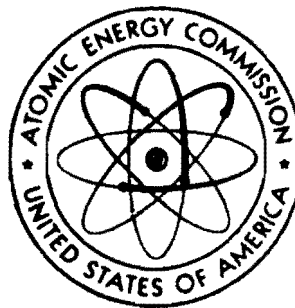


NVO-140  
VOLUME I

# ENEWETAK RADIOLOGICAL SURVEY



OCTOBER 1973

UNITED STATES ATOMIC ENERGY COMMISSION  
NEVADA OPERATIONS OFFICE  
LAS VEGAS, NEVADA

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# Contents

Abstract . . . . .	iii
Acknowledgments . . . . .	vi
I. Introduction (W. Nervik, Lawrence Livermore Laboratory) . . . . .	1
II. Enewetak (R. Ray, Nevada Operations Office, USAEC; J. Koranda and K. Marsh, Lawrence Livermore Laboratory; and V. Nelson, University of Washington) . . . . .	3
III. Survey Execution . . . . .	47
Survey Plan (W. Nervik, Lawrence Livermore Laboratory) . . . . .	47
Aerial Radiological and Photographic Survey (T. P. Stuart and R. Meibaum, EG&G, Inc.) . . . . .	49
Terrestrial Soil Survey (O. D. T. Lynch Jr., Nevada Operations Office, USAEC, and P. H. Gudiksen, Lawrence Livermore Laboratory) . . . . .	81
External Dose Estimate (H. L. Beck and J. E. McLaughlin, Health and Safety Laboratory, USAEC; P. H. Gudiksen and D. E. Jones, Lawrence Livermore Laboratory; O. D. T. Lynch, Jr., Nevada Operations Office, USAEC; and T. P. Stuart, EG&G, Inc.) . . . . .	117
Marine Program (V. Nelson, Laboratory of Radiation Ecology, University of Washington, and V. E. Noshkin, Lawrence Livermore Laboratory) . . . . .	131
Terrestrial Biota Survey (J. J. Koranda, J. R. Martin, S. E. Thompson, Jr., M. L. Stuart, and D. R. McIntyre, Lawrence Livermore Laboratory; G. Potter, Environmental Protection Agency) . . . . .	225
Air-Sampling Program (B. Clegg and D. Wilson, Lawrence Livermore Laboratory) . . . . .	349
Engineering Survey - Radiological Aspects (O. D. T. Lynch, Jr., Nevada Operations Office, USAEC) . . . . .	372
Analytical Program (R. W. Hoff, J. W. Meadows, H. D. Wilson, A. L. Prindle, R. Gunnink, and K. O. Hamby, Lawrence Livermore Laboratory) . . . . .	426
Enewetak Survey Radiological Controls (O. D. T. Lynch, Jr., Nevada Operations Office, USAEC) . . . . .	486
Dose Assessment and Evaluation . . . . .	491
Dietary and Living Patterns (W. L. Robison, Lawrence Livermore Laboratory) . . . . .	492
External Dose Determination (H. L. Beck and J. E. McLaughlin, Health and Safety Laboratory, USAEC; P. H. Gudiksen and D. E. Jones, Lawrence Livermore Laboratory) . . . . .	498
Evaluation of the Inhalation Pathway (D. W. Wilson, Lawrence Livermore Laboratory) . . . . .	507
Appendix A - Relationship Between Resuspended Plutonium in Air and Plutonium in Soil (L. R. Anspaugh, Lawrence Livermore Laboratory) . . . . .	515

Contents (continued)

Dose Estimates for the Marine Food Chain (W. L. Robison, Lawrence Livermore Laboratory)	526
Evaluation of the Dosage from Terrestrial Foods (Y. C. Ng, B. J. Berger, D. J. Pederson, Y. E. Ricker, and S. E. Thompson, Jr., Lawrence Livermore Laboratory)	542
Summary of Dose Assessment (W. L. Robison, Lawrence Livermore Laboratory)	612
IV. Summary of Findings (W. Nervik, Lawrence Livermore Laboratory)	626
Appendix I - Planning and Operations Directive (NVO-121) - 1972 Enewetak Atoll Precleanup Radiological Survey	696
Appendix II - Survey Results by Island	Vols. II-III

## Abstract

The AEC has conducted a survey of the total radiological environment of Enewetak Atoll in order to provide data for judgments as to whether or not all or any part of the Atoll can be safely reinhabited. More than 4500 samples from all parts of the marine, terrestrial, and atmospheric components of the Atoll environment were analyzed by instrumental and radiochemical methods. In addition, an aerial survey for gamma-radiation levels was conducted over all land areas.

$^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{239}\text{Pu}$  are the predominant radioactive isotopes now present, but their distribution is far from uniform. Islands on the southern half of the Atoll from ALVIN to KEITH have lev-

els of contamination comparable to or less than those due to world-wide fallout in the United States. On the northern half, islands ALICE to IRENE are most heavily contaminated, KATE to WILMA are least contaminated, and JANET is at an intermediate level.

These radiological data have been combined with the best information currently available on the expected diet of the Enewetak people to estimate potential whole-body and bone doses to the population for six living patterns at 5-, 10-, 30-, and 70-yr intervals after return. Thirty-year integral dose estimates for unmodified (i.e., current) conditions are shown in Table A.

Table A. The 30-yr integral dose for six living patterns, assuming unmodified conditions.

Living pattern	30-year integral dose, rem Unmodified conditions									
	Inhalation			External Bone, W. B.	Terrestrial		Marine		Total	
	Bone	Lung	Liver		W. B.	Bone	W. B.	Bone	W. B.	Bone
I	7(-4)	9(-4)	4(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.029	0.036	0.016	1.6	2.7	33	0.053	0.84	4.4	35
III	0.10	0.13	0.056	4.0	6.1	75	0.053	0.84	11	80
IV	0.47	0.59	0.24	10	21	210	0.053	0.84	31	220
V	0.11	0.13	0.058	2.9	2.7	33	0.053	0.84	5.7	37
VI	0.090	0.11	0.049	4.4	9.6	130	0.053	0.84	14	135

Living pattern	Village island	Agriculture	Visitation
I	FRED/ELMER/DAVID	ALVIN through KEITH	Southern islands
II	FRED/ELMER/DAVID	KATE through WILMA plus LEROY	Northern islands
III	JANET	JANET	Northern islands
IV	BELLE	BELLE	Northern islands
V	JANET	KATE through WILMA plus LEROY	Northern islands
VI	JANET	ALICE through IRENE	Northern islands

The main contribution to the population dose comes through the terrestrial food pathway, followed in decreasing order of significance by the external gamma dose, marine, and inhalation pathways. In the terrestrial food pathway, the main contribution to both whole-body and bone dose is due to pandanus and breadfruit. Percentage contributions to the 30-yr integral dose for each of the terrestrial food items for a population engaged in agriculture on JANET are shown in Table B.

Corrective actions to reduce population doses will be most beneficial if they are directed at the primary contributors, i.e., pandanus and breadfruit in the diet and external gamma dose in the residence areas. Since neither pandanus nor breadfruit are now growing on the Atoll in sufficient amounts to provide a significant dietary component, control of the location and manner in which they are reestablished will have a direct influence on the population doses from these fruits. If their growth were limited to the southern islands, for example, and the population living on JANET were to import them

Table B. Percentage of total 30-yr terrestrial food dose to a population engaged in agriculture on JANET.

Food	<sup>90</sup> Sr dose to bone, %	<sup>137</sup> Cs dose to whole body, %
Domestic meat	17	26
Pandanus fruit	40	35
Breadfruit	34	29
Wild birds	0.005	0.003
Bird eggs	0.05	0.002
Arrowroot	2	0.3
Coconut meat	6	9
Coconut milk	0.9	1

rather than grow them locally, the expected 30-yr bone dose would be reduced from 80 to 25 rem and the whole-body dose from 11 to 6.5 rem. Similar results would be obtained if uncontaminated soil were imported to JANET for the establishment of these plants. Attempts to obtain the same results by removal of <sup>90</sup>Sr- and <sup>137</sup>Cs-contaminated soil from JANET would require denuding of the entire island because of the relatively uniform distribution of these isotopes over the land surface.

Significant reduction of the external gamma dose may be achieved by placing a 2-in. layer of clean gravel in the village areas and by plowing the agricultural areas. On JANET, for example, use of these procedures reduces the expected 30-yr external dose from 4.0 to 1.7 rem.

Thus, from Table A it is clear that a very broad range of population doses may be expected, depending on village island, agricultural island, and living pattern. It is equally clear that substantial reductions of the higher doses can be achieved through relatively simple modification of the agricultural practices and of the soil. Table C summarizes the reduction that could be expected from these actions for a population living on JANET.

The island of YVONNE presents a unique hazard on Enewetak Atoll. Pure plutonium particles are present on or close to the ground surface, randomly scattered in "hot spots" over most of the area from the tower to CACTUS crater. Examination of these "hot spots" has revealed the presence of occasional milligram-size pieces of plutonium metal, as well as smaller pieces which are physically indistinguishable in size from the

surrounding coral matrix. Given these current conditions, it must be assumed that pure plutonium particles of respirable size are now also present on the surface or may be present in the future as weathering effects oxidize and break down the larger particles. Lung dose assessments for this area, therefore, must be based on inhalation of pure plutonium particles rather than those having the average plutonium content of the soil.

The potential health hazard via the inhalation pathway is sufficiently great to dictate two basic alternatives for remedial action for this island: (1) Make the

entire island an exclusion area—off limits to all people, or (2) conduct a cleanup campaign which will eliminate the "hot-spot" plutonium problem and remove whatever amount of soil is necessary to reduce the soil plutonium concentration to a level comparable to other northern islands. As an indication of the volumes of soil involved, removal of a 10-cm thick layer of topsoil in the area in which "hot spots" have been detected involves approximately 17,000 m<sup>3</sup> of material. Further removal of soil to reduce the maximum plutonium contamination levels to 50 pCi/g or less involves an additional 25,000 m<sup>3</sup> of material.

Table C. 30-yr integral doses from all pathways compared to U.S. external background dose.

Location	30-yr integral dose, rem <sup>a</sup>			
	Unmodified soil case		Modified soil case <sup>b</sup>	
	W. B.	Bone	W. B.	Bone
Enewetak Atoll living pattern III (JANET-current conditions)	11	80	8.9	78
Enewetak Atoll living pattern III (JANET-pandanus and breadfruit imported)	6.5	25	4.2	23
Enewetak Atoll living pattern III (JANET-all agriculture confined to southern islands)	4.2	7.0	1.9	4.7
Enewetak Atoll living pattern I (southern islands)	1.0	3.8	1.0	3.8
U.S. background only <sup>c</sup>	3.0	3.0	3.0	3.0

<sup>a</sup>Sum of all pathways for the Enewetak living patterns (i.e., external, inhalation, marine, and terrestrial).

<sup>b</sup>Soil modified by placing 2 in. of clean gravel in the village area and plowing the agricultural area.

<sup>c</sup>Based upon background of 100 mrem/yr at sea level.

## Acknowledgments

Successful completion of the Enewetak Radiological Survey was the result of the effort and cooperation of many organizations. However, organizations are composed of individuals, and it really has been the attitudes and abilities of these people upon which so much has depended. We wish to acknowledge most heartily the efforts of all participants—those who worked in the field, those who worked in the laboratories at home, and those who provided support services so important to an efficient operation.

The list is long, but that is indicative only of the size and complexity of the operation. Very likely, in spite of our most diligent efforts, the names of some who participated have been omitted. To them we extend our apologies and our appreciation.

All of the following organizations and individuals have made significant contributions to the success of the AEC Enewetak Radiological Survey. To them, collectively and individually, we express deepest thanks for a difficult job done well. This report is long, and it contains an enormous amount of information, but it does not come close to telling the whole story of what happened to all the individuals concerned from September 1972 to October 1973. That is the stuff of which reminiscences are made.

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## I. Introduction

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On April 18, 1972, Ambassador Franklin Haydn Williams, U. S. Representative to the Micronesian Status Talks, and TTPI High Commissioner Edward E. Johnston issued at Saipan a joint announcement which stated that "the United States Government is prepared to release legally the entire (Enewetak) Atoll to the Trust Territory government at the end of 1973, subject to the retention of some minor residual rights." This announcement was welcomed by the Enewetak people, who for many years have sought to obtain a commitment from the U. S. Government for return of their ancestral homeland to their own jurisdiction. They had been moved from Enewetak in December 1947 in order that the Atoll could be used for the nuclear weapon testing program and ever since have been living on Ujilang, an atoll approximately 125 mi southwest of Enewetak.

The announcement went on to state that "prior to the actual settlement of the Atoll, it will be necessary to carry out the same type of survey, cleanup, and rehabilitation procedures that have been utilized for Bikini Atoll. As in Bikini, the schedule for resettlement will depend on the results of the survey and the pace of the rehabilitation program."

In May 1972 a U. S. Atomic Energy Commission (AEC) survey team visited Enewetak Atoll to conduct a preliminary radiological reconnaissance. They could not visit all islands in the Atoll in the time available, but of those they visited,

they found what they considered to be significant radiological hazards still existing on BELLE, JANET, SALLY, URSULA, and YVONNE.\* Initial cleanup and rehabilitation cost estimates based on data from this survey had, of necessity, to incorporate a wide range of assumptions, due partly to the lack of information on the extent of the radiological contamination, partly to the lack of a detailed analysis of the dose-to-man implications for each isotope comprising that contamination, and partly to uncertainties as to the manner of disposal of radioactive debris. Acceptability of disposal methods and plans would require detailed consideration of bioenvironmental impact, of political concerns, and of the desires of the Enewetak people. Since estimates based on these assumptions indicated that cleanup costs could run to tens of millions of dollars, it was considered essential that much more comprehensive

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\*For the sake of simplicity, U. S. alphabetical designators for all islands will be used in this report. A cross-reference to all names we understand to be in use for each island may be found on p. v of Appendix II. An exception to this approach applies to the name for the Atoll itself. As Dr. Jack Tobin points out, "It is called Enewetak by the Atoll people and the rest of the Marshallese. The people of the Atoll say that it means island (ene) toward, or pointed toward, the east or wetak; hence, Enewetak." Since there is a commitment to return the Atoll to TTPI jurisdiction in the near future, this seems an appropriate time and place to begin using the Marshallese spelling.

and detailed information on the radiological condition of the Atoll be obtained before the start of cleanup and rehabilitation operations.

On September 7, 1972, at an inter-agency meeting in Washington, the AEC agreed to assume responsibility for conducting this comprehensive radiological survey; the Department of Defense agreed to assume responsibility for conducting such cleanup operations as were required; and the Department of the Interior agreed to assume U.S. Government responsibility for rehabilitation and resettlement of the native population.

This report describes the radiological survey which has been executed by the AEC as a consequence of the September 7 commitment and presents data which have been obtained from that survey. Recommendations for cleanup and/or other corrective action based on these data will

be the subject of separate action by the Atomic Energy Commission.

In Section II a fairly detailed description of the Enewetak Atoll and a history of the Enewetak people are presented to set the framework within which the Survey has been conducted.

Section III contains a separate chapter for each major component of the Survey, including Plans, Aerial Survey, Terrestrial Soil and Radiation Survey, External Dose Estimation, Marine Survey, Terrestrial Biota Survey, Air Sampling, Engineering Survey, Analysis Program, Radiological Controls, and Dose Assessments.

Section IV contains a Summary of Findings.

The large number of photographs and figures needed to present the data are contained in the Appendix as Volumes II and III.

## II. Enewetak

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### FOREWORD

Portions of this chapter are largely drawn from a working draft of the manuscript which is to become the Draft Environmental Impact Statement for Enewetak cleanup. This statement is being prepared by Holmes and Narver, Inc. under contract to the Department of Defense. We are indebted to the Defense Nuclear Agency for permitting use of the statement and to Dr. Stanley Kaplan of Holmes and Narver for his assistance toward its timely availability. Dr. Jack Tobin, a major contributor to the Kaplan effort, was also consulted extensively on history and anthropology in relation to other sections of this report. The last section of this chapter is drawn from field trip reports of Kenneth Marsh and Victor Nelson.

### ENEWETAK ATOLL—HISTORY AND STATUS

#### Enewetak Atoll Island Names

Because the native names of most of the islands in the Enewetak Atoll are difficult for English-speaking people to pronounce and spell, male and female first names were assigned to the islands during the U.S. occupancy. Site names were also given to several points in the lagoon and on the reef where scientific structures had been erected. Nearly

all documents and maps made subsequent to 1952 include these site names, and in some cases the native names are also shown in parentheses.

Table 1 presents a correlation of these site names with the native names obtained from the Enewetak people during the Ujilang field trip in August 1973, and from the U.S. Hydrographic Office Charts. It is interesting to note the influence of the Japanese romanization on the names given in the hydrographic charts.

#### Physical Description of Enewetak Area

##### Geography

Enewetak Atoll is the northwesternmost atoll in the Western (Ralik) Chain of the Marshall Islands, forming the northern part of Micronesia in the central Pacific Ocean (regional map, Fig. 1). The location is 11° 21'N, 162° 21'E, approximately 550 naut mi southwest of Wake Island, 189 naut mi west of Bikini Atoll, and 2380 naut mi southwest of Honolulu.

