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ENIWETOK PRECLEANUP SURVEY

SOIL AND TERRESTRIAL

RADIATION SURVEY

(Lynch, Gudiksen and Jones)

44878

Introduction

Eniwetok Atoll is significant in the nuclear world because it was one of the sites of our atmospheric nuclear testing program during the late 1940's and 1950's. As the Eniwetok Proving Grounds (EPG) and the headquarters of the Pacific Proving Grounds (PPG), the Atoll experienced the effects of some 40 nuclear detonations, including the world's first thermonuclear explosion.

The United States' testing program in the Pacific was extensive, involving thousands of personnel. Large complexes were constructed to house these personnel, their experiments and equipment. Numerous test structures were emplaced throughout the Atoll: bunkers, photo and device towers, test stands, experiment holders, etc.

During the years of testing, many of these structures were expended in pursuit of the program. As structures were destroyed or rendered useless by a test, they were abandoned, pushed aside or buried. New structures took their place.

From hindsight we observe that radioactive contamination, resulting from the test detonations and related experiments, was distributed primarily as fallout over much of the Atoll. Islands on which surface ground zeros (SGZ) were sited, and those which experienced close-in, intense fallout, received a substantial insult to their environment from each test. Depending on subsequent needs of the program, construction activities--building new or replacing expended test structures--moving earth, "decontaminating" areas--redistributed the radioactivity from the surface of the ground to various depths on several islands or onto the surrounding reef or into the nearby lagoon waters.

As the years passed, the nuclear testing program ended. Other programs took its place, adding their changes to the Atoll's environment--new structures, topographical features, etc.--some of these over the pre-existing nuclear test structures.

In 1973, 15 years after the last nuclear detonation, the Atoll is quite different from what it was prior to the testing program. It is significantly different from what it was when the program ended. This environment, now somewhat reclaimed by nature and changed by man, was investigated for the precleanup survey.

Recent information and experience with similar problems were considered from previous radiological surveys, the cleanup of Bikini Atoll, and very cursory surveys of Eniwetok Atoll in July 1971 and May 1972. Considering the historical situation outlined above, the purpose of the precleanup survey and the need for information which would be required to evaluate the present conditions, a comprehensive approach was taken to the soil and terrestrial radiation survey problem.

The resulting soil collection plan was developed by O. D. T. Lynch, Jr., AEC/NV, with the generous and able assistance of Drs. Richard Gilbert and Lee Eberhart, Batelle Northwest (BNW). It was reviewed by Drs. Seymour, Held, Nelson, Welanda, and Shell of the University of Washington and Mr. Tommy McCraw, DOD/HW. The field effort was executed by Mr. O. D. T. Lynch, Jr., AEC/NV, and Dr. Paul H. Gudikson, LLL Health and Safety, Livermore, with the assistance of Messrs. Charles F. Costa and William E. Moore of the Environmental Protection Agency (EPA), Las Vegas, and monitors from EPA and Eberline Instrument Corporation, Santa Fe. Thermoluminescent Dosimeters (TLD) were fielded under the direction of Dr. Donald Jones, LLL H&S. Data interpretation, evaluation and reporting were accomplished by Drs. P. H. Gudikson and D. Jones, and Mr. O. D. T. Lynch, Jr.

Presurvey Planning - Background Studies

The testing program impact on the Eniwetok environment complicates any realistic attempt at evaluation. To formulate a practical survey plan, all available information had to be reviewed.

Background information was obtained from all possible sources. The laboratories which conducted the experiments had reports and data on the original nuclear devices, their composition, associated experiments, etc. Actual test information, fallout patterns, radiological safety reports, etc., came from AEC sources, in-house. Construction drawings and information on modifications to the topography were available from the testing support contractor, Holmes & Narver, Inc. (H&N).

Other organizations, including the various universities which conducted environmental studies during and after the testing program, had subsequent survey information. Several organizations had personnel who were associated and located at Eniwetok Atoll during the test operations. There was a wealth of information available in old reports, records, documents, etc., stored in archives. This information provided insight into what conditions could be anticipated and/or encountered.

Much useful information was forthcoming, along with some anticipated problems: contradictory statements and reports. On the whole, the effort was very successful and was a deciding factor in the development of the soil sampling and terrestrial radiation survey programs.

A fairly clear picture was formulated as to what the Atoll should be like at the present time.

Examination of reports from the laboratories, LLL and LASL, enabled us to estimate what radionuclides should be present as a result of the composition of nuclear devices and any experiments which were performed as part of the detonations. These are listed in Table.1. The quantities of "environmental" materials, structural steel, concrete, wiring, pipe, etc., were also determined and helped to establish what debris should have remained after a shot. This information engendered questions on the ultimate disposition of these materials after the tests, stimulating further search efforts.

The operations reports made to the Test Manager indicated fallout patterns for nearly every event. From these, as a crude but reasonable effort to develop an idea of residual conditions, the Atoll's islands were graded as a function of the reported fallout insult (measured exposure rates) corrected to H+1 hour past detonation. The resulting gradation is shown as Table 2. This crude attempt proved to be reasonably accurate, and a useful planning device.

Radiological Safety Reports made during and after the several test operations prompted more questions and consternation than answers. These reports indicated some acute radiological problems which were subsequently corrected, such as serious alpha contamination, decontamination activities, radioactive debris/waste disposals, etc. Unfortunately, these reports failed to provide sufficient detail to determine, in all cases, the eventual fate of the radioactivity itself, where it was disposed of--land, lagoon or sea, and how or how well.

TABLE 1

RADIOISOTOPES OF INTEREST FOUND IN ENIWETOK ATOLL SOIL

Radioisotope	Source	Material*
Americium-241	Plutonium Contamination	D, S
Plutonium-240	Plutonium Contamination	D
Plutonium-239	Plutonium Contamination	S
Plutonium-238	Plutonium Contamination	S, D
Uranium-238	Unburned Weapon Fuel	S
Uranium-235	Unburned Weapon Fuel	S
Bismuth-207	Fission Product	S
Europium-155	Fission Product	S
Europium-154	Fission Product	S
Europium-152	Fission Product	S
Samarium-151	Fission Product	S
Promethium-147	Fission Product	S
Cesium-137	Fission Product	S
Antimony-125	Fission Product	S
Rhodium-102	Fission Product	S
Strontium-90	Fission Product	S
Nickel-63	Fission Product	S
Cobalt-60	Activation Product	A
Iron-55	Activation Product	S
Carbon-14	Activation Product	S
Tritium		S, W

*S = Soil
A = Act. Metal or Scrap
D = Debris
W = Water

TABLE 2

ENIWETOK ATOLL

RANKING ISLANDS ACCORDING TO FALLOUT INSULT R/HR AT H+1 HR

Island Code Name	Local Name	Total R/Hr.	Total Events	SGZs
YVONNE	RUNIT	62,849	24	8
RUBY	EBERIRU	10,643	16	2
EDNA	SANILDEFENSO	9,533	16	0
IRENE	BOGON	6,184	24	1
HELEN	BOGAIRIKK	5,277	23	0
PEARL	RUJORU	4,329	13	1
DAISY	COCHITI	3,554	20	0
JANET	ENGEBI	3,501	26	3
ALICE	BOGALLUA	3,383	28	0
BELLE	BOGOMBOGO	3,382	25	0
CLARA	RUCHI	3,154	24	0
MARY	BOKONAARAPPU	2,785	18	0
SALLY	AOMON	1,981	16	3
LUCY	KIRINIAN	1,776	10	0
KATE	MUZIN	1,753	11	0
OLIVE	AITSU	1,252	12	0
NANCY	YEIRI	1,251	7	0
TILDA	BIIJIRI	774	17	0
URSULA	ROJOA	651	12	0
CORAL HEAD (MACK)	-	452	10	0
WILMA	PIIRAAI	294	13	0
VERA	AARAANBIRU	270	11	0

TABLE 2 (continued)

Island Code Name	Local Name	Total R/Hr.	Total Events	SGZs
LEROY	RIGILI	235	13	0
KEITH	GIRIINIEN	31	3	0
JAMES	RIBAION	23	3	0
IRWIN	POKON	19	3	0
HENRY	MUI	13	3	0
GLENN	IGURIN	11	3	0
ELMER	PARRY	2.6	5	0
FRED	ENIWETOK	2.6	4	0
ZONA	"M"	2.5	1	0
BRUCE	ANIYAANII	1.5	4	0
DAVID	JAPTAN (MUTI)	1	3	0
TOM	—	0	1	0
SAM	--	0	–	0
URIAH	—	0	1	0
VAN	—	0	1	0
ALVIN	CHINIEERO	0	2	0
OSCAR	—	0	2	0
CLYDE	CHINIMI	0	1	0
REX	JIERORU	0	1	0

Interviews with test personnel produced some answers. Due to time versus memory, these also indicated some contradictory recollections of activities and fate of contamination. These interviews did confirm that burial and relocation of high-level radioactive contamination was attempted, many times and many places. Verification of several of these activities by documentation has been very difficult and unsuccessful. With this information, the magnitude of the problem of locating buried contamination seemed to grow; however, everything indicated radioactive debris/contamination would probably be buried only on islands that had surface ground zeros. A list was then made of suspected or known burial sites (Table 3). These locations are shown in Figures 1, 2, 3, and 4.

Two cursory radiological surveys, conducted in July 1971 and May 1972, confirmed suspected conditions on most of the islands and provided initial reliable data on soil concentrations. These provided crude values for the soil concentration variability estimates used to develop the statistical plan for soil sampling.

Although the July 1971 survey was limited (six days, two monitors), the following information was obtained:

1. Many of the islands were still radioactively contaminated.
2. Much of the Atoll was heavily revegetated and difficult to traverse.
3. There were no obvious indicators (signs, posts, fences, etc.) of buried radioactivity in clear sight.
4. There was significant activated/contaminated radioactive debris on YVONNE (Runit Island) at the CACTUS crater lip and also a seam of plutonium-contaminated soil outcropping on the oceanside beach, mid-island.

TABLE 3

SUSPECTED OR KNOWN BURIAL SITES FOR RADIOACTIVE CONTAMINATION/DEBRIS

ENIWETOK ATOLL

Island	Contamination	Quantity	Location	Confidence	Source
IRENE	Soil	Large	Unknown/Central Island	Fair	1
JANET	Activated Metal	Large	Around SGZ's	Fair	2
PEARL	Activated Metal	Unknown	Around SGZ	Suspected	2
RUBY	Soil/Activated Metal	Unknown	Old SGZ	Positive, High	3
SALLY	Debris	Unknown	Western SGZ Area	Suspected	1
	Pu Debris	Unknown	KICKAPOO SGZ	Absolute	3
	Pu Debris	Unknown	Western SGZ Area	Absolute	3
	Pu Debris	Unknown	Causeway, SALLY/TILDA	Absolute	3
YVONNE	Pu Debris	Large	FIG/QUINCE SGZ - Lagoon Side	Absolute	4
	Pu Debris	Unknown	Disposal Area - Location Unknown	Positive, High	4
	Activated Metal	Unknown	Anywhere - Exact Locations Unknown	Absolute	5
	Cont. Debris	Unknown	West of CACTUS Crater	Suspected	6
	Cont. Debris	Unknown	ERIE SGZ	Positive, High	7
	Cont. Soil	Unknown	North of HT. Sta. 1310	Positive, High	8

Sources:

1. Interview
2. Standard Assumption
3. H&N Drawing GS-6270, April 9, 1957, and FS-6287, April 18, 1957
4. Task Group 7.5 Rad-Safe Support, HARDTACK, Phase I, OTD-58-3, April 1959
5. Survey, 1971, 1972
6. ~~Test Manager~~'s Completion Report, Operation HARDTACK, PHASE I
7. H&N Drawing 25-002-G7, January 20, 1958
8. H&N Drawings 25-002-C3, 4, 5, January 20, 1958

