

Price: paper copy $3.00; microfiche $.95.

080 5009017

[redacted]

SWRHL-111r

REPORT OF THE RADIOLOGICAL CLEAN-UP OF BIKINI ATOLL

by
Allan E. Smith and William E. Moore
Office of Dose Assessment & Systems Analysis
Western Environmental Research Laboratory

ENVIRONMENTAL PROTECTION AGENCY

Published January 1972

This study performed under a Memorandum of
Understanding (No. SF 54 373)
for the
U.S. ATOMIC ENERGY COMMISSION

[redacted] 5009018

ABSTRACT

As a result of a decision by President Johnson in 1968, the Atoll of Bikini was the subject of an intensive clean-up effort in 1969 by a joint AEC-DASA task force. The task force was responsible for rehabilitating the islands of Bikini and Eneu in preparation for the resettlement of the Bikinian people to their home islands. Radiological Safety Advisors were provided by the Western Environmental Research Laboratory, Environmental Protection Agency. Objectives of the clean-up effort were: removal of all debris from the islands; determination of existing radiation levels on each island; analysis of available food items for radionuclide distribution; and clearing of vegetation from land for agricultural redevelopment. Upon completion of these objectives, the islands were turned over to the Trust Territories for the agricultural phase of the program. This report describes the radiological conditions detected before, during and following the clean-up effort.

The highest exposure-rate measured on the islands of Bikini and Eneu was 120 μR/hr. The mean exposure-rate for the proposed village area on Bikini was 44 μR/hr. Integral dose calculations involving theoretical time periods spent in various areas of the island and on the lagoon and considering shielding values from coral aggregate in the village area were made. The projected external whole body dose for a person born on Bikini in 1970 and living there for 70 years would be less than 10 Rad.

[redacted]
5009019

TABLE OF CONTENTS

LIST OF FIGURES

[redacted]009021

LIST OF TABLES

INTRODUCTION

During the period 1946 through 1958, the atoll of Bikini, centered about $11^{\circ}36'$N, $165^{\circ}22'$E, was the site of approximately 23 nuclear detonations. After the atoll of Bikini was selected as a test area the native population, numbering approximately 166, was eventually resettled in 1948 on Kili, a single island in the southern Marshalls, following brief stays on Rongerik and Kwajalein atolls. Discrete test series were conducted at Bikini Atoll in 1946, 1954, 1956, and 1958 and included both fission and fusion devices. Due to their proximity to the detonation sites, or the vagaries of the weather, all of the islands of the atoll were contaminated to some extent by radioactive fallout.

In 1964 and again in 1967, radiological surveys of the atoll were conducted under the auspices of the Division of Biology and Medicine of the U. S. Atomic Energy Commission. The 1967 survey yielded an extensive amount of data relative to the external radiation levels(1) and the concentration of radioactive materials in the marine environment as well as in the edible land plants and animal life.(2)

Following the 1967 survey, an Ad Hoc Committee was convened to evaluate the radiological hazards of resettlement of the Bikini Atoll. The conclusions of the committee included the following statement: "The exposures to radiation that would result from the repatriation of the Bikini people do not offer a significant threat to their health and safety."(3) On August 12, 1968, President Johnson announced the decision to return the Bikinians to their atoll. A joint AEC-DASA effort was initiated to eliminate any physical or radiological hazards remaining on the atoll and to prepare the islands of Bikini and Eneu for agricultural redevelopment. This phase of the clean-up program was initiated in February 1969. The data provided in this report result, for the most part, from the radiological clean-up effort associated with this aspect of the program. Air sampling data collected during a follow-up survey in May-June 1970 are also reported.

OBJECTIVE OF CLEAN-UP PHASE

The conclusions of the Ad Hoc Committee stated that the islands of Bikini and Eneu could be used for continuous occupancy and agricultural development sufficient to support the returning population. The clean-up of these islands called for:

1. the removal of all test related debris with disposal at sea of all radioactive debris
2. stripping of the vegetation to permit planting of coconuts, pandanus, breadfruit, etc. This was accomplished by cutting swaths which were approximately 20 feet wide on 56-foot centers through the vegetative cover
3. determining residual external radiation levels at each step of the clearing and stripping operations, and
4. obtaining samples of available food items for laboratory analysis for comparison with previously collected data.

Although permanent occupancy was to be limited to the islands of Bikini and Eneu, the Ad Hoc Committee further concluded that "radioactive scrap should be removed from the islands adjacent to former shot sites." Since these islands may be used for the collection of birds, turtles, and their eggs for human consumption, removal of radioactive debris would make the scrap unavailable for collection by the natives.

The final objectives of the clean-up program, therefore, included the elimination of all physical hazards and the disposal of all radioactive scrap from each island of the atoll in addition to the specific measures cited for Bikini and Eneu.

The Western Environmental Research Laboratory (WERL), which conducts radiological surveillance operations in the Pacific for the AEC, was requested to provide Radiological Safety Advisors to the AEC Project Manager for the clean-up effort. In addition, a comprehensive sampling program was to be conducted of all edible varieties of food found to be growing there. Analyses of samples were to be perfomed by WERL at one or both of its two laboratories, located in Honolulu, Hawaii and Las Vegas, Nevada.

CRITERIA

Rather than establish firm, restrictive criteria for the removal of radioactive artifacts, or the elimination of high background* areas from the islands of the atoll, each situation was viewed in terms of the potential exposure versus benefit. All debris or artifacts having little or no useful value was removed. All scrap metal or concrete with contact readings greater than 100 micro-Roentgen per hour (μR/hr) was treated as radioactive waste and buried at sea. Three specific locations were selected for this burial (Figure 1). In some cases, scrap reading less than 100 μR/hr was buried on land together with non-radioactive debris. This was only done on islands where areas exhibiting background levels in excess of 100 μR/hr were found. No radioactive debris at any level of activity was buried on the islands of Bikini, Eneu, or Aerokoj.

The exterior of several bunkers, located on the northern complex (Iroij, Odrik, Lomilik, and Aomen) and Nam, exhibited levels of radioactivity up to 7,000 μRad/hr ($\beta + \gamma$) at contact. The net gamma levels were 200 μR/hr maximum. The levels inside the bunkers were less than 10 μR/hr, however. Since the potential for personnel exposure was negligible, and the bunkers were desired as typhoon shelters and storage buildings by the natives, the larger bunkers were left intact.

Several instances of high background levels, greater than 200 μR/hr, due to soil contamination were also encountered. It was the consensus that attempting to reduce these levels by removing the top layer of soil would destroy the limited agricultural capability of the area, therefore, most such areas were left essentially undisturbed.

---

*The term "background" as used in this text denotes the radiation levels at the time of survey and includes that portion resulting from testing operations as well as from natural sources. Natural background levels in this part of the world result primarily from Cosmic rays and are generally less than 5 μR/hr.

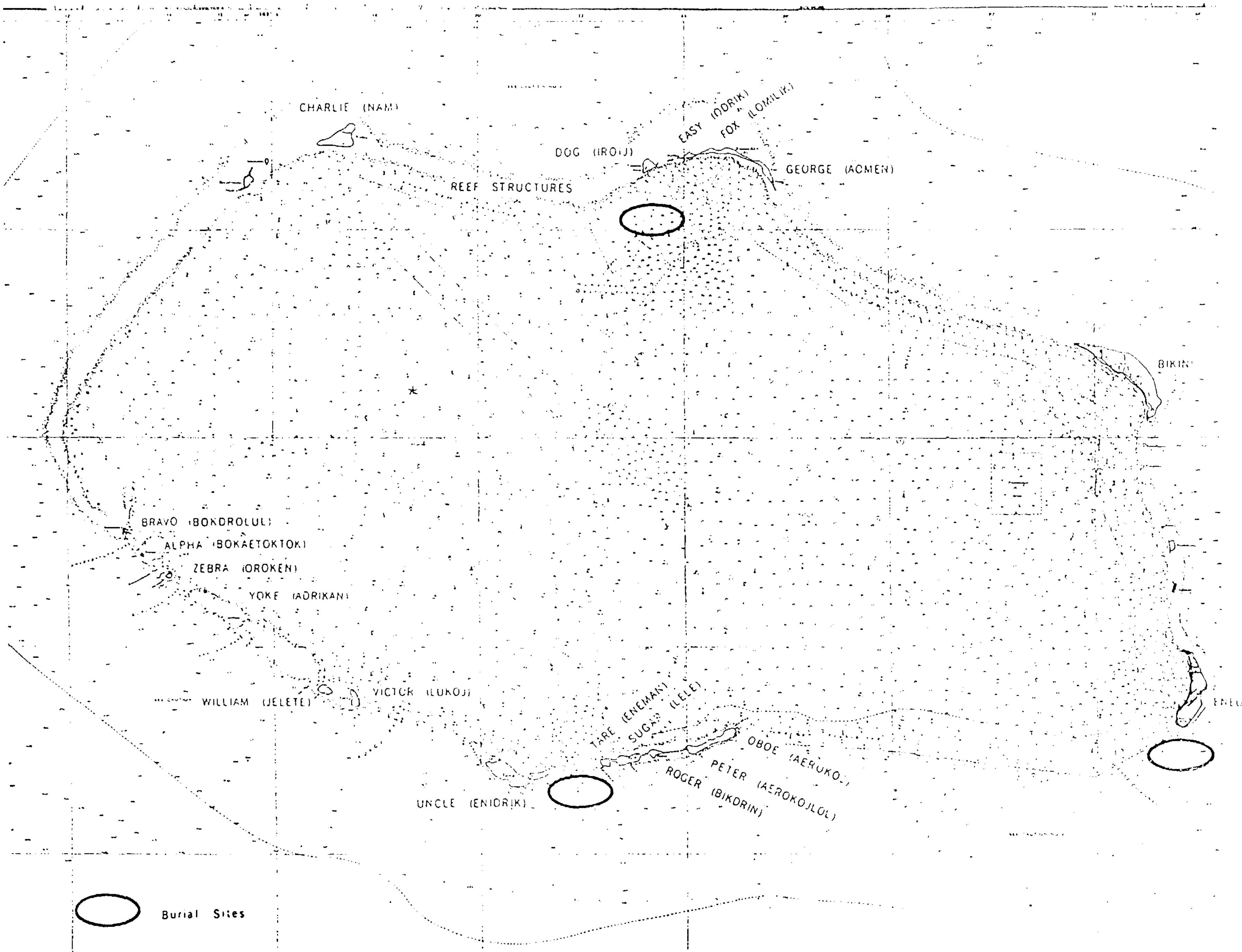


Figure 1. Bikini Atoll

SURVEY INFORMATION

Tabulations for the islands of Bikini Atoll on the following pages will indicate:

1. the background gamma exposure rates as measured with a Baird Atomic NE-148A scintillator calibrated against ^{137}Cs,
2. a summary of the radiological waste removal and disposal,
3. results of sample analyses and,
4. when appropriate, projection of the background decay as a function of time.

CONCENTRATION-EXPOSURE RATE RELATIONSHIP

In order to estimate the expected reduction in exposure rate for the various islands as a function of time, it was necessary to develop weighting factors for each of the gamma emitting radionuclides identified in the analysis of soil samples.

For purposes of this report, it was assumed that the various radionuclides were uniformly distributed by depth throughout the soil and that the only change in relative concentrations is due to the differential decay rates. This is obviously an oversimplification but would tend to give conservative results. The data of Crocker, Connors, and Wong[4] were used to indicate the relative effect of each nuclide on the exposure rate. Since ^{102m}Rh was not among the nuclides included in their tabulation, data from their table were normalized by effective energy and number of photons per disintegration and plotted. The exposure rate factor for ^{102m}Rh effective energy 0.62 MeV was taken from this curve and corrected for 2.96 gamma per disintegration.* The final tabulation of the composite exposure rate reduction was then calculated using the decay factor, initial concentration and exposure rate weighting factor.

*Decay scheme taken from Table of the Isotopes - Ledever, Hollander, and Perlman.

PROCEDURES [6]

Gamma ray spectrum analysis and strontium analysis on all coconut, pandanus, and arrowroot samples were performed at the WERL Pacific Operations Laboratory in Honolulu, Hawaii. Edible portions of the samples were ground and counted without drying on a 4- by 4-inch NaI(Tl) crystal multi-channel analyzer system. The spectral range covered was zero to two MeV. At the concentrations of ^{137}Cs encountered in these samples, the counting error is approximately ten percent. (All errors referenced in this section are 2 sigma confidence level.)

Following gamma spectrum analysis the samples were ashed and the inorganic residue was analyzed for ^{90}Sr. Due to the small amount of ash produced, it was often necessary to composite samples from adjacent locations. Counting was performed on a low background beta counter. The analytical error associated with this procedure is approximately ten percent at the levels of ^{90}Sr encountered.

All tritium and plutonium analyses were performed at WERL, Las Vegas, Nevada. Tritium was determined by liquid scintillation counting of the water recovered from coconut milk and from selected soil samples. The minimum sensitivity for this procedure is 0.4 pCi/ml for five ml of recovered water. At this concentration the error term for the 2 sigma confidence level is ± 100 percent. Analyses of the coconut milk and soil samples indicated the concentrations of tritium were less than the minimum detectable level.

Plutonium analyses which were performed on soil samples were by radiochemical separation followed by pulse height analysis using a lithium-drifted silicon detector. The analytical error is approximately ten to fifteen percent.

The analytical error associated with the results for plutonium on prefilters is approximately ± 25% at the 2 sigma confidence level.

Unless otherwise specified each soil sample represented the top one to two inches of a one-square-foot area at each location. Prior to plutonium analysis, gamma ray spectrum analysis was performed to identify the most abundant radionuclides and to estimate their relative contribution to the total activity.

[redacted] 5009028

BIKINI ISLAND

The island of Bikini is the largest in the atoll, having an area of about 0.6 square miles and has traditionally been the "home island" of the Bikinians. Individual land rights extend from the lagoon to the ocean. It is anticipated that the village will be rebuilt along the lagoon shore with community buildings being located about midway along the length.

The island was prepared for agricultural redevelopment by cutting parallel strips through the vegetation along the length of the island. The strips, cut on 56-foot centers, were approximately 20 feet wide. The vegetative cover was knocked down and left in place to provide additional organic matter for the soil. The strips were surveyed and background gamma radiation levels recorded at 250-foot intervals along their length. Figure 2 illustrates the background variation by depicting the range and average of radiation measurements for areas consisting of approximately four strips.

Although a large amount of debris was found on Bikini (from testing program and World War II) with one exception, none was radioactive. One pile of roofing paper scraps contaminated primarily with ^{137}Cs was located northwest of center on the lagoon side of the island. This material, which showed a contact reading of approximately 200 μR/hr, was loaded into 55-gallon drums and disposed of in the ocean south of Eneu.

The measured exposure rates* were 10 μR/hr or less along the beaches, and ranged from 20-120 μR/hr inland. Soil samples taken at three locations having measured backgrounds of 20, 70, and 100 μR/hr showed ^{137}Cs and ^{60}Co to be the major gamma emitting contaminants. These were present in Cs/Co ratios of approximately 25/1, 50/1, and 30/1 respectively for the three samples, and thus the projected exposure rate decrease will very closely approximate the decay of ^{137}Cs. In addition, ^{90}Sr was present in amounts ranging from 10-50% of the ^{137}Cs concentrations. Both ^{137}Cs and ^{90}Sr are very significant contributors to the potential internal exposure which may result from eating locally grown food items.

---

* Unless indicated as a contact measurement all exposure rate measurements were taken at 3 feet.