The Atoll consists of 40 islands on an elliptical reef approximately 23 by 17 naut mi, with the long axis running northwest to southeast. The total land area is 2.75 mi<sup>2</sup>, with the land height generally averaging 10 ft above mean sea

Table 1. Comparison of site and native names.

Site	Native names from U. S. Hydrographic Office charts		Native names <sup>a</sup>
	1946	1968	
ALICE	Bogallua	Bogallua	BOKOLUO
BELLE	Bogombogo	Bogombogo	BOKOMBAKO
CLARA	Ruchi	Eybbiyae	KIRUNU
DAISY	__b	Lidilbut	LOUJ
EDNA	__b	__b	BOCINWOTME
HELEN	Bogairikk	Bogeirik	BOKAIDRIK
IRENE	Bogon	Bogon	BOKEN
JANET	Engebi	Engebi	ENJEBI
KATE	Muzinbaarikku	Mujinkarikku	MIJIKADREK
LUCY	Kirinian	Billee	KIDRINEN
PERCY	__b	__b	TAIWEL
MARY	Bokonaarappu	Bokonarppu	BOKENELAB
NANCE	Yeiri	Yeiri	ELLE
OLIVE	Aitsu	Aitsu	AEJ
PEARL	Rujoru	Rujyuru	LUJOR
RUBY	Eberiru	Eberiru	ELELERON
SALLY	Aomon	Aomon	AOMON
TILDA	Bijjiri	Bijjiri	BIJILE
URSULA	Rojoa	Rojoa	LOJWA
VERA	Aaraanbiru	Arambiru	ALEMBEL
WILMA	Piirai	Piirai	BILLAE
YVONNE	Runit	Runit	RUNIT
SAM	__b	__b	BOKO
TOM	__b	__b	MUNJOR
URIAH	__b	__b	INEDRAL
VAN	__b	__b	__b
ALVIN	Chinieero	__b	JINEDROL
BRUCE	Anyaani	Japtan	ANANIJ
CLYDE	Chinimi	Chinimi	JINIMI
DAVID	Japtan	Muti	JAPTAN
ELMER	Parry	Parry	MEDREN
WALT	__b	__b	BOKANDRETOK
FRED	Eniwetok	Eniwetok	ENEWETAK
			Native names from Dr. Jack A. Tobin
GLENN	Igurin	Igurin	IKUREN
HENRY	Mui	Buganegan	MUT
IRWIN	Pokon	Bogan	BOKEN
JAMES	Ribaion	Libiron	RIBEWON
KEITH	Girunien	Grinem	KIDRENEN
LEROY	Rigili	Rigile	BIKEN
REX	Jieroru	Bogen	JEDROL
OSCAR	__b	__b	DREKATIMON
MACK	__b	__b	UNIBOR

<sup>a</sup>As confirmed by the Enewetak people during the Ujilang field trip of July 1973.

<sup>b</sup>No native name.



level. The vicinity map (Fig. 2) shows the Atoll configuration.

The lagoon, which is about 388 mi<sup>2</sup> in area, has three entrances: an east channel approximately 180 ft deep, between DAVID and ELMER; a 6-mi wide channel to the south; and a shallow (approximately 4 fathoms maximum depth) channel to the southwest. Tidal currents vary from up to 2 knots in the deep channel to 1 knot in the south channel.

### Geology

Enewetak Atoll is 15,000 ft above the ocean floor, while the top of the eroded volcano forming the island base is approximately 4200 ft below the surface. Steep coralline reefs reaching to the surface form a flat oval ring of reef and low-lying islands, within which is a shallow lagoon with a maximum depth of about 200 ft.

Enewetak is a classic example of the Darwinian concept of atoll formation in which an atoll is born when an oceanic volcano surrounded by a fringe coral reef begins to slowly subside below the ocean level. As the coral and coralline algae (which require shallow, clear, warm, oxygenated marine waters) maintain an upward growth commensurate with the subsidence, a fringe reef flourishes, particularly on the ocean side. As the volcano continues to subside, the fringe reef gives way to a barrier reef, and then to an atoll.

Since the northeast trade winds vary little in their direction, the reefs on the windward and leeward sides of the atoll are distinctly different. A greater volume of ocean water, carrying nutrients necessary for coral growth, flows over the windward side due to the wind-generated ocean currents. Therefore,

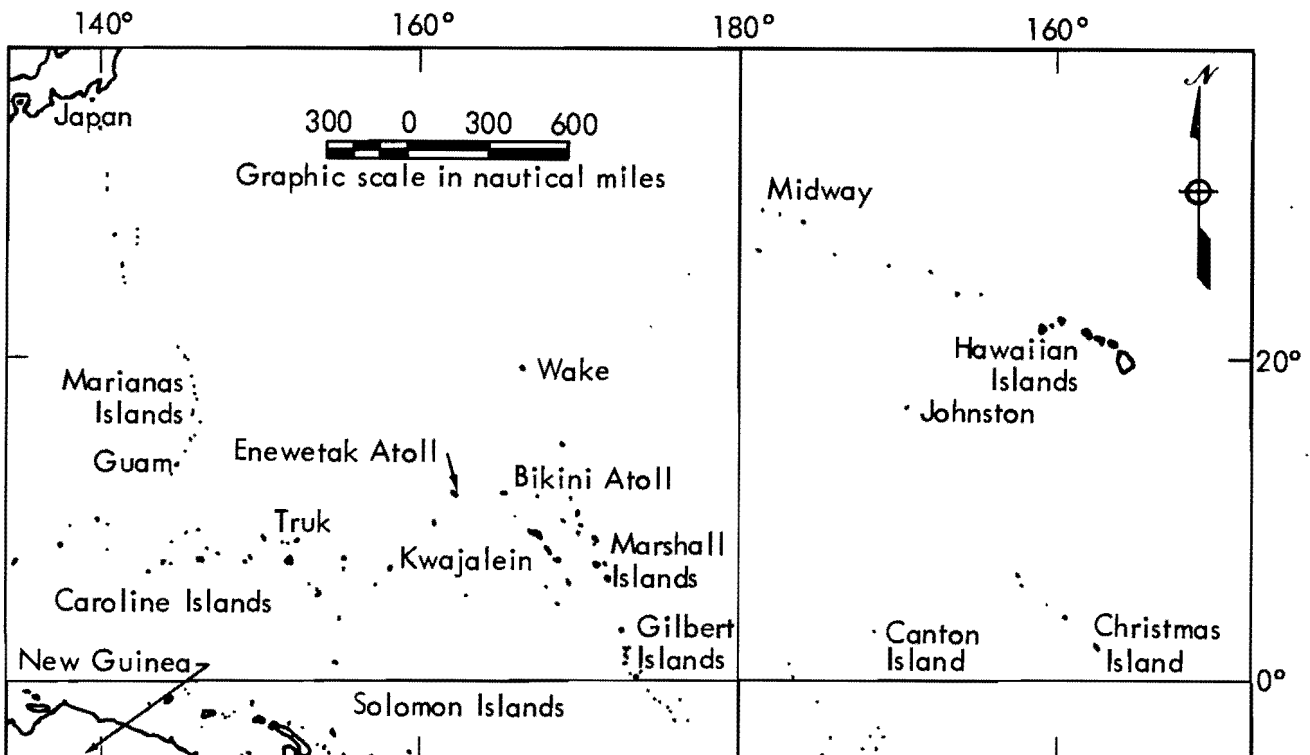


Fig. 1. Regional map—Central Pacific Ocean.

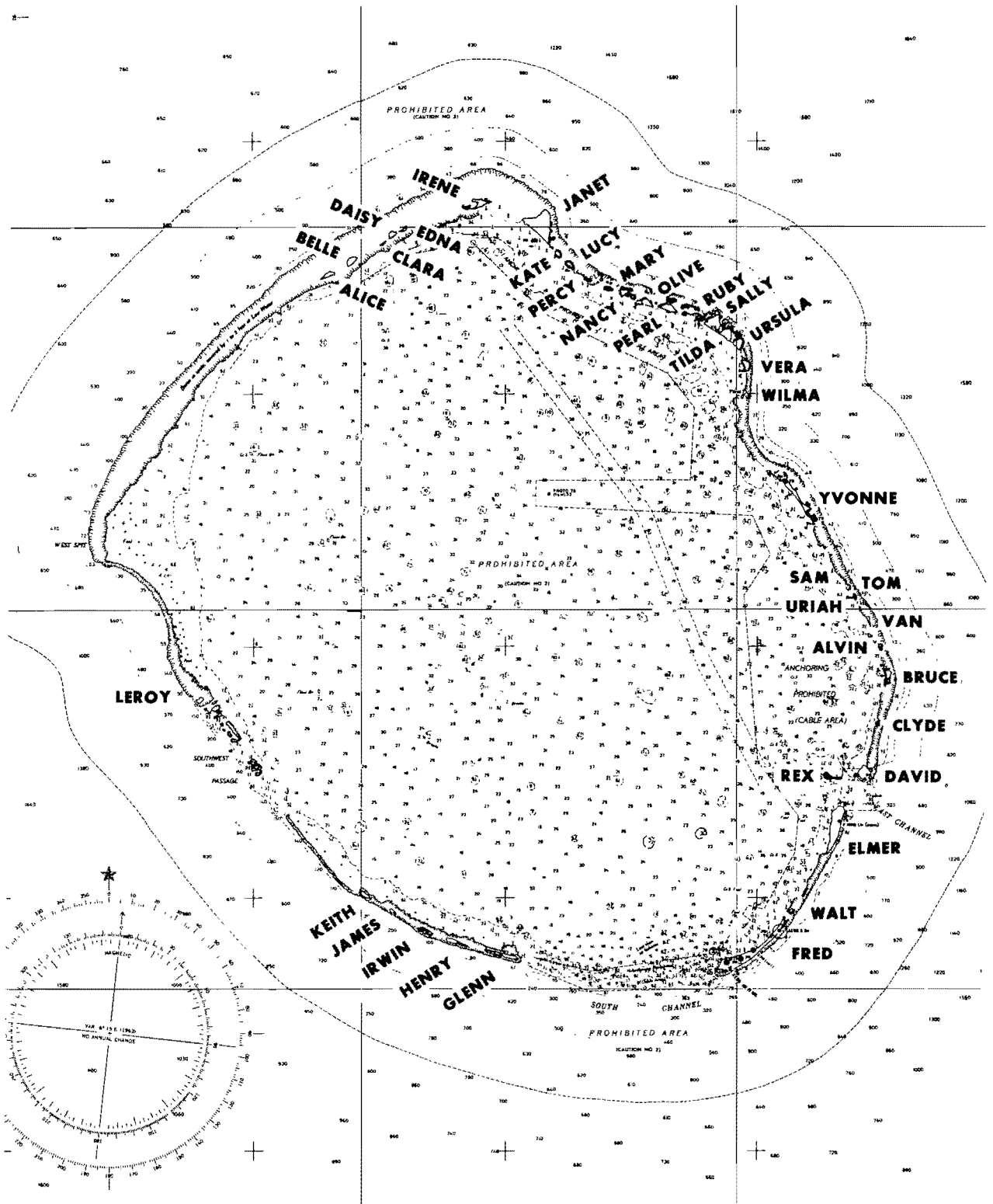


Fig. 2. Vicinity map—Enewetak Atoll.

more rapid growth occurs on the windward side, which has a slightly elevated ridge at the reef edge, while there is none on the leeward side. The leeward side drops sharply to ocean depths up to 200 ft, whereas the windward reef slopes seaward at about a 45-deg angle.

Four near-surface geologic regions can be distinguished at Enewetak Atoll: island, interisland, ocean reef, and lagoon. Descriptions of the island and ocean reef geology can be given, based on core samples from 50 holes drilled during the nuclear testing program (Cooper and Pratt, 1968). No records are available of the interisland and lagoon geologies; hence, these can only be inferred.

The island geologic profile consists of unconsolidated coral sands and gravels, saturated below the water table and extending from the surface to a maximum depth of 150 ft. The water table varies with the tide; its amplitude decreases rapidly with distance from shore. Typical water depths (elevation of island above mean tide) are 5 to 8 ft. At the intertidal level, a 1- to 5-ft layer of beach rock (calcium-carbonate-cemented coral sands and gravels) is usually found; the exposed portions of the rock form most of the shore line. The rock strength ranges from hand-crushable to high-strength sandstone, decreasing in strength as well as thickness from ocean to lagoon. Below the unconsolidated coral sands and gravels, there is an old reef horizon going from the ocean to lagoon side at depths of 50 to 150 ft. This reef horizon is gradational and porous, consisting of large detrital and in situ coral fragments, with fine sands and muds occupying the voids.

The ocean reef profile shows a similarity to the island profile, except that the upper surface layer consists of a wave-planeated, dense, algal-limestone reef flat composed of detrital and in situ coral. The thickness of the upper reef horizon varies from 0 to 15 ft, progressing outward from the island, and is composed of a dense algal limestone. Of two holes drilled into the SALLY reef proper, one penetrated a 35-ft sand and gravel horizon between the upper and lower reefs; the other did not. It is inferred, based upon limited drilling and general atoll physiography, that the ocean reef geology is more heterogeneous than the island geology, containing numerous large coral heads, caverns, etc.

The interisland geologic profile can be presumed to be similar to the island geologic profile, except for the possibility that the top 10 to 40 ft of rock and sand has been eroded away by the sea.

The lagoon geologic profile probably consists of soft, fine sediments to a depth of a few hundred feet, with intermixed and sporadic lagoonal coral heads. The depth of the lower reef horizon, if it exists, is probably greater than a few hundred feet.

#### Climatology

Enewetak's climate is the tropical marine type, with temperatures ranging from 71 to 94°F and relative humidity in the 73 to 80% range. There is much cumulus cloud cover, moderate rainfall (57 in. mean annual rainfall), and, to a lesser extent, constant northeasterly trade winds (0 to 30 knots). Most depressions or tropical storms occur during the months of September through December,

although they are possible at any time of the year. A climatological summary of Enewetak Atoll for a 12-yr period, as prepared by the U.S. Air Force Environmental Technical Applications Center, is shown in Table 2.

### Hydrology

Enewetak Atoll relies on rainfall for its supply of fresh water. Since the soil is extremely porous, drainage of rainfall by downward percolation through the ground is rapid. This "groundwater" makes contact at its lower face with marine water that has infiltrated through the porous rock from the sea and lagoon. Fresh water poured on an open body of salt water will quickly spread over the surface of the salt, and through currents and waves will become thoroughly mixed

with the salt water. Porous rock, however, interposes an obstacle to this rapid spread and restricts the mixing of the light fresh water with the denser salt water. The fresh water is only about 40/41 as heavy as salt seawater and floats on the salt water, displacing 40 parts of seawater for each part of fresh water floating above the normal saltwater level. That is, fresh water seeping to basal groundwater level on coral atolls and other porous islands has a depth that is about 40 times the head or elevation of its water table above sea level (Fig. 3). This head or hydraulic gradient of water tends to seek sea level by lateral flow through the restricting rock. This principle of freshwater displacement of salt water in islands and coastal areas is known as the Ghyben-Herzberg law, after its discoverers. As the head of water

Table 2. Meteorological observations for Enewetak Atoll over a 12-yr period.

Parameter description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Absolute max temp, °F	88	88	89	90	91	90	92	91	93	91	94	88	94
Mean max temp, °F	85	85	86	86	86	87	87	87	88	87	86	86	86
Mean min temp, °F	78	78	78	78	78	79	79	79	79	79	79	78	79
Absolute min temp, °F	71	73	73	72	73	73	71	72	72	71	72	71	71
Mean relative humidity, %	73	73	75	76	78	79	80	80	79	79	78	76	77
Mean precip., in.	1.03	0.85	1.73	2.47	5.65	4.06	7.12	6.67	6.76	9.76	7.26	3.61	57.0
Mean No. days precip. ≥ 0.1 in.	3.4	2.5	4.3	5.3	9.2	9.6	13.0	13.1	13.1	14.0	13.0	7.2	108.3
Mean No. days of thunderstorms	0.0	0.0	0.0	0.0	0.2	0.4	1.3	0.9	1.4	1.9	0.5	0.2	6.0
P freq. wind spd ≥ 17 knots	47.4	56.2	49.4	47.9	38.7	27.8	11.4	9.3	7.0	9.1	34.7	47.5	32.2
P freq. wind spd ≥ 28 knots	0.2	0.3	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.7	1.5	0.3

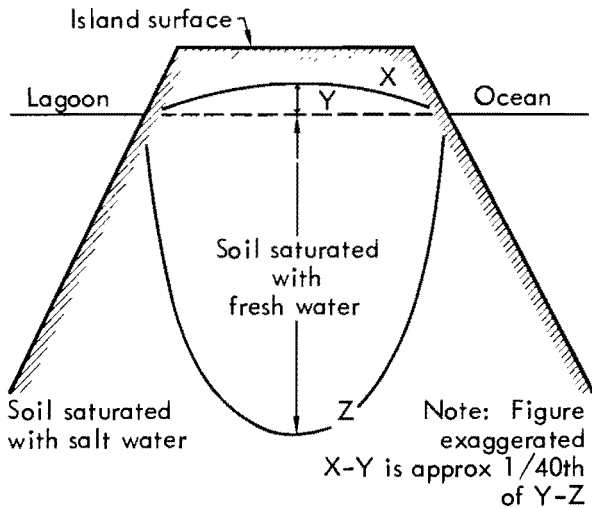


Fig. 3. Schematic representation of an island freshwater lens.

moves outward, the depth of the fresh water becomes less until at the edge of the shore, where the fresh water seeps into the sea, it is just about at sea level, disregarding the fluctuations of the tide.