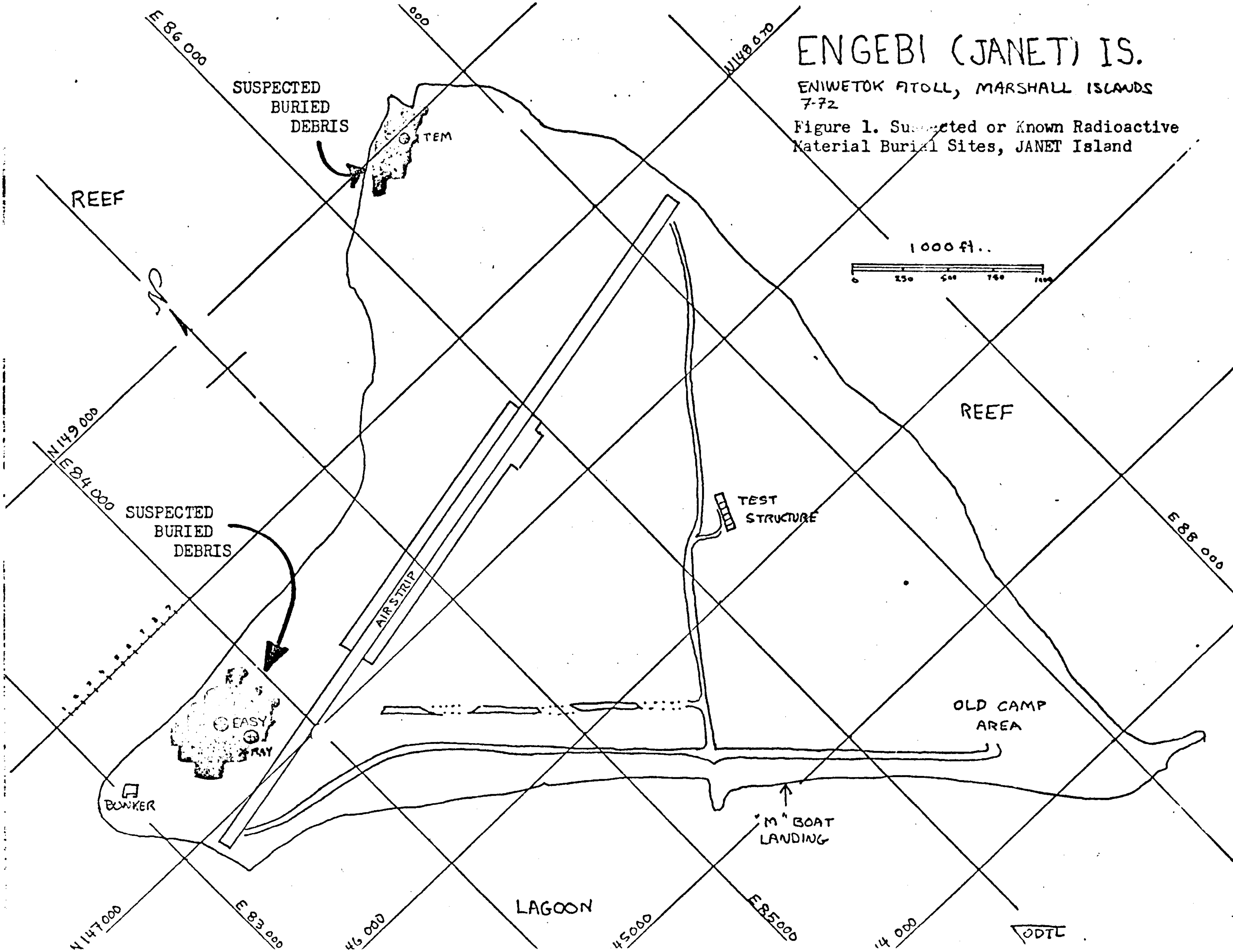


Figure 1. Suspected or Known Radioactive Material Burial Sites, JANET Island

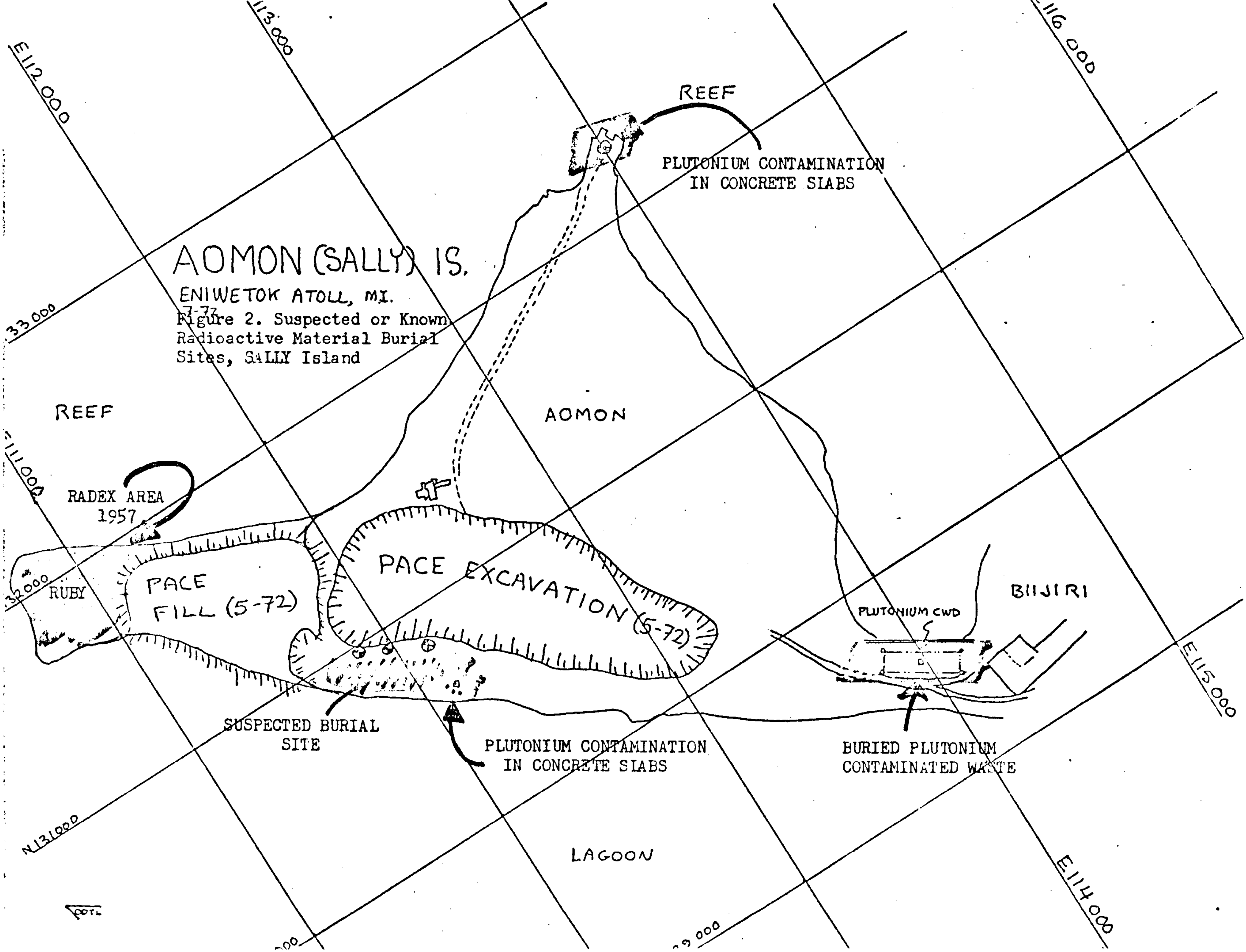


Figure 2. Suspected or Known Radioactive Material Burial Sites, SALLY Island

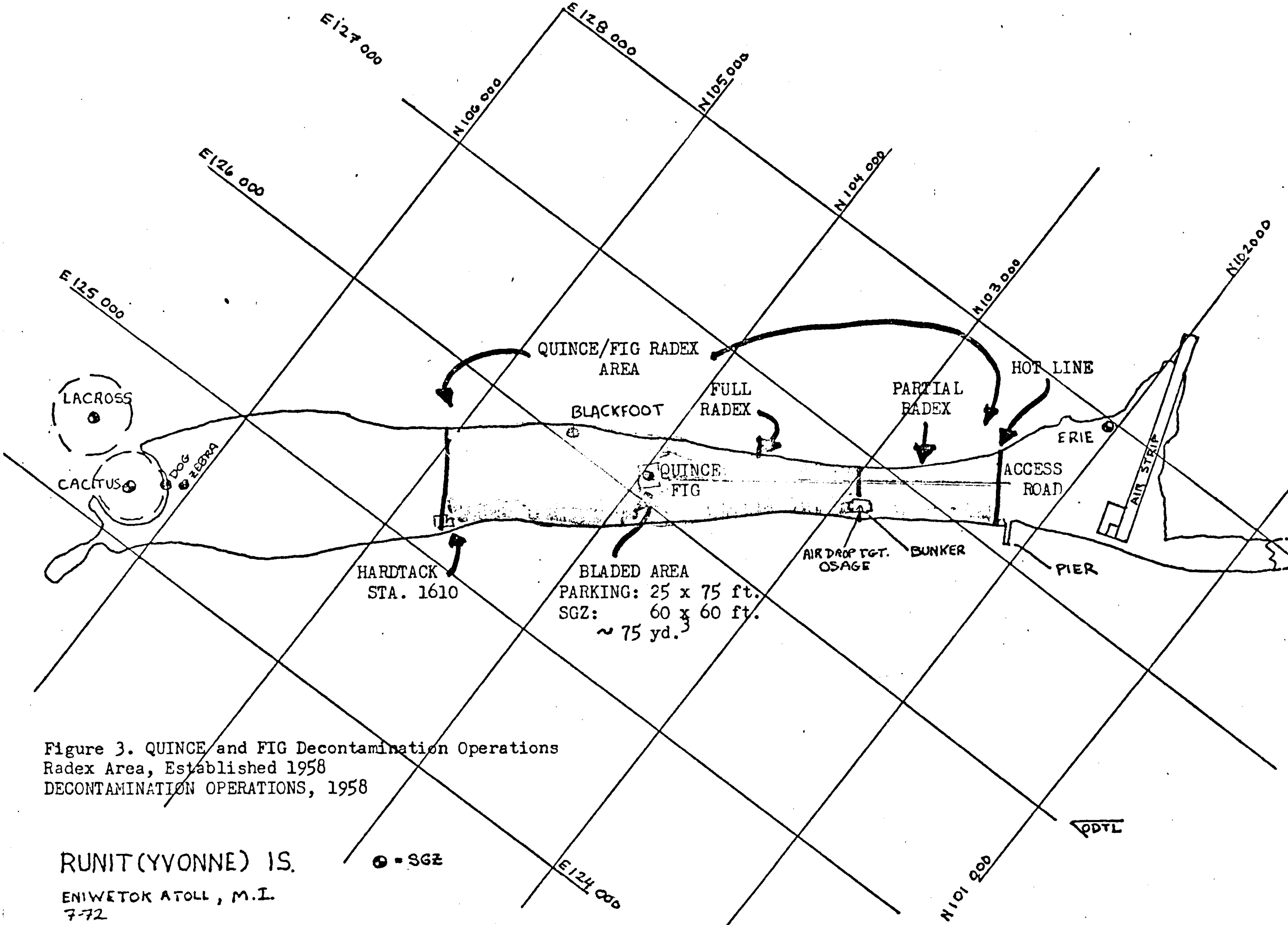


Figure 3. QUINCE and FIG Decontamination Operations
Radex Area, Established 1958
DECONTAMINATION OPERATIONS, 1958

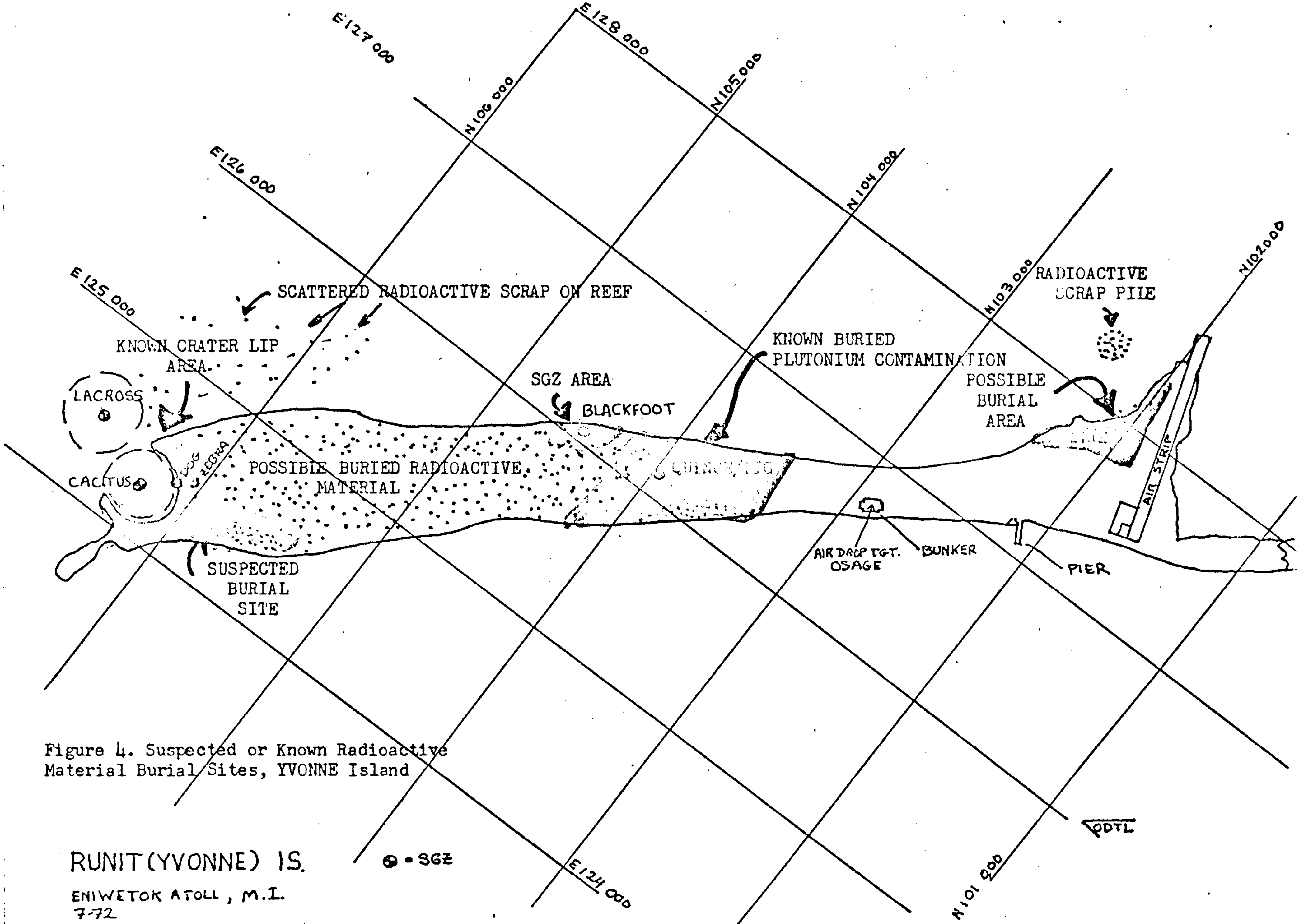


Figure 4. Suspected or Known Radioactive Material Burial Sites, YVONNE Island

5. There appeared to be a definite pattern to the exposure rates encountered, with the higher rates observed on the northern half of the Atoll.

6. Only six islands were visited: IRENE, JANET, SALLY, TILDA, URSULA, and YVONNE.

As a result of this survey, the AEC's 1972 Bikini radiological resurvey was extended to cover Eniwetok Atoll in a very limited reconnaissance effort in May 1972. An attempt was made to cover as many islands as possible. Of the 43-some islands in the Atoll, 18 of these were visited in May 1972. Adding these to 3 other islands visited by the July 1971 effort, recent data on 21 of the islands were made available. Although this was slightly less than half of the total number of islands, it was somewhat representative of the whole. The results of this survey also showed the Atoll-wide pattern of contamination suggested by the 1971 survey and the ranking of islands according to fallout insult. The gamma exposure rates known as of May 1972, a compilation of these two surveys, are shown as Figures 5, 6, 7, and 8. These data were obtained using a Baird-Atomic Scintillation Detector ~~(Na-I)~~ (NaI) calibrated on Cesium-137 and do not represent the true Dose Rate, which would include contributions from low-energy gamma and cosmic radiation.