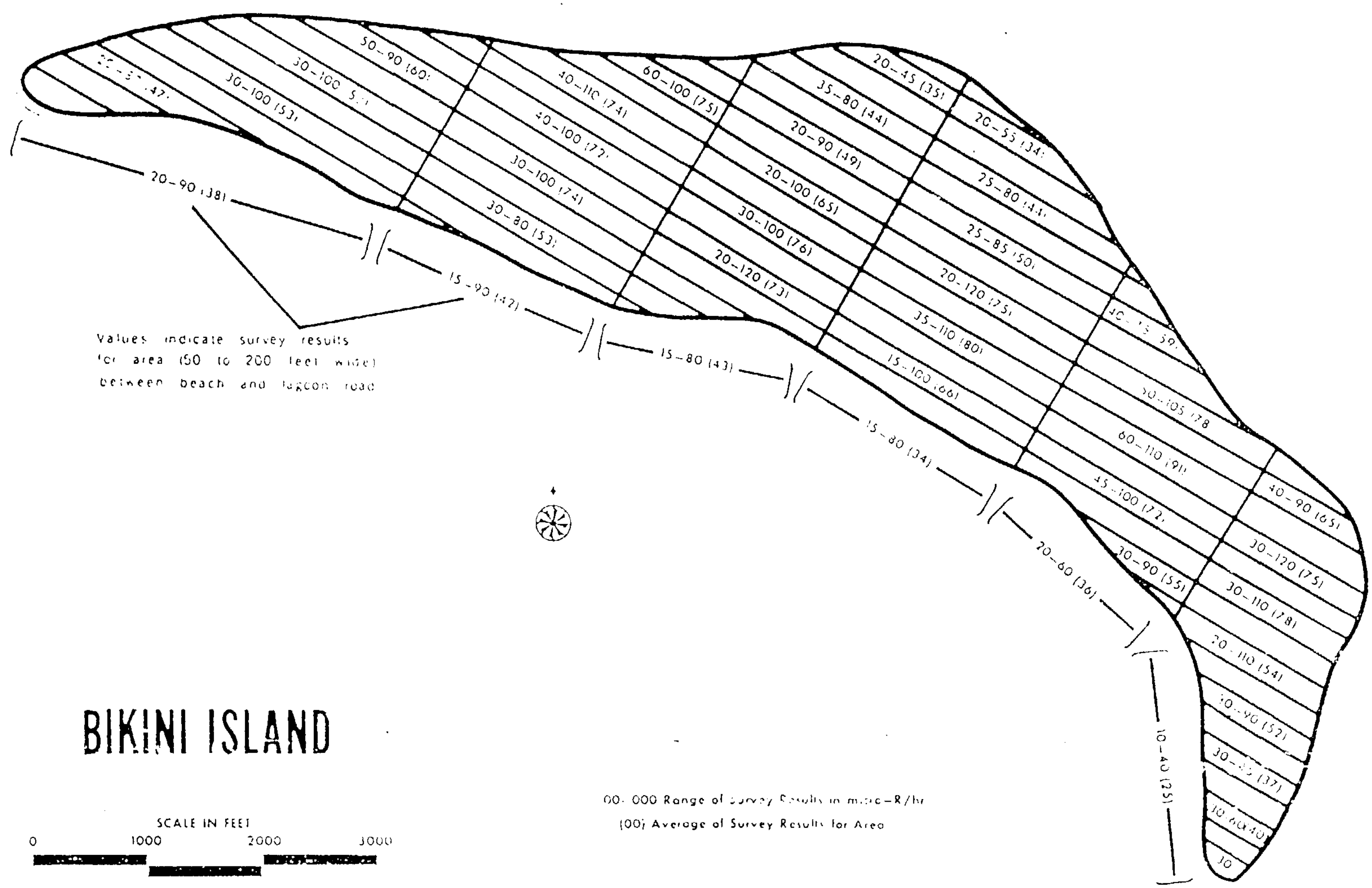


Figure 2 Bikini Island - Background Radiation Survey Results

[redacted] 5009030

Nineteen coconut samples were collected from thirteen different locations on the island. Green coconuts were used for almost all samples and the meat and milk were analyzed separately. Only ^{137}Cs and ^{90}Sr were detectable in any of the samples. Tritium analyses were performed on the milk from selected coconuts but all results were below the lower limit of detection (0.4 pCi/ml).

Table 1. Mean ^{137}Cs and ^{90}Sr Concentration in Food From Bikini Island (pCi/g wet weight)

Sample	1969 ^{137}Cs	1969 Range	1967* ^{137}Cs	1969 ^{90}Sr
Coconut meat	120	4 - 480	200 ± 2.6	0.31
Coconut milk	130	48 - 270		
Pandanus	130	26 - 400		28
Arrowroot†	0.6	0.4 - 1.1		2.4

*Data from reference number 2.

†Prepared by grinding, rinsing three times with salt water and once with fresh water. (Marshallese method of preparation)

ENEU ISLAND

The second largest island in the atoll, and the site of the base camp for the cleanup operation, Eneu, was found to be considerably lower than Bikini in external background (Figure 3). Although an exposure rate of 50 μR/hr was obtained at one depressed location during the early stages, filling of this "borrow pit" area reduced the level to approximately 10 μR/hr. The exposure rate generally ranged from less than 10 to 20 μR/hr. Of particular interest was an aircraft decontamination pad adjacent to the parking apron of the airstrip which bisects the island. Surveys of this area showed background levels to be less than 20 μR/hr for all exterior surfaces. The interior of the drain measured approximately 50 μR/hr.

Thirteen cable spools, giving a combined contact reading of 200 μR/hr, represented the only radioactive scrap located on the island. These were removed and disposed of at sea.

[redacted] 5009031

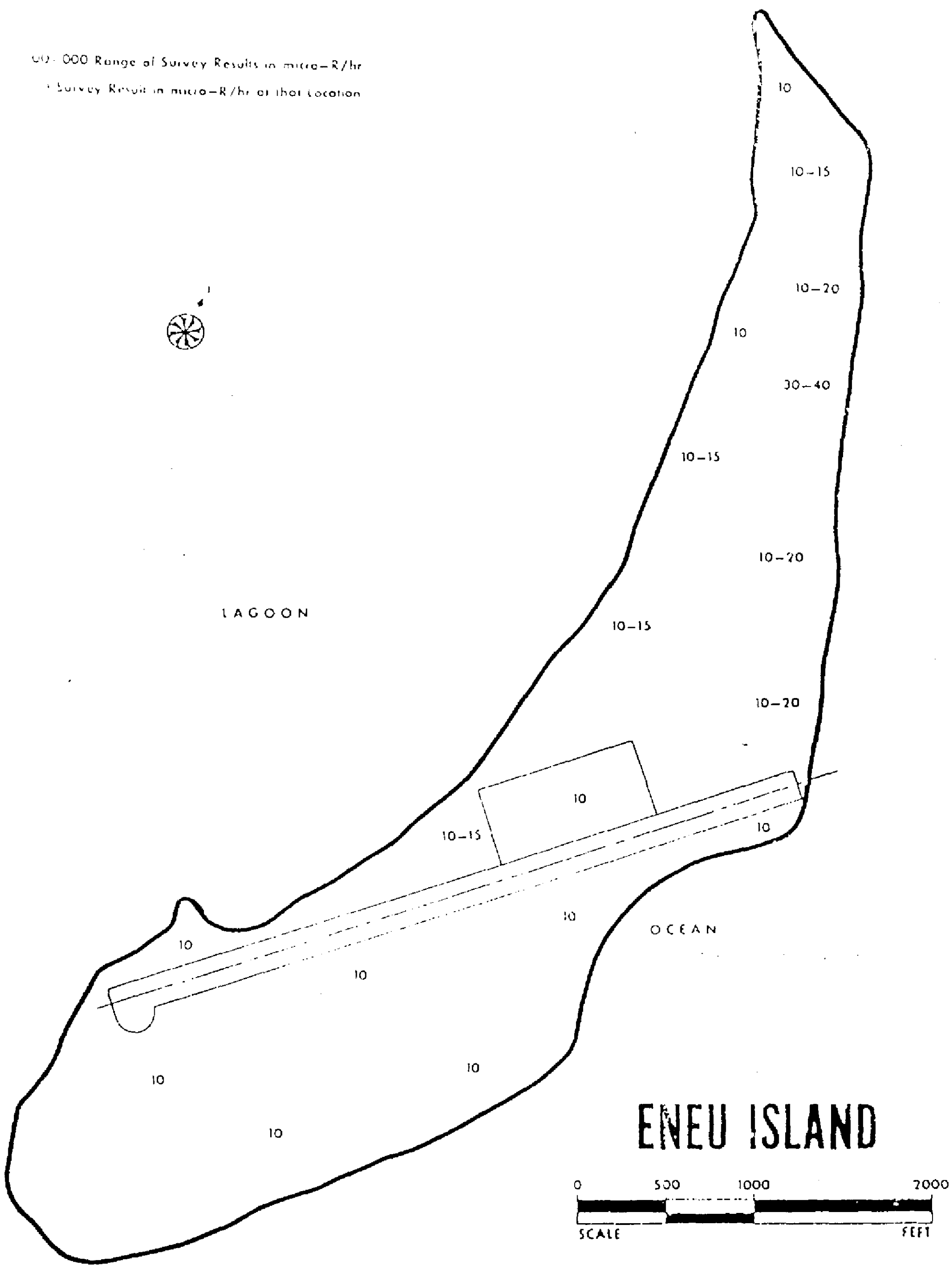


Figure 3. Eneu Island — Background Radiation Survey Results

[redacted] 5009032

The areas southeast and northwest of the runway were stripped for planting in the same manner as Bikini.

Coconut, arrowroot, and pandanus samples were collected and analyzed (Table 2). In addition, coconut crabs and marine life were sampled by the Laboratory of Radiation Ecology of the University of Washington.

Table 2. Mean ^{137}Cs and ^{90}Sr Concentration in Food from Eneu Island (pCi/g wet weight)

Sample	^{137}Cs	^{90}Sr	^{137}Cs-1967*
Coconut meat	21	.08	28 ± 0.42
Coconut milk	23		
Pandanus	87		14 ± 0.24
Arrowroot†	0.7	0.4	

*Data from reference number 2.

†Prepared by grinding, rinsing three times with salt water and once with fresh water. (Marshallese method of preparation)

OBOE (AEROKOJ) - TARE (ENEMAN) COMPLEX

Located on the southern side of the atoll, this complex consists of five islands, Aerokoj, Aerokojlol, Bikdrin, Lele, and Eneman with man-made causeways connecting Bikdrin to the islands on each side of it.

OBOE (AEROKOJ) - PETER (AEROKOJLOL) - ROGER (BIKDRIN)

As indicated by Figure 4 the first two islands are contiguous and are connected to Bikdrin (Figure 5) by a causeway. The measured background gamma radiation levels were 10 μR/hr or less over all of these islands. No radioactive scrap reading in excess of 30 μR/hr was found on the land or reef areas near these islands. Gamma spectroscopy showed ^{60}Co to be the contaminating radionuclide in the few pieces of scrap metal found.

The only coconut trees on the complex were found on the east end of Aerokoj. No pandanus or arrowroot was found.

[redacted]

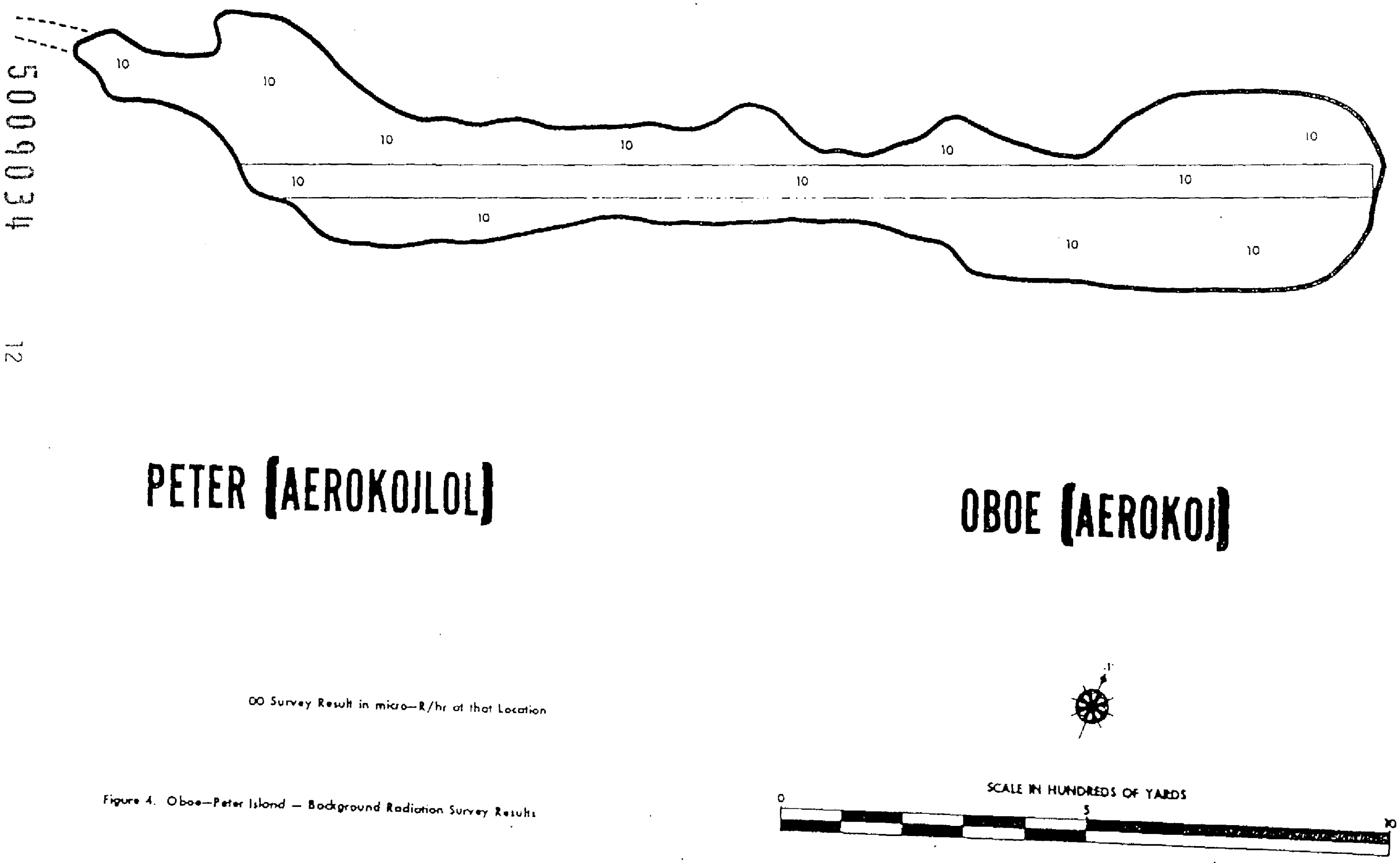
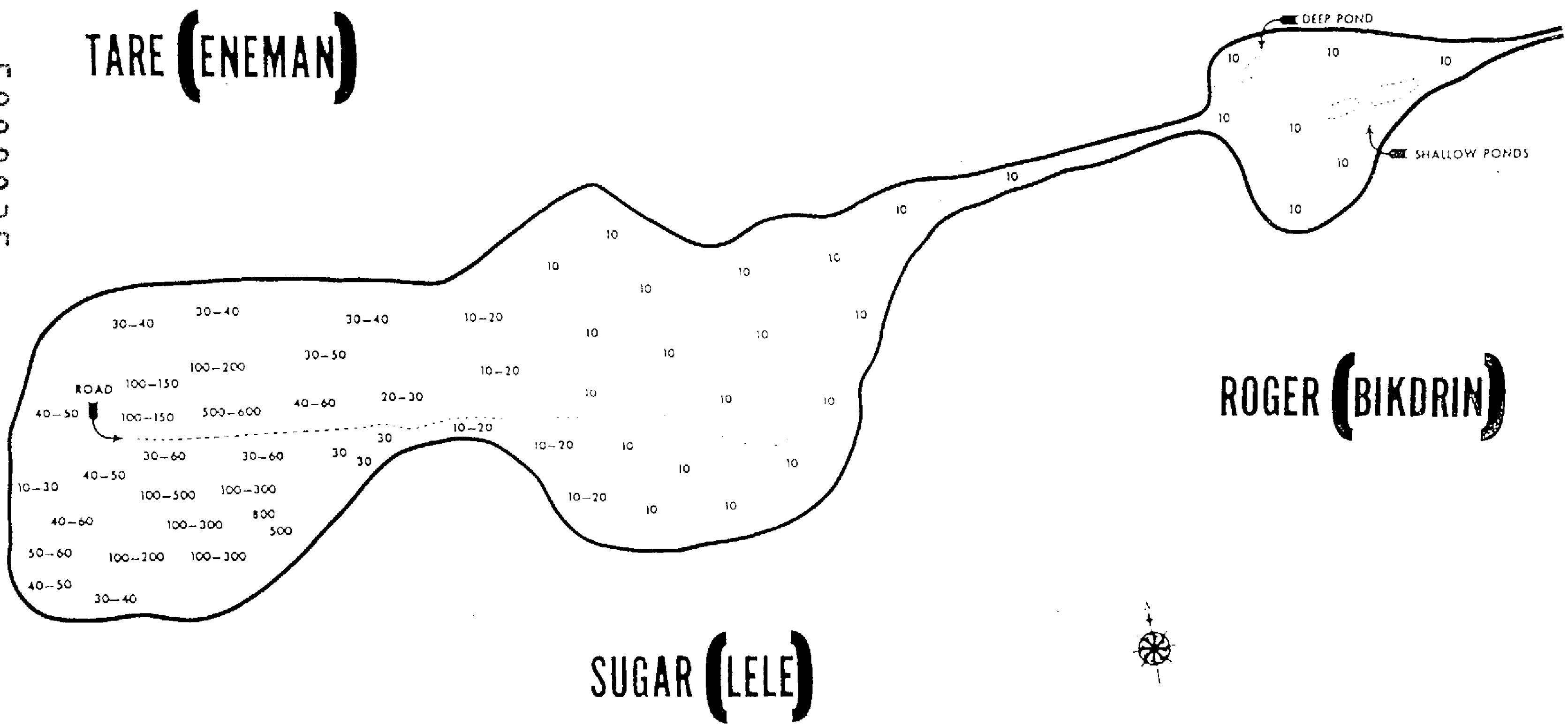