In a roughly round island of uniform permeability, the body of fresh water floating upon the salt water assumes the shape of a lens, the edges of which approximate the edges of the island, with the upper face of the lens only slightly convex compared with the deeply convex lower surface at the salt water interface. A pictorial representation of an ideal freshwater lens is shown in Fig. 3. It should be noted that the water shown in Fig. 3 does not lie in a large pool beneath the island, but is trapped within the porous media making up the island. Ideally, the saltwater/freshwater interface would be clearly defined; however, this is the exception to the rule because the lens is a dynamic system rather than a static system. When the interface moves with respect to the porous fluid-containing medium, the sharpness is diffused, creating a transition zone in which the

quantity of mixing is proportional to the rate of movement of the interface (Fig. 4).

Normally, the interface moves constantly due to tidal action and seasonal changes in the amount of recharge (rain-fall percolation) which affects the thickness of the lens. This movement of the interface up and down alternately brings the invasion of salt and the dilution of salt water with fresh water. Thus, the contact zone is not sharply defined in terms of salinity or freshness, but shows a transition in salinity. At the center of an island of uniform permeability, the tidal fluctuation is at a minimum, and the depth of fresh water is at a maximum. At the shore the tidal range is at a maximum and there is a reverse gradient at high tide carrying salt water into the island. Therefore, all of the water emerging at the shore line is brackish.

### Terrestrial Ecology

The terrestrial ecology of Enewetak Atoll in the northern Marshall Islands presents many interesting facets of plant and animal adaptation, biogeography, and

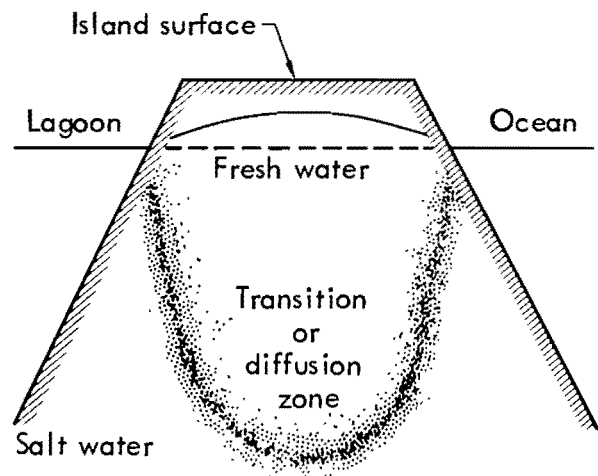


Fig. 4. Freshwater lens diffusion zone.

trophic relationships in a relatively discrete ecosystem. The geology and soils of the Atoll are derived from the skeletal and structural residues of plant and animal organisms that are present as coralline and algal limestone and their erosional products. On this unique substratum, a terrestrial ecosystem has evolved—the product of the disseminative agents of the Pacific basin, namely, wind, water, and biotic vectors, including man, who has played a prominent role in determining the present biota.

In its greatest expression, the terrestrial ecosystem of Enewetak Atoll is represented by a forest habitat that is comparable to those found on continents. The diversity in species composition of that forest is admittedly low because of historical, geographic, and climatic factors which have influenced the evolution of the Atoll biota. Isolation from source regions, oceanic current circulation, and the relative aridity of the northern Marshall Islands determine the plant and animal species that will arrive at the Atoll, and then subsequently determine which of those species will survive.

The indigenous biota of Enewetak Atoll therefore are characterized by organisms highly adapted to the marine environment; they arrived at the Atoll primarily by ocean currents in the prehistoric past. A second component of the biota is represented by organisms introduced from other regions by man, either intentionally or by accident. Weedy plants and roof rats are examples of this biotic component. The flora of Enewetak Atoll demonstrates the dual origin of the biota very well. St. John (1960) (see Table 3) describes the Enewetak flora and

lists 42 species of plants, four of which are native to Enewetak Atoll and all in the genus Pandanus. Although Pandanus was disseminated by both primitive and contemporary man, the endemic species are believed to have evolved on Enewetak, and their initial colonization occurred long ago when seeds or fruits reached the Atoll by ocean currents. The number of adventive weeds introduced by man on Enewetak Atoll is 27 species, and the food and ornamental species which may not persist number 26. There are seven species of plants that are known only from their seeds and fruiting structures that were found on Enewetak beaches, such as Barringtonia asiatica. The entire flora is represented by 95 species, more than half of which were introduced by man.

The natural climax vegetation of Enewetak Atoll, based on the relatively undisturbed examples available for study, appears to be the Pisonia grandis forest. Only a few other tree species are found in this almost pure forest type. The Pisonia forest is best expressed on the larger islands, although single individuals or clumps of trees may be found on smaller islands, but mainly those that are recovering from disturbance. Ochrosia oppositifolia, another large broad-leaved evergreen tree, is occasionally found in small clumps in the Pisonia forest on DAVID and GLENN Islands, but seldom forms a continuous stand on these islands.

The Pisonia forest on Enewetak Atoll usually occurs in dense stands where the only reproduction within the stand is Pisonia. Scattered individuals of the coconut palm, Cocos nucifera, occur in

Table 3. The flora of Enewetak Atoll (as reported by St. John, 1960).

Scientific name	Species		Remarks
	Common name	Vernacular name	
Trees			
<u>Pandanus brachypodus</u>	Pandanus	Punmusi	Pandanus leaves are used for weaving plaited goods and thatch.
<u>Pandanus enchabiensis</u>		Maok	
<u>Pandanus korrorensis</u>		Bop	
<u>Pandanus odoratissimus</u> var. <u>novocaledonicus</u>		Bop	
<u>Pandanus odoratissimus</u> var. <u>novoguineensis</u>		Bop	
<u>Pandanus pulposus</u>		Jilebar	
<u>Pandanus rectangulatus</u>		Anilip	
<u>Pandanus rhombocarpus</u>		Papparawa	
<u>Pandanus utiyamai</u>		Bop	
<u>Cocos nucifera</u>	Coconut palm		Used for food and copra production.
<u>Artocarpus incisus</u>	Breadfruit	Me	Of aboriginal cultivation. Tree 8 m tall observed on Japtan, 1944.
<u>Pisonia grandis</u>		Kangae	Abundant, forming forests on better habitats.
<u>Hernandia sonora</u>		Bingbing	Fruits found on beaches, 1958.
<u>Aleurites moluccana</u>			Found only as seed on sea drift.
<u>Sapindus saponaria</u>			Found as seeds on beaches.
<u>Carica papaya</u>	Papaya	Keinapu	Recently introduced fruit tree. Observed 1958.
<u>Rhizophora mangle</u>			Introduced tree, restricted to tidal salty shores.
<u>Terminalia samoensis</u>		Kugung	
<u>Ochrosia oppositifolia</u>		Kijebar	Tissues poisonous.

Table 3 (continued)

Scientific name	Species		Remarks
	Common name	Vernacular name	
Trees (cont.)			
<u>Cordia</u> <u>subcordata</u>	Heliotrope	Kono	Evergreen tree to 16 m.
<u>Messerschmidia</u> <u>argentea</u>		Kirin	Small tree. Leaves may be eaten.
<u>Guettarda</u> <u>speciosa</u>		Wut	A tree to 8 m.
<u>Morinda</u> <u>citrifolia</u>	Indian mulberry	Nen	Medicinal use.
Large Shrubs			
<u>Ximenia</u> <u>americana</u>		Kalikelik	Sour, edible fruit.
<u>Suriana</u> <u>maritima</u>		Ngiungi	
<u>Ricinus</u> <u>communis</u>			Introduced ornamental.
<u>Pemphis</u> <u>acidula</u>		Kungi	Hard wood. Leaves edible.
<u>Nicotiana</u> <u>glanca</u>	Tree tobacco		Introduced weed.
<u>Scaevola</u> <u>frutescens</u> var. <u>frutescens</u>		Mar kinat	The most abundant shrub, especially near the shore. Leaves used medicinally; wood hard.
<u>Scaevola</u> <u>frutescens</u> var. <u>sericca</u>		Mar kinat	
<u>Wedelia</u> <u>biflora</u>		Marguegue	
Small Shrubs			
<u>Phymatodes</u> <u>scolopendria</u>		Kino	Recorded only in 1944.
<u>Cyperus</u> <u>javanicus</u>		Wujoet in ion buil	Probably of aboriginal introduction.
<u>Fimbristylis</u> <u>atollensis</u>		Berelitchman	Native sedge, abundant on most habitats.
<u>Achyranthes</u> <u>velutina</u>			
<u>Sida</u> <u>fallax</u>		Kio	
<u>Pluchea</u> <u>indica</u>			Introduced weed.
Vines and Creepers			
<u>Caesalpinia</u> <u>bonduc</u>			Found only as drift seeds on the beaches.



Table 3 (continued)

Scientific name	Species		Remarks
	Common name	Vernacular name	
Vines and Creepers (cont.)			
<u>Canavalia microcarpa</u>		Marlap	
<u>Dioclea reflexa</u>			
<u>Entada phaseoloides</u>			Known here only as seeds in the sea drift.
<u>Maguna urens</u>			Drift seeds on beach of Engebi.
<u>Phaseolus vulgaris</u>	String beans		In gardens.
<u>Vigna marina</u>		Markinejojo	
<u>Triumfetta procumbens</u>		Adat	A trailing vine used in weaving.
<u>Ipomoea pes-caprae</u>		Marginejojo	
<u>Ipomoea purpurea</u>	Common morning glory		Cultivated ornamental.
<u>Ipomoea tuba</u>		Marbele	
<u>Citrullus vulgaris</u>	Watermelon		Once grown in gardens.
<u>Cucumis melo</u>	Cantaloupe		Once grown in gardens.
<u>Cucurbita maxima</u>			Observed in gardens, 1944.
Grasses			
<u>Cenchrus brownii</u>			Introduced weed.
<u>Cenchrus echinatus</u>	Sandbur	Legalek	Introduced weed, abundant and troublesome in disturbed soils.
<u>Chloris inflata</u>			Introduced weed.
<u>Cynodon dactylon</u>	Bermuda grass		Deliberately introduced as lawn grass and as sand binder.
<u>Dactyloctenium aegyptium</u>			Introduced weed.
<u>Digitaria pruriens</u>	Crab grass		Introduced weed.
<u>Eleusine indica</u>	Goose grass		Introduced weed.
<u>Eragrostis amabilis</u>	Love grass	Wujoich	Common, but apparently an introduced weed.
<u>Lepturus repens</u> var. <u>repens</u>		Ujos aitok	The commonest native grass.
<u>Setaria verticillata</u>	Bristly foxtail		Introduced weed, abundant in disturbed soil near settlements.

Table 3 (continued)

Scientific name	Species		Remarks
	Common name	Vernacular name	
Grasses (cont.)			
<u>Sorghum bicolor</u> var. <u>technicum</u>	Sorghum		Cultivated crop grain.
<u>Thuarea involuta</u>		Ujos maroro	Local, uncommon, found on or near the sea beaches.
<u>Tricachne insularis</u>			Introduced weed.
<u>Tricholaena repens</u>			An introduced weed.
<u>Zea mays</u>			Once cultivated, observed 1944.
Herbs			
<u>Cyperus odoratus</u>	Sedge	Ujoet	Introduced weed, wet places.
<u>Allium cepa</u>	Onions		Onions reported in gardens in 1944.
<u>Crinum asiaticum</u>	Spider lily		Observed in gardens, 1944.
<u>Tacca leontopetaloides</u>	Arrowroot	Mokmok	Tubers grated and washed to obtain edible starch.
<u>Fleurya ruderalis</u>		Nenkutkut	
<u>Achyranthes aspera</u>		Kaleklek	Introduced weed.
<u>Amaranthus dubius</u>			Introduced weed.
<u>Amaranthus viridis</u>			Introduced weed.
<u>Boerhavia diffusa</u> var. <u>diffusa</u>		Matok aitok	Abundant.
<u>Boerhavia diffusa</u> var. <u>tetrandra</u>		Rabitchragai	
<u>Mirabilis jalapa</u>	Four-o'clock	Emen aur	Introduced, probably as an ornamental.
<u>Portulaca lutea</u>		Kiran	
<u>Portulaca oleracea</u>			
<u>Portulaca samoensis</u>		Bujon	
<u>Cassytha filiformis</u>		Kenen	Parasitic entwining herb.

Table 3 (continued)

Scientific name	Species		Remarks
	Common name	Vernacular name	
Herbs (cont.)			
<u>Brassica oleracea</u>	Cabbage		Cultivated vegetable.
<u>Brassica pekinensis</u>			Cultivated vegetable.
<u>Raphanus sativus</u>	Radish		Cultivated vegetable.
<u>Tribulus cistoides</u>	Caltrop		
<u>Euphorbia chamissonis</u>	Spurge	Berol	
<u>Euphorbia hirta</u>	Spurge		Introduced weed.
<u>Euphorbia thymifolia</u>	Spurge		Introduced weed.
<u>Phyllanthus amarus</u>			Weed introduced from America.
<u>Malvastrum coromandelianum</u>			Introduced weed.
<u>Physalis angulata</u>	Ground cherry		Weed introduced from North America.
<u>Solanum lycopersicum</u>	Tomato		Cultivated for its edible fruit.
<u>Erigeron bonariensis</u>			Introduced weed.
<u>Lactuca sativa</u>	Lettuce		In gardens, 1944.
<u>Pluchea odorata</u>			Introduced weed.
<u>Vernonia cinerea</u>		Senailing nagailing	Introduced weed.
<u>Zinnia elegans</u>	Zinnia		In American gardens, 1944.

some of the Pisonia forests. The canopy is usually complete, creating deep shade in the interior of the forest of pale, cream-colored compound trunks. Reproduction is both vegetative and by seedlings. The accumulation of organic matter is obvious in the Pisonia forest and is produced by the leaf fall which may occur during the drier portions of

the year. Acidification of the alkaline soil materials eventually occurs after organic matter has accumulated, resulting in the dissolution of the calcareous soil materials, and in the precipitation of phosphates if significant quantities of bird excrement are present. There is a strong correlation between the occurrence of Pisonia forests and phosphatized soil materials.

Occasionally a large specimen of Messerschmidia argentea may persist in the Pisonia forest stand, usually at the outer edge. The other ubiquitous tree species, Scaevola frutescens, is seldom found in the Pisonia forest.

Two halophytic tree species are widespread on Enewetak Atoll and are found on most land surfaces, creating dense scrubby stands on islands recovering from test-period activities. The scattered to continuous stands of Messerschmidia argentea and Scaevola frutescens very likely represent a subclimax stage of the Atoll vegetation which will eventually develop into the Pisonia forest. Two other woody species occur occasionally in the vegetation types found on the Atoll, either in the Messerschmidia-Scaevola stands or at the edges of the Pisonia forest. These trees are Morinda citrifolia and Guettarda speciosa. Scattered individuals of these species are found on most of the islands, even those recently disturbed, which seems to indicate an effective means of seed dispersal. Another tree, Cordia subcordata, occurs on islands with well-developed forest types on them, but stands of any great extent have not been seen. Four other species of woody plants may be found occasionally, mixed in with Messerschmidia and Scaevola or at the edges of the Pisonia forest. These are Ximenia americana, Suriana maritima, Pemphis acidula, and Terminalia litoralis. Most of the woody plant biomass of the islands on Enewetak Atoll is formed by the four species, Messerschmidia argentea, Scaevola frutescens, Pisonia grandis, and Cocos nucifera.

The following simplified vegetation types are suggested and provide a useful framework of habitats upon which the rest of the biota depends, either for food or shelter and nesting sites:

- Pisonia grandis forest with coconut palms.
- Messerschmidia-Scaevola scrub forest: scattered to dense stands, with young coconut palms.
- Sedge-grass-morning glory meadows: often with the parasite Cassytha, scattered shrubs such as Pluchea and Sida.
- Grassy flats and beaches: usually near bird rookeries on small, recently formed islands.

Obvious relationships between plant species distribution and the low-relief topography are not apparent, although the general pattern of Messerschmidia-Scaevola scrub vegetation surrounding a central forested area occurs on most of the larger, undisturbed islands. The unobservable factor of substratum water conditions is very likely a strong determinant in the plant ecological characteristics of a given site. The vascular plants depend either upon rainwater held in the interstitial space of the coral sand or deeper groundwater for their water requirements. The presence of Ghyben-Herzberg lenses of fresh or brackish water at shallow depths in lenses beneath the central portions of the larger islands undoubtedly affects and promotes the lush growth of these habitats.