In November 1972 an aerial radiation survey was made of all islands within the Atoll. The results of this survey were directly beneficial to the soil sampling and terrestrial radiation survey efforts. The emerging fallout pattern evident in May 1972 was confirmed as well as the accuracy of the ranking of each island by fallout insult. The aerial survey also eliminated the need to conduct close grid ground radiation surveys which had been planned before aerial data were available.

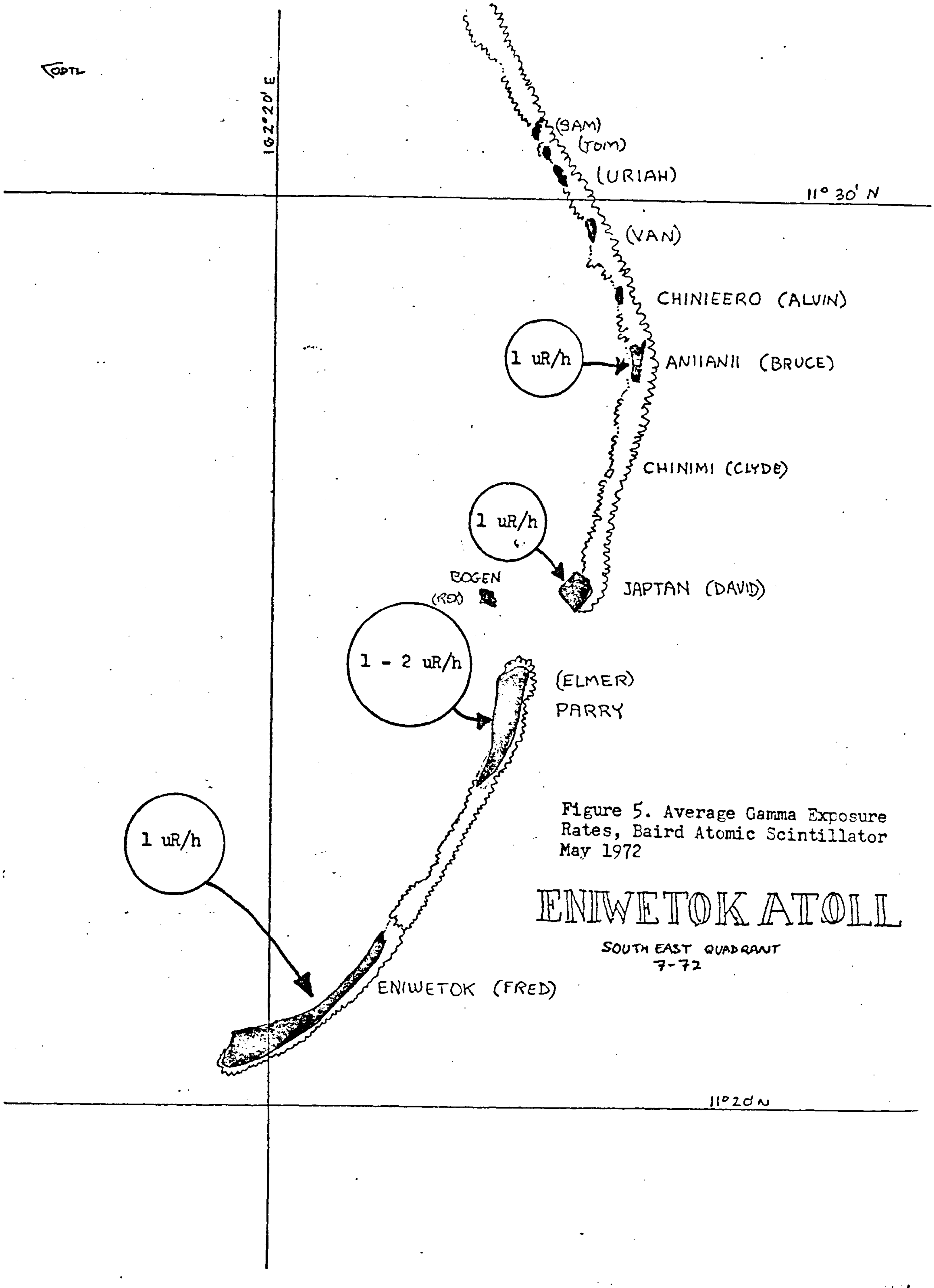


Figure 5. Average Gamma Exposure Rates, Baird Atomic Scintillator May 1972

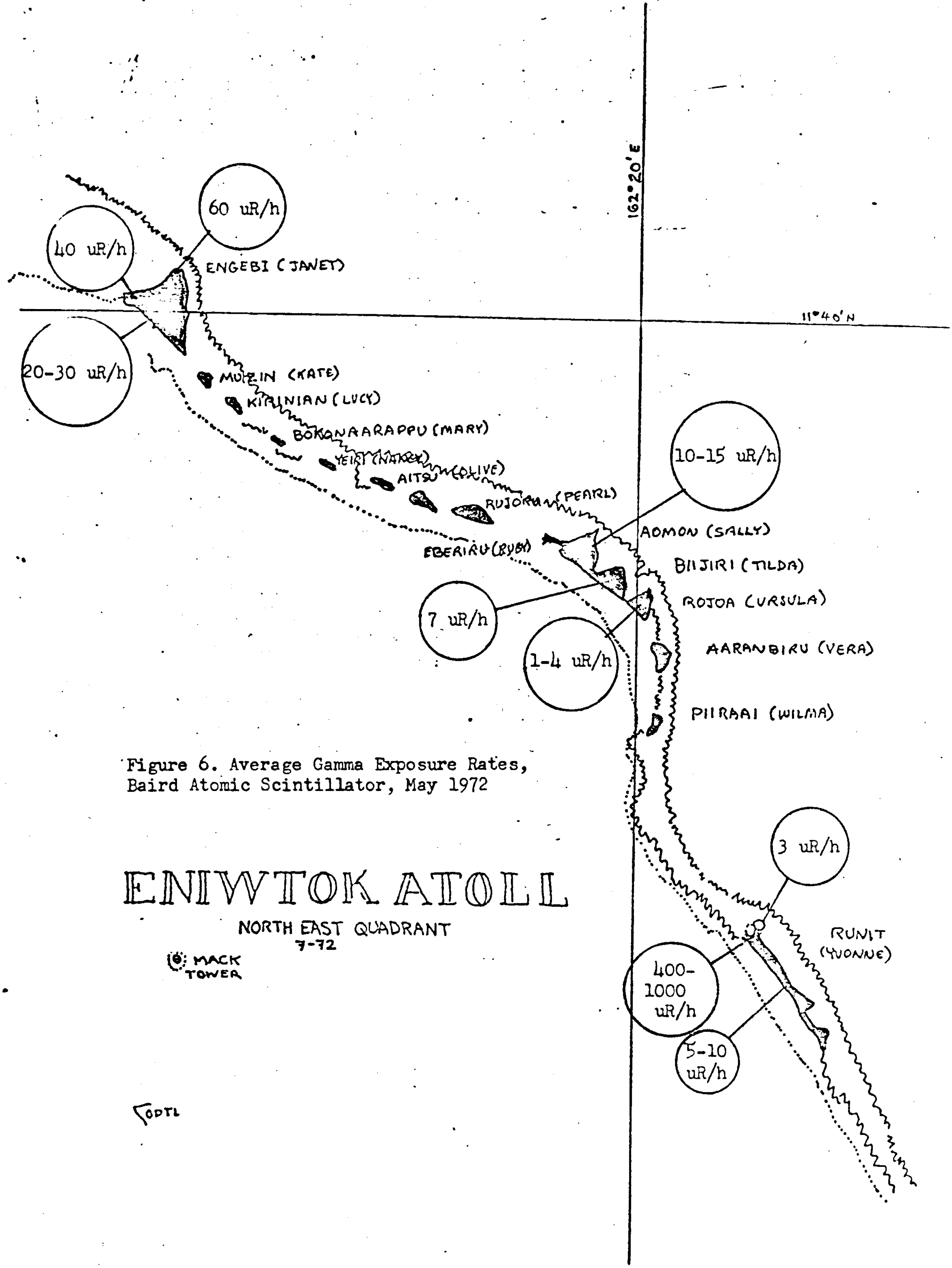


Figure 6. Average Gamma Exposure Rates, Baird Atomic Scintillator, May 1972

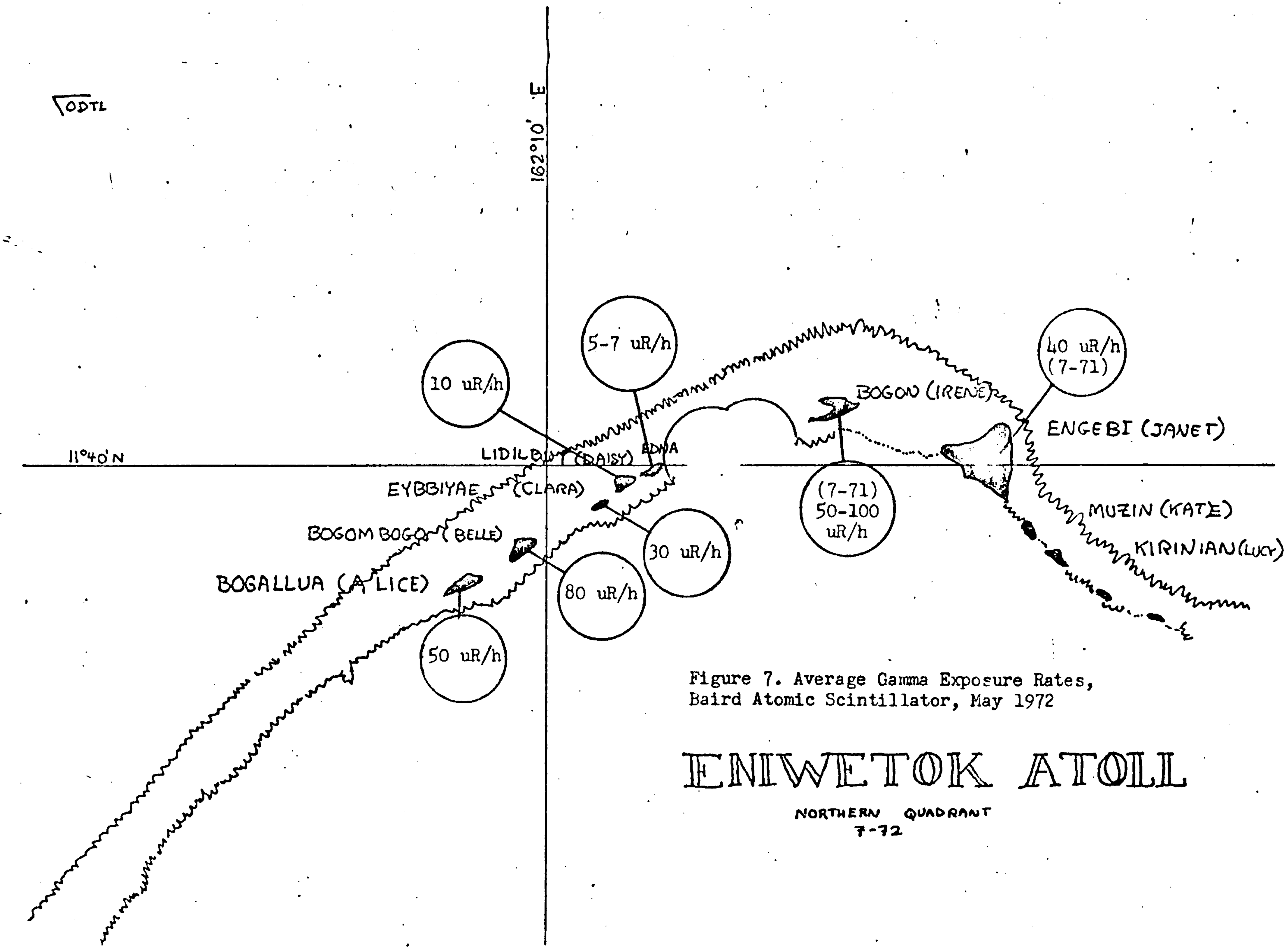


Figure 7. Average Gamma Exposure Rates, Baird Atomic Scintillator, May 1972

ENIWETOK ATOLL

NORTHERN QUADRANT
7-72

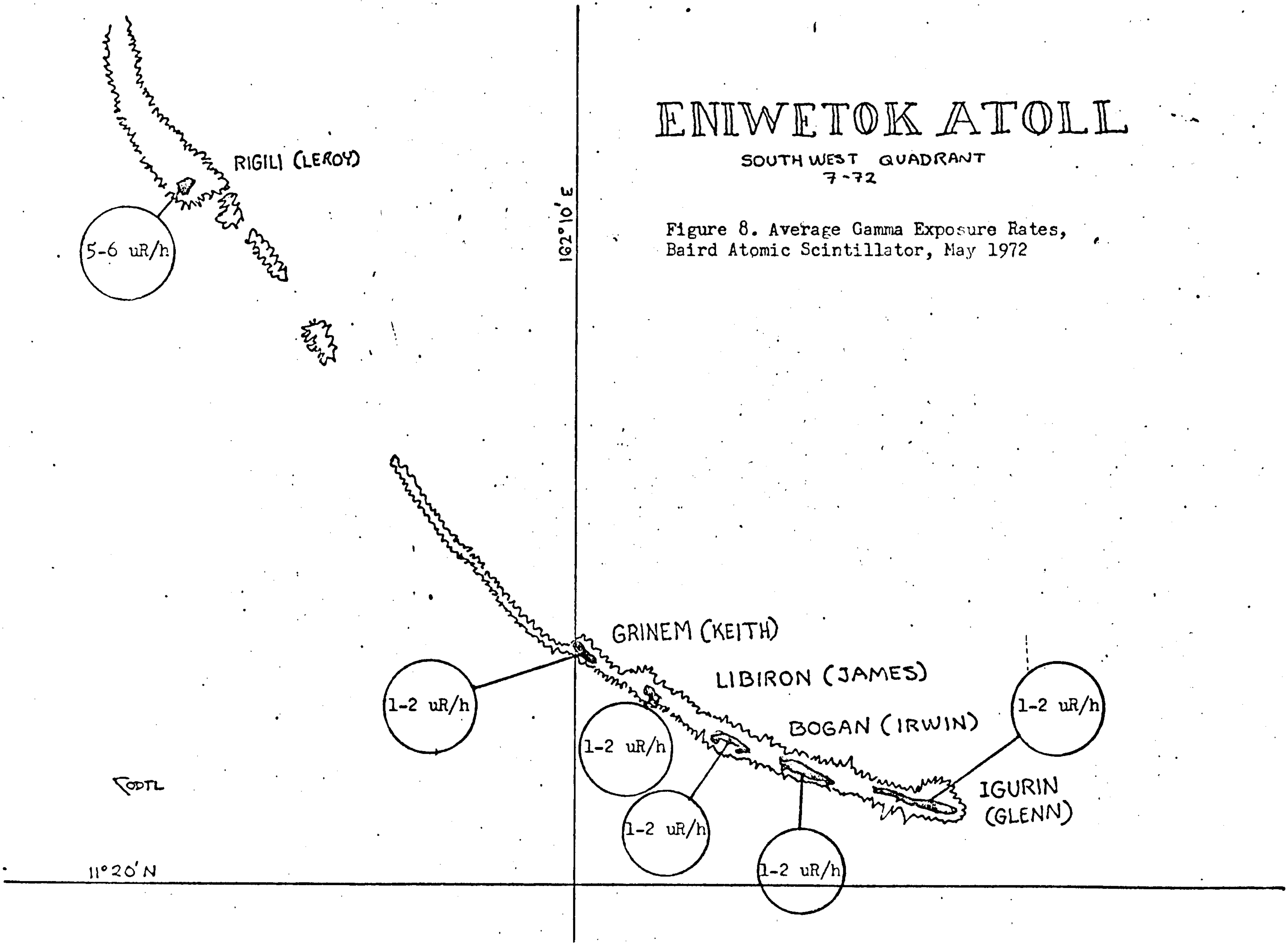


Figure 8. Average Gamma Exposure Rates, Baird Atomic Scintillator, May 1972

The aerial survey revealed hot spots on several islands which then received special attention from the terrestrial effort. Concern over the contradictory nature and adequacy of the earlier rad-safe support reports was justified when the aerial survey also located an abandoned ^{60}Co source at the site of an old dosimeter calibration facility on Parry Island (ELMER). This source was recovered and taken to the Nevada Test Site for burial in an approved disposal site.

A complete set of aerial photographs of all the land and reef areas of the Atoll was obtained as a byproduct of the aerial survey. These photographs were invaluable: assisting in locating the safest approach to islands for landing efforts, locating survey party positions and objects more exactly in the field, and determining the most efficient route to locations.

Statistical Planning

Basic Objectives

The general objective of the Eniwetok Precleanup Survey was stated to be:

> "to thoroughly evaluate radiological conditions on all islands of the Atoll prior to commencement of cleanup activities in order to provide sufficient radiological intelligence to be able to develop an appropriate cleanup program to be accomplished."1/

This overall objective was interpreted to provide specific goals for the soil and terrestrial radiation survey program. These extended objectives were:

1. To conduct a sample collection and terrestrial radiation survey program which would assure truly representative sampling of the soils and determination of the radiation

explosure rates in the environs of Eniwetok Atoll.

2. To assure proper analysis of soil samples on an analytical basis and a correlative basis to provide meaningful data and evaluation/verification of the sample collection scheme and techniques.

3. To evaluate the soil and terrestrial radiation data to determine the limitations on interpretation and utilization of these data.

4. To provide, as an end result, a complete statement of the radiological conditions of the soils of Eniwetok Atoll and their contribution to the radiation exposure rate of the environment.

In planning to accomplish these goals, every effort was made to utilize, to a maximum advantage, all of the background information and experience gained from the preplanning "research" effort.

An implicit requirement to get the most effort from the least amount of money within the limited time period allowed and yet provide a valid result had a major impact on the soil program design. Cost estimates of around $80.00 per sample (plutonium/strontium) for radiochemical analysis for several thousand soil samples as well as similar quantities of samples from the biota and marine sampling programs engendered concern for affording statistically adequate numbers. The quantity of samples also required a realistic evaluation of the total national capability for their analysis. To provide a meaningful statement of the radiological condition of the soil of the 43 islands of Eniwetok Atoll under the above constraints would require maximum efficiency of sample collection design efforts and no

1/ Reference TWX. MAJ. GEN. P. A. CAMM, AGM/MA, WASH DC
TO MAHLON E. GATES, MANAGER, NV, LAS VEGAS, NEVADA, DATED SEPTEMBER 13, 1972

unnecessary collections and/or analyses. Every effort was made to determine the minimum numbers of samples required to provide a meaningful statement of the conditions. This was done by random sampling techniques, careful grouping of islands, stratification only when necessary or indicated, objective investigations of known anomalies, burial areas and trouble spots, austere depth distribution determinations (profiles), etc. For example, the problem of finding a proverbial "needle in a haystack" (say, a 10-foot wide by 50-foot-long burial trench) within the total land area of approximately 2.5 square miles, with probability of nearly 1.00, would require, on a random basis alone, over 100,000 locations to be sampled to a minimum depth of the top of the suspected burial mass. Consideration of such a task was obviously out of the question. On the other hand, use of insight gained from the background study would limit locations for such burials down to just a few areas on particular islands. This insight was extended to the whole soils effort to minimize the required collections to a manageable and practical quantity.

Required Information