Figure 4. Oboe—Peter Island — Background Radiation Survey Results

5009034



00–000 Range of Survey Results in micro–R/hr
00 Survey Result in micro–R/hr at that Location

SCALE IN YARDS
0 750 1500

Figure 5. Roger–Sugar–Tare Islands – Background Radiation Survey Results

Table 3. Mean ^{137}Cs and ^{90}Sr Concentration in Aerokoj Coconuts (pCi/g wet weight)

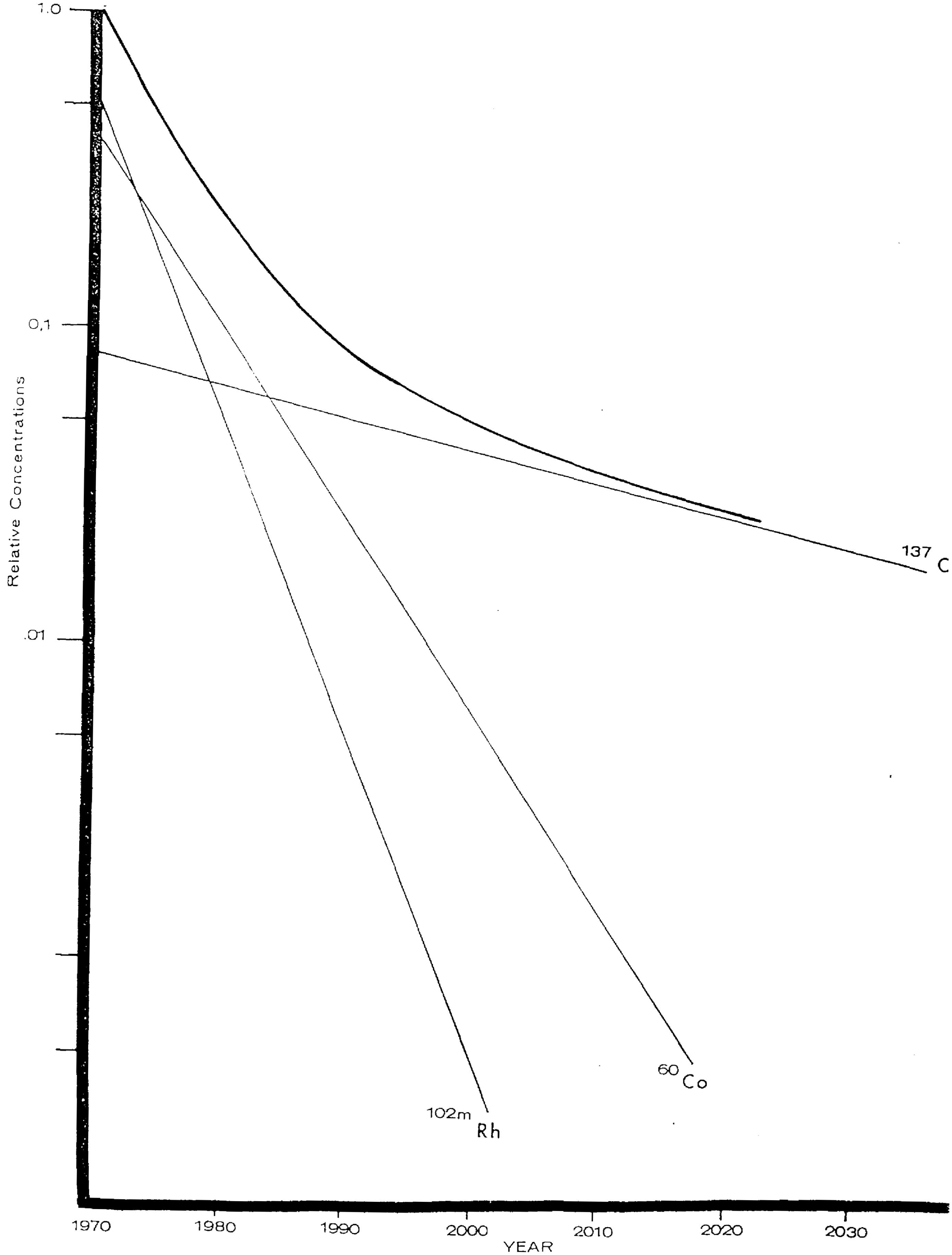
Sample	^{137}Cs	^{90}Sr
Meat	2.6	0.009
Milk	3.0	

SUGAR (LELE) AND TARE (ENEMAN)

For all practical purposes these are one island, although marked differences in background levels are seen between the east and west ends (Figure 5).

Several nuclear detonations occurred on the west end of Eneman which as a result is only about half its original size.

Soil samples were taken at four locations on Eneman where measured backgrounds were 60, 100, 250, and 500 μR/hr respectively. Each sample represented approximately one square foot to a depth of one to two inches. Three main contributors to the gamma exposure rate were identified: ^{60}Co, ^{137}Cs, and ^{102m}Rh. Although the ^{102m}Rh component of the gamma spectrum probably contained some ^{106}Ru-Rh, the concentrations were calculated assuming only ^{102m}Rh to be present. A wide variation in the relative amount of ^{137}Cs was seen, but in general the amounts varied inversely with the background exposure rates. Figure 6 shows the projected decay of the sample taken in the 500 μR/hr background area. The relative amounts of each nuclide are indicated at T_o (July 1969). Figure 7 gives the projected exposure rate as a function of time. Two of the samples were also analyzed by radiochemical methods for alpha emitting nuclides (Table 4).



[redacted] Figure 6. Tare Soil — Composite Decay Projection

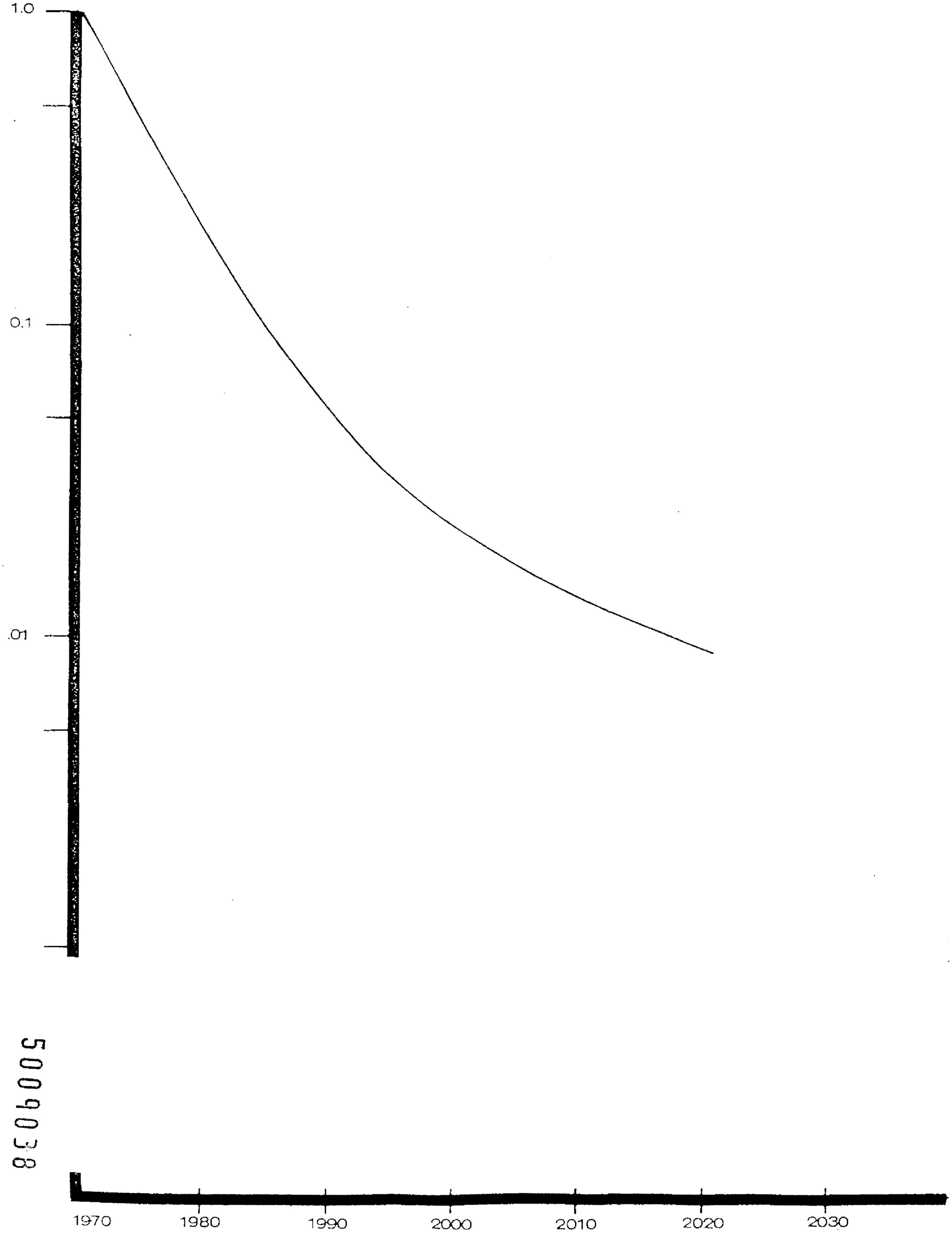


Figure 7. Tare — Projected Exposure Rate Reduction

Table 4. Alpha Emitting Nuclides in Soil - Eneman (pCi/g air-dried weight)

Nuclide	100 μR/hr area	500 μR/hr area
$^{239, 240}Pu$	27	410
^{238}Pu	11	220
^{241}Am	2	40

UNCLE (ENIDRIK)

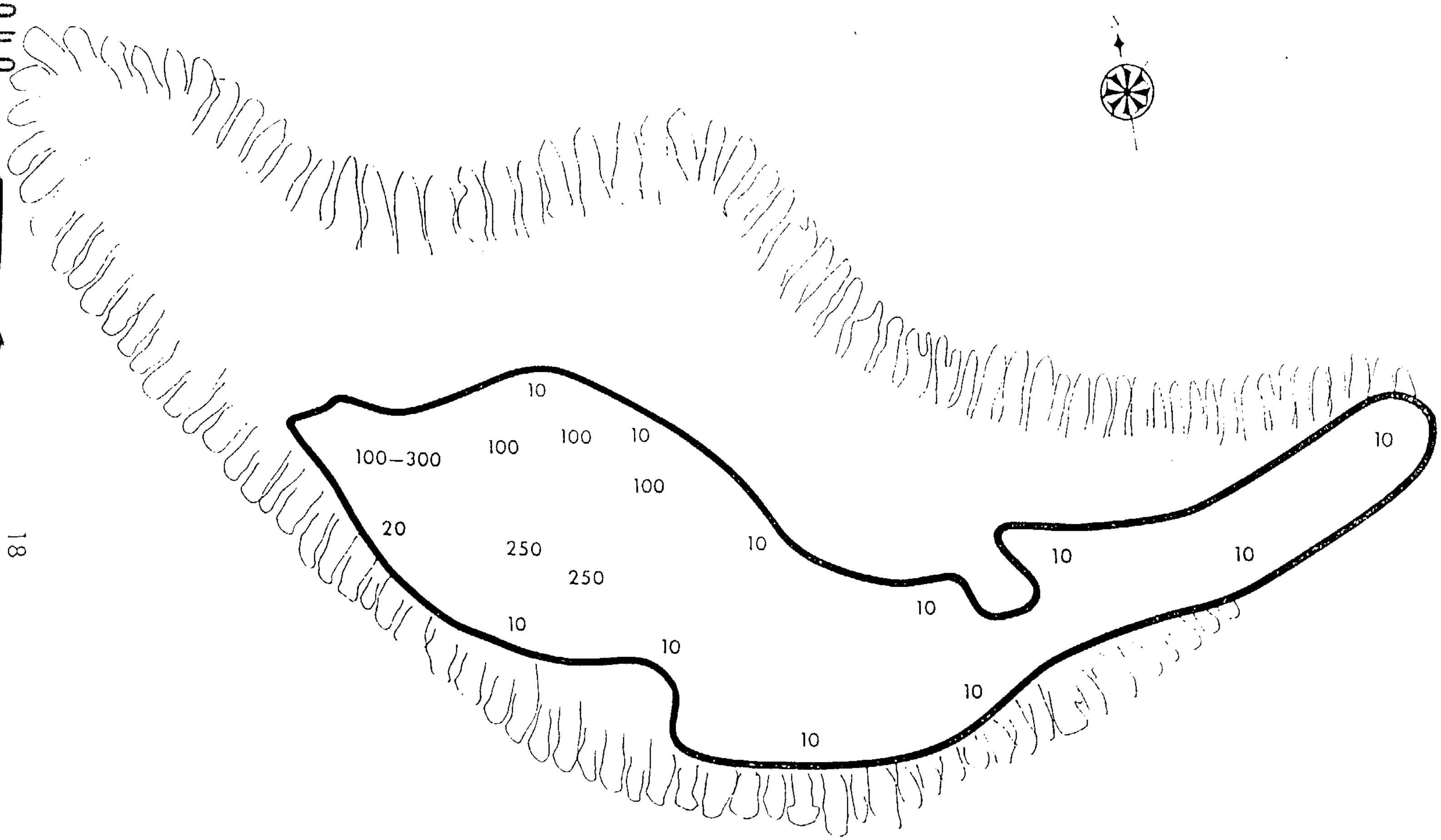
The island of Enidrik is located west of Eneman on the southern rim of the atoll (Figure 8). The northwest end of the island is heavily vegetated and showed background radiation levels of 100 to 300 μR/hr over most of the area.