The position of the island on the reef and exposure to storm waves may create conditions that favor the growth of the more halophytic species in the flora. Of

the two common trees, Scaevola is apparently more salt-tolerant than Messerschmidia. It is often found at the edges of the beaches with Pemphis acidula and Suriana maritima, and is occasionally found in this exposed position. However, Messerschmidia is the primary woody plant invader of a newly formed islet or sandbar, and is often the only woody species on small islands.

The three woody species described above (Messerschmidia-Scaevola-Pisonia), plus the coconut palm, Cocos nucifera, are the most common component of the terrestrial flora on Enewetak Atoll. The coconut palm was introduced into the Marshall Islands sometime in the early 1800's. Hager (1885) provides the first descriptions of the northern Marshall Islands; very few observations of coconut palms were mentioned in his account, which placed the population of Enewetak Atoll at 40 people. The present pantropical distribution of the coconut palm is now generally attributed to deliberate dispersal by man. The lifespan of the coconut palm has been estimated at 50 to 60 yr, at which time nut production is declining. It is likely that the zenith of coconut-palm development on Enewetak Atoll was before World War II. Most of the trees on the Atoll at this time (1973) were planted after World War II or during the nuclear test period.

Within the rather limited framework of the vegetation types present on Enewetak Atoll, a small terrestrial fauna exists and perpetuates itself in this almost closed ecosystem. Mammals are represented by rats of two species, all of which were introduced to these islands, either during man's recent activities on

the Atoll or in the prehistoric past. The Polynesian rat, Rattus exulans, is found on most atolls of the Marshall Islands, and is quite abundant on some of the southern atolls. This rat feeds on seeds of native plants and will eat fallen coconuts, although the general opinion is that their use of coconuts does not affect crop production when it is being harvested for copra. This rat is generally found in the sedge-grass-morning glory meadows and at the edges of the Messerschmidia-Scaevola thickets.

A second and larger animal, Rattus rattus, the roof rat, was introduced by man, earlier on trading vessels and more recently from ships carrying men and equipment during World War II, and during the nuclear test period. This larger rat is usually associated with dwellings and even though it competes successfully with Rattus exulans, it does not seem to thrive in the natural environments of the Atoll. The roof rat is said to eat green coconuts and has been known to seriously damage stored copra.

A third small rodent that may be found on the Atoll is the house mouse, Mus musculus, and is another product of man's activities on the Atoll. These rodents are probably found today only on DAVID Island, and possibly on ELMER and FRED Islands. They are not a significant component of the terrestrial fauna and are usually found around dwellings, where they scavenge food scraps.

No birds that are considered strictly land birds were seen on Enewetak Atoll during the recent survey of the islands. It is possible that the New Zealand cuckoo (Eudynamis taitensis) could be seen in the northern Marshall Islands as a migrant

species. Most bird species observed at Enewetak Atoll are either reef or sea-birds. The seabirds range across the open sea and some may be considered pelagic, coming to rest only occasionally on remote atolls. The reef birds typically obtain their marine food source within the Atoll, either on the reefs or in the lagoon. A third avian component of the biota is represented by migrant species. The migrant birds typically nest in the high latitudes of the northern hemisphere and winter in the South Pacific area. The golden plover, Pluvialis dominica fulva, is a good example of a migrant atoll bird species.

The fairy tern, Gygis alba, and the common noddy, Anous minutus, are examples of reef birds frequently seen at Enewetak Atoll. The sooty tern, Sterna fuscata, and the red-tailed tropic-bird, Phaeton rubricauda, range offshore on the open sea. Reef herons, Demigretta sacra sacra, are frequently seen at the water's edge on the islands of the Atoll. The bristle-thighed curlew, Numenius tahitiensis, and the whimbrel, N. phaeopus, and various species of sandpipers are migratory species in the Atoll avifauna.

Two crustaceans are found in the terrestrial habitats on Enewetak Atoll. The coconut crab, Birgus latro, occurs on most islands that support producing coconut palm trees. The islands in the southwestern portion of the Atoll have comparatively large populations of coconut crabs, and islands such as Igurin (HENRY) may be supporting maximum populations of this crustacean. The coconut crab excavates a shallow burrow in the organic matter around the bases of coconut trees, often

beneath the crown of the tree itself. The coconut crab spawns in the lagoon waters, and the larvae leave the water and grow to maturity on land.

Another crab, the hermit crab, Coenobita perlatus, may be found on islands of Enewetak Atoll, scavenging vegetal and animal debris within the forests and along the beaches. Another species of Coenobita occurs on the Atoll, but it is primarily an inhabitant of the beaches.

The previously described Atoll habitats and the animals constitute the major features of the Enewetak terrestrial ecosystem. Other species are present and may play small roles in the functioning of this unique ecosystem, but the ones described here are the most prominent biotic features of the Atoll. The uniqueness of the Enewetak environment lies in the relative isolation of the Atoll, the evolution of the specialized biota, and the functioning of the terrestrial ecosystem, which is strongly affected by the local marine environment.

#### Marine Ecology

General features of the ecology of the Enewetak marine fauna may be described as follows:

On the reef and in the lagoon there is an abundance of plant and animal life in which the competition between different species for space and food is evident. Masses of reef-building coral are competing with the coralline marine algae for space, one often overgrowing the other. Fleshy patches of algae are pressed tightly against the surface of the coral and thus hold against the surges of the water pushed across the reef by the

crashing breakers. Sea urchins and clams grind niches into the hard coral; some of them feed on the cover of bacterial and algal film which is constantly being replaced. The clams, the corals, some small fish, and other forms are ceaselessly removing from suspension in the water the small, often microscopic, plants, animals, and bits of debris which make up the plankton. In regions of quieter water, where sand has been deposited, sea cucumbers and spider snails, among the larger forms, turn the sand continuously in their gleaning for food.

Large schools of goatfish, mullet, surgeonfish, and other plant and plankton feeders are a common sight. Preying on unwary or disabled members of these schools are the carnivorous fish—the groupers, tuna, jacks, and sharks. Ultimately the waste products and carcasses of these and other carnivores are returned to the lagoon and reef to complete the cycle. In the biological cycling of materials, there is not only an abundance of organisms, but also a wide variety of species, some 700 among the fishes alone, so that whatever is not utilized by one is quickly taken by another. There is here a perfect economy of use of substance essential to life. The phytoplankton comprise the foundation of the food chain in the sea. By their diurnal vertical migration, plankton carry materials from the deeper waters of the lagoons to the surface or even up onto the reefs and eventually to the islands. Minerals as well as organic materials, concentrated and incorporated into the algae, are passed on in the food chain to the animals that feed upon them.

Invertebrates make up the great bulk of the animal life of an atoll. Sea cucumbers have been compared with earthworms in their ceaseless turning of the gravel and sand as they obtain their nutrition from bacteria and algae. Corals and clams remove microorganisms and particulate matter from the water and are eroded by algae and sponges, which bore holes in the skeleton or shell, thus contributing to a return of carbonates to the water. Crabs, sipunculid worms, and others also attack the skeleton of the corals. Some of the land crabs drag fish and algae ashore when feeding. In short, within the invertebrates and their symbionts alone, complete biological cycles occur from land to sea and back again.

#### Historical Background of Enewetak Atoll

The recorded history of Enewetak dates from the sixteenth century and can be separated into four distinct periods: the discovery era from 1526 to 1885; the German Protectorate from 1885 to 1914; the Japanese Mandate from 1914 to 1944; and the U. S. Trusteeship from 1944 to the present time.

#### Discovery Era

The Atoll was first reported sighted by Spaniards in 1526, three years before a landing was made by Alvaro de Saavedra in October 1529. Several other sightings were reported by the British from 1792 through the end of the 18th century. However, it appears that no significant contacts were made before the 19th century, although the first official survey and charting was made in 1798.

### German Protectorate

In 1886, the Germans formally established a protectorate over the Marshall Islands, following some years of trading. The Marshallese, including the Enewetakese, accepted coconut seedlings from German traders and sold the resulting copra back to the Germans for trade goods and food. This involved the Enewetak people in a move from a subsistence economy to a mixture of a cash and a subsistence economy. The Enewetakese were somewhat on their own because the Germans did not have a resident agent, nor were there other resident Europeans, and foreign visitors were kept to a minimum.

### Japanese Mandate

The Japanese Mandate commenced with the seizure of Enewetak and all other German Micronesian possessions in 1914. As in the case of the Germans, visits to Enewetak were made by the Japanese Navy in 1920, as well as by Japanese traders, but no attempts were made to establish a full-time administration. Both Enewetak and Ujilang were administered from Ponape in the Carolines, and the only foreign residents on Enewetak were a Japanese trader and his two assistants. Aside from a weather station, established in the 1930's, Japanese contact with the Atoll languished until the years 1939-1941. During this period, the Japanese decided to make Enewetak a strategic base in their conquest of the Pacific. The Atoll was elaborately fortified and a large airfield was built on JANET, using both Marshallese and imported labor. Thousands of Japanese military personnel then occupied the Atoll.

### U. S. Trusteeship

Enewetak remained as a key bastion of the Japanese until it was captured by the U.S. forces in February 1944. The United States occupied the Atoll until the end of the war, using it as an advanced base for further operations to the east. The Enewetakese were moved to SALLY during the occupation.

At the conclusion of the war, the United States was given a trusteeship of the Marshall Islands by the United Nations.

Use as a Test Site—Between 1948 and 1958, the United States used Enewetak as a nuclear weapon proving ground and conducted 43 nuclear tests on the Atoll.

The U. S. Coast Guard has maintained a loran station on the island of Enewetak for several years; since the early 1950's, the University of Hawaii has operated the Eniwetok Marine Biological Laboratory under the auspices of the U.S. Atomic Energy Commission.

Relocation of Enewetak People—During the U.S. occupancy of Enewetak Atoll, 141 people were in residence. Prior to the 1944 invasion of Enewetak, the population of the Atoll was divided into two communities; one was located on Enewetak Island (FRED) and the other on Engebi Island (JANET). After the invasion, both communities were moved to Aomon Island (SALLY), which was under the authority of the Chief of the Enewetak Island Community (Chief Ioanej). Later, the Engebi community moved (at their own request) to Bijile Island (TILDA) because the latter was under the authority of the Chief of the Engebi community.



Thus, the Engebi people were moved twice prior to relocation to Ujilang (Engebi to Aomon to Bijile), whereas the Enewetak people were moved once (Enewetak to Aomon) prior to relocation to Ujilang. In December 1947, the people were transferred 124 mi to the southwest to then uninhabited Ujilang, where they have remained.

#### Anthropology—Enewetak People

Most anthropologists are of the opinion that the Marshalls and other islands of Micronesia were settled by peoples who migrated from the area of Indonesia and into the insular Pacific centuries ago. Reflecting the ancient migration patterns in Oceania, the Marshallese language belongs to the large Malayo-Polynesian language family which is spread from Madagascar, through the Indonesian area, and across Micronesia, Polynesia, and some regions of Melanesia. With regard to physical type, the Marshallese are relatively short in stature and of slender build. They have brown skin, brown eyes, broad flat noses, straight to curly black hair, and sparse body hair.

According to their own oral traditions, the people of Enewetak had always lived on Enewetak Atoll prior to their relocation to Ujilang; in their own words: "We were there from the beginning." Because of Enewetak Atoll's isolated location in the northwestern region of the western of the two island chains which comprise the Marshallese archipelago, the people had relatively little contact with others prior to the European era. As a consequence, the language and culture of the Enewetakese became differentiated from those of other Marshall Islanders, and the people

did not identify themselves with the others. Rather, they thought of themselves as a people who were separate and unique, "the people of Enewetak" as opposed to the islanders to the east and south.

The past and current accomplishments of the Enewetakese reflect intelligence and qualities of ingenuity, self-reliance, and hardiness which have allowed them to meet the challenge of the atoll environment which is quite restrictive in comparison to the high volcanic islands of Oceania. Long before the advent of Europeans, they had developed a culture which represented a sophisticated adaptation to their ecological setting. They were skilled navigators (an art which has been lost with the availability of travel on the vessels of foreigners); they remain expert builders of sailing canoes and are among the world's best fishermen. In response to traders, missionaries, and the successive colonial governments which have dominated the islands over the past century, they have been quick to learn and adjust to the different categories of outsiders. Today, they have achieved a good understanding of the behavior and values of Americans, and several have distinguished themselves in government and mission schools.

#### Economic and Cultural Resources

Throughout the Marshall Islands, the traditional forms of settlement pattern and exploitation of the natural resources are characterized by several general features. First, the people of an atoll reside on one or more of its largest islands. Secondly, the people are quite mobile as a nonintensive type of agriculture and various fishing and collecting

activities are extended to embrace every niche of the environment. Regular expeditions are made to all islands in an atoll to make copra and collect coconuts, breadfruit, pandanus, arrowroot, and other vegetable foods in season. The brush is cleared and crops are planted during these visits. The marine resources are also exploited and a wide variety of marine animals are utilized. Routine expeditions are made to catch fish, collect shellfish, and capture turtles and gather their eggs. Several species of birds are also captured as a food source. The Enewetak people may be expected to continue this way of life to some degree when they return to their home atoll, as influenced by their contacts with Western culture.

#### Sociopolitical Pattern

Before their relocation to Ujilang, the Enewetakese were divided into two separate and distinct communities (community is defined as the maximal group of persons who normally reside together in face-to-face association) which were located on the two largest islands of the Atoll. One was situated on Engebi Island on the northern rim, and the other was located on Enewetak Island, across the lagoon in the southeast quadrant of the Atoll. The traditional settlement pattern of both communities was dispersed; residences were located on separate land parcels and were scattered along the length of the lagoon beach.

Members of the two communities intermarried and cooperated in certain economic activities. Each functioned, however, as a separate sociopolitical unit, and its members had their own identity.

In contrast to the identity of "the people of Enewetak," as they defined themselves in reference to all other populations, the people of the Engebi community were identified as driEngebi, "the people of Engebi Island," and those of the Enewetak community were driEnewetak, "the people of Enewetak Island."

The sociopolitical structure of the two communities was identical. Each was headed by an hereditary iroij or chief, and succession to the office was patrilineal. Chiefs directed the affairs of their respective communities, arbitrated disputes, and consulted one another with regard to concerns of the entire Atoll and the total population's relations with outsiders. Each of the chiefs had authority over one of the two domains into which the Atoll was divided. The domain of the Enewetak chief began with the Islands of Kidrenen, Ribewon, Boken, Mut, and Ikuren in the Atoll's southwest quadrant, extended counterclockwise around the Atoll's south and western rims up to and including Runit Island, and also included Aomon on the northeast rim. With the exception of Aomon, the Engebi chief's domain began north of Runit with Billae Island and extended counterclockwise around the Atoll's northern and western rims, up to and including Biken Island.

Relations between the two communities and the traditional dispersed pattern of residence were altered with the invasion of Enewetak Atoll. Because Enewetak and Engebi Islands were devastated by warfare, the U.S. Navy resettled all of the people in a compact village on Aomon Island which, as indicated above, fell within the domain of the Enewetak Island chief. After several months, the Engebi

people moved to the nearby and adjacent Bijile Island which was within the domain of their own chief. With these relocations within Enewetak Atoll, the Engebi and Enewetak peoples were no longer separated by the Atoll's large lagoon, and while retaining their dual political structure, they in fact became a single community.

The consolidation of the population into one community and the new compact settlement pattern were perpetuated with the islanders' resettlement on Ujilang Atoll. It has only one sizable island, Ujilang Island, and the entire population was resettled there. Navy officials established a dividing line at the midpoint of the island and allotted the western half to the Engebi people and the eastern half to the Enewetak people. A compact village was constructed in the middle of the island, with the Engebi and Enewetak peoples occupying houses on their respective sides of the dividing line. Later, each group divided the land on its portion of the island. At a still later date, other islands in the atoll were divided among members of the two groups.

During the initial years on Ujilang, the traditional political structure remained intact. The chiefs functioned in their accustomed roles, and they resisted American efforts to introduce democratic institutions. (According to American designs, each atoll population was to be governed by an elected council of elders headed by an elected magistrate.) By the early 1960's, however, some change was observable. Both chiefs were by then aged men, and because they were men who had matured in a former era, some contemporary problems required that the

decision-making process be opened to include younger men who had attended schools and/or had some other experiences with the American administration. Meetings of all males were occasionally held, and some decisions about community affairs were decided by a majority vote. The authority and status of the chiefs further declined in the late 1960's, when the old Engebi chief died and was succeeded in office by his younger brother, who was also aged and suffered from frequent poor health.