Since a cleanup effort would require preliminary cost estimates on amounts of soil to be disposed of a sample plan was designed to provide at least gross estimates of volumes of contaminated soils on those islands where such volumes were thought to exist or had high probability for existence.

Where construction activities were extensive, the past mixing of contaminated soils would make a specific determination of soil volumes impossible without an economically excessive number of soil samples being required. Obviously such fine definition would have to be deferred to the actual cleanup effort; therefore, some limit to the required information had to be determined, depending on many different aspects. The overall objectives of the survey had to be interpreted very carefully, bearing in mind that this survey was a precleanup effort and not the cleanup operation. Estimates would necessarily have to be crude, some very crude and not exact in any way. Enough information would have to be generated to make possible policy decisions and budgetary estimates for cleaning up the Atoll. The conclusions which could be drawn would depend on the number of samples collected and analyzed, as well as the judgment of the designer as to what information he would really expect to be required to obtain. It was a question of defining approximately the conditions on an island or a large fraction thereof, with a realistic cost/sample number estimate versus defining a specific volume of soil on a specific island and having an astronomically expensive and unmanageable quantity of samples. A compromise had to be made resulting in the sampling program requirements indicated in the following pages.

Stratification

The Atoll was stratified into groups of islands, individual islands, or specific areas of islands, depending on what was known or suspected about the area and what was required to be known. Although other radionuclides were present, the soils effort was based on ^{239}Pu concentrations. Previous experience with this long half-life isotope indicated it was of major importance in cleanup considerations. Using the results from previous surveys, the ranking of the islands according to fallout insult, knowledge of particular problems, and considerable insight, the Atoll was divided into four main phases based on assumed contamination conditions. Additional stratification was accomplished, depending on: the information required, the known or assumed contamination levels, the number of samples required to give the information, and assumed soil concentration

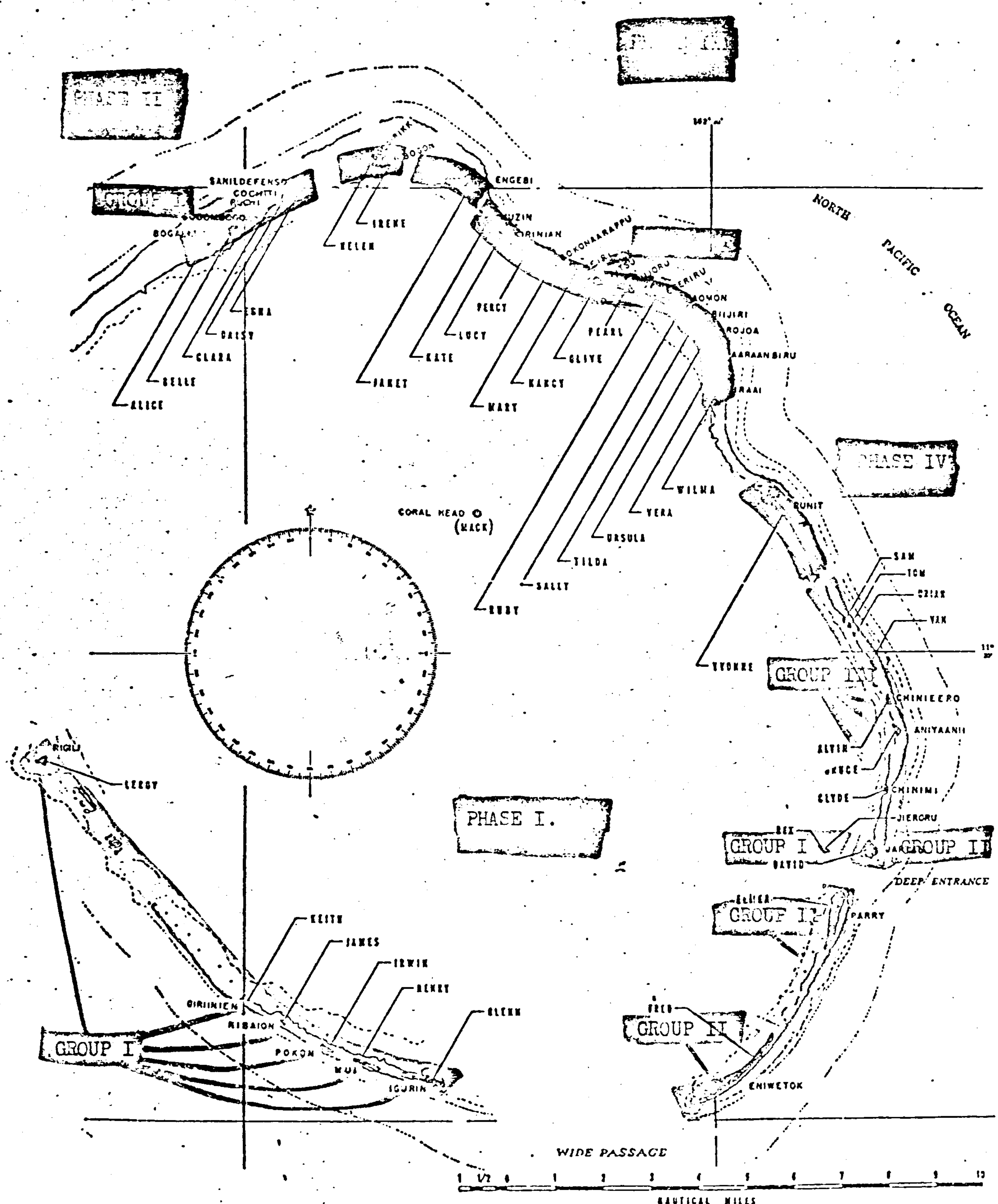


Figure 9. Statistical Stratification of Eniwetok Atoll for Soil Sampling Program

There was some minor concern for the islands of FRED and ELMER, for these were the base camp islands and had decontamination pads used for aircraft and/or equipment. These pads were clearly marked on the drawings and would be treated differently from the rest of the Phase I effort.

The islands of Phase I were stratified into three groups as follows:

PHASE I - GROUP I

BRUCE (ANIYAANII)	IRWIN (POKON)
REX (JIERORU)	JAMES (RIBAION)
GLENN (IGURIN)	KEITH (GIRINIEN)
HENRY (MUI)	LEROY (RIGILI)

PHASE I - GROUP II

DAVID (JAPTAN) ELMER (PARRY) FRED (ENIWETOK)

PHASE I - GROUP III

SAM TOM URIAH WALT VAN ALVIN CLYDE

The islands of Phase I, Group I would be treated as a group, not individually. Considering their cleanliness, inaccessibility due to terrain and vegetation, and approach (all beaches on most were on windward side with dangerous surf), sample collection would be difficult at best and this should be minimized.

The expected mean concentration value (hereafter called the mean or mean value) of ^{239}Pu activity in the soil was relatively small, less than 1 pCi/g dry soil. These similar islands were treated as a single stratification. As such, the number of surface samples, locations, 116 total, would allow for the determination of the mean (with a precision of

± 13%) for the entire group and also individual islands (to lesser precision for surface samples to a depth of 5 or 15 cm (depending on which samples were analyzed). Additionally, for the group, a mean value could be determined for profiles to a depth of approximately 35 cm. The number of samples for each island in Phase I, Group I would allow for a determination of its surface mean only, but would not be sufficient to differentiate any one island from another.

On first inspection, this information seems to be somewhat insufficient; however, these islands are essentially clean, and for an anticipated mean value for soil concentrations like 0.5 to 1.0 pCi/g a plus or minus twenty percent or so is really quite adequate for precleanup survey requirements. This is certainly sufficient information to make estimates on volumes of soil contaminated to unacceptable levels.

The islands of Phase I, Group II were treated differently from Phase I, Group I islands. These were sites of considerable construction activity. They would also be the sites for primary habitation upon the return of the Eniwetok people. Although these islands were on the southeastern side of the Atoll, and from all appearances very clean, it is prudent to take a very careful look at them. These islands were sampled sufficiently, somewhat excessively, in fact, to be able to stratify as a group, an individual island or within each island to allow as much as three to five stratifications, if necessary.