The central portion of the island consists of coral rubble overgrown by ipomoea vines and the background radiation levels are generally 10 μR/hr or less. Progressing toward the narrow eastern end of the island the vegetative cover remains thin. Two large sandy areas, devoid of vegetation, dominate this end. Background levels remain at 10 μR/hr or less over the great majority of the eastern end.

No coconut trees were found on the island. A few scattered mature pandanus were seen, and one small grove of immature pandanus was located on the western end. One arrowroot sample was taken at this last location where the background was 250 μR/hr. The ^{137}Cs concentration in the arrowroot was 0.2 pCi/g (wet weight) after processing as previously described.

A soil sample taken in a 300 μR/hr area showed ^{102m}Rh, ^{137}Cs, and ^{60}Co to be the major gamma emitting contaminants (78%, 14%, and 8% respectively by concentration).

Only a few pieces of radioactive debris were found and these were removed for burial at sea.



UNCLE (ENIDRIK)

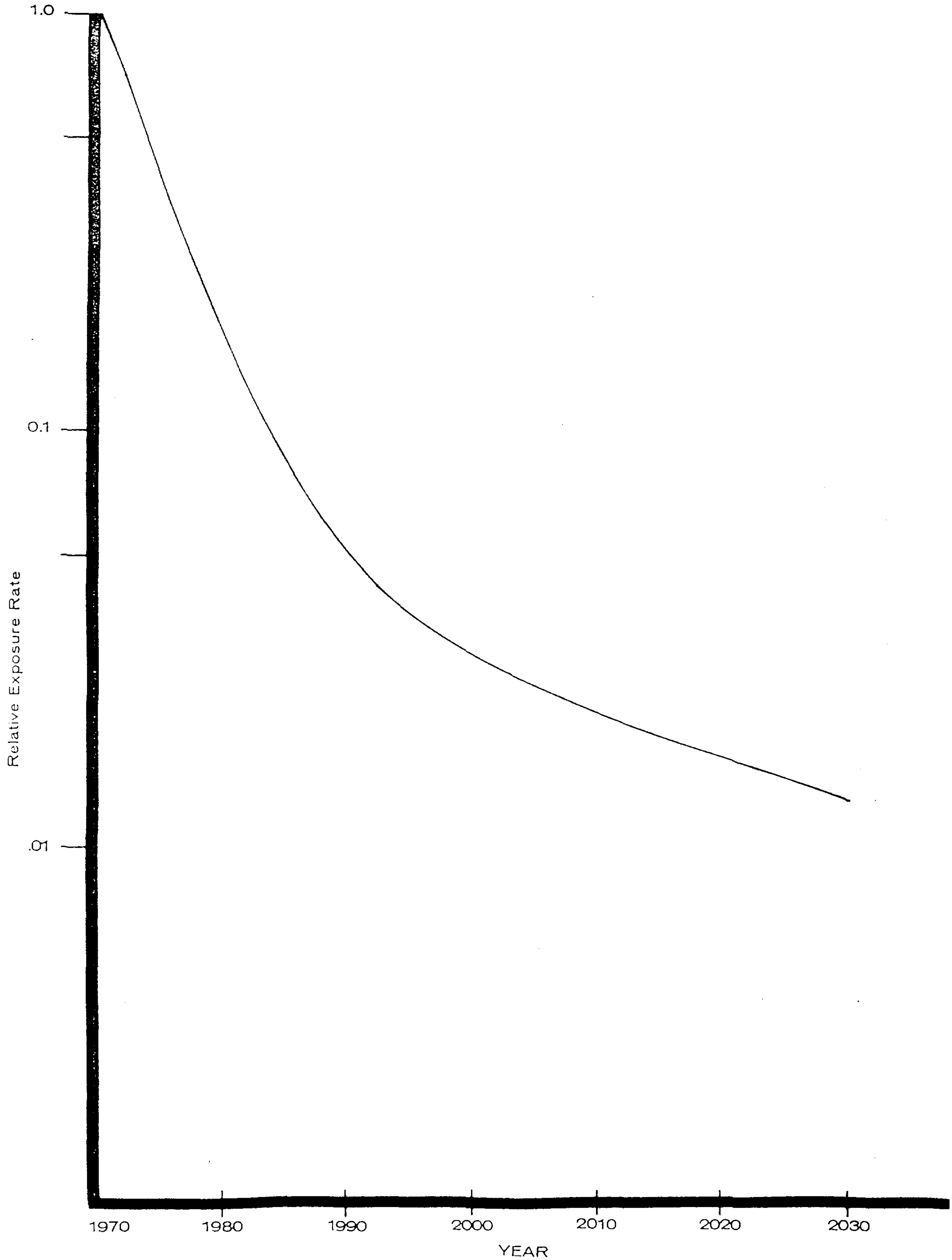
SCALE IN THOUSANDS OF YARDS

0 1 2

00–000 Range of Survey Results in micro–R/hr

00 Survey Results in micro–R/hr at that Location

Figure 8. Uncle Island — Background Radiation Survey Results



[redacted]

Figure 9. Uncle — Projected Exposure Rate Reduction

VICTOR (LUKOJ) AND WILLIAM (JELETE)

These two adjacent islands located at the southwest end of the atoll are very similar in vegetative cover and background radiation levels. In general, the background ranges from 10 to 180 μR/hr on Lukoj and 10 to 150 μR/hr on Jelete (see Figures 10 and 11). No radioactive debris was found on either island.

A soil sample taken on Jelete showed the primary contaminants to be ^{137}Cs (75%), ^{60}Co (12.5%) and ^{102m}Rh (12.5%). Figure 12 indicates the projected exposure rate reduction based upon these percentages. This sample also contained 82 pCi/g of ^{239,240}Pu and 42 pCi/g of ^{238}Pu (air-dried weight).

There are few coconut trees on either island. A single sample from Jelete gave the concentration of ^{137}Cs to be 5.4 pCi/g wet weight.

YOKE (ADRIKAN), ZEBRA (OROKEN), ALPHA (BOKAETOKTOK), AND BRAVO (BOKDROLUL)

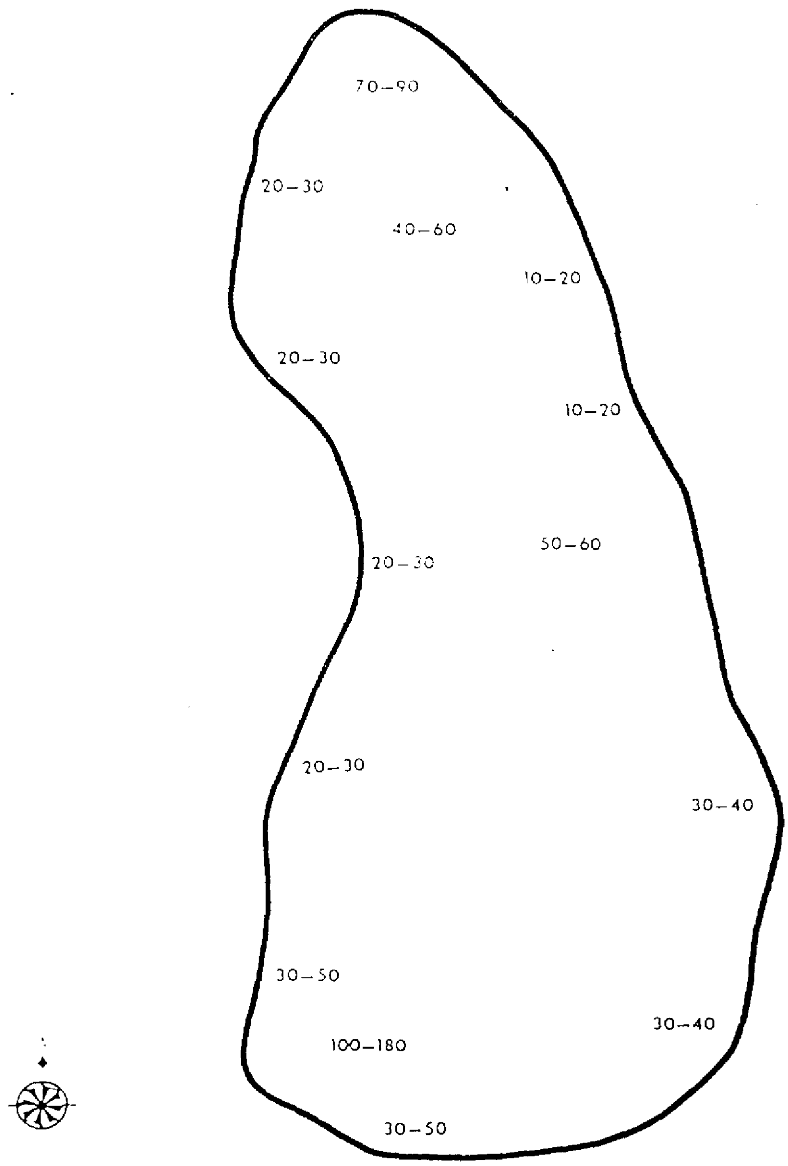
These four small islands located along the western side of the atoll displayed uniformly low levels of background radiation. Maximum exposure rates due to gamma radiation were:

- Adrikan - 50 μR/hr
- Oroken - 30 μR/hr
- Bokaetoktok - 15 μR/hr
- Bokdrolul - 25 μR/hr

No radioactive scrap was encountered on any of these islands. Traditionally the islands are used by the Bikinians for the collection of birds and eggs which are abundant. Samples of birds, eggs, and crabs have been collected by the Laboratory of Radiation Ecology, School of Fisheries, University of Washington.

Two soil samples taken on Oroken in the same location indicate ^{137}Cs to be 20-25% by concentration of the gamma emitting radionuclides. One sample (surface to one inch deep) showed ^{125}Sb to be about 75% of the total and ^{60}Co about 5%, while in the other (one inch to six inches in depth) ^{125}Sb was not detectable by gamma spectroscopy, ^{60}Co contributed about 50% and ^{102m}Rh the remaining 25%.

VICTOR (LUKOJ)



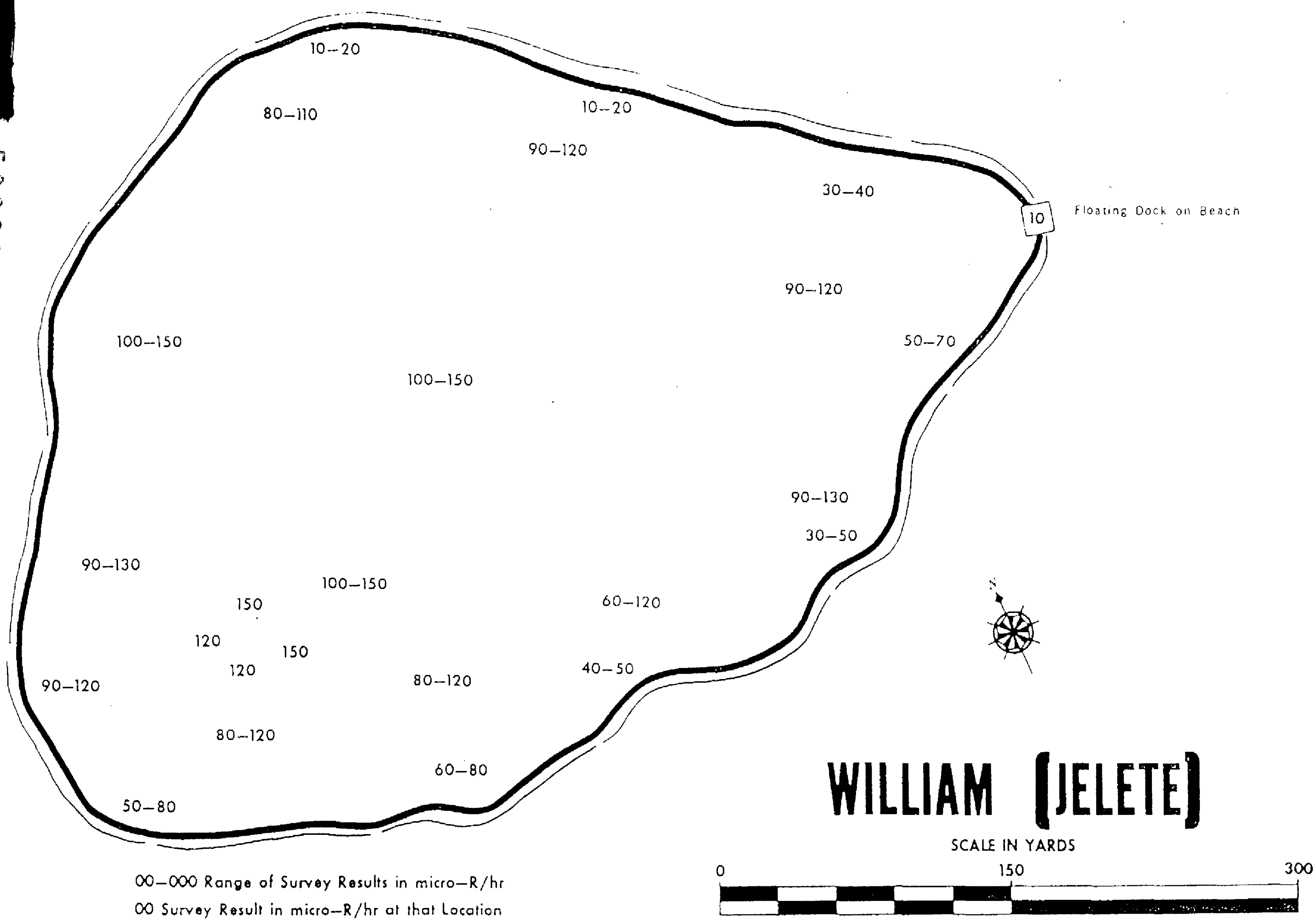
00–000 Range of Survey Results in micro–R/hr

SCALE IN YARDS
0 250 500

5009043

[redacted]