The combination of the above events precipitated a major transformation in the political structure. The chiefs yielded to younger men who desired and had been gaining a greater voice in community affairs. Then, in 1968, a magistrate and a council of 12 men were elected; reflecting the traditional division of the population, the Engebi people elected six councilmen from among their ranks, and the Enewetak people elected six. The magistrate became the head of the entire community, and the council became the legislative body governing the people's affairs. In a very recent election, however, the 12 councilmen were elected from the population at large and not from the two groups. Thus, the current council reflects a demise of the traditional system and indicates that the old division between the Engebi and Enewetak peoples has lost much of its meaning. The council is now a representative body drawn from the entire population and reflects a unified community with acknowledged common goals. The chiefs, however, remain important figures as advisors and men of influence.

### Church and Religion

The church is the focal point for many community social activities of the Enewetak people. The prevailing religious system is a conservative type of Protestantism in which church services, Bible classes, church group meetings, and hymn singing have replaced traditional intertribal wars, sports, games, and dancing.

The minister is the spiritual leader of the community and is supported and assisted by the chiefs of the clans. The church functions are time-consuming and require a considerable effort from the membership. Sundays in particular are devoted almost entirely to church services and related activities. Thus, it is apparent that the church influences the life of the Enewetakese to a great degree.

### Land Ownership

The Enewetak Atoll soil is poor, and thus agriculture is limited. For centuries, subsistence has been marginal and precarious for the island inhabitants, despite hard work. Nevertheless, the residents have always maintained a deep emotional attachment to their home islands and ancestral land.

The land parcels, or wato, at Enewetak Atoll were like those found elsewhere in the Marshalls. Most commonly, each was a strip of land stretching across an island from lagoon beach to ocean reef and varying in area from about 1 to 5 acres. The resources of all ecological zones were thus available to the individuals who held right to the land. Less commonly, a parcel was divided into two or more portions with transverse boundaries. This usually occurred when an

island (e.g., Engebi) was very wide. Boundaries were usually marked by slashes on the trunks of coconut trees, or less commonly, ornamental plants. Also, other features of the natural topography (e.g., large boulders on the ocean reef and the very configuration of an island) were used to fix the position of landholdings. The latter type of markers were employed by the Bikini people, for example, after all other markings had been obliterated.

One facet of Enewetak Atoll culture that differed from that of the rest of the Marshalls was the system of land tenure and inheritance. In contrast to the rest of the Marshalls, where matrilineal descent groups known as bwij or lineage constitute landholding corporations, the land tenure system at Enewetak was in ideal and practice a bilateral one. In most cases, a married couple divided the land they had each inherited among their children, and a child usually received some land from both his father and mother. As younger islanders matured, they worked the land with their parents. As the parental generation died and as members of the next generation married and produced children, the process was repeated with parents allocating land among their offspring.

The islanders resided on their landholdings on Engebi and Enewetak Islands. Households were either extended or nuclear family groupings. In most cases, households were headed by males and were situated on land held by them. Ideally, residence was patrilocal; i.e., upon marriage, females moved to their husbands' households, although exceptions to the rule did occur.

Every individual possessed rights to some land on islands away from the settlements on Enewetak and Engebi. All land in the Atoll was held by someone, except for one parcel on Enewetak Island which was donated to the mission.

PRESENT STATUS OF THE  
ENEWETAK PEOPLE ON  
UJILANG

Comparison of Ujilang  
and Enewetak

Ujilang lies 124 mi southwest of Enewetak (see Fig. 5). In pre-European

times, Ujilang was inhabited by a Marshallese population. In the 1890's a typhoon decimated the atoll, and killed all but a handful of people who were moved to the southern Marshalls. The atoll was then developed as a commercial copra plantation during the German and Japanese colonial eras. During the plantation period, a small group of islanders from the Eastern Carolines served as wage laborers on the atoll. However, it was abandoned during World War II and was thus uninhabited and available for the relocation of the Enewetakese.

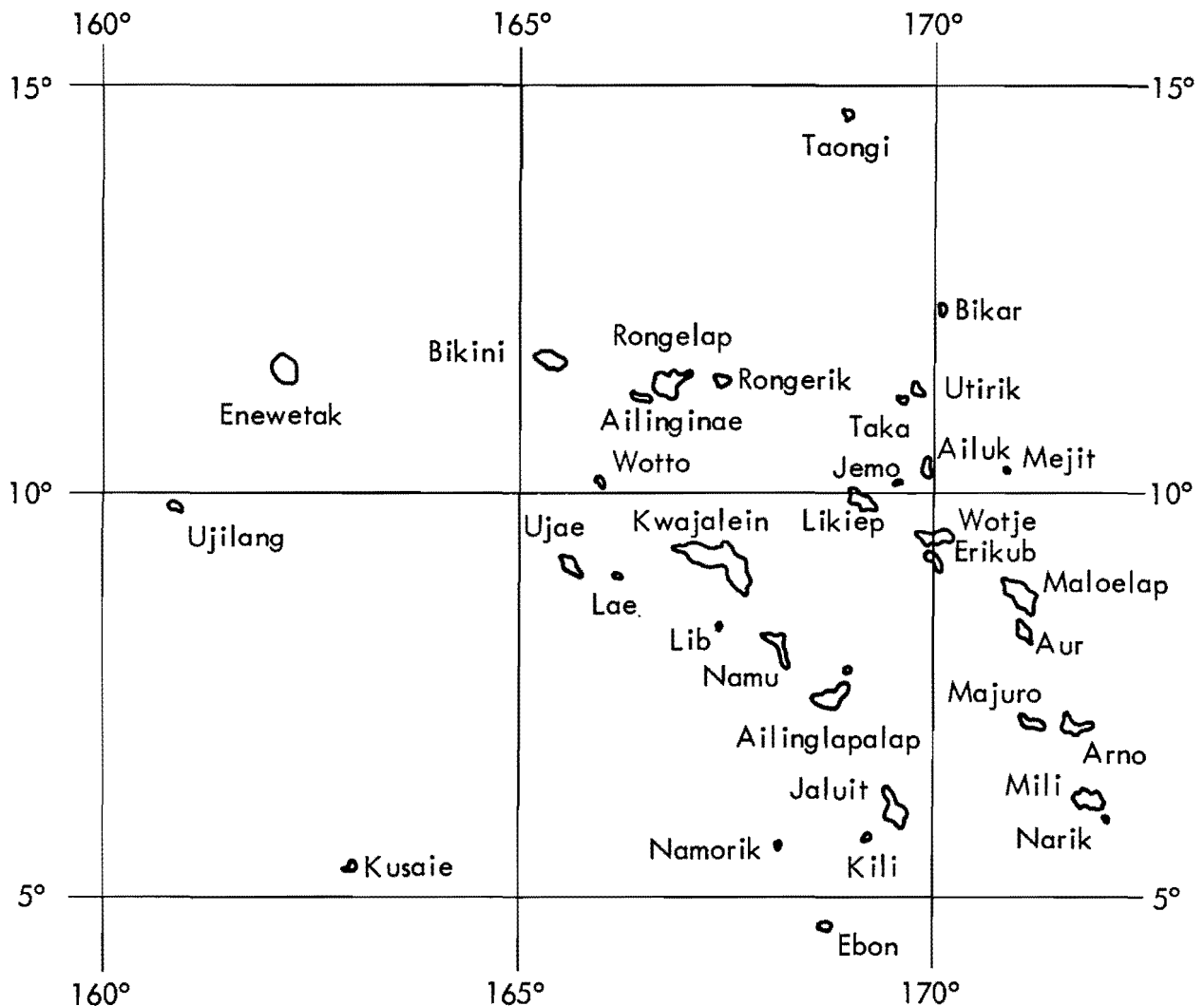


Fig. 5. Marshall Islands.

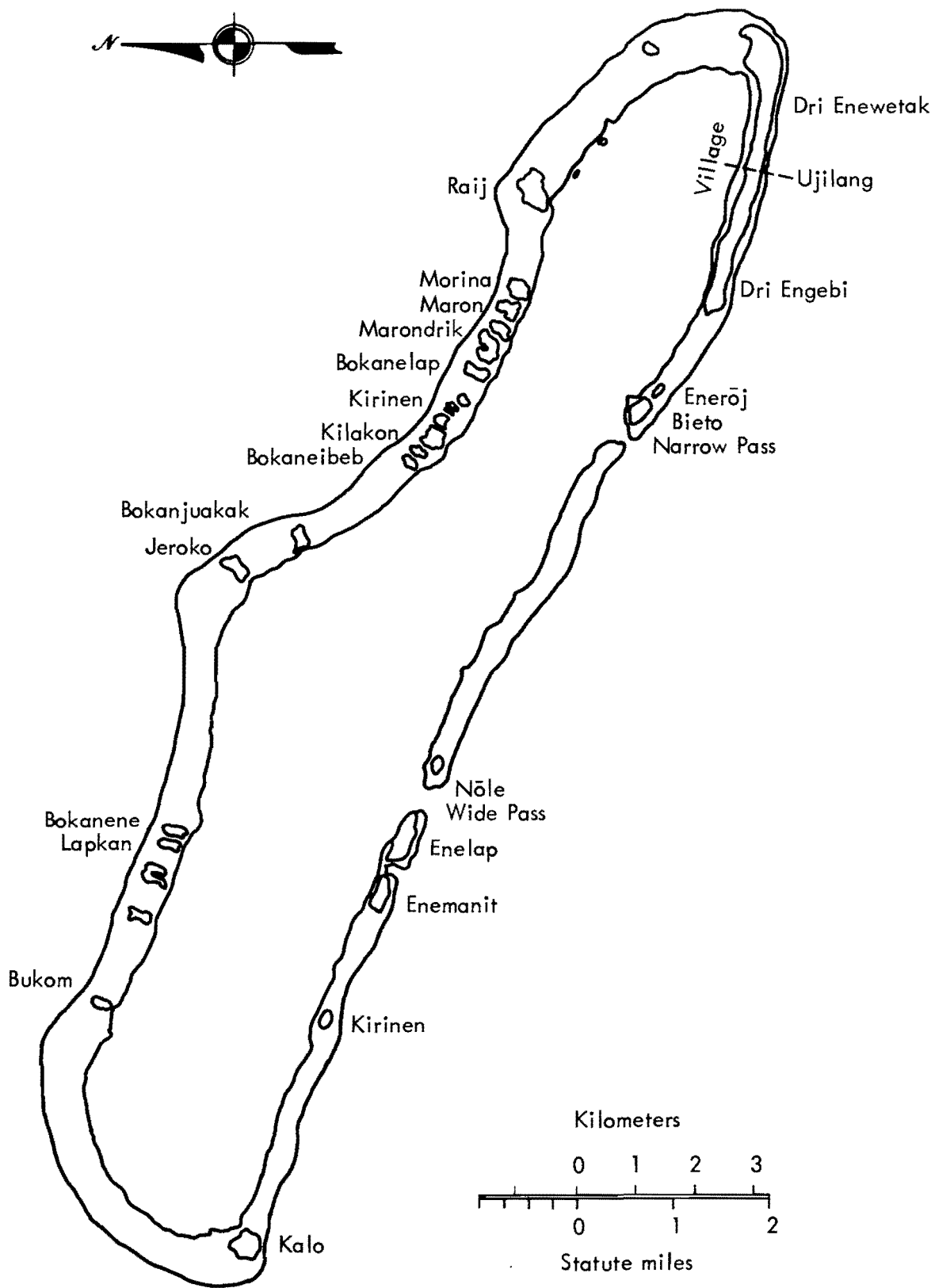


Fig. 6. Ujilang Atoll.

Ujilang is also smaller than Enewetak, both in size of the lagoon and in the total dry land area (see Fig. 6). A comparison of the areas of both atolls shows:

	Area, mi <sup>2</sup>	
	<u>Lagoon</u>	<u>Dry land</u>
Ujilang Atoll	25.47	0.67
Enewetak Atoll	387.99	2.26

From this comparison, it is apparent that the potential for production of food from the reefs and lagoon is considerably less on Ujilang than it is on Enewetak. The limited food potential on Ujilang has made it necessary to import more commodities than would normally be required on Enewetak. This has been reported to have presented some difficulty because Ujilang is located further from the sources of the needed commodities than Enewetak.

#### Living Conditions on Ujilang

The U. S. Navy constructed a village on the main island of Ujilang for the displaced Enewetakese, and a brush-clearing program was in progress when they arrived on the atoll. Coconut trees planted during German and Japanese administrations were still standing and bearing. Seedlings of breadfruit and pandanus were brought ashore and planted. After the Enewetak people had settled in, the Navy departed. There was no U. S. official remaining on the atoll, nor was there any radio communication with the outside world.

The former Enewetak inhabitants attempted to adjust to their new location. They had, and still have, several formidable problems with which to cope. The most obvious, and one which they have

uppermost in their minds, is the great disparity in the sizes of Ujilang and Enewetak, as previously mentioned. The traditional Marshallese pattern of habitation is for family units to live on their land parcels, not in a village cluster. While it is common for community buildings, church, school, dispensary, and warehouse to be centralized for convenience and access to all, dwellings are usually dispersed over the length of the lagoon beach of an island. This pattern is obviously desirable from the point of view of environmental sanitation and public health. As described, the traditional settlement pattern of the Enewetakese was disrupted because of their relocations.

#### Natural Resources

The people practice a nonintensive type of agriculture but utilize the environment to the maximum, using the plants that can survive and produce in the atoll environment. Coconut is converted to copra for cash sale to the visiting Trust Territory supply ship. Consumer goods are purchased from the ship with the proceeds of the copra sales. The interest payments from the trust funds provided by the TTPI administration also help buy needed commodities. Rice, flour, sugar, canned meats, and other canned goods are staple items of the diet and have been for many years. Fish, clams, lobster, turtles (flesh and eggs), sea birds (flesh and eggs), chickens, and pigs provide protein in the diet. The marine resources are extremely important in the diet of these people.

Coconuts, pandanus, breadfruit, and arrowroot are the main vegetable

products used. Bananas, papayas, and squash are used to a lesser extent, probably due to the relative scarcity of the banana and papaya which do not seem to grow well on Ujilang.

The Enewetak population shares the upward trend of the rest of the Marshall Islands and Micronesia. Records show an increase from 104 in 1925 to 432 in 1972. This tendency toward increased population among the Enewetak people is resulting in a further drain on the inadequate resources of Ujilang. A census made in early November 1972 produced the following data on the location of Enewetak people:

Ujilang Atoll	340
Majuro Atoll (DUD)	31
Majuro Atoll, Rongron Is.	18
Maloelap Atoll, Marshall Is.	3
Kili Island, Marshall Is.	7
Ponape, Eastern Caroline Is.	5
Crew members on Trust Territory ships	4
Residing in the United States	<u>3</u>
Total Enewetak people	411
Married to Enewetak people and living on Ujilang (integral part of the community)	<u>21</u>
Grand total	432
Males	226
Females	204
Sex not reported	<u>2</u>
Grand total	432

(Tobin, 1973)

#### Economic Status

The TTPI administration has attempted to upgrade copra production and subsistence agriculture for the past several years with some noticeable improvement. However, the Enewetak

people are not as economically well off as they would have been if they had not been uprooted from the larger Atoll.

The unfavorable economic situation and the persistent desire to return to Enewetak finally stimulated aggressive action by the people. They threatened to evacuate the atoll in 1967, and in 1968 the leaders petitioned the United Nations for assistance in returning to Enewetak. In 1968, they again threatened to evacuate the atoll and come to Majuro. Economic help was given them by the administration, and relief shipments of food were sent to the community. An ex gratia payment of \$1,020,000 was made to them in 1969 and placed in a trust fund; the interest from the fund has helped. Funds were also allocated for a construction program to improve the housing on Ujilang and for the construction of badly needed public facilities on the atoll. The Ujilang community assumed the responsibility for doing the actual labor involved.

#### Preferences of the Enewetak People for their Future

Efforts to ameliorate living conditions on Ujilang, while welcome, did not lessen the desire of the people to return to their ancestral homeland. They continued to press for this goal. Discussions and meetings were held with government officials. Finally, on April 18, 1972, the High Commissioner informed the District Administrator that Enewetak Atoll would be returned to the jurisdiction of the TTPI by the end of 1973.

It is expected that all of the 432 Enewetakese will return to their Atoll. However, it is not known whether those who



have interests elsewhere will remain permanently, or leave after visiting their relatives and old land claims. It is assumed that these people will eventually retire on Enewetak.

A planning council has been formed, consisting of Enewetakese, who are empowered by the people to make decisions within specified limits on matters pertaining to short-term, intermediate, and long-range planning. The council will be augmented by technical advisors to assist them in translating the desires of the Enewetak people into workable plans. The advisors will work closely with the planning group and other Enewetakese in their particular fields, e.g., architecture, short- and long-range economic development, and agriculture.

#### EXPECTED LIVING PATTERNS AFTER RESETTLEMENT

##### Introduction

The successful resettlement of the people of Enewetak will depend strongly on the interaction of their current life style with the provisions made for them by the U.S. Government. While the present life style is a result of over a hundred years of first German, then Japanese, and finally American influence, the greatest impact has occurred since the end of World War II. The creation, under U.N. charter, of the Trust Territory of the Pacific Islands, and the subsequent military development of strategic defense areas in the Marshall Islands, has brought the simple food-gathering culture of the Marshallese into close contact with twentieth-century technology.