Relatively deep profiles (to 120 cm, 4 ft.) were taken in quantities sufficient to develop a mean value for each Phase I, Group II island. The depth was selected to allow for the deep disturbances expected from construction activities.

The decontamination pad on ELMER was treated separately with sufficient samples taken to differentiate this small area from any other portion of the island. The decontamination pads on FRED were made of concrete and could not be sampled.

Radiologically, the Phase I, Group II islands did not differ from the Phase I, Group I islands. Had they not been the sites for habitation, their sampling would have been considerably reduced.

The Phase I, Group III islands differed from the other Phase I islands only in size. At the beginning of the survey, these islands were not considered in the sampling effort; they were too small. After the aerial survey, which did not indicate any elevated levels on these islands, it was thought prudent to include them in the sampling effort. They were very small islets in between other islands of Phase I and were expected to have the same radiological conditions. They were to be treated in the same manner as Phase I, Group I islands and stratified as a single group.

Phase II Islands. The Phase II islands were termed to be "lightly" contaminated based on the historical background, ranking of islands from insult, and previous surveys. The term "lightly contaminated" is, of course, only a relative one. The islands were expected and assumed to be significantly more contaminated than any of the Phase I islands. Using the exposure rates found on ALICE through EDNA from previous surveys, and their relative positions (and fallout insult) to the SGZ islands and sites, two groups of islands were developed: Phase II, Group I, those islands which had been visited, and of which something was known, and Phase II, Group II islands which had not been recently visited (with two exceptions, TILDA and URSULA), but from all indications would appear to be similar in fallout insult and exposure rate to the Phase II, Group I islands.

Soil samples were available from the May 1972 survey for the islands of ALICE, BELLE, CLARA, DAISY, and EDNA. These samples were very limited, and, unfortunately, were composited during collection. They did indicate the islands were contaminated, and there appeared to be some difference between the lagoon side and the ocean reef side of the islands. This was also seen in exposure rates. Plutonium-239 values on these islands (May 1972) were relatively high for the Atoll, ranging from about 17 pCi/g on EDNA to a maximum of 129 pCi/g on BELLE. A crude mean of 50 pCi/g was assumed for planning purposes for this chain of islands (ALICE through EDNA), but, because of the compositing process, could actually be much higher.

This mean value was applied to all Phase II islands. Because of those islands which were not visited prior to the precleanup survey and their geographical locations, those "unknown" islands received an increased allocation of samples. These two Phase II groups consisted of the following:

PHASE II - GROUP I
("Known" Islands)

ALICE (BOGALLUA) BELLE (BOGOMBOGO) CLARA (EYBBIYAE)

DAISY (LIDILBUT) EDNA (SAN ILDEFONSO)

PHASE II - GROUP II
("Unknown" Islands)

KATE (MUZIN) OLIVE (AITSU)

LUCY (KIRINIAN) PEARL (RUJORU)

PERCY TILDA (BIIJIRI)*

MARY (BOKONAARAPPU) URSULA (ROJOA)*

NANCY (YEIRI) VERA (AARANBIRU)

WILMA (PIIRAAI)

*Visited July 1971.

Although TILDA and URSULA had been visited in July 1971 and soil samples and exposure rates were obtained, only one soil sample was taken on each island, not enough to really work with. The exposure rates were a little lower than the ALICE through EDNA chain, but well above mean rates for Phase I islands. Also, the proximity to SGZ's and fallout insult rank placed these islands in a category by themselves.

The island of PEARL had an SGZ and probably should have been placed with the other islands with surface ground zeros (Phase III). Its uniqueness to the rest of the islands of Phase II, Group II was recognized. It did receive a much greater sampling density.

Because of the anticipated contamination levels and exposure rates, the numbers and depths of the soil samples were chosen to provide enough information (statistically) to be able to determine the following:

Phase II, Group I (Design Values)

1. Mean soil concentration value for the group to ± 15% of group mean.
2. Mean concentration for each individual island to ± 30% of island mean.
3. Excluding EDNA, (a sandbar) stratification into two parts (equal sample number) for each island; i.e., lagoon versus ocean side to ± 35% of strata mean.
4. Gross profile to a depth of 35 cm of the group to ± 44% of the group mean.

Phase II, Group II (Design Values)

1. Mean concentration for the goup to ± 10% of group mean.

2. Mean concentration for each individual island to ± 30% of the island mean.

3. Stratification into two parts (equal sample numbers) for each island, to ± 40% of the strata mean.

4. Gross profile to a depth of 35 cm of the group to ± 27% of the group mean.

5. For arbitrary areas (strata), with sufficient number of samples, estimate crude volumes of soil.

With these requirements above, there should be enough information to formulate an estimate of what could be expected to be cleaned up by island, given appropriate criteria. In most cases, these islands are relatively small and fractions of them would be a sufficient precleanup estimate to work upon. The exact volumes of soil requiring cleanup would have to wait cleanup criteria and the massive sampling program such an effort would require.

Phase III Islands. These islands were designated with the relative term "moderately contaminated". Four islands and a tiny new islet are included in this phase: IRENE (BOGON), JANET (ENGEBI), RUBY (EBERIRU), SALLY (AOMON), and what we chose to call SALLY'S CHILD, a small islet on the reef apparently formed by the deposition of sand and debris from the region between SALLY and TILDA.

All of these islands in Phase III were the sites of surface ground zeros whose events had left their obvious marks upon the islands. The historical search indicated that there had been considerable insult done to these islands from close-in fallout and some had or were expected to have burial grounds.

IRENE (BOGON) was a medium-sized island whose single nuclear test left a sizeable crater now filled with water. This island had massive construction efforts during the setup for its own shot (SEMINOLE), as well as considerable activity in preparation for the MIKE and KOA events. During the preparation phases for the KOA and SEMINOLE events, much contamination from the MIKE test was buried in constructing the line-of-sight (LOS) pipes and other test structures. Exposure rates in the order of 50-100 u R/h were observed during the 1971 survey effort. The fallout H+1 hour insult was some 6,184 R/h from a total of 24 nuclear tests. This was sound indication of both fallout and probable buried contamination on (or under) much of the island's area. Correspondingly, the soils program took this into account in developing the following information requirements:

1. Provide sufficient sample numbers to stratify the island into a minimum of three stratifications of equal numbers (surface only).
2. Detect an area as small as 10% of island to a depth of 70 cm, which would be contaminated due to construction mixing with a probability of 1.0.
3. Detect an area as small as 25% of island with a probability of 1.0 to a depth of 190 cm (6 ft) contaminated due to construction mixing.
4. Determine only large volumes of soil for cleanup.

JANET (ENGEBI) is the second largest island on the Atoll and was the site of three early nuclear tests. Historically, JANET had much to consider. The site of one of the bloodiest battles of World War II, the island harbored artifacts from not only nuclear testing but also from the extensive fortifications built by the Japanese and the munitions expended by the U. S. Marines in demolishing those fortifications. The beaches and interior are littered with debris from the war and testing. Everywhere can be found unfired small arms ammunitions, unexploded naval and field artillery shells, rusted land and beach mines (Japanese), and unexploded bombs, etc. Superimposed upon this war debris are the activated remnants (up to 12 mR/h in 1971) of the nuclear testing days. Test structures are everywhere. The island was also the site of a large base camp. It was also a primary site of native habitation and would probably be so again.

Soil profiles taken in 1971 reflected the construction earth-moving activities, with plutonium and other radionuclides found in rather constant or increasing concentrations down to soil depths of 20 cm -- the limit of that sampling effort.

Although no burial grounds were indicated in those records researched, it was highly probable that burial grounds of sorts were associated with each SGZ area. Evidence of construction was everywhere.

This background was taken into account when the information requirements were formulated. The statistical sampling program was then designed to determine the following information:

1. Stratify the surface (0-5 or 0-15 cm) into five arbitrary groups ± 25% of strata mean.
2. Define contamination to depth of 180 cm (6 ft.) over large (not small) areas.
3. Determine only large volumes of contaminated soil.

SALLY (AOMON)-RUBY (EBERIRU)-SALLY'S CHILD were grouped together. Presently RUBY is integral with SALLY. SALLY'S CHILD developed from the debris and sand from between SALLY and TILDA, and was treated as part of SALLY.

Both SALLY and RUBY were the sites of multiple SGZ's. Buried contamination was expected, but not necessarily located prior to the survey effort. An additional complication, that of Project PACE excavation, affected the utility and the execution of a meaningful soils effort. SALLY had huge areas excavated by PACE, some adjacent to SGZ's and suspected burial sites. Also, the excavated material had been deposited on the remaining surface areas of SALLY and between SALLY, and what remains of RUBY. The islands had clearly been disturbed. Because of this an attempt was made early in the survey to delete these islands from the effort. PACE was then active and any earth moving or other land modifications conducted by them would negate any survey results before they could even be reported. However, while the survey was in progress, PACE was enjoined by court action to cease all activities on the Atoll. At that time it was determined to be prudent to include these islands in the precleanup survey efforts. Thus, the soils survey was extended to include only the UNDISTURBED areas of SALLY, RUBY and SALLY'S CHILD.

The following information was considered necessary to the cleanup estimate effort:

1. Stratify the islands into three arbitrary groups.
2. Define to a depth of 180 cm (6 ft.) contamination over very large areas.
3. Determine only large volumes of contaminated soils.
4. Limit study to only those areas not disturbed by Project PACE.

Phase IV Island. YVONNE (RUNIT) was the only island classified in Phase IV, "severely contaminated". YVONNE is at the top of the list in the fallout insult ranking, the site of eight SGZ's, with a total H+1 hour insult of 62,849 R/h. Historically, the island is the most disturbed testing location on the Atoll. Records searches produce many conflicting reports of radioactive materials disposed of on or near the island. They all show considerable construction and reconstruction activity. "Old-timers" indicated the island was plowed while looking for experiments dispersed during several nuclear tests. The island is the known site of tons of activated or contaminated scrap and undetermined quantities of plutonium-contaminated soil.

Every recent survey effort from July 1971 through the several cursory surveys conducted late in 1972 and early in 1973 confirms the indication that the northern half of the island is a ~~homo~~heterogeneous conglomeration of radioactive contaminated debris buried to great depth (up to 10 ft.) at known and unknown locations. On the northern half of the island, samples taken at one location are not necessarily representative of any other location within that area at any proximity. With such conditions, survey efforts short of actual cleanup of the northern half are probably academic exercises.

A statistical approach to such conditions would appear meaningless for a cleanup estimate. This portion of the island would require treatment with objective sampling techniques to provide any meaningful evaluation.

The southern portion of the island, from Hardtack Station 1310, south, also has unknowns and an SGZ near the airstrip. Most of the area, however, was subjected to nearby fallout and could be approached by a statistically meaningful evaluation. An attempt was made to evaluate the conditions on YVONNE Island. The island was divided into two groups: the northern half which would be sampled objectively, to some depth, 120 to 180 cm (4 to 6 ft.), and the southern half which would be sampled statistically in some attempt to produce data useful for cleanup estimates.

The northern end of YVONNE would be sampled to determine the extent of known serious contamination situations. No attempt would be made to search for unknown deposits. Those areas suspected of having buried debris would be investigated, but in no great detail. This area can be evaluated to detail only by actually cleaning it up.

The southern portion of the island was approached as if it were a Phase III island. The number of samples was chosen to allow for the following:

1. Stratification of the island into four distinct and arbitrary groups (of equal sample numbers) for surface concentration values (0-5 or 0-15 cm).
2. Detection of contaminated soil areas as small as 10-15% of the southern half-island's area to a depth of 180 cm (6 ft.).
3. Determination of rough volumes of soil.

Discussion of Statistical Basis

Assumptions

Several assumptions were used as the basis for developing the statistical approach for the soils effort. As in any real situation, however, assumptions hold only partially, and this would certainly be true for Eniwetok.

First, it was assumed that, over the majority of the islands, the area sampled was rather unformally contaminated as far as surface distribution of radionuclides. Actually, activity levels would probably approximate a log normal distribution if the contamination was examined on a concentration versus frequency basis. However, over the area of any individual island any particular activity level would be distributed with equal probability. This is probably true for the Phase I islands, even ELMER ~~AND~~ and FRED. For the Phase II islands on which there were no SGZ's, the assumption is approximate, and thus modified. Phase III islands, with SGZ's and evidence of construction activities, presented some problems with this assumption, but, with appropriate modifications and careful interpretation for at least portions of these islands, the assumption could be approximate.

The island of YVONNE, the single Phase IV island, was the exception. Uniformity was out of the question for the northern half. The southern half, on the other hand, was treated as uniform after considering previous survey data.

The modification to save the uniformity assumption was to make another assumption. If the island's contamination was not uniform it was distributed on the surface with a slowly changing gradient. This would then lead to stratification into assumed uniform surface groups. This modification was applied to the Phase II, III and IV islands. The data would, of course, verify or reject these assumptions.

These assumptions have certain limitations, which, for the purposes of a precleanup survey, are not unacceptable. Assuming surface uniformity over an entire island or major fraction thereof means we can look only at large areas or whole islands, or even just groups of islands in any kind of "detail". We cannot subdivide further without changing methods (objective sampling) and increasing the number of samples to unmanageable quantities. The application of the uniformity concept depends on the variability of concentrations within the surface soil data, the range, mean, and number of samples -- all to be accurately determined as results of the soils effort.

The random sampling process was chosen as the primary method of soil sample location selection with the assumptions stated above. Random sampling would produce a better overall coverage of the Atoll than an objective technique and would achieve this with a minimum number of samples. This technique would also remove bias inherent in choosing an objective sampling method which could lean toward collecting samples from the easiest places or in patterns which would eliminate large portions of the islands because they were not "in line". The random technique selects, equally, samples from clearings, under bushes, in groves of trees, etc., producing a comprehensive sampling of the contaminated surface.

Objective techniques have merit and were applied when appropriate (hot spots, anomalies, etc.). Using an objective technique over the entire Atoll would, however, require astronomically large quantities of samples to produce the same overall precleanup data that the random sampling program would produce with a minimum of samples.