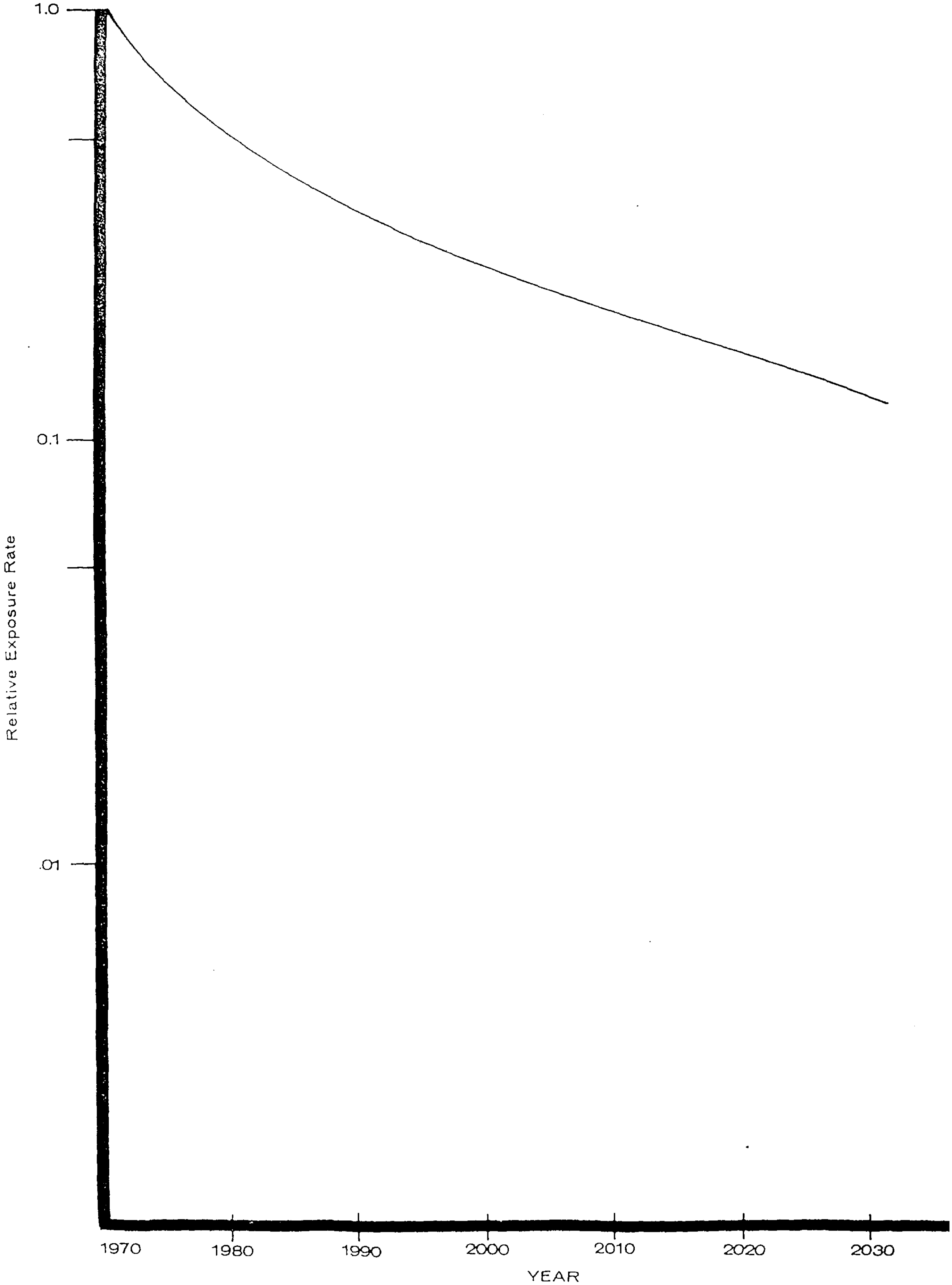
Figure 10. Victor Island – Background Radiation Survey Results



00–000 Range of Survey Results in micro–R/hr

00 Survey Result in micro–R/hr at that Location

Figure 11. William Island – Background Radiation Survey Results



5009045

Figure 12. William — Projected Exposure Rate Reduction

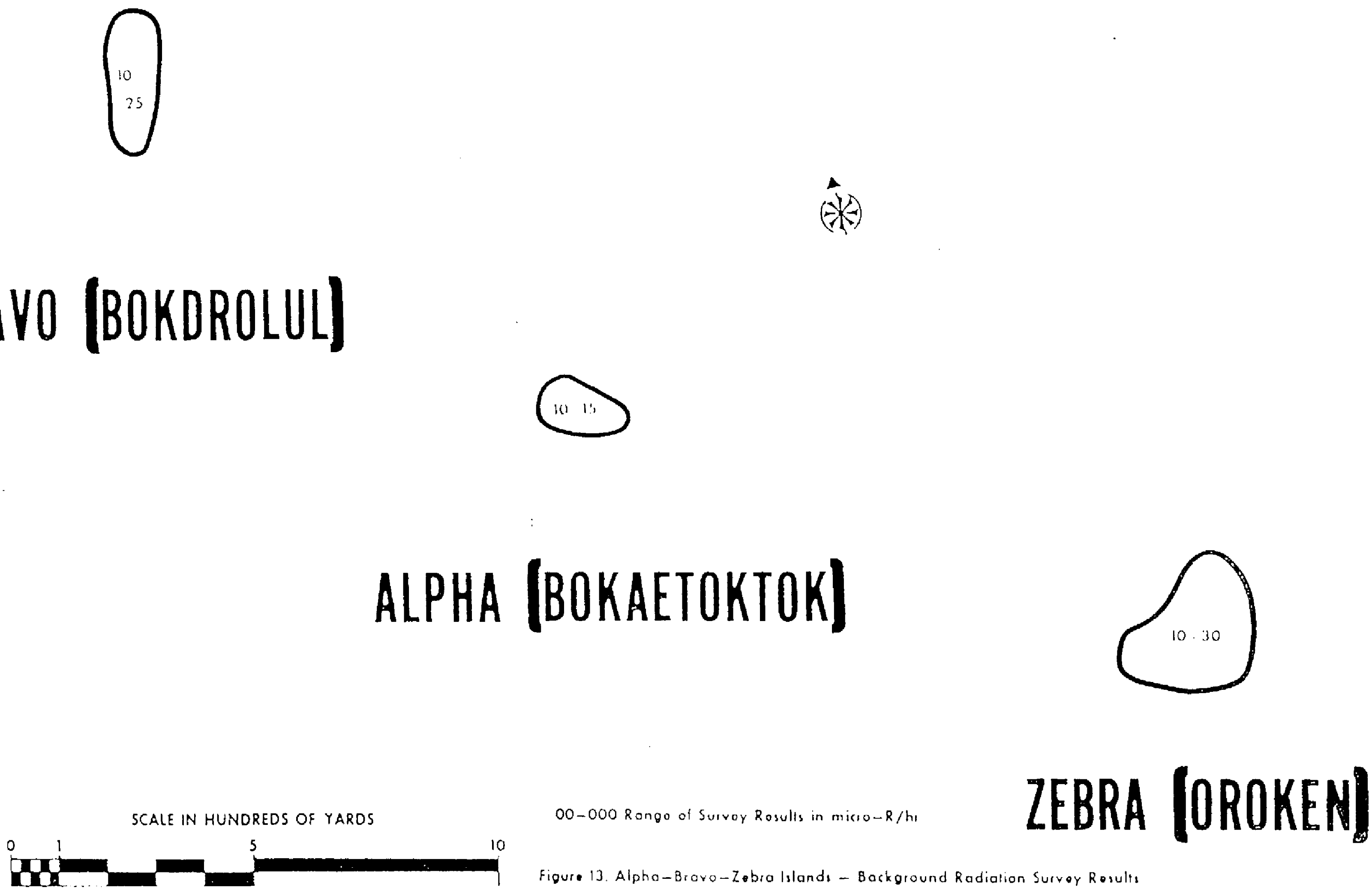


Figure 13. Alpha–Bravo–Zebra Islands – Background Radiation Survey Results

A single soil sample from Bokdrolul showed approximately 85% ^{137}Cs and 15% ^{60}Co.

No edible plants were found on any of these islands.

Since the maximum exposure rate found for this group was 50 μR/hr, the exposure rate reductions were not projected.

CHARLIE (NAM)

As indicated by Figure 14, the external radiation levels on Nam, located in the northwest corner of the atoll, are slightly higher than those on Bikini with one "hot spot" of 500 μR/hr found near the northwest side of the island. A single soil sample taken in a background area of approximately 200 μR/hr showed the concentration of gamma emitting nuclides to be composed of about 50% ^{137}Cs, 33% ^{60}Co, and 17% ^{125}Sb. The exposure rate reduction as a function of time for this composition is given in Figure 15.

Radioactive scrap was found at several locations on the island. The maximum reading obtained on any piece of scrap was 500 μR/hr. All radioactive scrap reading in excess of 100 μR/hr (gamma) was buried at sea. Less radioactive material was buried on land with the non-radioactive debris.

Although this is the third largest island and one which had been previously utilized as a source of food materials by the Bikinians, there are at present no edible land plants or coconut crabs on the island.

A sample of fresh water from Nam, taken in 1964 and supplied to WERL by the Laboratory for Radiation Ecology, contained 15 pCi of ^{3}H/ml. Tritium levels in all other water samples from various islands were less than 0.4 pCi/ml.

A sample from a Portulaca plant (high water content) taken in June 1969 contained 1.5 pCi of ^{3}H/ml of extracted water. The concentration of ^{137}Cs in the plant material was 210 pCi/g and of ^{60}Co was 3.8 pCi/g wet weight.

[redacted] 5009041

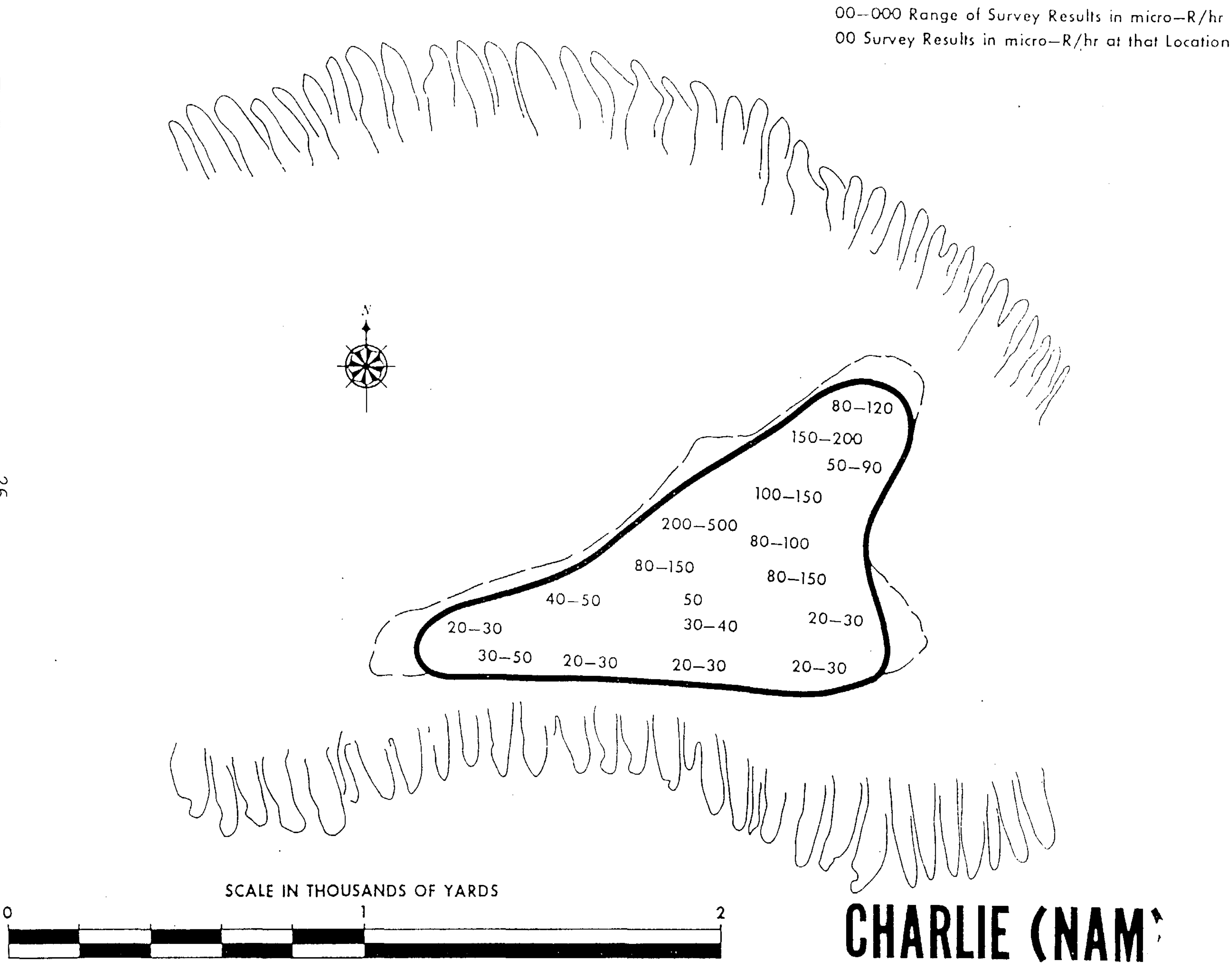
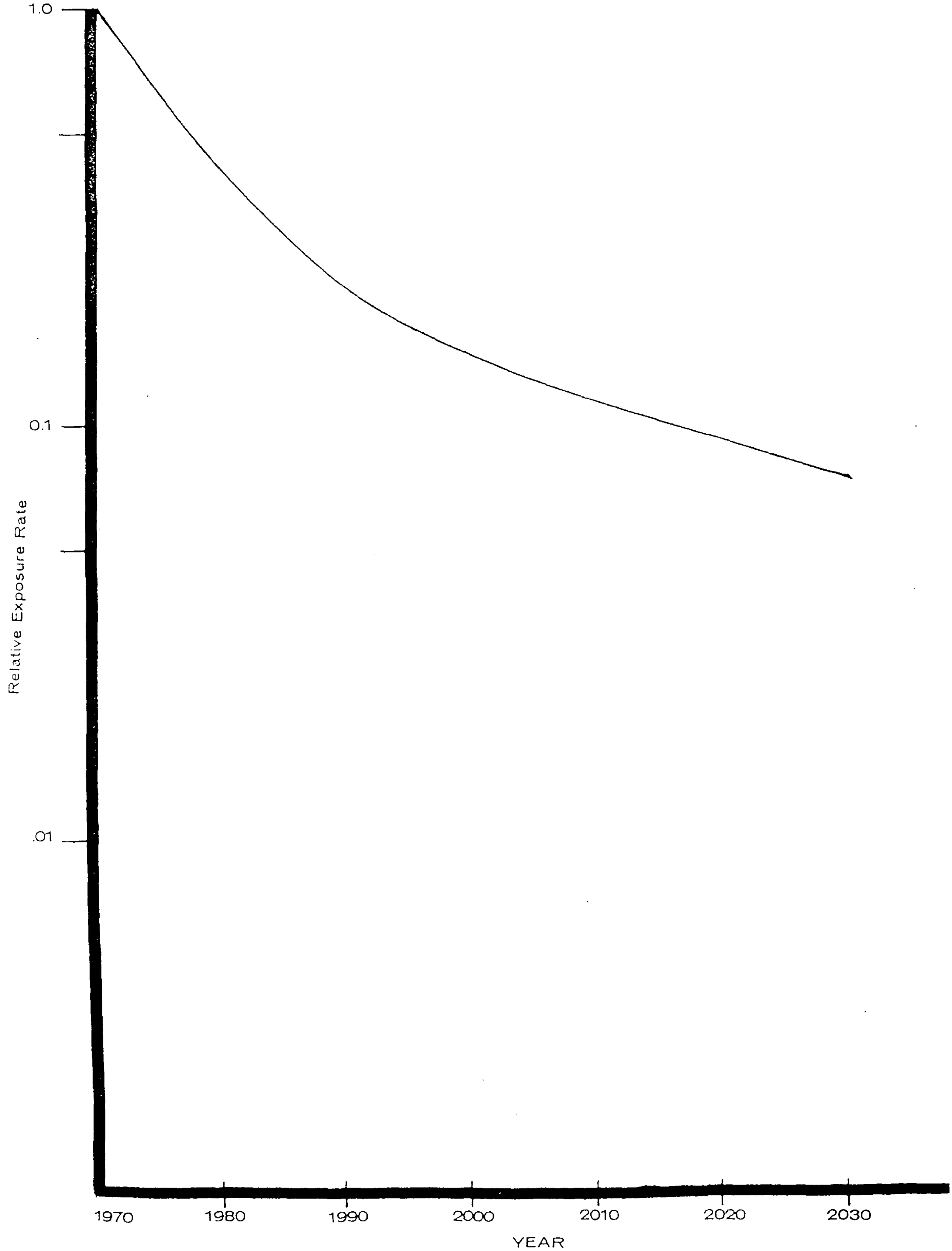


Figure 14. Charlie Island -- Background Radiation Survey Results

5009048



5009049

Figure 15. Charlie — Projected Exposure Rate Reduction

DOG (IROIJ), EASY (ODRIK), FOX (LOMILIK), AND GEORGE (AOMEN)

The northern complex of islands is shown in Figures 16 and 17. Iroij and Odrik are connected by a long man-made causeway, while Odrik is in turn connected to Lomilik by a shorter causeway. Lomilik and Aomen are differentiated only by a narrowing of the land mass.