In order to gather some first-hand information on the living habits, attitudes,

and desires of the modern Enewetakese, a field team spent the period of July 21-31, 1973, on Ujilang. The team was composed of Carlton Hawpe (Holmes and Narver architect), Howard Schoss (Peace Corps architect), John Stewart (AEC/NVOO), Kenneth Marsh (LLL), and Thomas Makiphie (interpreter from Micronesian Legal Services). Hawpe and Schoss were to meet with the Enewetak planning council to determine where and how the people intended to live on Enewetak, what types of houses they preferred, and what they wanted in the way of cooking and sanitary facilities. Stewart and Marsh were to collect specific information on the people's daily activities and their diet, with particular regard for the implications to radiological dose-assessment calculations.

Victor Nelson, University of Washington marine biologist, was to be a member of the team, but transportation difficulties resulted in a two-week delay on Enewetak and, because of other commitments, Nelson had to return to Seattle. During the two weeks on Enewetak, however, he spent considerable time with Smith Gideon, a native of Enewetak who was then Magistrate of Ujilang, collecting data on the fish preferences of the Marshallese. In his report (see p.46) Nelson recommends that a composite of the Ujilang, Bikini, and Rongelap diets be used to estimate the average diet of the Enewetakese.\*

Originally, the present residents of Ujilang lived as two tribes (dri) on separate islands around the Enewetak lagoon, the driEngebi on Engebi in the northern

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\*See Chakravarti and Held, J. Food Sci. 28 (2) (1963).

half of the atoll, the driEnewetak on Enewetak in the southern half. The Ujilang Atoll, by contrast, has only one island large enough for permanent habitation; hence, today everyone lives on the main island of Ujilang. This island, roughly the same size as Enewetak, is about 2.5 mi long by 0.1-0.2 mi wide. The "town square" divides the island in half and consists of the meeting hall, dispensary, church, and school. The half of the island east of the town square belongs to the Enewetak people, while the western half belongs to the Engebi people. Even though the two tribes have intermarried to such an extent that, as Magistrate Smith Gideon says, "we are one big family," the old division is maintained.

Almost everyone lives in the village, which extends a few hundred feet to either side of the town square. There are a few houses scattered over the rest of the island, but these are used only a few days at a time, mostly by older people on food-gathering trips. Houses are constructed of plywood and corrugated sheet metal, with the floors usually about 0.7-1 m above ground. The space under the houses is used for relaxing in the shade, and the pigs generally rest there as well.

An increase in the birthrate has resulted in a very young population. Ninety percent of the people are under 40 years of age, and almost 50% are under ten. During the field team visit, a population anomaly existed in that there were no children of high school age on the island, even though they comprise about 10% of the population. This is explained by the fact that the high school is located 800 mi away at Majuro and, while school had

been out over a month for summer vacation, no ship had been available to return the students to Ujilang.

There were many opportunities for misunderstandings to occur. Makiphie spoke Marshallese and English fluently, but had no knowledge of radioecology. Hawpe and Schoss spoke good Marshallese, but also had no knowledge of the radiological aspects of Enewetak. On the other hand, neither Stewart nor Marsh, the radiological experts, spoke any Marshallese. The tendency of the people to want to be polite and to please their visitors by giving what they believed to be the desired answer, a problem mentioned by other investigators, was evident and probably had some effect, but much of the data in this report is based on personal observations. These problems do, however, lend weight to Nelson's suggestion that a composite of data would best forecast living habits after resettlement.

This section was reviewed in draft form by Jack Tobin, Trust Territory Community Development Advisor, and many of his comments have been incorporated into the final version.

#### Development of Island Communities

The islands of Medren (ELMER) and Engebi (JANET) are preferred for permanent dwellings, with possibly some people living on Enewetak (FRED), depending on facilities remaining after the rehabilitation. Japtan (DAVID) has been suggested as a temporary location for a work force during the cleanup, but might develop into a semipermanent settlement. If too many restrictions remain on and around Engebi for comfortable permanent habitation, the

people may divide Medren in half and live there, probably as they do now on Ujilang. Second-home houses on Engebi would still be desired by some people, and could be built either as part of the rehabilitation or by the people themselves at a later time. If the plan suggested by Carlton Hawpe is adopted by the Enewetakese, there will be three to six houses per cluster on each wato. The houses will be located about 100 ft or so inland from the lagoon beach, behind a "green belt" of coconut trees. A wato is a strip of land extending from the lagoon side to the ocean side, occupied by a single family group (10-40 people). On wide islands, such as Engebi, the wato may not include both beaches, but access to both sides of the island will be provided.

Houses will be constructed with the floors about 0.7 m above grade, the intervening space filled with concrete and coral aggregate. The floors themselves will be either concrete or plywood, and the walls will be either poured concrete or concrete block. Roofs will be corrugated sheet metal, provided with troughs for collecting and transporting rainwater to cisterns. A high degree of resistance to typhoons is desired.

There is no furniture in a typical Ujilang house, and no decorations on the walls. Some food may be stored inside and a few possessions like mirrors, hand-cranked sewing machines, kerosene lanterns, or anything subject to rain or pig damage are kept there, too. These items are usually on the floor and very rarely are there any shelves or definite storage facilities.

Areas around the houses will be covered with coral gravel. The Ujilang

people renew and add to this covering from time to time by scattering gravel collected from the ocean beach. This area is kept free of grass and trash.

Rainwater, collected from the roofs of buildings, will be the principal source of fresh water. Ujilang has several concrete cisterns, but most people have two or three 55-gal drums, fed from the roofs of their homes. One of the concrete cisterns has a 10,000-gal capacity and uses the roof of the church as a catchment. It is used by the general community, and probably a similar cistern would be built on Enewetak. The proposed plan for the Enewetak houses calls for a built-in cistern in each house, with a storage capacity sufficient for several weeks. Well water is brackish and not used at all when rainwater is plentiful; however, as rainwater stocks decline, well water will be used first to wash clothes, then for the daily bath, and only as a last resort for drinking or cooking. It should be noted that Enewetak receives somewhat less rainfall than Ujilang, and therefore well water might have to be used to a larger extent. However, this same lack of rainfall also is responsible for a more brackish well water on Enewetak, making it even less palatable. Well depths on Ujilang varied from 2.5 to 6 or 7 m, but several people who lived on Enewetak remembered the wells there as deeper than any on Ujilang (therefore estimate about 10 m). Medren Island presently has considerable area in the form of concrete slabs and metal roofing which could be used for catchment purposes. The airfield alone on Enewetak could probably supply the entire population with water, given a collection

and distribution system. It should be possible to make up in area what is lacking in rainfall, at least for the southern islands of the Atoll.

#### Routine for Daily Activities\*

A few activities are common to all members of the household. Families retire for the night between 10 and 11 p.m. Everyone sleeps inside the house on a woven pandanus-leaf sleeping mat spread on the floor. A typical mat is made up of a double thickness of leaves, about 75-100 cm wide by 150-180 cm long, and weighs about 1 kg. Double mats are also used, with the width and weight increased about a factor of two. Almost everyone arises between 6:30 and 7:30 a.m.

Two or three days a year the entire family will go on a one- or two-day picnic to one of the other islands. However, transportation is a real problem, and there was one girl, 14, who had never been off the main island of Ujilang.

Married women (essentially all women over 16-17 years of age) spend the whole

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\*Tobin feels that the presence of the survey party had a strong influence on the daily habits of the people, especially the men. He says the Marshallese are naturally curious and tend to stay close to visitors. Also, the action and excitement were a welcome change from their usual routine. For these reasons, copra production and outer-island trips were probably curtailed. This points up the difficulty of gathering reliable information. The presence of the observers tends to affect that which is observed, but on the other hand, too much reliance on interviews runs the risk of bias from "cooperative answers." Again, the best picture is a composite from several sources. With regard to the survey party's effect on the people's routine, however, it should be mentioned that for at least several years after the resettlement of Enewetak, frequent and numerous visitors may be expected.

day in or around the house attending small children, cleaning, washing clothes, and cooking. The Marshallese are very concerned with personal cleanliness. Everyone bathes every day and washing clothes is a daily activity. Houses are swept several times a day, and the custom is to remove shoes or zories (if any) before entering the house. Clothes are washed outside, usually by teenage girls or older women. Many people have set aside a particular area for laundry by making a raised bed consisting of a framework of coconut logs filled with coral gravel. These beds are typically 2-3 m on a side and 1/2-1 m high. Clothes are washed in a pan (~50 cm diam) with soap powder, if available, by a combination of wringing, rubbing on flat rocks or plywood, and pounding with a stick. They are then rinsed and hung on a line to dry. This treatment is a little rough on the fabrics, but they are clean. Cooking and food preparation will be discussed in another section.

Men spend the morning hours in and around the houses, cleaning up outside the house, smoking, visiting with each other, and generally taking it easy. Afternoons are spent much the same way, although these days considerable time is spent in meetings regarding the return to Enewetak. If a breadfruit- or coconut-gathering trip is made away from the village, it will usually be early in the morning before the heat of the day. Similarly, a fishing trip near the village might be planned to take advantage of known fish movements. The only significant deviation from this routine occurs on Saturday, when the cooperative fishing

trip to other parts of the lagoon takes place. Fishing in general will be discussed in a separate section.

Children up to the age of about 3-6 years spend most of their time around the village close to or inside their houses, under the supervision of their mother and older children. Children from about 6 years up to about 10-15 years spend their time in school and playing around the village between the ocean and lagoon.

At least half of the children's free time is spent playing on the lagoon beach and in shallow water; the remainder is about evenly divided among the village, surrounding forest, and ocean beach. Girls from about 12 to 15 perform many of the arduous household tasks, such as grating coconut or preparing breadfruit. Boys of this same age climb the coconut and breadfruit trees to harvest green "drinking coconuts" or ripe breadfruit.

School was not in session in July; they observe a June-to-September recess. Children start first grade at about 6 years and are required to attend through the eighth grade. School hours are 8-12 a.m. and 1-3 p.m. The school

is a one-room structure, and students sit on the floor. Subjects taught are English, mathematics, social studies, science, and physical education. Most eighth grade graduates can read and write Marshallese. If students wish to attend high school, they go to the district center at Majuro, and the official language is English. At about age 15, if they do not attend high school, children begin to assume more of the duties of adults.

Table 4 provides a rough estimate of the amount of time spent by men, women, and children in various locations. For dose-assessment calculations, hours per week is probably the best unit. Hours per day would carry a large standard deviation (~20-50%), while hours per month would be unnecessarily coarse, except for time spent off the main island. How these estimates would change for Enewetak is very difficult to predict. With the much larger and less protected lagoon there, transportation will have a strong influence. If reliable boats are available, the total time spent by men on the lagoon water and other islands would probably about double or triple, at the

Table 4. Time spent in various areas of the Ujilang Atoll.

Location	Time, hr/wk		
	Men	Women (children to age ~5)	Children (~5 to ~15)
Inside houses	60	60	60
Interior of island—outside	80	95	43
Lagoon beach	10	10	50
Lagoon water (boat)	5	0	7
Other islands	5	1	1
Ocean beach	3	2	7
Open sea	5	0	0

expense of time on the home island. Women's and children's time distribution would probably not change more than 10-20%, because their lives are more centered around the home and community. The table gives the time distribution of the residents of Ujilang who have lived there 26 years. It is probably typical of a completely rehabilitated Enewetak. After the cleanup, if the houses are completed, even the first year would be about as described.

### Diet

At the time of the trip to Ujilang, no Trust Territory ship had called there for over two months. The people were subsisting on the local products, consisting of breadfruit, coconut, and fish. The survey party took 350 lb of flour, 150 lb of rice, 50 lb of sugar, and assorted canned goods to Ujilang; thus it was possible to observe the impact of imported food on the native diet. It could only be described as profound. There is little doubt that, given the opportunity, Marshallese consumption of imported foods would constitute at least 80% of their diet. The favorite imports, unanimously reported, are rice, flour, sugar, canned corned beef, and assorted canned fish, usually tuna, salmon, and mackerel. Marshallese who live on Majuro and Ebye (Kwajalein Atoll) and who, therefore, have money and access to "American" food, live almost entirely on imports, including such accessories as soft (and hard) drinks, beer, candy, cigarettes, and convenience foods, limited only by their ability to afford them. However, these people become hungry for the native diet (breadfruit, coconut, and fish),

and a once-a-week Marshallese meal is traditional. However, the Marshallese foods are of limited availability due to population pressures. Thus an interesting picture emerges of the outer-island people desiring unavailable imported foods, while those in the population centers desire equally unavailable traditional foods. The lack of reliable inter-island transportation contributes greatly to this problem. Dose calculations based on the diet observed at Ujilang should provide good upper limits on ingestion of radio-nuclides at Enewetak, modified, of course, by a few factors such as the greater availability at Enewetak of some food sources (e.g., sea birds).

Cooking and eating are not big social events in Marshallese life. Food is usually cooked in the evening, some eaten then, and the rest during the next day. Families will sometimes eat together, but usually everyone eats whatever is available whenever he is hungry. When more cooked food is required, it is prepared then; thus cooking and general food preparation may take place at almost any time of the day, and usually is going on somewhere in the village all the time. On special occasions large meals will be prepared, and everyone, often the whole village, will eat together. This is about as close as the Marshallese come to the "American family dinner." A typical day's food consumption would be a light meal in the morning, usually a handful or two of food left over from the previous evening meal, perhaps a drinking coconut and some copra around the middle of the day, and then a larger meal of freshly cooked food in the evening. There were no plates or flatware in use on Ujilang;

everyone ate with his fingers from leaves of the breadfruit or coconut. In the case of large fish or meat, people would eat directly from the carcass, often passing it from person to person. Eating takes place outside the houses, and everyone sits on the ground.

A typical Marshallese "kitchen" has an area set aside for raw food preparation, a single-burner kerosene stove, an underground oven or um (rhymes with zoom), a fire pit with a grate for broiling or general cooking if there is no kerosene stove, and sometimes a pit for food storage. Again, everything is on the ground, and the cook sits or squats on the ground while cooking. Large pieces of coral serve to support pans and food baskets. Food is commonly gathered, as well as stored, in these baskets woven of coconut fronds. The kitchen is usually attached to the house by extending two walls and sometimes the roof; in other cases, the kitchen has its own roof. The fourth side is usually at least partially closed in, but rarely has a hinged door. The proposed houses to be built on Enewetak will have similar areas.

The um exists in two styles, shallow and deep. A shallow um is excavated in the coral to a depth of 10-20 cm, but is often not excavated at all. A fire is built on the rocks, and when only glowing coals remain, the food is wrapped in breadfruit leaves and laid on the coals. Everything is covered with more breadfruit leaves, then with sand and gravel, and finally with coconut fronds or burlap. Cooking time is about an hour. The deep um is excavated to 50-60 cm and is used in the same way, mostly for baking bread, which requires a higher temperature and

longer baking time. Most people prefer a Coleman oven set on a kerosene stove, but these are rare. The food storage pit is excavated to a depth of about 50-75 cm (but not over an arm's length). These pits are used mostly to store preserved breadfruit, but may be used to store cooked leftovers. All food to be stored is wrapped in breadfruit leaves, and the pit is lined with either breadfruit or pandanus leaves.

Obviously the Marshallese kitchen is considerably more portable than the American version. Many fire pits and ums are located outside; in fact, they may be constructed and used at the food-gathering site. Kerosene stoves are valuable possessions which are kept under cover, although seldom in the house itself. There was one four-burner model occupying a place of honor in one Marshallese house. For broiling in an um, a fire is started with dry coconut frond; then either Messerschmidia wood, coconut shells or husk, or pandanus wood is added. Most other woods may be used, but coconut shell is preferred for the um because it produces good coals.

The important native foods on Ujilang, and presumably on Enewetak, are fish, coconut, breadfruit, and arrowroot. Pork and chicken are consumed in varying amounts, and water consumption is highly dependent on the availability of tea and coffee. Fish, coconut, and breadfruit are eaten both raw and cooked in a variety of ways. Only cooked arrowroot is eaten. Table 5 represents an attempt to quantify the Marshallese diet on a daily basis and is based on information supplied by Dr. Mary Murai of the University

Table 5. Summary of Marshallese daily diet.<sup>a</sup>

Food item	At time of return, g/day			10 yr post return, g/day
	Men	Women	Children (older than 3-4 yr)	
Fish	600	600	400	600
Domestic meat <sup>b</sup> (pork, chicken)	60	60	35	60
Pandanus fruit	0	0	0	100 (200-400 for children)
Wild birds	100	100	60	10
Bird eggs	20	20	15	5
Arrowroot	0	0	0	40
Coconut	20	20	20	100
Green coconut milk	20	20	20(?)	300 (0-1500)
Ripe coconut milk	20	20	15	100
Coconut crabs	25	25	15	0-5
Clams (and other shellfish)	10	0	0	25
Garden vegetables	100	100	80	200
Breadfruit	0	0	0	200
Imports <sup>c</sup>	400-1000	200-1000	150-800	0-1600
Total	~1600	~1600	~1300	~1800

<sup>a</sup>Every entry in this table is subject to qualifications and should not be used without reading the accompanying text.