Number of Samples

In using a random selection technique for choosing the sampling locations, the controlling factor is variability within samples and between samples, and not the number of samples per unit area. If the surface contamination is assumed to be uniform, to some degree, then the same concentration results would be obtained if a certain fixed number of samples were chosen at random as would be obtained if a certain number of samples per unit area were collected, regardless of the size of the area sampled. Obviously, the number of samples collected on a per-unit-area basis would be small for small areas and large for large areas. This could be too small for the small areas to be statistically meaningful, and too large for large areas to be economically collectible.

With a random sampling scheme, the precision, dependent on variability and the number of samples, is chosen for the area being sampled. This sets the minimum number of samples, regardless of the size of the area. Thus, the precision and the number of samples are predetermined and their ratio maximized.

For the random sampling portion of the soils program, the minimum number of sampling locations per island was fixed at five, even on the smallest island. There was an overall trend to develop the number of samples on a per-unit-area basis, but the actual numbers were optimized according to the desired precision based on an assumed coefficient of variation. This coefficient was developed by experience and review of soils data from several different sources. Experience has shown that the coefficient of variation is a relatively constant value from group to group for radioactivity in soil. However, as this was used as an assumption for the basis of the soil collection technique, this would have to be verified by the data for the effort to have merit.

With the above in mind, the following approach was used in selecting the number of sample locations per stratification (group, island, portion of island):

1. The planning would be based on the soil concentrations of Plutionium-239.
2. A coefficient of variation with a value of 0.7 was assumed based on the review of previous soils data and the presumed conditions from the ranking of islands, historical reports, etc., previously discussed.
3. The standard error was expressed in terms of the assumed coefficient of variation and the mean soil concentration value.
4. Confidence limits, the probable error (PE) which is taken as two standard errors were thus expressed as a proportion of the mean:

SE = standard error $= \frac{\sigma}{\sqrt{n}}$, where: σ is the standard deviation

n is the number of samples in the specific area being investigated (number).

c = coefficient of variation $= \frac{\sigma}{\bar{x}}$,

where: $\bar{x}$ is the arithmetic mean concentration value of the samples collected for the specific area being investigated (mean).

Putting σ in terms of c: $\sigma = c\bar{x}$.

Substituting this into the standard error: $SE = \frac{\sigma}{\sqrt{n}} = \frac{c\bar{x}}{\sqrt{n}}$.

Expressing the standard error as a proportion of the mean, $\bar{x}$:

$$SE_m = \frac{SE}{\bar{x}} = \frac{c\bar{x}}{\sqrt{n}\ \bar{x}} = \frac{c}{\sqrt{n}}.$$

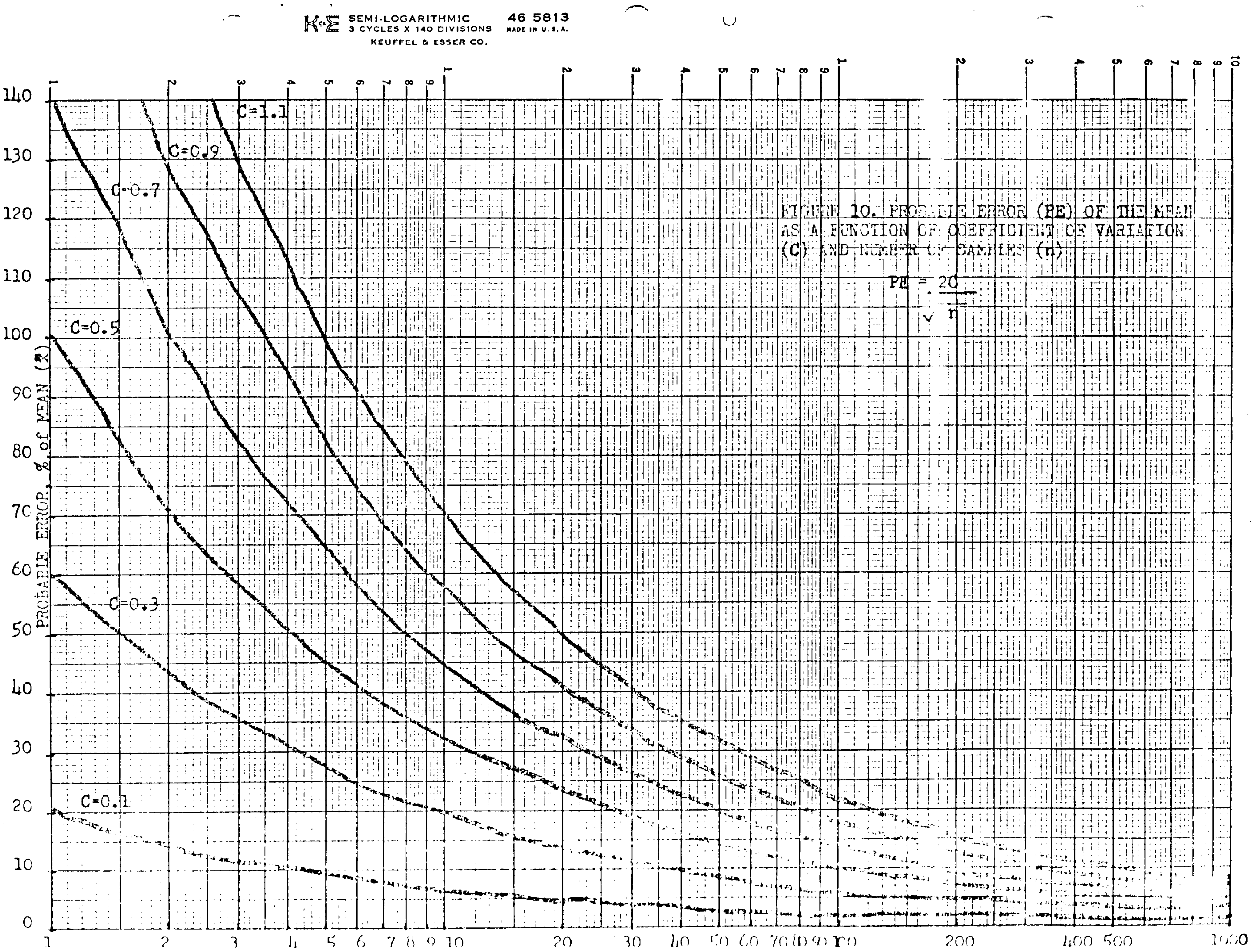
Defining the confidence limits as the probable error (PE), equal to 2 standard errors, 2 SE, and setting it as a proportion of the mean, $\bar{x}$, the PE_m would be 2 SE_m :

$PE_m = 2\ SE_m = \frac{2c}{\sqrt{n}}$ and the mean, $\bar{x}$, with these confidence limits would become:

$$\bar{x} \pm \frac{2c}{\sqrt{n}}$$

These confidence limits (the probable error) are shown graphically in Figure 10 for values of c of 0.1 to 1.1 in 0.2 increments and in tabular form for the 0.7 value of c in Table 4. Inspection of Figure 10 will show the effect of increasing the number of samples or of assuming or having a different value of the coefficient of variation. For any particular value of the coefficient of variation, the effect of increasing the sample numbers on the left side of the curve (less than 30 samples) has a much more positive effect on the precision than increasing the same number on the right side (greater than 30 samples). For example, using a coefficient of variation of 0.7, thirty samples produce an expected Probable Error of ± 27%. An increase of precision to ± 15% would require eighty samples, and to ± 10%, one hundred eighty samples. The law of diminishing returns is obvious.

Further inspection of the figure will illustrate the necessary compromises considered in establishing appropriate confidence limits. The actual confidence limits were established according to the information required. These limits then indicated the number of sample collection locations required. The actual numbers of sample locations by island and strata group, with the indicated assumed confidence limits and assumed mean are listed in Table 5. They did not differ too greatly from the designed values.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3 CYCLES X 140 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.
FIGURE 10. PROBABLE ERROR (PE) OF THE MEAN AS A FUNCTION OF COEFFICIENT OF VARIATION (C) AND NUMBER OF SAMPLES (n)
PE = 2C / √n
PROBABLE ERROR, % of MEAN (X)
C=1.1
C=0.9
C=0.7
C=0.5
C=0.3
C=0.1
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
200
400
500
1000

TABLE 4

CONFIDENCE LIMITS AS A PERCENT OF MEAN CONCENTRATION
BASED ON ASSUMED COEFFICIENT OF VARIATION OF 0.7

NUMBER OF SAMPLES PER STRATIFICATION	PROBABLE ERROR $\pm$ % of MEAN CONCENTRATION
5	63
10	44
20	31
30	26
40	22
50	20
60	18
100	14
200	10
500	6.3
1000	4.4

Confidence Limit = $PE_m = \frac{2(0.7)}{\sqrt{n}}$ (as a proportion of the mean)

TABLE 5.

NUMBERS OF SAMPLE LOCATIONS BY ISLAND AND STRATA GROUP, WITH INDICATED DESIRED CONFIDENCE LIMITS AND ASSUMED MEAN
ASSUMED COEFFICIENT OF VARIATION, c = 0.7

Island	Stratification	Sample Locations: Island Sfc	Pro	Total	Strata	Assumed mean x 239 Pu	Probable Error in % $\bar{x}$: Group	Island Surface	Stratification Surface	Stratification Profile
BRUCE	PHASE I - GROUP I	10	3	13	Phase I, Group I. - 116 sfc; Phase I, Group I. - 25 pro	1 pCi/g	Phase I, Group I. sfc ± 13%; Phase I, Group I. pro ± 28%; Phase I, Gps. I + III, surface 154 locations for ±11%	±39		
REX		4	3	7		"		±54		
GLENN		28	4	32		"		±25		
HENRY		14	3	17		"		±34		
IRWIN		9	3	12		"		±41		
JAMES		6	3	9		"		±47		
KEITH		12	3	15		"		±37		
LEROY		8	3	11		"		±43		
DAVID	PHASE I - Group II	53	7	60	3 at 20 sfc 7 profile	"		±18	±31	±53
ELMER		80	10	90	5 at 18 sfc 10 profile	"		±14	±34	±44
FRED		64	8,7	79	4 at 20 sfc 15 profile	"		±16	±31	±36

TABLE 5, Continued

Island	Stratification	Sample Locations: Island Sfc	Island Pro	Island Total	Strata	Assumed mean x 239 Pu	Probable Error in % $\bar{x}$: Group	Island Surface	Stratification Surface	Stratification Profile
SAM	PHASE I - GROUP III	4	1	5	Phase I, Group III 38 sfc Phase I, Group III 8 pro	1 pCi/g	Phase I, Group III sfc ±23% Phase I, Group III pro ±50%	±63		
TOM		4	1	5		"		±63		
URIAH		2	2	8		"		±50		
WALT		4	1	5		"		±63		
VAN		5	1	6		"		±58		
ALVIN		4	1	5		"		±63		
CLYDE		3	1	4		"		±70		
ALICE	PHASE II - GROUP I	22	4	26	2 at 13 Phase II, Group I 102 sfc Phase II, Group I 17 pro	50 pCi/g	Phase II, Group I ±14% sfc Phase II, Group I ±34% pro	±27	±38	
BELLE		33	4	37	2 at 18	"		±23	±32	
CLARA		9	3	12	1 at 12	"		±40		
DAISY		15	4	19	1 at 19	"		±32		
EDNA		6	2	8	1 at 8	"		±50		

TABLE 5, Continued

Island	Stratification	Sample Locations: Island Sfc	Sample Locations: Island Pro	Sample Locations: Island Total	Sample Locations: Strata	Assumed mean x 239 Pu	Probable Error in % $\bar{x}$: Group	Probable Error in % $\bar{x}$: Island Surface	Probable Error in % $\bar{x}$: Stratification Surface	Probable Error in % $\bar{x}$: Stratification Profile
KATE	PHASE II - GROUP II	22	2	24	2 at 12 (Phase II, Group II - 302 sfc; Phase II, Group II - 37 pro)	50 pCi/g	Phase II, Group II, sfc ± 8%; Phase II, Group II, pro ± 24%	±28	±40	
LUCY		22	4	26	2 at 13	"		±27	±40	
PERCY		5	1	6		"		±57		
MARY		22	3	25	2 at 12	"		±28	±40	
NANCY		22	4	26	2 at 13	"		±27	±40	
OLIVE		23	4	27	2 at 13	"		±27	±40	
PEARL		45	4	49	2 at 24	"		±20	±28	
TILDA		33	5	38	2 at 19	"		±23	±32	
URSULA		27	4	31	2 at 15	"		±26	±37	
VERA		22	3	25	2 at 12	"		±28	±40	
WILMA		22	3	25	2 at 12	"		±28	±40	
IRENE	3 arb. sfc strata	20	7,7	34	3 of 11	100 pCi/g		±24	±42	
JANET	5 arb sfc strata	132	12	144	5 of 28	50 pCi/g		±11	±26	

TABLE 5, Continued

Island	Stratification	Sample Locations: Island Sfc	Sample Locations: Island Pro	Sample Locations: Island Total	Sample Locations: Strata	Assumed mean x 239 Pu	Probable Error in % $\bar{x}$: Group	Probable Error in % $\bar{x}$: Island Surface	Probable Error in % $\bar{x}$: Stratification Surface	Probable Error in % $\bar{x}$: Stratification Profile
SALLY (Incl. RUBY & SALLY'S CHILD)	3 arbitrary sfc strata *SALLY*SALLY'S CHILD RUBY Group	30 (34)	7 *(9)*	37 (43)*	3 of 12 or 3 of 14	50 pCi/g West end 10 pCi/g elsewhere		±24 ±21	±40 ±38	
SALLY'S CHILD		4	2	6						
YVONNE (South)	4 arbitrary sfc strata	51	9	60	4 of 15	20 pCi/g		±18	±36	
YVONNE (North)	--	--	46	46	--	--	--	--	--	--

Selection of Sample Locations

Two methods of selection were utilized to choose sample locations. The primary method was by statistically random selection and was used on all islands where the surface contamination was considered uniform (or with a slow-changing gradient which could be stratified into approximately uniform areas). When a "hot spot" or anomaly was encountered, or a burial site was suspected, and at nearly all SGZ areas, an objective selection method was used to choose the sample locations. The purpose, in this case, was to determine to a rough degree the extent of the contaminated mass and give some value of its soil concentration. No attempt was made to define anything more than very crude area limits. Determination of actual boundaries of such contamination and specific estimates of volume were considered cleanup projects.