Only Lomilik contained any significant amount of radioactive debris and displayed relatively high levels of external background. The maximum exposure rate due to soil contamination measured on each of these islands was:

Iroij - 40 μR/hr
Odrik - 10 μR/hr
Lomilik - 500 μR/hr
Aomen - 100 μR/hr

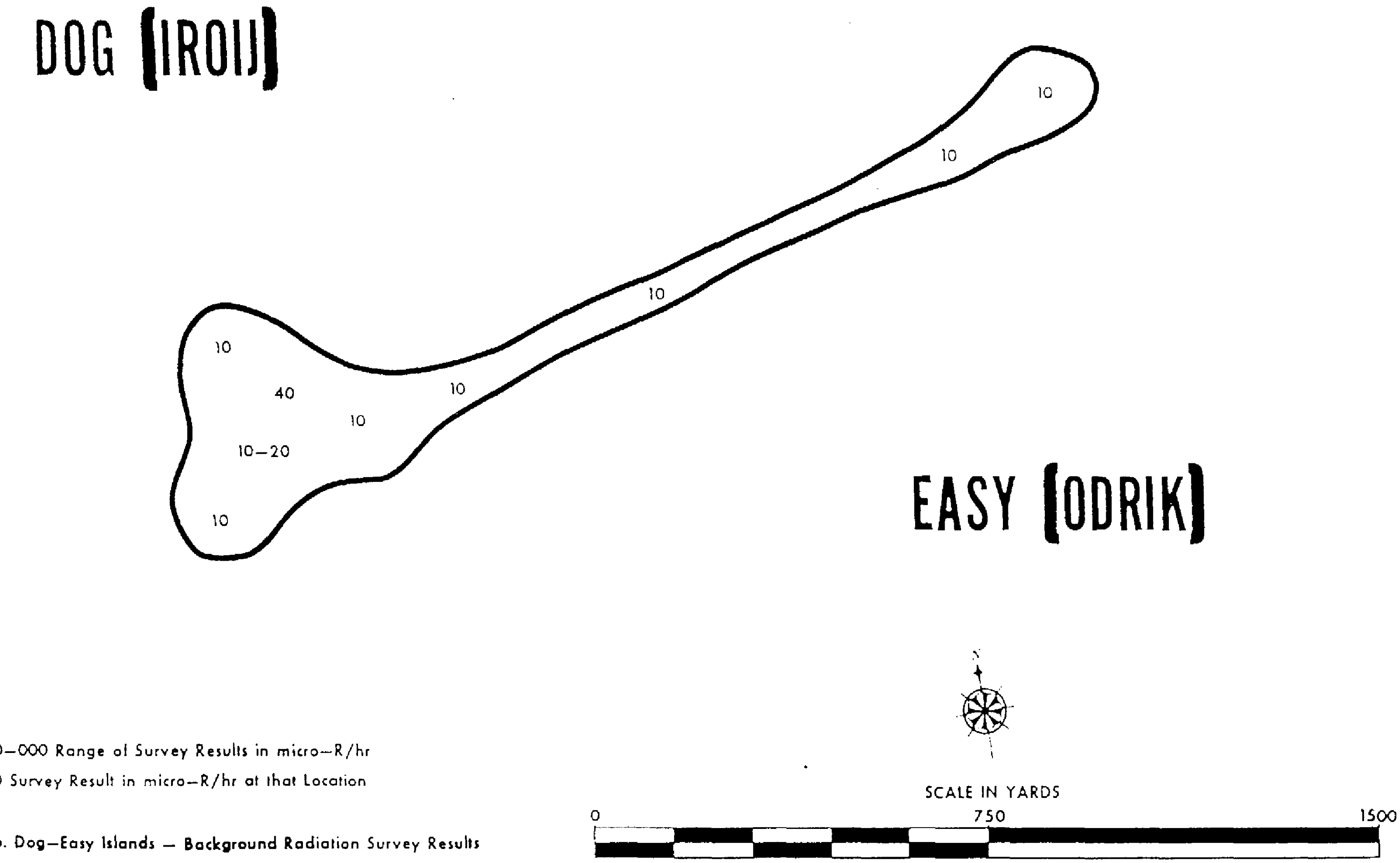
The debris from Iroij, Odrik, and Aomen was buried on land. A large amount of non-radioactive scrap was removed from the ocean reef on Aomen and also buried on land.

All radioactive metallic debris on Lomilik (maximum 500 μR/hr) was removed and buried at sea. Fragments of concrete from scientific installations, all of which measured less than 100 μR/hr, were buried on land.

One low lying, algae encrusted area on Lomilik showed background radiation levels of 500 μR/hr. A soil sample taken at this location contained approximately 55% ^{102m}Rh and 45% ^{60}Co as measured by gamma ray spectroscopy. The projected exposure rate reduction for this location is given by Figure 18. Since the absence of ^{137}Cs would indicate that this sample is atypical, a plot is also shown assuming that 20% of the total activity is due to ^{137}Cs and that the ^{102m}Rh and ^{60}Co retain their same relative concentrations. This might be more applicable to other locations on Lomilik.

Two concrete bunkers on Aomen had areas on the tops and sides which read 5-7,000 μR/hr ($\beta + \gamma$) at contact. The gamma exposure rate was less than 200 μR/hr. Since the potential for exposure to individuals from these sources was negligible, it was decided to leave the bunkers as typhoon shelters.

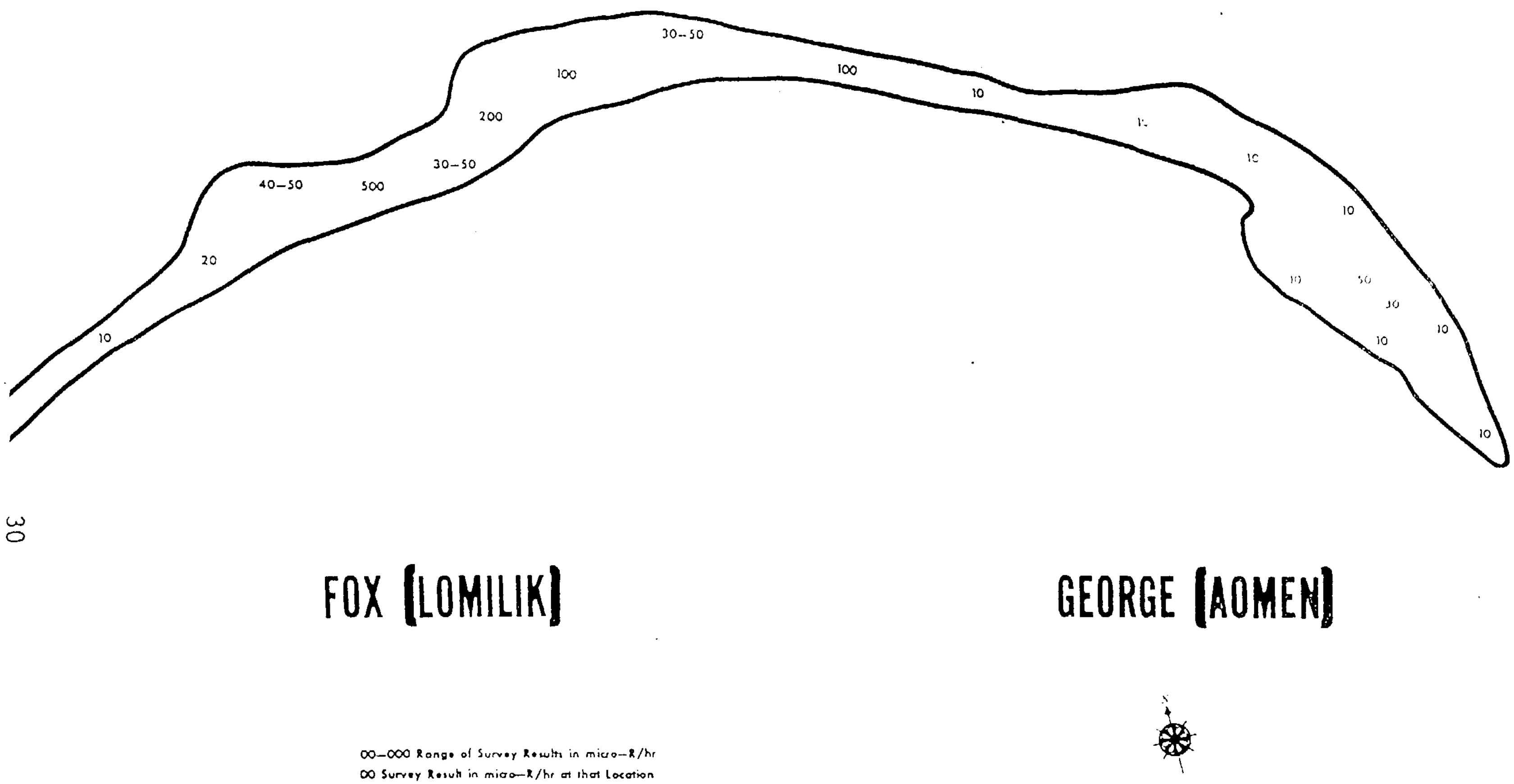
[redacted] 0009051



00–000 Range of Survey Results in micro–R/hr

00 Survey Result in micro–R/hr at that Location

Figure 16. Dog–Easy Islands – Background Radiation Survey Results



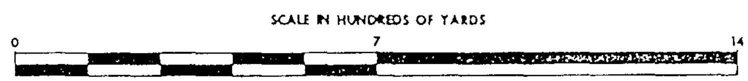


Figure 17. Fox—George Islands — Background Radiation Survey Results

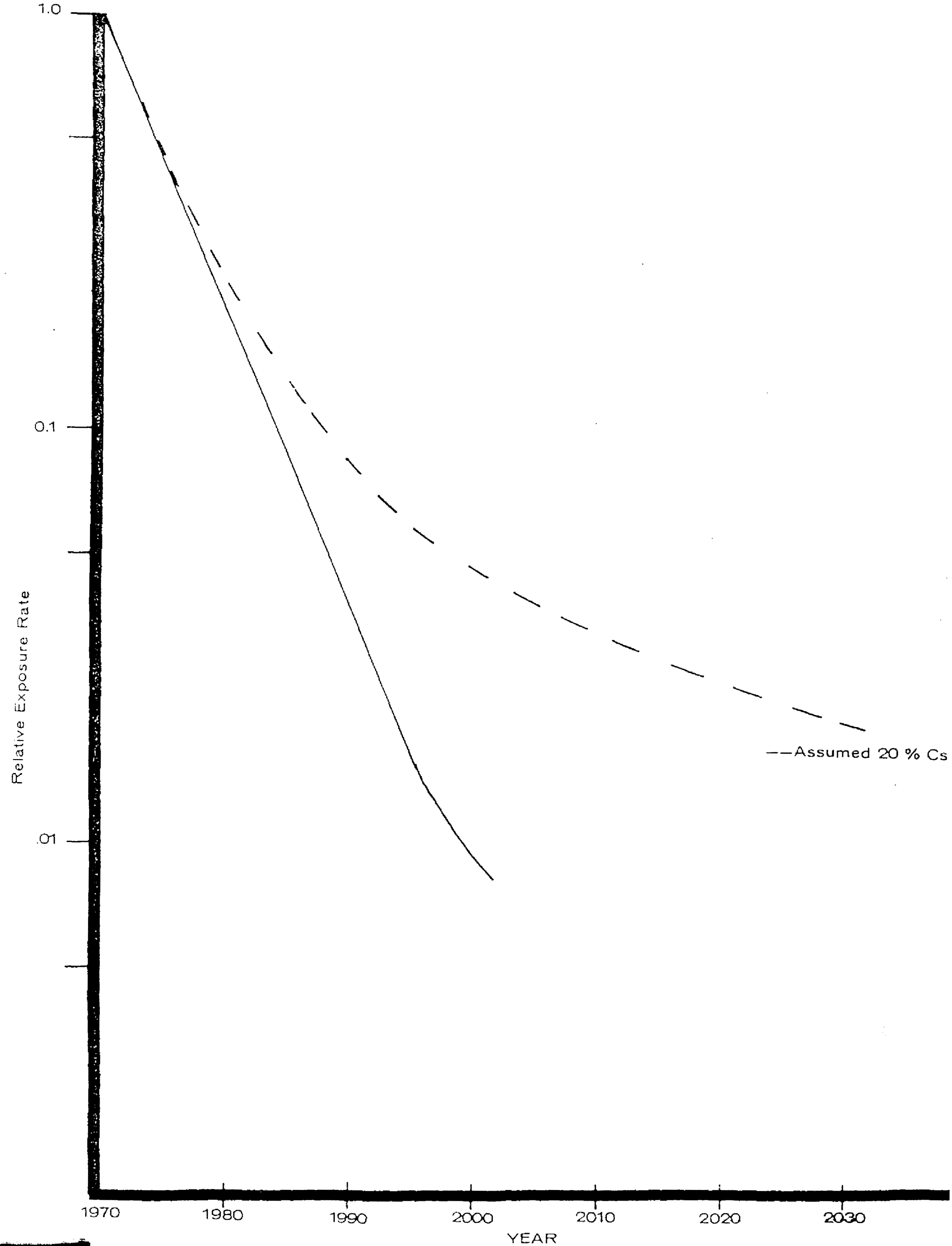


Figure 18. Fox — Projected Exposure Rate Reduction

[redacted]

5009053

No edible land plants were found on the complex.

REEF STRUCTURES

Several large structures, mostly reinforced concrete, constructed on the coral reef are found between Nam and Iroij and one is located near the sand bar, Bokbata, southwest of Nam. All of these structures were surveyed with the following results:

1. Able (Bokbata) Reef Structure - one small door and several metal pieces on reef 200-300 μR/hr. Remainder 5-40 μR/hr.

2. Charlie (Nam), Dog (Iroij) Reef Structure #1 - several small metal plates on top of concrete foundation 100-500 μR/hr (these are awash at high tide). Remainder 5-10 μR/hr.

   Structures #2 and #3 - all readings less than 10 μR/hr.

These structures were judged to constitute no radiological hazard and Trust Territory representatives assessed the physical hazard as insufficient to justify the costly and time consuming effort which would be required to remove them.

DOSE ASSESSMENT

The traditional living pattern of the Bikinians centers around communal life on the island of Bikini where the permanent village and social and religious centers were located. Temporary settlements were located on other islands, primarily Eneu. In view of the Ad Hoc Committee's recommendation to limit initial resettlement to these two islands, it is assumed that the doses received from brief visits to other islands in the Atoll will be small relative to that received from residence on Bikini. In addition the uniformly low exposure rates encountered on Eneu represented a potential exposure which is negligible even for continuous occupancy. For this reason, the treatment of dose considerations will be limited to the island of Bikini.