<sup>b</sup>Ranges from 0 to 250 g/day due to individual possession of swine and fowl.

<sup>c</sup>Flour, rice, sugar, tea, canned meats, and canned fish are by far the favorites. These will comprise from 0 to 80% of the diet, depending on availability.

of California (Berkeley), and on observations gathered during the 10 days on Ujilang. It should be emphasized that imported foods are highly favored by the Marshallese and will constitute anywhere from 0 to 80% (perhaps even 100% for short periods) of the daily diet. The critical factor influencing the quantity of imported food consumed is availability, which for the Ujilangese means transportation. The breakdown into men, women, and children is perhaps more

misleading than informative, particularly for the women and children, because they are constantly exposed to food during the daily preparation and their intake is highly variable.

Pregnant women eat the regular diet, sometimes reducing their intake for weight-control purposes. Infants are nursed up to about 1-1½ years of age, when they are weaned onto the current diet with only a modification in food preparation. Certain foods may be mashed



or cooked somewhat longer to make them more suitable for infants. The meat of the green coconut, which is naturally soft, and arrowroot paste are popular infant foods.

Pandanus is the lollipop of the Marshall Islands, much favored by children and to a certain extent by adults.\* Fried breadfruit is a favorite snack food, especially of older women who may spend many afternoons eating fried breadfruit, smoking, visiting, and playing bingo. Averaged over a monthly basis, the numbers in Table 5 are probably good to  $\pm 50\%$ , the "10-year postreturn" column is strictly a guess; much depends on what becomes of Enewetak. The diet will depend greatly on the extent of American (or Japanese) influence.

Because it is very difficult to express the Marshallese diet in grams per day, the following discussion of the various food items and their uses is given.

### Seafood

Fish is certainly a favorite item in the Marshallese diet. Even if imported food is available, local fish remains high on the list of variety foods. If imported food is not available, fish probably sup-

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\* According to Tobin, pandanus is probably more important in the diet than this report indicates. The fact that it was out of season during the visit may have contributed to the impression that it is not widely consumed. Tobin states that it is a very nutritious food, and that its consumption should be encouraged by planting it in abundance on Enewetak. Perhaps the amounts given in Table 2 should be doubled or tripled for the 10-year post-return consumption. Murai originally estimated 200 g/day without regard to age or sex.

ply the entire protein intake. The favorite fish at Ujilang, and those observed caught and eaten, approximately in order of abundance are: rabbitfish (*Siganus*), grouper (*Epinephelus*), convict surgeon (*Hepatus*), goatfish (*Mulloidichthys*), pompano (*Hynniss*), surgeonfish (*Naso*), bonito (*Sarda?*), squirrelfish (several varieties), ulua (*Caranx*), and yellowfin tuna (*Neothunnus*). Bonito, ulua, and tuna must be caught by trolling; therefore their importance in the diet depends strongly upon motorboat availability. All three are a favorite fish, particularly for sashimi (raw).

Almost any fish which is caught and cooked will also be eaten raw. The head of the smaller fish is considered a delicacy, and the heart and liver are also occasionally consumed. Fish which are to be cooked within a few minutes of being caught are seldom eviscerated. Fish eaten raw, and those which will be kept even an hour or so are eviscerated. Large fish, such as the tuna and jacks, are usually cleaned back at the village because the heart and liver are practically always cooked and eaten. The smaller reef fish are cleaned on the spot, often just with fingers and teeth. Fish are usually cooked with the skin and scales left on; the scales peel off easily after cooking, and most of the skin is usually discarded. However, whether or not the skin is eaten depends on both the fish and the diner. Sashimi is always skinned first.

The Marshallese are opportunists and will tend to eat what they catch; however, they know where and when their favorite fish are likely to be found and plan their trips accordingly. Their techniques are

also directed toward certain types of fish. The two principal factors which discriminate against certain fish in the diet are flavor and the occurrence of ciguatera or other forms of poison. Sharks are good examples of the flavor factor. The meat contains large quantities of urea, requiring laborious preparation which, when combined with the generally unpleasant disposition of these fish, serve to eliminate them from the diet. Moray eels, barracuda with three gill rakers, and one species of mullet are examples of fish which frequently contain ciguatera. The puffer fish and such obvious species as the stonefish and scorpion fish are also excluded from the diet.

Frying in oil or lard and broiling over coals are the principal methods of cooking fish, although boiling and baking in the um (particularly for large fish) are sometimes used. Cooked fish may be kept for several days by wrapping it in breadfruit leaves and covering it with coconut or pandanus fronds. It is reported that fish can be stored over longer periods by salting it raw and drying it in the sun. The Ujilangese make their own salt by evaporating ocean-side water in kettles over a fire. The preserved fish are rinsed in fresh water before they are eaten. Since fish are abundant, the daily intake depends mostly on personal preference. Many interviews indicated that the 600 g/day, wet weight, estimated by Murai and included in Table 5, is probably accurate to within 10-20%.

Tridacna and hippopus clams are about the only other seafood eaten in any significant quantity. Clams of edible size are not common at Ujilang (or Enewetak, for that matter), and most are consumed on

the spot by the fisherman. The large adductor muscle is eaten raw, as well as the mantle, but dark parts are discarded. It is possible that some clam meat, particularly the mantle, finds its way into the diet of the women and children, but certainly not much. Sea turtles, spider snails, and helmet shell snails are also sometimes consumed, but again are only a small portion of the diet. Sea cucumber (Holothuria) and small crabs are not eaten. A variety of small snail (Littorina) is a delicacy, but the quantities consumed are insignificant.

### Coconut

Until one has lived awhile with the Marshallese, it is impossible to realize what a useful tree the coconut palm is to these people. Essentially every part of it is used in at least one way. The leaves are used to make baskets, to thatch roofs, and for various handicrafts. The trunks are used for firewood and as logs for general building purposes. Coconut husks make good fire-building material, while the shells make good charcoal and are also used as cups and bowls. The sap from the blossom of a tree 4-5 years old is gathered and used as a syrup; it gives a pleasant coconut sweetness to several foods. This same sap may be fermented to produce an alcoholic drink; however, drinking is against the law for the Ujilang people. Small roots of the tree (~1-2 mm diam) can be bleached in the sun, dyed with the water extract of colored crepe paper, and woven into a variety of baskets. Hearts of palm are rarely eaten. The tree must be 4-5 years old before the top is cut off and the growing core is harvested. This

yields about 4-5 kg of material and kills the tree.

The coconut itself is a dietary mainstay. A drinking nut, ni (pronounced "knee"), is full grown but totally green, and contains about 250-350 ml (grams) of liquid. The meat at this stage is only about 4-5 mm thick and, while firm, is covered with a gelatinous coating on the inside. Consumption of drinking nuts is highly variable. They are traditional at festive occasions and make an excellent "coffee-break" drink. Usually they are not used to quench thirst because water is preferred, but they are used more as the Marshallese version of soda pop. However, if water is not available, a working man might consume up to a dozen nuts or so a day. On Ujilang they are plentiful and there for the taking, which makes an accurate estimate of the consumption impossible. The meat of the drinking nuts, a popular baby food, is consumed only in small quantities by older children and adults.

Ripe coconuts, similar to those for sale in American stores, are consumed in a variety of ways, but mostly raw. Some of the liquid is used in cooking, and the meat, called "copra" by the Marshallese, may be eaten in pieces with fish, or grated and added to other foods. Favorite recipes include a mixture of grated coconut, wheat flour, water, and a little sugar which is baked in the um; a similar mixture containing baking powder which is deep-fried ("doughnut" in Marshallese); a mixture of breadfruit and grated coconut baked in the um; and grated coconut and coconut sap, mixed with steamed rice. All of the people interviewed said they ate about half a

coconut per day. Since an average coconut yields about 200 g of copra, the figure of 100 g/day listed in Table 5 is fairly accurate. This also agrees well with Murai's estimate.

Commercial copra is prepared by spreading pieces of coconut meat on a grate about 2 m above an open fire. Coconut husks and shells are the favorite fuel, and complete drying requires about 24 hr. After drying, the copra is stored in burlap sacks to await a Trust Territory field ship. Copra-making was not in evidence on Ujilang because, the people said, it often spoiled before a ship would arrive. However, while the survey party was there, Smith Gideon built a copra-drying shed which he said would dry several hundred pounds at a time.\*

There is a stage of the coconut between ripe and sprouted when it is not consumed. Once sprouted, the layer of meat is gone and the inside is filled with a pithy, yellowish mass called iu (pronounced ("you")), which is highly prized by the Marshallese. Iu may be eaten raw

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\* According to Tobin, most copra is dried in the sun rather than over a fire, and official Trust Territory figures list the copra production of Ujilang as 51.6 tons (\$5000) in fiscal 1971 and 110 tons (\$11,000) in fiscal 1972. If these figures are reliable, it would seem that much more copra-making goes on than was evident during the survey party's visit. It is possible that copra is made on other islands, but the people generally said they did not make much copra. Certainly on the main island there did not appear to be an area large enough to sun-dry more than 100 tons of copra, even in a year. Current copra production is of little importance to dose-assessment calculations, but if copra is to be an important cash crop in the future, careful attention should be given to potential radionuclide levels.

or used like copra. In what is probably the favorite recipe for iu, it is grated together with copra and perhaps a little sugar, then slurried with ni to make a thick drink, a sort of Marshallese milkshake. On Majuro this mixture is frozen on sticks and sold like Popsicles.

Breadfruit is the third main component of the Marshallese native diet and was in season during the visit there. Three varieties exist, two of which must be cooked, and the third, somewhat less plentiful, can be eaten either cooked or raw. A typical breadfruit will be about 15 cm long, 10 cm in diameter, slightly ovoid, with a rough, light-green skin and orange flesh. The general appearance is that of a very large avocado. Average weight is 1100 g, with about 10% as peel and core. The variety eaten raw is smaller, weighs perhaps 700-800 g and contains about 100 g of seeds which look like small chestnuts. These seeds can be roasted and eaten. Breadfruit is cooked in several ways, much as we would cook potatoes. However, the skin is never eaten. The breadfruit may be peeled and cored, then cut up and boiled, or it may be baked whole with the skin on, either over coals or in the um. A favorite way, especially of older women, is to peel and core the breadfruit, then slice it perpendicularly to the long axis, salt lightly, and deep-fry. This produces a product resembling fried pineapple rings, but somewhat larger, and is a good snack food, a sort of Marshallese equivalent of potato chips. Once cooked, breadfruit can be covered and kept for several days.

Another method of preparing breadfruit is to peel and core about a dozen fruits and let them soak about 24 hr in a

coconut-frond basket in the lagoon. They are then rinsed in fresh water and kneaded together on a rock or board until the product resembles orange-colored bread dough. This is then divided into "loaves" of a kilogram or so apiece, wrapped in breadfruit leaves, and stored underground in a pit as already described. It is said to keep several months this way, and may be used like fresh breadfruit after another rinse in fresh water. This product is usually mixed with grated coconut and baked in the um.

Arrowroot grows all over Ujilang and is the principal undergrowth in the coconut forest. In July, the tubers were small because the harvest season begins around November. The preparation of arrowroot has been described by Tobin and consists of digging, then washing and grating the tubers, and placing the pulp in a burlap sack or one woven of coconut roots. The sack is immersed in salt water, squeezed out by hand, and the milky extract, consisting of a fine suspension of starch, is collected. In an hour or so the starch coagulates and is washed several times by decantation with salt water, then fresh water. The starch is then spread in the sun to dry, ground lightly to break up lumps, and stored away where it will keep indefinitely. Arrowroot starch is not at all like wheat flour and is only used as a thickening agent in soups or stews. It resembles our familiar cornstarch. When questioned, the Ujilangese all stated a preference for wheat flour over arrowroot starch. Flour can be used as a thickener, as well as for other purposes. They said that given both, they would use up the

flour first and then fall back on the arrow-root. From start to finish, arrowroot production is a long, tedious process, resulting in a product which has no flavor and limited usefulness.

Pandanus was just coming into season during the July trip. When questioned, most adults said that they eat hardly any pandanus. It is consumed mostly by the children. Tobin reports a method of sun-drying pandanus on coconut fronds; the Ujilangese acknowledged this, but claimed that they do not make it often. Pandanus is not abundant on Ujilang and probably will not be on Enewetak either.

About the only other native food consumed in any quantity on Ujilang was pork and, in even lesser amounts, chicken. The quantity of pork consumed varies greatly from family to family, because pigs are private property, and there is no obligation to share them. Some families have many pigs and may eat pork two or three times per week, replacing fish on a gram-for-gram basis, while other people have few or no pigs and hence eat little or no pork. Chickens are in the same category but are very scarce. The reason for this seems to be that the cats, originally imported to control the rats, did such a good job that they had to move on to the chickens. All animals are free-roaming and forage anywhere on the island.

Little need be said for other native foods. Coconut crabs and wild birds have been essentially wiped out on Ujilang but may be important at Enewetak, especially for the first year or two. The coconut crabs are highly prized for food. Their legs and claws are broken off and cooked immediately; then the crab is

force-fed until the tail doubles in size, when it is used for soup. Almost all of the sea birds are eaten except the golden plover, which is believed to contain spirits of departed souls. The young birds just getting feathers are a favorite food item. Again, the Marshallese recipe is simple: catch the bird, wring its neck, and cook it over an open fire, entrails, feathers, and all. The liver and heart are eaten. Bird eggs are eaten but are not a favorite food item.

The only garden vegetables growing on Ujilang were two pumpkin vines, neither of which had any pumpkins, but one was in blossom. The lack of agriculture is explained first by the fact that there is practically no soil, just rocks, and second, that the pigs are free-roaming and fond of anything edible. The latter fact, when combined with the cat-chicken situation, provides a real insight into the Marshallese philosophy of life, "play it where it lies."

Methods of cooking imported foods have been described as they accompanied the native diet. Flour, in addition to the products mentioned, is also made into bread, baked in the um. Rice is exclusively boiled with the standard proportions of two parts of water to one of rice. Tea is drunk hot and is much preferred to coffee. In fact, the order of preference in beverages is tea, coffee, water, soft drinks, and ni. Sugar is added to several foods, and almost everyone uses sugar in tea and coffee. Canned meats such as corned beef, tuna, salmon, and mackerel are eaten with no more preparation than heating, and they replace fresh fish on a gram-for-gram basis.

### Medicines and Remedies

This was the only area where there seemed to be a definite desire for secrecy. Apparently the Marshallese medicine, like the folk medicine in parts of the United States, is a family secret and not shared extensively, especially with outsiders. Part of this reticence may be due to the fact that the Marshallese realize the sophistication of American medicine and are afraid of ridicule. It was inferred that many of the Marshallese themselves did not have much faith in their medicine, but it was worth a try, particularly if the American version did not work or was unavailable. Held's article (op.cit.) contains some information regarding the local remedies of Rongelap. The reported uses of Messerschmidia and Scaevola were confirmed on Ujilang. The use of Messerschmidia is particularly important with regard to dose assessment, because leaves are used as a first-aid bandage and as a poultice to cover open wounds.

A few general remarks regarding health care should be made. Ujilang is the most remote of the Marshall Islands and as such, suffers even more than the others from a lack of readily available first aid, much less real medical care. The dispensary stock consisted of aspirin, tetracycline capsules, penicillin, dextrose solution, normal saline solution, and miscellaneous odds and ends of patent medicines. A Marshallese medical attendant was in charge. A kerosene refrigerator was operable but out of fuel, and there was no other medical equipment or furniture of any kind. In case of a medical emergency, the usual proce-

dure is to divert a Trust Territory ship and take the victim to Majuro. Usually this means a minimum of three days' delay. The people all appeared very healthy and vigorous, and there seemed to be no evidence of malnutrition or illness. However, it was reported that all through the Marshall Islands a baby's first birthday is a big event and a cause for celebration.

### Agricultural Considerations

Just what the level of agriculture will be in Enewetak is very difficult to say. Certainly the two staples, coconut and breadfruit, will be grown, especially on the islands of Medren, Japtan, and Engebi. Some pandanus and arrowroot will also be raised. The fact that no agriculture is practiced on Ujilang and the reasons why have already been mentioned. Whether things will be different at Enewetak remains to be seen. Many Ujilangese interviewed remembered that the Japanese raised a variety of vegetables as row crops on Engebi and Enewetak. These were irrigated with either cistern or well water containing human waste. No one knew whether vegetables could be grown on any other islands (probably Japtan) but, since irrigation is necessary, the availability of fresh water would be a crucial factor. The implication is that, given some effort and perhaps some fertilizer, a variety of crops could be grown. One Ujilangese, Balik by name, worked as a Trust Territory agriculturalist on Majuro for a year. He also lived on Enewetak at the time of the Japanese occupation and recalls their growing pumpkins, cucumbers, watermelons, potatoes, sweet potatoes, green

onions, cabbage (bok choy), carrots, and maybe soybeans. Thus there is certainly a potential for augmenting the standard diet of coconut, breadfruit, and fish. It is reported by Tobin and confirmed by others that the Ujilangese are quite industrious and will probably grow at least some vegetables, but will probably not practice American-style truck farming.