Random Selection. The sample locations for the random program were ~~indeed~~ chosen by a statistically random process. Each island was divided by a grid into relatively small areas (actually represented on available maps, drawings and photographs). An attempt was made to make the grid spacing as small as 50 feet or to get several thousand squares on a large island. Each of these grid squares or points was numbered. Areas which would be impossible to sample, such as concrete pads, coral reef, runways, paved roads, etc., were excluded during the gridding process, the appropriate grid square not being numbered.

The sample locations were chosen for each island according to the design criteria using random number tables.[2] An excess of 10% was chosen to allow

[2]Handbook of Mathematical Functions, USDC, NBS Applied Mathematics, Series 55, USGPO, Washington, 1965, pp. 991-995 (Table 26.11).

for additional locations which could not be sampled due to coral outcroppings, concrete pads, beach erosion, etc., which were not apparent on the drawings used during the location selection process. These locations were then replotted on the work maps and drawings, and also photographs, as available. Both surface and profile locations were determined in this manner, so that the profile would produce an additional surface sample and would also be randomly located.

The exact location of the sample collection was to be the center of the area chosen by the grid and random number technique above. It was realized that the determination of such a point with any great precision or accuracy in the field was technically impractical in most cases. It was most important, however, that the sample collector made every reasonable effort to locate the position as closely as possible. In particular, the sample was to come from within a 10-foot by 10-foot area defined as the center area for the grid point. Ideally, the sample would come from the exact center of this limited area. In the field the location was to be identified as indicated on the map or photograph, but would probably be located by pacing or other field direction. The spot so determined by such pacing would be the actual spot at the end of the designated number of paces and no other. If there was some obstacle to sampling at this specified location (which had not been eliminated prior to the random selection process), then that fact would be recorded in the field and no sample taken. In this way, bias due to a collector choosing the easiest location to sample, such as a clearing rather than within a dense thicket, would be minimized. This protocol was followed rigidly and did, in fact, result in some collection groups going to great effort cutting through jungle, arriving at the designated location to find it to be on a large pad of concrete or outcropping of coral. On JANET each sampling point was located to great precision and accuracy by an engineering survey team fielded for that purpose. This additional effort was expended because of the island's large size and dense vegetation cover.

The sample locations selected by the random selection technique are shown on photographs of each island in the data section of the Appendix.

Objective Selection. The objective technique was utilized where the random selection process and its necessary assumptions were not applicable. The aerial survey and terrestrial radiation survey identified hot spots on several islands. SGZ areas, assumed to have elevated concentrations of radionuclides, and suspected or known burial sites had been indicated by historical research. All of these locations were sampled using objective selection techniques to evaluate the specific situation. Only enough samples were collected to identify the radionuclides present and verify the existence of the area in question. When justified, a crude attempt was made to determine the extent of such elevated areas. The following specific areas were sampled objectively:

Table 5, Objective Sampling Areas (Excluding TLD)

Island		No. of Samples	
IRENE	Seminole Crater Area	10	Surface
	Interior	7	Profile
	Hot Spot (Engrg. Survey)	1	Profile
JANET	SGZ'	1 ea.	Profile (180 cm)
	Hot Spot (Engrg. Survey)	1	Profile
ELMER	Decontamination Pad		
LUCY	North End (Hot Spot)	2	Profile
		1	Surface
BELLE	Hot Spot (Engrg. Survey)	1	Profile
DAISY	Hot Spot (Engrg. Survey)	1	Profile
OLIVE	Hot Spot (Engrg. Survey)	1	Profile
SALLY	Hot Spot, West End (Engrg. Survey)	1	Profile

Table 5, Objective Sampling Areas (Excluding TLD) - Cont'd

Island		No. of Samples	
	CAPS Kickapoo SGZ (Engrg. Survey)	1	Profile
PEARL	Hot Spot (Engrg. Survey)	1	Profile
YVONNE	North End	46	Profiles (120-180 cm)

In addition to those samples collected objectively from hot spots, etc., where elevated concentrations were expected or observed, special samples were collected at each site where thermoluminescent dosimeters (TLD) were placed for exposure rate determination. (The TLD program will be discussed with the terrestrial radiation survey effort further in the text.)

At each of these sites, two sets of surface samples were collected. The first set included double core samples from the surface to 5 cm depth. The second set included cores from the surface to 15 cm depth. Each set was made up from a composite taken from the area directly under the TLD and from a location about 10-15 feet from the TLD at each cardinal point. Thus, for the shallow set, two cores each were taken from five separate locations and composited into a single shallow sample (i.e., 10 cores). For the deep set, single cores were taken from the same five locations and composited into a single deep sample (5 cores).

These samples would be analyzed to provide representative soil data around each TLD location to assist in evaluating the soil contribution to the terrestrial radiation exposure rate.

The objective sampling locations for the TLD study are indicated in Table 6. There were approximately 860 collections made, composited into 172 separate samples in support of the TLD effort.

Table 6, Objective Sampling Locations (TLD Study)

Island	Number of TLD Stations	Composited 0-5 cm Samples	Composited 0-15 cm Samples
IRENE	-	-	-
JANET	29	145	145
ALICE	10	50	50
BELLE	11	55	55
CLARA	7	35	35
DAISY	11	55	55
PEARL	18	90	90

Soil Collection and Terrestrial Radiation Survey Execution

The soil collection and terrestrial radiation survey efforts were executed concurrently. Early in the field execution phase of these programs, it was decided to abandon a rigid grid survey plan for the terrestrial radiation evaluation. Utilizing the aerial survey information, portable instrument readings were taken on the ground at each soil collection location. Thus, the aerial and ground readings could be correlated directly with the soils data. These would then be evaluated with the TLD information to produce an integrated statement of the terrestrial radiation exposure rates for all areas of the Atoll. The physical effort utilized to collect both soil samples and obtain instrument radings would then be minimized.

The execution of a program to collect several thousand soil samples and obtain a similar number of instrument readings from an atoll with 43 separate islands was no mean feat. A brief discussion of what was involved in the field effort is appropriate to engender an appreciation of the problems encountered in conducting such a program and their effect on program design, scope and execution.

The soils/radiation survey was conducted over a period of eight weeks by roughly 18 people on an atoll of 43 islands. These islands ranged from tiny bare sandbars to large (31-acre) densely vegetated islands infested with wasps and spiders. With the exception of FRED (Eniwetok Island), the islands of the Atoll were accessible only by ~~water~~ boat. Only five of the islands had usable personnel piers: FRED, ELMER, DAVID, YVONNE, and URSULA. All other islands had to be landed upon using a small rubber dinghy or amphibious craft, when possible. Depending on the weather, tides and location on the Atoll, these landings had to be effected in Force 4 (11-16 kt) trade winds through surf of various conditions onto sandy beaches or rugged coral reefs. These access conditions had considerable impact on what instrumentation could be utilized and the handling of the soil samples collected.

Vegetation on the islands ranged from none on small sandbars to sparse on several islands to very dense on most of the islands to be surveyed. It seemed that the vegetation was most dense and thus nearly impenetrable on those islands which had been swept clean or most seriously affected by the nuclear testing program. This vegetation, of course, had its effect on the survey effort. The survey parties had to cut into the dense jungle to reach sample locations, clear areas to effect collections and to locate themselves with sufficient precision to carry out the random selection aspects of the program.

The samples were taken from a wide range of soil conditions. Everything was experienced from soft coral sand to rough coral aggregates. These, in turn, were interlaced by vegetation roots and scrap metal junk. The very real possibility of encountering unexpected World War II ordnance was a constant threat on several islands, particularly JANET, where a U. S. Army EOD team assisted in the soils collection effort.

The field effort was supported by appropriate marine operations. Several vessels ranging from various small craft to a large ~~amphibious~~ LCU were used for the complete survey effort. The soils/radiation crews utilized, for their primary water transportation, an AEC-owned, 24-foot fiberglass boat. This, of course, put additional limitations on personnel, equipment, instrumentation and soil samples which could be safely carried aboard and landed through the various surf conditions in the rubber dinghy. The dinghy was also carried aboard the boat.

Soils Collection

The soils collection effort was scheduled under two basic conditions. First, an effort was made to address the least contaminated islands first and then proceed to the more heavily contaminated islands. Second, due to time and vessel limitations, full advantage had to be taken of the current weather and sea conditions.

The first condition reflected good laboratory practice to prevent cross-contamination of samples. The second condition was primarily safety-oriented and took precedence. Following these constraints resulted in a grouping of the islands by phase, as planned; however, the Phase I, Group II islands of DAVID, ELMER and FRED were held in reserve because of their easy access. Whenever bad weather prevented up-Atoll operations, the crews sampled these three "easy" islands.

Random Samples were usually collected on each island first and taken back to FRED for a quick gamma scan. If a hot spot or other radiological anomaly was indicated either by the gamma scan or the portable instrument readings, additional objective samples were taken.

TLD soil samples were collected concurrently with the random samples as the soils crews were in the area.

As indicated previously, a variety of soil conditions was encountered. The soils of Eniwetok Atoll are basically similar to those of other islands in the Ralik Chain of the Marshall Islands. Held and others have commented on these soils for several atolls.[3]

> "The parent material is primarily calcium carbonate, originating from corals, foraminifera, coralline algae and mollusk shells . . . In some areas, particularly along the seaward side of the islets, buried . . . horizons are formed as deep as 80 inches. These highly organic horizons presumably result from storm debris covering previously established soil and vegetations."

Although these remarks, describe the relatively pristine conditions of Rongelap Atoll, they are certainly applicable to the majority of islets on Eniwetok Atoll. Modified conditions are found, as expected, on these islands on which testing and/or construction were conducted.

Soil profiles observed on most of the islets consisted of a surface layer of vegetative litter of varied thickness followed by a somewhat thicker layer of dark coral soil containing some root structure, and other organic material. This layer also varied in thickness, being thicker on undisturbed islands and thinner or absent on disturbed islands. This second layer was usually followed by the basic coral sand structure of the island which prevailed down to the hard coral limestone bedrock. Buried horizons were found at almost any depth. Coral fragments of nearly any size infiltrated the soils and could be encountered almost everywhere.

The vertical distribution of radioactivity in coral soils has been the

[3] E. E. Held, S. P. Gessel and R. B. Walker, ATOLL SOIL TYPES IN RELATION TO THE DISTRIBUTION OF FALLOUT RADIONUCLIDES, University of Washington, August 1965, UWFL-92 (TID-4500)

subject of much investigation. In the cases of normal fallout and subsequent leaching and other vertical movement mechanisms, the concentrations of the various radionuclides with depth is expected to approximate an exponential or log normal distribution. From the limited number of soil profiles obtained during previous survey efforts, this distribution seemed to hold for undisturbed soils. Of course, it did not hold where the soil had been disturbed by mechanical mixing.

Recognizing the types of soil, the vertical distribution of radionuclides expected to be encountered, and the range of typical fission product gamma rays, the collection process was designed to sample in three different ways. Two surface samples were taken, a shallow and a deep core. Where vertical distribution information was required, a side wall sample profile was obtained to depth from a trench. The soil sampling tools are illustrated in Figures 11, 12 and 13.

RESERVFD

FOR

FIGURES 11, 12 and 13

SOIL SAMPLING TOOLS

"RESERVED FOR FIGURES 11, 12 AND 13"

The two surface samples were taken to provide an optional evaluation, depending on the vertical distribution determined by the profiles, and to obtain samples which would contain a significant fraction (>50%) of the activity deposited by fallout. The shallow ~~core,~~ 0 - 5 cm by 30 cm^2 core would collect samples to a depth comparable to the range of typical fission product gamma rays. This would facilitate the correlation between the activities of the various gamma emitting radionuclides with the terrestrial exposure rates measured by field survey meters held one meter above the sampling location. The deep 0 - 15 cm by 30 cm^2 core would generally contain a significant fraction of the activity deposited in areas subjected only to close in fallout but not be so deep as to unduly dilute the radioactivity of the sample.

An attempt was made to obtain a sample of approximately 500 grams. For this reason, two of the shallow cores were taken, side by side, and composited for each location. The deep core provided a sufficient sample from a single collection and was not duplicated.

The sidewall sampled profiles were taken at nominal depth increments of: 0-2, 2-5, 5-10, 10-15, 15-25, 25-35 cm and at 10 cm increments to total depth. Further, if soil horizons were encountered, an attempt was to be made to choose the interface lines as additional increments. The shallow portion of the profile could also be used as a surface-only sample, since the increments allowed averaging over 0-5 and 0-15 cm.

Special tools were used to assure uniformity of sampling and ease of collection. The shallow core was obtained using a "cookie cutter" type tool. The sampler was a section of hardened steel pipe exactly 5 cm deep with an internal cross-sectional area of 30 cm^2. A handle on top assisted in pushing the tool down into the soil to its depth. The surrounding soil was then scraped away and a cutting tool (a flat piece of steel) was inserted beneath the tool, cutting the sample free. Excess debris was blown or wiped off the cutter surface, and the sample was bagged and numbered.

The deep core was obtained with a similar device, a hardened steel pipe with 1 cm increments marked on the side to a depth of 15 cm. The pipe, 30 cm^2 in cross-section was driven into the soil. The surrounding soil was then removed, the cutter inserted, and the sample then treated as was the shallow core.

Profile samples were obtained using another special tool designed by Wayne Bliss of the EPA. This consisted of a drawer-like sample collector, with the back of the drawer absent, which was inserted into the sidewall of a trench dug to total profile depth. The drawer was 10 by 10 cm on top, with a depth of 5 cm. After the drawer was inserted into the soil, a cutter (large putty knife) was inserted as the back of the drawer, severing the sample free. The sample was then removed, bagged and numbered.