EXTERNAL DOSE ASSESSMENT

As indicated previously the island of Bikini was extensively monitored with portable gamma survey meters. Because the soil samples indicated

[redacted]

a large abundance of ^{137}Cs relative to other gamma emitting nuclides no effort was made to correct the readings obtained from the scintillators which were calibrated against ^{137}Cs.

The islands can be divided into essentially three domains:

1. Beach Area - uniformly low background of approximately 10 μR/hr.

2. Village Area - located along lagoon side of the island. For purposes of this report two sets of data were obtained:

   a. From lagoon road to approximately 250 feet inland the mean background was 52 μR/hr.

   b. From lagoon road to beach - 35 μR/hr. Considering these two areas together the mean background would be 44 μR/hr.

3. Interior - used for agriculture. This was considered to include the area within the perimeter road, excluding the village area. The mean background was 86 μR/hr.

Experience obtained during the clearing operation indicates that total removal of the vegetative cover and turning of the soil as occurred during the grading of the perimeter and cross island roads results in a rapid reduction of the measured exposure rate. If it is assumed that the village area will be essentially cleared and covered with crushed coral as is customary, it would seem that an expected reduction of the mean exposure rate by a factor of two would be a conservative estimate.

Figures 19 and 20 show the integrated exposure for the village and interior areas. (The beach is assumed constant at <10 μR/hr). By making assumptions as to the residence time in each domain, the external gamma dose may be estimated.

If the following assumptions for residence time shown in Table 5 are taken, the integral (at any age) dose to children born on Bikini in 1970 would be the figures shown in Table 6.

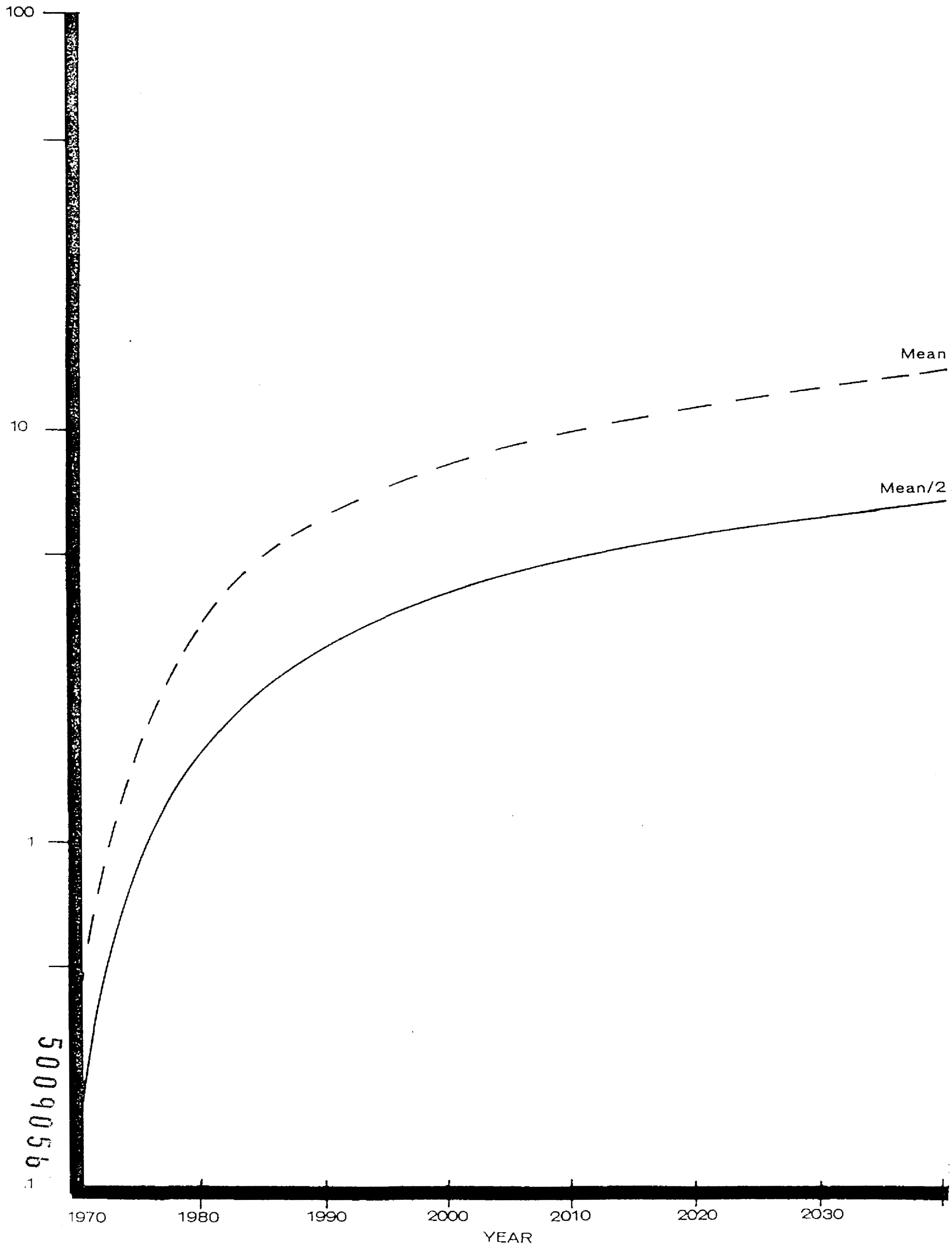
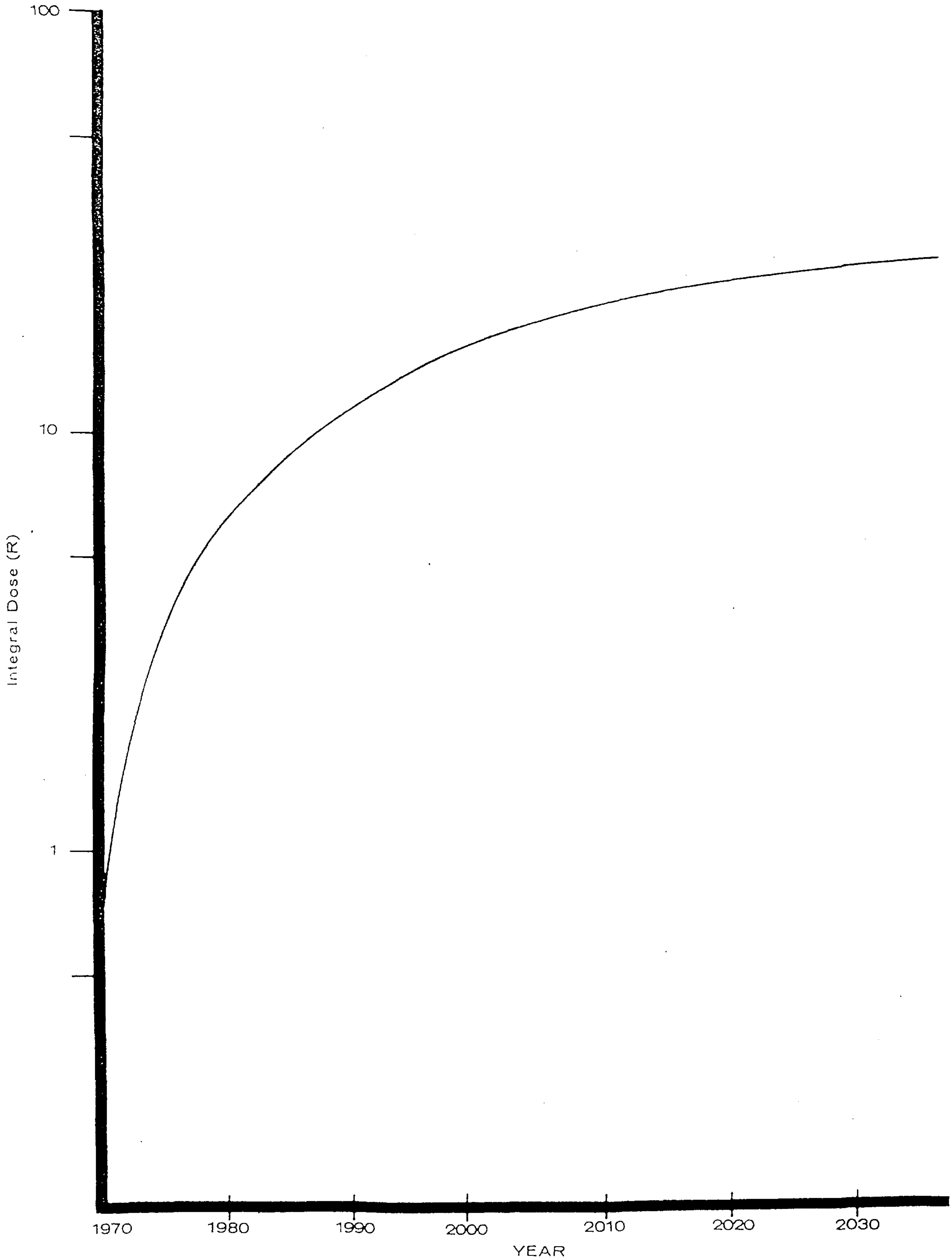


Figure 19. Bikini Integral Dose Projection — Village Area

[redacted]



[redacted]

Figure 20. Bikini Integral Dose Projection — Interior

Table 5. Estimate of Where Time Is Spent by Age.

Age	Beach	Percent Time Spent in Each Location		
		Village	Interior	Over Water
0-3	0	100	0	0
3-10	20	70	10	0
10-70	10	60	20	10

Table 6. Projected Integral Dose for A Child Born in 1970 (Bikini Island)

Time Interval (years)	Integral Dose (mRad)
5	750
10	1695
20	3545
30	5275
50	7735
70	9355

For purposes of the above calculation, the exposure rate on the beach was assumed constant at 10 μR/hr, on the water at 5 μR/hr, and for the village the modified (mean/2) exposure rate was used. It is felt that all of these estimates are conservative.

THERMOLUMINESCENT DOSIMETER PROGRAM

As a check on the validity of the gamma exposure rates as measured by survey meters, thermoluminescent dosimeters were placed at six locations on Eneu and twelve locations on Bikini. Three dosimeters were placed at each location and left for approximately thirty days. These dosimeters were then collected and shipped by air to WERL where they were read. One set of three dosimeters served as controls for each placement period. Survey meter readings at these locations ranged from essentially zero to ninety μR/hr. Because of the relatively large

[redacted] 5009058

contribution of the exposure in transit as compared to the exposure during the placement period, wide fluctuations in net exposure as measured by each of the three dosimeters at each location were noticed. However, a regression analysis was performed comparing survey meter readings to the mean TLD results at each location. The linear relationship between the two was described by:

$$TLD = -1.5 + 0.8 \text{ (survey meter)}$$

The correlation coefficient was 0.94 and the average error associated with the replicate TLD measurements was 35%.

Throughout this report survey meter readings as obtained in the field have been used. If it is assumed that the mean TLD value for each station is a more accurate representation of the exposure rate, then a further element of conservatism has been added to the external dose estimates which are based on survey meter readings.

AIR SAMPLING RESULTS

During May-June 1970 a joint AEC-U. of W.-WERL follow-up survev was conducted on Bikini and Eneu. The purpose of this survey was to determine the amounts of ^{239}Pu in the soil and air. WERL was responsible for the air sampling program.

The air sampler chosen for this effort was the Model 102 developed and used by Reynolds Electrical and Engineering Company at the AEC's Nevada Test Site. It was felt that the Model 102, which was designed for rugged outdoor use under extreme weather conditions, was well-suited for the Bikini operation. The sampler consisted of a constant-volume pump, belt-driven by a gasoline powered engine. The only adjustments necessary were to the carburetor for sea-level operation. All samplers were re-calibrated for flow-rate at Bikini and the calibration was checked frequently during the operation.

Four samplers were placed on Eneu, Figure 21, and five samplers on Bikini, Figure 22. Bikini No. 5 and Eneu No. 1 are considered to be background stations since they were located on the windward side of the respective islands, overlooking the beach. Air filters were exchanged every 24 hours for a period of 15 days on Eneu and 14 days on Bikini. Tables 7 and 8

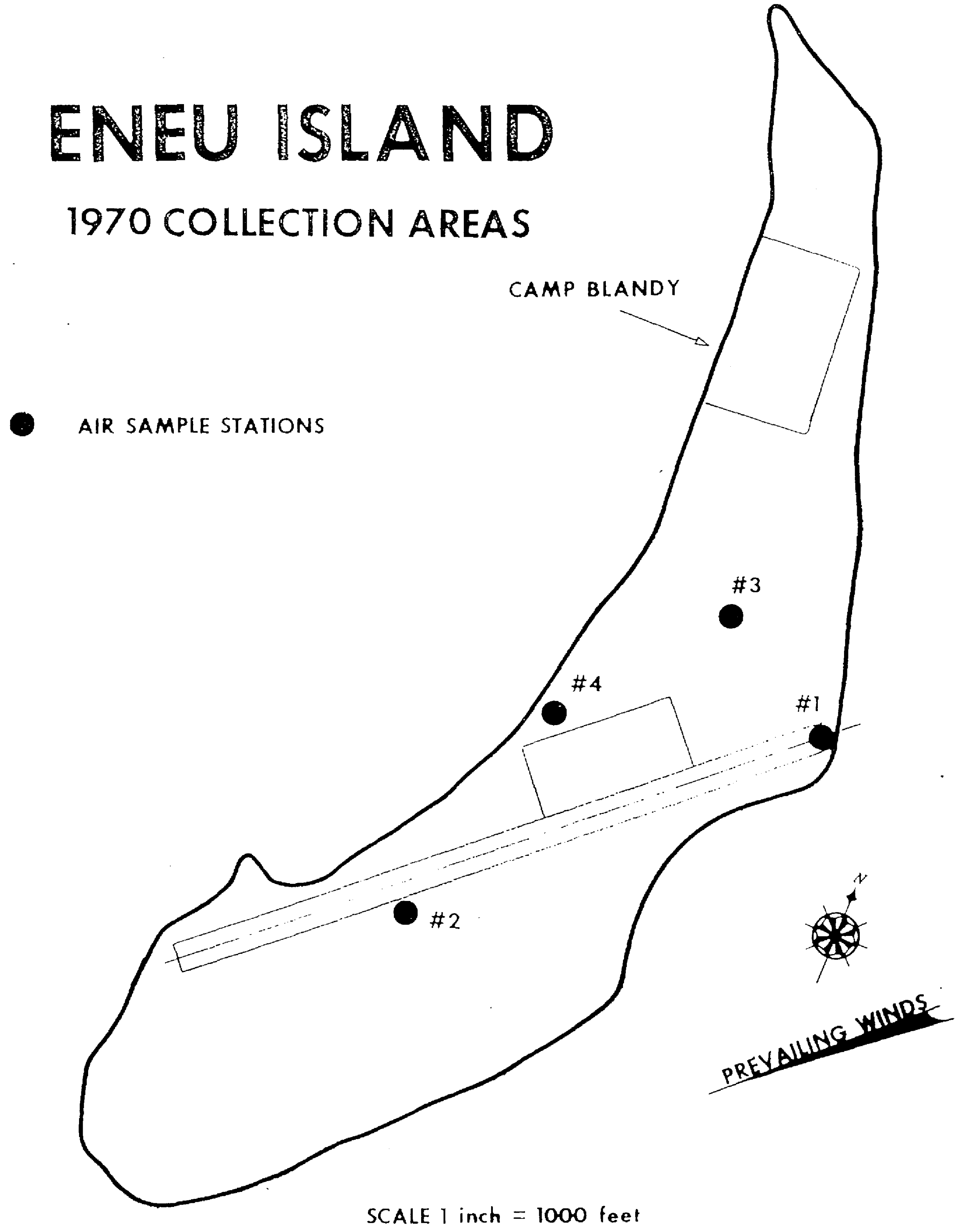


Figure 21. Eneu Island — Air Sampling Locations

[redacted] 5009060

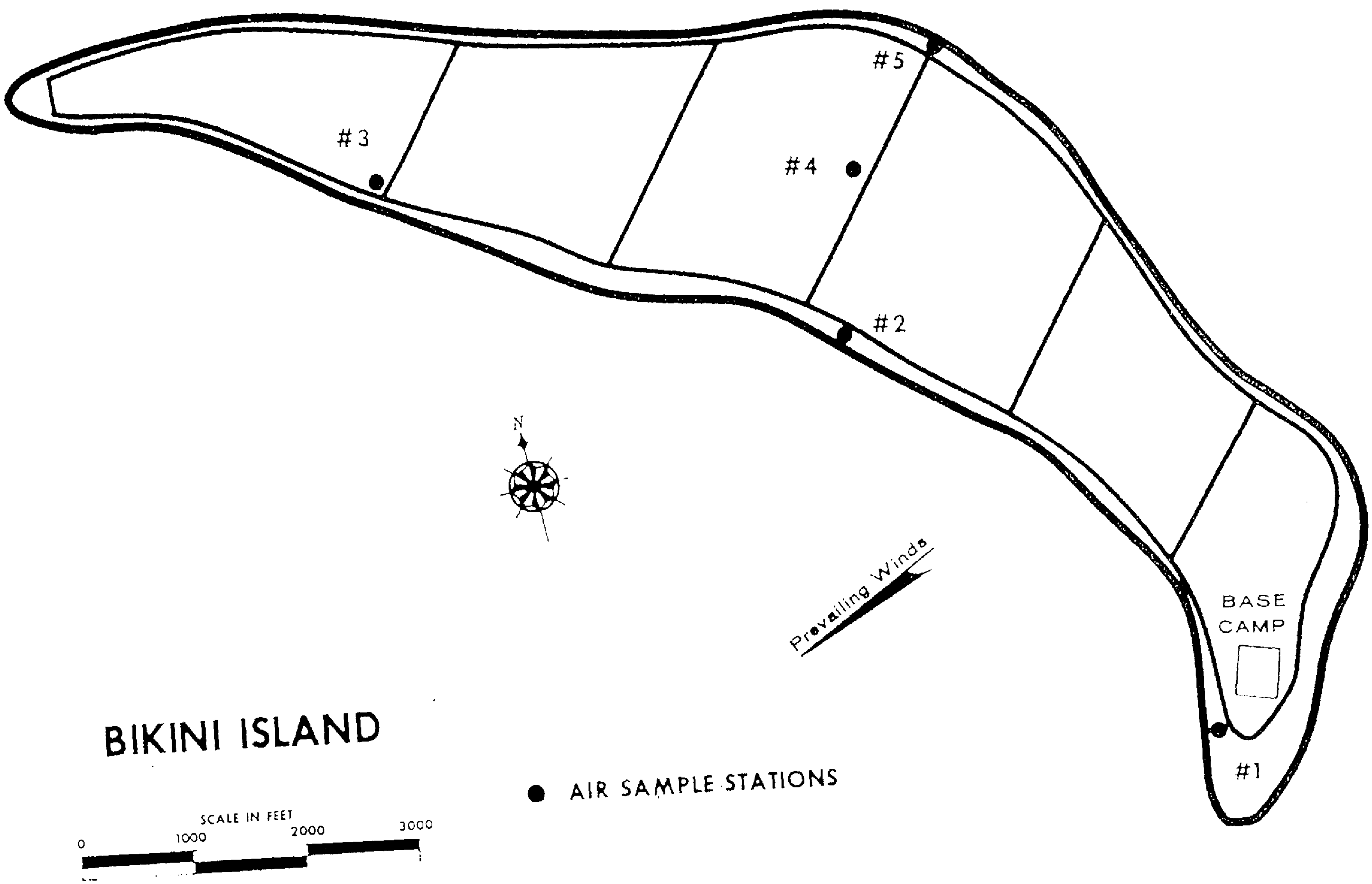


Figure 22. Bikini Island — Air Sampling Locations

Table 7. Composite ^{239}Pu in Air Results for Bikini Island - 1970

Station	Date	^{239}Pu (pCi/m^3)	^{238}Pu (pCi/m^3)
1	5/29 - 6/12	5.4×10^{-4}	$<0.1 \times 10^{-4}$
2	5/29 - 6/12	1.1×10^{-4}	$<0.1 \times 10^{-4}$
3	5/29 - 6/12	1.0×10^{-4}	0.1×10^{-4}
4	5/29 - 6/12	0.6×10^{-4}	$<0.1 \times 10^{-4}$
5	5/29 - 6/12	1.2×10^{-4}	0.1×10^{-4}

Table 8. Composite ^{239}Pu in Air Results for Eneu Island - 1970

Station	Date	^{239}Pu (pCi/m^3)	^{238}Pu (pCi/m^3)
1	5/28 - 6/12	0.4×10^{-4}	0.1×10^{-4}
2	5/28 - 6/12	0.4×10^{-4}	0.1×10^{-4}
3	5/28 - 6/12	0.4×10^{-4}	0.1×10^{-4}
4	6/2 - 6/12	0.4×10^{-4}	$<0.1 \times 10^{-4}$

list, respectively, the composite ^{239}Pu in air results for Bikini and Eneu. The composite results were obtained by analyzing one half of the filter for each day and compositing by station over the total sampling period. For Bikini the ^{239}Pu results ranged from 0.6×10^{-4} pCi/m^3 to 5.4×10^{-4} pCi/m^3. All results for Eneu were 0.4×10^{-4} pCi/m^3. For comparison the average value for ^{239}Pu background in the U.S. during 1968 was 0.4×10^{-4} pCi/m^3. In order to assess the daily variation in air concentration, the remaining one-half of the individual filters from station No. 1 on Bikini were analyzed separately. These results are listed in Table 9. The results ranged from $<0.7 \times 10^{-4}$ pCi/m^3 to 7.9×10^{-4} pCi/m^3. The average for all samples at this station is 4×10^{-4} pCi/m^3 which compares quite favorably with the value of 5.4×10^{-4} pCi/m^3 for the composite. Although some variation in daily levels is evident from these data, the distribution of results appears to be about what might be expected allowing for slight differences in wind conditions. It should be noted that station No. 1 is located on the downwind side of the lagoon road and was subjected to frequent clouds of dust stirred up by the survey party's jeep. In any event, it is doubtful that significantly higher concentrations would be encountered under normal weather conditions. Although it is assumed that the plutonium us present in the oxide form (incoluble), when comparison is made to the more stringent FRC guide for soluble plutonium of 6×10^{-2} pCi/m^3 for an individual in the population, the above results are lower than the guide by approximately two orders of magnitude. This is not meant to imply however, that unfavorable weather conditions sufficient to create Pu concentrations high enough to be of some radiological concern could not exist during other times of the year.

SUMMARY AND RECOMMENDATIONS

External radiation levels were measured on all islands of Bikini Atoll as part of the clean-up program. The highest exposure rate was measured on Tare(Eneman) where a low lying algae covered area showed 800 μR/hr. The maximum exposure rate encountered on the islands scheduled for rehabilitation, Bikini and Eneu, was 120 μR/hr in the interior of Bikini. Other islands exhibiting exposure rates greater than those found on Bikini were:

Uncle (Enidrik)	- 300 μR/hr
Victor (Lukoj)	- 180 μR/hr
William (Jelete)	- 150 μR/hr
Charlie (Nam)	- 500 μR/hr
Fox (Lomilik)	- 500 μR/hr

[redacted] 5009063

Table 9. Daily ^{239}Pu in Air Results for Station 1 Bikini Island - 1970

Date Collected	Hour	^{239}Pu (pCi/m^3)
5/30/70	1010	$<0.7 \times 10^{-4}$
5/31/70	1330	0.7×10^{-4}
6/01/70	0750	1.2×10^{-4}
6/02/70	0725	7.2×10^{-4}
6/03/70	0755	5.5×10^{-4}
6/04/70	0730	4.0×10^{-4}
6/05/70	0840	7.9×10^{-4}
6/06/70	0745	4.7×10^{-4}
6/07/70	0730	2.5×10^{-4}
6/08/70	0730	4.8×10^{-4}
6/08/70	2335*	6.1×10^{-4}
6/10/70	0700	1.2×10^{-4}
6/11/70	0700	2.6×10^{-4}
6/12/70	0955	4.0×10^{-4}

*Estimated time of sampler shutdown due to heavy rainstorm. Based on vibration hour meter.

Soil samples taken on Bikini showed greater than 95% of the exposure rate to be due to the ^{137}Cs and thus the reduction in exposure rate can be assumed to closely follow the decay of ^{137}Cs. Soil samples from the other islands showed varying amounts of ^{60}Co and ^{102m}Rh in addition to the ^{137}Cs. The reduction in exposure rate due to radioactive decay on these islands should be much more rapid than for Bikini. Comparing the decay curves for these islands with that for Bikini, it can be seen that within approximately ten to fifteen years only Eneman will have an external background higher than that of Bikini. It is recommended that a re-survey to verify this projection be conducted in about ten years in anticipation of unrestricted use of the atoll. In the meantime, the recommendation of the Ad Hoc Committee that occupancy of the above islands be limited to visits of short duration should be followed.

The remaining islands of the atoll are lower in radiation levels than Bikini and should not be restricted against continuous occupancy on that basis. This is particularly true of the Oboe (Aerokoj), Peter (Aerokojlul), Roger (Bikdrin) complex where the lowest levels on the atoll were found. In addition, coconut samples from Aerokoj were lower in ^{137}Cs and ^{90}Sr content than those from Bikini or Eneu. Agricultural development of these islands should be encouraged. While the external levels on Sugar (Lele) are as low as those on the other three islands, the fact that it is contiguous with Tare (Eneman) would make it advisable to restrict the use of this island at the present time. The causeway joining Lele to Bikdrin makes a logical dividing line for indicating this restriction.

Sampling of food items presently growing on the atoll indicated mean concentrations of ^{137}Cs and ^{90}Sr which are essentially in agreement with those obtained in 1967. It should be pointed out that the planting of new species of foods on the islands will require additional sampling at the time of their reaching maturity in order to assess the potential internal dose. Internal dose estimates have been performed by Gustafson[5] utilizing the 1967 data and would appear to be valid for the 1969 data as well. Results of the 1970 survey for plutonium in air are approximately two orders of magnitude below the FRC guide for an individual in the population and would not significantly affect these estimates. As a result those computations have not been repeated here.

The concentrations of ^{90}Sr would seem to be of greatest concern with respect to internal dose. In this regard the recommendations of the Ad Hoc Committee for removal of top soil from the site of newly planted pandanus and possibly breadfruit trees, and the addition of a calcium supplement to the diet should be most effective in reducing the dose due to ^{90}Sr.

REFERENCES

1. Beck, H. L., B. G. Burton, T. F. McCraw. External Radiation Levels on Bikini Atoll. HASL-190. (May 1967).

2. Held, E. E. Letter with attachments to J. N. Wolfe. University of Washington. (January 8, 1968)

3. Report of the Ad Hoc Committee to Evaluate the Radiological Hazards of Resettlement of the Bikini Atoll. Attached to AEC News Release No. L-191. (August 12, 1968)

4. Crocker, G. R., M. A. Connors, D. T. K. Wong. Some factors for the calculation of infinite plane exposure rates from gamma radiation. Health Physics. (September 1966)

5. Gustafson, P. F. Radiological Report on Bikini Atoll, April 1968 and Additions to Radiological Report on Bikini Atoll, May 1968. DBM-AEC. (1968)

6. Johns, Frederick B. Southwestern Radiological Health Laboratory Handbook of Radiochemical Analytical Methods--SWRHL-11. (March 1970)

DISTRIBUTION

1 - 15 WERL, Las Vegas, Nevada

16 Robert E. Miller, Manager, NVOO/AEC, Las Vegas, Nevada

17 Robert H. Thalgott, NVOO/AEC, Las Vegas, Nevada

18 Henry G. Vermillion, NVOO/AEC, Las Vegas, Nevada

19 Chief, NOB/DNA, NVOO/AEC, Las Vegas, Nevada

20 Robert R. Loux, NVOO/AEC, Las Vegas, Nevada

21 Donald W. Hendricks, NVOO/AEC, Las Vegas, Nevada

22 Technical Library, NVOO/AEC, Las Vegas, Nevada

23 Mail & Records, NVOO/AEC, Las Vegas, Nevada

24 Martin B. Biles, DOS, USAEC, Washington, D. C.

25 Director, DMA, USAEC, Washington, D. C.

26 John S. Kelley, DPNE, USAEC, Washington, D. C.

27 Philip Allen, ARL/NOAA, NVOO/AEC, Las Vegas, Nevada

28 Gilbert J. Ferber, ARL/NOAA, Silver Spring, Maryland

29 Stanley M. Greenfield, Assistant Administrator for Research & Monitoring, EPA, Washington, D. C.

30 Acting Deputy Assistant Administrator for Radiation Programs, EPA, Rockville, Maryland

31 Paul C. Tompkins, Acting Director, Division of Criteria & Standards, Office of Radiation Programs, EPA, Rockville, Maryland

32 Ernest D. Harward, Acting Director, Division of Technology Assessment, Office of Radiation Programs, EPA, Rockville, Maryland

33 Bernd Kahn, Chief, Radiological Engineering Laboratory, EPA, Cincinnati, Ohio

34 - 35 Charles L. Weaver, Acting Director, Division of Surveillance & Inspection, Office of Radiation Programs, EPA, Rockville, Maryland

36 Gordon Everett, Director, Office of Technical Analysis, EPA, Washington, D. C.

37 Regional Administrator, EPA, Region IX, San Francisco, California

38 Eastern Environmental Radiation Laboratory, EPA, Montgomery, Alabama

39 Acting Director, Twinbrook Research Laboratory, EPA, Rockville, Maryland

40 William C. King, LLL, Mercury, Nevada

41 James E. Carothers, LLL, Livermore, California

42 Roger E. Batzel, LLL, Livermore, California

43 William E. Ogle, LASL, Los Alamos, New Mexico

44 Harry S. Jordan, LASL, Los Alamos, New Mexico

Distribution (cont'd)

45 Arden E. Bicker, REECo, Mercury, Nevada

46 Clinton S. Maupin, REECo, Mercury, Nevada

47 Charles F. Bild, Sandia Laboratories, Albuquerque, New Mexico

48 Robert H. Wilson, University of Rochester, Rochester, New York

49 Richard S. Davidson, Battelle Memorial Institute, Columbus, Ohio

50 Frank E. Abbott, USAEC, Golden, Colorado

51 John M. Ward, President, Desert Research Institute, University of Nevada, Reno

52 - 53 DTIE, Oak Ridge, Tennessee (for public availability)

54 Frank Cluff, NVOO/AEC, Las Vegas, Nevada

55 Thomas F. McCraw, DOS, USAEC, Washington, D. C.

56 William Hills, USAEC, Honolulu, Hawaii

57 Edward E. Held, Lab. of Radiation Ecology, Univ. of Washington, Seattle, WA

58 Robert A. Conard, Brookhaven National Lab., Upton, N. Y.

59 - 63 Edward Johnston, Trust Territory-Pacific Islands, Saipan, Mariana Is.

[redacted] 5009069