The next sample was then taken immediately below the previous one, continuing down the groove thus formed until the bottom of the profile had been reached.

The trenches used to collect the profiles were dug by hand on most islands. On those islands where deep (greater than 120 cm) profiles were required, a backhoe was landed and used to dig the trenches.

Each soil sample collected was placed in a plastic bag, that bag numbered, then placed inside of another plastic bag. The double-bagged sample was then placed in a field pack, with other samples, and transported to the shore where all samples were placed in large plastic bags for transport back to FRED, via rubber boat and larger craft.

Upon arrival at FRED, the samples were taken to a sample processing area for short-term storage, sample control processes and bag checks (to assure rebagging of those samples whose bags were damaged in transport).

Each sample was then gamma-scanned in the field counting lab, and then placed into storage until it could be shipped to the laboratory on-continent.

All shipments of soil samples were made according to current USAF, DOT and DOA regulations. Samples were transported by air from Eniwetok Atoll to Honolulu, Hawaii, to Livermore, California. Appropriate Department of Agriculture exemptions were obtained to allow for samples to pass unopened through U. S. Ports of Entry.

On-Site Counting Facility. A radiation counting laboratory was established on FRED. This laboratory had a 3" x 3" NaI detector and an intrinsic Ge detector together with associated electronics. This capability allowed scanning of soil samples for gamma-emitting fission and neutron activation productions, as well as for Americium-241, associated with Plutonium-239.

The data obtained by this scanning process provided information which influenced the soils program. Additional soils samples were obtained from hot spots found only by the scanning process. The information was also valuable in determining future analysis performed on the samples when they arrived on-continent. This preliminary activity estimate of samples with obvious large concentrations of radionuclides also assisted in assigning appropriate shipment classifications, according to DOT regulations.

Terrestrial Radiation Measurements

Radiation exposure rate measurements were obtained on the surface of every island in Eniwetok Atoll. There were two basic methods utilized, portable survey instrumentation and objectively placed TLD's. The purpose of the terrestrial radiation measurement program was multifold:

1. Produce a detailed examination of the geographical variability of the gamma exposure rate of air on each island due to the gamma rays of greater than 100 KeV emitted by radionuclides deposited in the soil.

2. Produce surface (1 meter) exposure rate measurements which could be correlated with the aerial radiation survey data.

3. Develop general, representative exposure rate values for the entire Atoll, correlating:

   a. Aerial measurements.

   b. Surface instrument measurements.

   c. TLD measurements.

   d. Soil concentration data.

4. Identify "hot spots" and other radiological anomalies for further examination.

At the initiation of the field effort of the survey in October 1972, it was planned to make terrestrial radiation exposure rate measurements on 50 to 100-foot rectangular grids, covering each island in detail. After the first island was surveyed, the dense vegetation encountered persuaded the teams to drop the 50-foot grid attempt, adopting, instead, a 100-foot grid, unless specific indications made finer surveys prudent. Shortly thereafter, Typhoon OLGA forced postponement of the soils/radiation survey until January 1973.

During the interim, an aerial radiation survey was performed by EG&G (November 1972). The resulting data were considered sufficient to warrant a significant modification of the terrestrial radiation survey effort. It was determined that gamma exposure rates taken by portable instruments at the same locations at which the soils samples were collected would be sufficiently representative of the area exposure rates to correlate data from the aerial survey, the soils and TLD programs. This concept was executed throughout the remaining portable instrument survey activities, being modified only at hot spots, etc., where some more detailed determination of exposure rate variability was necessary.

Portable Survey Instrumentation. The following instrumentation was utilized and is discussed below:

1. Alpha Radiation Detectors.

Alpha detection is a problem on Eniwetok Atoll. The moisture associated with the tropical rainfall not only masks alpha emitters in soil, but also causes electrical problems with all portable survey instrumentation.

The soil moisture problem was so great that until the very short "dry" season of January (when the average rainfall was only 1.02 inches per month and it had not rained for three weeks) alpha contamination was only detected by portable instruments on grossly contaminated surfaces.

a. PAC-1S. Early in the survey, and during previous surveys, the principal alpha radiation detection instrument was the PAC-1S. Aircraft restrictions prohibited carrying of gas for the PAC-4G, a more sensitive and desirable instrument, and left only the PAC-1S as an alternate. This instrument detects alpha radiation using an alpha scintillation detector with an active area of 59 cm^2 and an aluminized mylar window thickness of 1.5 mg/cm^2. The scintillation crystal is ZnS(Ag), silver activated zinc sulfide.

The detector was connected to a survey meter which had 4 linear ranges, 0-2K, 20K, 200K and 2,000K counts per minute, full scale at 2π geometry. The complete assembly was weather resistant, but the probe was easily damaged by any sharp object, even a blade of grass. When thus damaged, it then became very sensitive to light, direct or reflected, and was rendered useless.

b. LLL "Blue Alpha Meter." As the soils/radiation field effort progressed, an LLL modification of a well known air chamber type alpha survey instrument became available to the Eniwetok survey teams. Although not ruggedized like the PAC 1S, the instrument was much more sensitive, using an air chamber with an effective area of 100 cm^2 and an aluminized (on both sides) mylar effective window thickness of 0.85 mg/cm^2. Also, the probe guard was half again as thin as the PAC-1S probe and enabled near contact measurements of surfaces to be made. The air chamber was also subject to damage by sharp objects. More so, in fact, than the PAC-1S. However, unless a large hole had been torn in the mylar it was still serviceable.

The detector was connected to a nonruggedized survey meter which had three ranges, 0-1,000, 0-10,000, 0-100,000 counts per minute, full scale with 2π geometry.

Both the PAC-1S and the LLL "Blue Alpha Meter" were calibrated on ^{239}Pu. Alpha sources, attached to the survey instruments were used for field checking.

2. Beta-Gamma Detectors.

Two instruments were used for beta-gamma detection capability, the E-400B, G-M survey meter and the Ludlum Model 3 survey meter with a modified Model 44-9 "Pancake" G-M probe. These instruments were used to obtain contact readings on contaminated/activated radioactive scrap.

a. E-500B. This instrument is a portable Geiger counter used for conducting beta-gamma radiation surveys.

A tube sensitive to lower level gamma and beta radiation is located in the external probe. Discrimination between the two types of radiation is made by means of a rotary shield on the probe. The probe has an energy cut off at 0.31 MeV. The instrument was calibrated for gamma fields using ^{137}Cs.

b. Ludlum Model 3, with Model 44-9 "Pancake" Probe. This "thin window" detector was used for low energy gamma and beta radiation detection on scrap. The survey meter itself was used only as a relative indicator of contamination levels. The Model 44-9 "Pancake" Probe uses an LND 7311/8767 detector with an effective window thickness of 1.5 to 2 mg/cm^2 (mica) and diameter of 1.75 inches. The window thickness was increased to 7 mg/cm^2 by applying plastic tape to the probe face.

This instrument was calibrated for gamma radiation using ^{60}Co and for beta emissions using ^{90}Sr.

3. Gamma Detectors.

Again, two instruments were utilized for gamma radiation measurements, the Baird-Atomic Model NE-148 Scintillation Monitor 904-148, for low level gamma field measurement, and the FIDLER plutonium-americium gamma probe used only on the island of YVONNE for "hot spot"location.

a. NE-148 Scintillation Monitor 904-148. This was the "Baird-Atomic" portable survey instrument which was the mainstay of the surface terrestrial radiation exposure rate measurement program. The model 904-148 Scintillation Monitor is a highly sensitive instrument capable of measuring extremely fine variations of gamma radiation in three ranges from 0-30 uR/hr to 3 mR/hr.

The detecting element is of the same nature as that used in the aerial radiation survey, only smaller, being a 1 x 1 inch Sodium Iodide, NaI(Tl), crystal scintillator.

The instrument was calibrated using ^{137}Cs, for gamma fields. It proved to be an extremely reliable device which was very rugged for use in the field.

b. FIDLER probe.

Instrumentation Limitations. There are several significant limitations of the various portable survey instruments which must be considered before measurements made with them can be meaningfully interpreted and utilized. These limitations will be discussed here to prevent misinterpretation of such measurements and to show why certain instruments were not utilized more fully.

The soil moisture problem affecting the alpha instruments has been indicated. The problem was indeed a serious one. Until the survey made during the "dry" season in January, the surface alpha contamination on YVONNE could only be surmised from soil sample data. These data are sparce, even after the soils collection effort, and are certainly not enough to define the limits of surface alpha contamination on YVONNE to any satisfactory precision. The cost of collecting and analyzing sufficient soil samples to give better precision would be tremendously prohibitive.

Negative measurements made with alpha-only detecting instruments, with the usual existing soil moisture conditions, cannot be interpreted as confirming the absence of alpha contamination on those surfaces monitored. Such negative measurements can only be interpreted to mean that alpha contamination was not detected. Large quantities of surface alpha contamination could still be present, masked by the soil moisture. Indeed, they are, as evidenced by the dry season survey.

The single effort to survey the surface of YVONNE for alpha emitters with the sensitive LLL Blue Alpha Meter was quickly frustrated before monitors could get beyond the FIG/QUINCE area due to the return of the rain in February. What contamination that was detected was somewhat spotty, generally confined to the outer areas of the FIG/QUINCE SGZ area with levels of up to and over 100,000 dpm/100 cm^2.

For the above reasons, the alpha detectors were used for radiological control monitoring of personnel and equipment (in the dry state) and not for routine terrestrial survey measurements.

Interpretation of measurements made by beta-gamma detectors has always been questionable due to the nature of the radiation and the complex interaction with the detectors. The beta-gamma survey instruments utilized for the survey were G-M detectors, with appropriate shielding. The high range instrument, the E-500B, was used to evaluate scrap metal which was indicating gamma levels too high for the Baird-Atomic Scintillator. No real effort was made to determine, by shielding, the exact fraction of beta emissions. It was recognized that such contaminated scrap would be removed during the cleanup and only identification that it was radioactive was necessary.

The thin window beta-gamma detector, "Pancake" probe, was used, on specific occasions, to evaluate contaminated scrap according to current AEC directives which require surveying with a 7 mg/cm^2 window.

It is impossible in the field to obtain anything but gross estimates of activity with portable beta-gamma instruments. The limitations on energy dependence, inability to discriminate between low energy gamma radiation and beta emissions, and the rather severe geometry dependence were recognized, tne the instruments used accordingly, only as indicators. No attempt was made to determine activity per unit area or other estimate of relative concentration with these instruments.

The gamma-only detectors used in the field measurements effort also had their limitations. The Baird-Atomic Scintillator was calibrated with ^{137}Cs. The NaI scintillator crystal would respond differently to ^{60}Co and other radionuclide emissions, depending on the effective energy of the gamma ray detected. Geometry also had an effect. Gamma measurements would only have meaning if the geometry were somewhat fixed and remained so. For this reason, measurements were made at one meter above the ground surface.

Due to the shielding from the case and the canning of the crystal, there is a definite cut-off gamma energy of 100 KeV, below which no gamma radiation is detected.

These limitations are recognized and will be accounted for in any interpretation. The soils data will provide information on what radionuclides are present and their effect on the gamma exposure rate. The Baird-Atomic Scintillator measurements will be correlated with the soils data, TLD data, and the aerial survey data to produce meaningful results. The measurements made by the Baird-Atomic Scintillator are recognized to be relative and are interpreted as such.

The FIDLER probe was utilized on YVONNE for various measurements. This instrument has very severe limitations, which, if not recognized, can lean to gross misinterpretation of data and results. The FIDLER is a special configuration of NaI detector designed to measure plutonium contamination resulting from a nuclear weapons accident. The instrument was designed, specifically, to measure uniform plutonium contamination on the surface of a plane, normal to the cylindrical axis of the FIDLER probe without the presence of any other gamma emitters (except the associated ^{241}Am). The probe actually detects the gamma radiation from the associated Americium-241 and the weak X-radiation produced by Plutonium-239. A discrimination circuit looks at only the related gamma energies of 60 and 17 KeV. Of course, it detects any gamma radiation at these energies, without regard to the actual source. In other words, it detects the 60 and 17 KeV gamma of Americium-241 and the 17 KeV X-ray of Plutonium-239. It also detects 60 and 17 KeV Compton scattering radiation present from any other radionuclide emitting higher energy gamma radiation, such as ^{137}Cs and ^{60}Co.

Interpretation of FIDLER measurements made outside of the design criteria, i.e., in the presence of gamma emitters other than ^{239}Pu and ^{241}Am, or of buried plutonium, is very questionable, if a meaningful interpretation can be made at all. Other problems complicate the FIDLER, too. The instrument is very sensitive to temperature and moisture. Any temperature variations effect the calibration of the discrimination windows. Excessive moisture short circuits the high voltage lines required for the photomultiplier tube and other circuit components. The FIDLER probe is also very fragile and expensive and must be handled carefully at all times.

In spite of the complications indicated above several attempts to use the FIDLER for area surveys on YVONNE and other islands have been made. The net result has been a somewhat less precise reproduction of gamma survey measurements made with the Baird-Atomic Scintillator, only much less interpretable.

The precleanup survey did not attempt to use the FIDLER for area surveys recording FIDLER measurements. Instead, a speaker was attached to the FIDLER and the unit was used as a "hot spot" detector. The sound of the probe response served in the same manner as a radio direction finder making the location of hot spots and other local anomalies very easy to find. The FIDLER was also used, in the same manner, to survey equipment and personnel to detect any chunks of plutonium bearing material. To this end, the FIDLER did yoeman service.

Since the FIDLER could not discriminate between buried plutonium and other contaminated/activated scrap, nor could it be used reliably in relatively high gamma fields (CACTUS Lip), considerable thought must be given to any attempt to use the device for other than a hot spot probe on YVONNE or other islands of Eniwetok Atoll. The same thought must be given when attempting to interpret FIDLER area surveys of YVONNE.