Pigs and chickens will remain the only domestic animals raised for food; no one interviewed indicated otherwise. However, Tobin says that Muscovy ducks and turkeys do well in this part of the Marshalls. As on Ujilang, livestock will be allowed to forage on their own, although it would seem that for at least a few years after return, some sort of food supplement would be necessary. On Ujilang the pigs ate coconuts at all stages of ripeness, grass, the leaves of the trumpet morning glory (*Ipomoea*), fallen breadfruit, family garbage, and small

crabs and snails from the lagoon beach. Presumably the chickens consume a similar diet. It would seem that on Enewetak the confining of either the animals or the vegetables would be beneficial.

#### Marine Resources at Enewetak

During conversations and fishing trips with Smith Gideon, Ujilang magistrate, in a two-week period at Enewetak Atoll in July 1973, some information on the food habits of the Ujilang people was gained which may be used to help estimate dose rates from food intake. In general, the data gathered concern the use of fish in the Ujilang diet and specifically include data on meals eaten during fishing trips while on Enewetak.

Generally, it can be stated that the Ujilang people are opportunists and will eat most types of fish which they happen to catch. However, certain fish are preferred and special efforts are made to

Table 6. Average wet weights of tissues from common edible nearshore fish at Enewetak Atoll.

Common name	Tissue	No. of fish	Average wet weight	Wet/dry
Goatfish	Eviscerated whole	61	145	3.4
Goatfish	Viscera	61	13	3.5
Goatfish	Muscle		45-50 <sup>a</sup>	4.8 <sup>a</sup>
Mullet	Muscle	32	57	3
Mullet	Eviscerated whole	32	167	3
Mullet	Viscera	32	44	2
Rabbitfish	Muscle	9	200	3.9
Convict surgeon	Eviscerated whole	47	54	3.5
	Viscera	47	10	5.3
	Muscle		15 <sup>b</sup>	4.0 <sup>b</sup>
Parrotfish	Muscle	17	144	4.9

<sup>a</sup>Estimated from similarity to size and body shape of mullet.

<sup>b</sup>Estimated.

capture the preferred species. Also, certain fish are avoided either because they are known to be poisonous (ciguatera), difficult to prepare, or simply because they are not as flavorful as other species.

One apparently favorite fish is the goatfish, either "Jo" (*Mulloidichthys*) or "Jome" (*M. auriflamma*). The whole fish is laid on a grill (if available) and roasted over a bed of hot coals for about 10 minutes. The skin is then peeled off and the flesh eaten. The head of the goatfish is considered a delicacy and is often offered to a guest as a courtesy. The soft parts (brain, eyes) of the head are eaten, but the bones and viscera are discarded. All organic waste from a meal is placed in the fire and burned. This is a garbage disposal method and serves to keep the fly population down. One goatfish or mullet (see Table 6 for average weight of fish) is a reasonable intake at one meal; however, some people may eat three goatfish. The remainder of the meal usually consists of one-third of a copra coconut and a drinking coconut.

Another apparent favorite is the rabbitfish, "bejrok" (*Siganus*). Rabbitfish of other species are also known as "mole" or "molle" and are referred to several times in Tobin's 1955 journal as a favorite fish of the Ujilang people. The rabbitfish are cooked in the same manner as the goatfish. In fact, it appears that most fish are cooked in this manner, except for occasions when the um is used. Only the flesh of the rabbitfish is eaten, and one fish is the usual intake for a meal. One-fourth of a copra-type coconut (the kind usually sold in the U.S., with the meat dry), coconut crab legs

(100 g, wet), and a drinking coconut completed this meal as prepared at Enewetak.

Other fish which were captured on fishing trips and which are said to be eaten are mullet, convict surgeon, parrotfish, grouper, surgeonfish, and damselfish. These fish, along with the goatfish and rabbitfish, probably comprise the most common fish found in the nearshore water around the island of Enewetak, and hence will probably be the most common fish in the diet. Seven or eight convict surgeon, some copra, and a drinking coconut, or two to three convict surgeon, copra, rice, and a drinking coconut are typical meals.

There seems to be some conflicting opinion as to whether or not the Ujilang people eat mullet and parrotfish. Tobin, in one conversation, stated that the Ujilang people do not eat either mullet or parrotfish. However, Smith Gideon, when shown specimens of mullet and parrotfish, indicated that at least three different species of the smaller (<12 in.) mullet, both "ikare" (*Chelon vaiigiensis* or *Neomyxus chaptalii*) and "jomou" (*Mugil sp.*), and three species of parrotfish are eaten on occasion. The conflicting opinions may be due to the fact that one genus of mullet, "iol" (*Crenimugel sp.*), is considered to be poisonous and therefore is not eaten. Furthermore, parrotfish from the northern end of the Enewetak Atoll are also considered to be poisonous and are not eaten. Parrotfish from the David to James area of the Atoll are eaten. In addition, the fact that other species of fish (goatfish and rabbitfish) are preferred may have led to the confusion on this point. However, it seems



clear that the Ujilang people, on occasion, will eat both mullet and parrotfish.

Of the fish actually captured and shown to Smith, his preference in descending order seemed to be goatfish, rabbitfish, mullet, convict surgeon, and parrotfish, with grouper, surgeon and damselfish occupying indefinite intermediate positions between rabbitfish and parrotfish. These nearshore fish are captured by several methods, including use of throw-nets, gillnets, and a surround technique by which the fish are driven into shallow water where they are hand-captured or dip-netted. Additional thrownets and gillnets, along with appropriate mending materials, might be considered as a part of the rehabilitation program for the Enewetak people.

A fish not actually captured but indicated to be very good to eat is the flying fish, "jojo" (Exocoetidae). These fish are captured at night by building a fire in a boat and attracting them to within a range where they may be netted. Some flying fish also fall into the boat during their flight toward the attracting light. Small hooks on a line are also used in a manner similar to the jigging of herring or smelt which bite on the bare hooks that simulate the planktonic organisms they feed on.

Other fish which reportedly are eaten are barracuda with four gill rakers, "nidwa," tunas, and other similar lagoon fish such as jacks, mackerel, and dolphin. Although larger sharks (probably gray sharks but not thresher or nurse sharks) are eaten, they probably are a minor portion of the diet due to the length of time required in the preparation of the flesh to make it edible. This lengthy

preparation is due to the urea in the flesh which renders the fresh fish unpalatable: "a shark has a big smell."

In the preparation of shark flesh, the fish is boiled in hot water for about 10 minutes, after which the skin is removed. The flesh is then boiled for several hours, presumably until the smell goes away. Next, the boiled meat is fried or steamed (um) and then placed in the sun until it is dry. This process takes most of a day, but the finished product is considered good.

The capture of large lagoon fish requires boats and fairly heavy fishing lines, feathered jigs, and large hooks. Hence, the use of these fish in the diet is highly dependent on these items and is probably less than the utilization of the nearshore fish because of the present scarcity of adequate fishing gear and because the nearshore fish are so abundant and easily captured at most times. In general, at the present time, deepwater lagoon fish are probably not as abundant in the diet as they would be if more fishing gear were available to the people.

Other marine organisms which may be eaten include porpoise, tridacna clams, ("kabwur"), shore crabs, and large gastropods (en). Other smaller gastropods are also called en, but they are not eaten. These include spider snails and smaller Strombus species.

Porpoise are captured by surrounding them as they enter the wide pass or deep channel and herding them into shallow water. Herding is accomplished by banging rocks together underwater and splashing on the surface.

Three types of Tridacna are distinguished by the Enewetak people: (1) the

large killer clam, Tridacna gigas; (2) a white-mantle, medium-sized clam; and (3) small clams with colored mantles which are embedded in the reef. All types are called kabwar. No information was obtained on how these clams are prepared, but it is known that other Marshallese people do not eat the kidney, due to its very bitter flavor, and it may be presumed that this is the case for the Enewetak people until different information is obtained.

Another organism which will certainly be eaten by the returning Enewetak people, unless advised to the contrary, is the coconut crab, "baru lip" (Birgus latro). The first step in preparing this crab is to knock the pincer legs and the largest walking legs off with a machete. The legs appear to break off near the body at a natural breaking point, which quickly heals over. By doing this the crabs can be easily contained without causing damage to themselves or to their captors. Also, crabs can be held alive like this for several weeks. The legs and the bodies of crabs not to be saved are then roasted over a bed of coals.

From discussions with Smith Gideon, I would conclude that the diet of the Ujilang people is very similar to diets of the Bikini people, the Rongelap people, and other northern island groups in the Marshall Islands. This is true because the

basic foods are the same in all these areas. Breadfruit, pandanus, arrowroot, and coconut are the chief natural terrestrially grown vegetative foods, with imported rice and flour supplementing this portion of the diet to a degree which is very dependent upon the length of time from the visit of the last field-trip ship.

Fish, clams, and langousta from the lagoon and reef; birds and bird eggs from bird-nesting islands; domestic pigs and chickens raised on the village island; and imported meats (corned beef, sardines) provide the animal protein in the diet. Again, the proportions vary greatly with the availability of specific items; however, fish are indicated as being an important part of the diet at Ujilang and will probably be more important at Enewetak Atoll where the fish supply is greater.

It should be remembered that a diet determined for the Ujilang people over one short time period may differ greatly from a diet determined over another time period in a different season or at a different length of time from the last visit of a trade ship. I feel, therefore, that a composite diet, based on all available diet information for the Ujilang, Bikini, and Rongelap people, is the best information to be used in the calculation of dose rates from food intake.

### III. Survey Execution

W. Nervik, Lawrence Livermore Laboratory, Livermore, California

#### SURVEY PLAN

After agreeing to conduct the radiological survey, the AEC assigned responsibility for the program coordination to its Division of Military Applications (DMA). Major General F. A. Camm, Asst. Gen. Mgr. for Military Applications, then directed the AEC Nevada Operations Office (NVOO) to execute the program, using the following specific instructions:

"As a result of commitments made by Ambassador Williams and initial agreements reached during an interagency meeting held on September 7, 1972, it is the overall AEC purpose to gain a sufficient understanding of the total radiological environment of Enewetak Atoll to permit judgements as to whether all or any part of the Atoll can safely be re-inhabited and, if so, what steps toward cleanup should be taken beforehand and what postrehabilitation constraints must be imposed. It is necessary to thoroughly examine and evaluate radiological conditions on all islands of the Atoll and in the local marine environment prior to commencement of cleanup activities in order to obtain sufficient radiological intelligence to develop an appropriate cleanup program. Specifically, it is necessary:

1. To locate and identify contaminated and activated test debris,
2. To locate and evaluate any significant radiological hazards which may complicate cleanup activities, and

3. To identify sources of direct radiation and food-chain-to-man paths having radiological implications.

You are directed to plan, organize, and conduct a radiological field survey to develop sufficient data on the total radiological environment of Enewetak Atoll to permit the assessments on which the judgements described above can be made."

A number of factors strongly influenced the planning of the survey:

- Although a number of studies of Enewetak had been conducted previously, none provided either current or complete information on the radiological state of the Atoll. The Survey would therefore have to obtain data on all islands and all human dose pathways in sufficient detail and accuracy to permit reliable population dose estimates to be made for the future inhabitants.
- In September, 1972, the only field support facilities available at Enewetak were those operated by the U. S. Air Force, which then had custody of the Atoll. The base support resources were committed to certain military activities, but an open period in those activities permitted the scheduling of support to the AEC survey from mid October thru December 1972.
- Although Ambassador Williams had not promised the return of the Enewetak people to the Atoll at the end of 1973, his speech was widely interpreted to

mean just that, and therefore there was considerable pressure for the AEC radiological survey and dose assessment effort to be completed as quickly as possible.

- Given the size of the sampling program, the time constraints imposed by limited field support facilities, the large amount of radiochemical analytical work required, the complex dose assessments that were needed, and the growing hopes and expectations of an early resettlement, it was clear that no single technical organization was big enough to conduct this program by itself, nor were there many who could or would divert sizable numbers of highly qualified technical people from previous commitments on less than one month's notice.

With these factors influencing decisions, the Radiological Survey was organized in the following way:

- A Program Manager (Roger Ray) was assigned by NVOO to provide overall program responsibility, liaison and coordination among organizations operating in the field, and fiscal controls at the NVOO level.
- The Lawrence Livermore Laboratory (LLL) agreed to provide a Technical Director (Dr. Walter Nervik) for the program and to act as the focal point for technical activities associated with the program.
- Technical leadership for the various components of the program was assigned as follows:
  - Aerial Photography and Radiation Survey (J. Doyle, EGG)
  - Terrestrial Soil and Radiation Survey (P. Gudiksen, LLL, and

O. D. T. Lynch, NVOO)  
External Dose Estimates  
(J. McLaughlin, HASL,  
P. Gudiksen, LLL, and D. Jones,  
LLL)  
Marine Survey (V. Noshkin, LLL,  
and V. Nelson, U. Wash.)  
Terrestrial Biota Survey  
(G. Potter and J. Koranda, LLL)  
Air Sampling (D. Wilson and  
B. Clegg, LLL)  
Radiological Support to the DOD  
Engineering Survey (O. D. T.  
Lynch, NVOO)  
Analysis Program (R. Hoff, LLL)  
Radiological Controls (O. D. T.  
Lynch, NVOO)  
Dose Assessments (D. Wilson,  
Y. Ng, and W. Robison, LLL)

- These leaders then completed plans for the field sampling, analysis, and interpretation portions of their component and identified individuals who would be doing the work. Because of the scope and unusual nature of this program, individuals from an exceptionally large number of organizations have been involved, including NVOO, LLL, National Environmental Research Center (EPA, Las Vegas), Laboratory for Radiation Ecology (LRE) (University of Washington), University of Hawaii Enewetak Marine Biological Laboratory (EMBL), Trust Territory of The Pacific Islands (TTPI), McClellan Central Laboratory (MCL), Laboratory for Environmental Studies (LFE), Eberline Instrument Co. (EIC), AEC Division of Operational Safety, AEC Division of Biomedical and Environmental Research, EG&G, Inc.

(EGG), AEC Health and Safety Laboratory (HASL), the Defense Nuclear Agency (DNA), Holmes and Narver (H and N), the U.S. Navy, U.S. Marine Corps, and the U.S. Air Force field support contractors.

Given the directive to proceed on September 7, 1972, the Survey plan was completed, reviewed, and approved on September 18. (A copy of the final Survey plan appears in Appendix I.) The Field Survey party departed CONUS in two contingents, one on October 13 and the second on October 15, and field operations were begun on October 16 with the Soil, Marine, Terrestrial Biota, Air Sampling, and Engineering Survey Components all conducting their activities simultaneously. This put a very definite strain on the marine transport equipment (four boats), but all operations were proceeding smoothly until October 21, when the Survey party received its first alert warning of the approach of Typhoon Olga, predicted to pass directly over Enewetak on October 24 with winds of 125 knots and gusts to 165 knots. Survey activities ceased with that alert, all equipment was made secure, and everyone on the Atoll was evacuated to Kwajalein on the evening of October 23. Upon return to Enewetak on October 25, the power plant was found inoperative, and we were advised that the island could not support the Survey Party. All Survey personnel were sent home until support facilities could be provided once again.

Operations were resumed on November 8 with the initiation of the aerial survey. In the interim period from October 25 to November 8, changes in the scheduling of the military programs at

Enewetak provided further relief in the form of an extension of available field support. The AEC radiological field survey schedule was thus extended to mid February. The field effort actually terminated on February 14, 1973. In the following sections each component of the Survey is discussed in detail by those who were responsible for the effort.

## AERIAL RADIOLOGICAL AND PHOTOGRAPHIC SURVEY

T. P. Stuart and R. Meibaum  
EG&G, Inc., Las Vegas, Nevada

### Introduction

An aerial radiological and photographic survey of Enewetak Atoll was performed by EG&G during a 16-day period between November 8 and 23, 1972. This work was done in order to characterize the terrain, including the entire reef, and to determine the gamma-radiation levels and the spatial distribution of radioactive isotopes which are residues from earlier nuclear explosive experiments. Much of the fission-product and activation residues from the nuclear explosives experiments during the period 1948 through 1958 have remained to contaminate many of the islands and sections of the adjoining reef. In addition to fission and activation products, there is plutonium metal scattered at some locations as a result of explosive experiments which did not achieve a fission yield. Primary contaminants observed from the aerial radiological measurements are  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ , and  $^{239}\text{Pu}$ .

The aerial radiological and photographic survey was carried out from a

helicopter and covered all 39 islands of the Atoll. The photography covered four wavelength bands in the visible and near-infrared spectrum, and served to document the geographical features of the Atoll and serve as a basis for navigation in carrying out the radiological survey. The aerial radiological survey involved only gamma-ray measurements and included both gross gamma counts and energy spectral information in the 50-keV to 3-MeV range. The radiological measurements resulted in a determination of the spatial distribution of gamma-radiation exposure rate in  $\mu\text{R/hr}$  at one meter above the ground, as well as isotopic concentration for  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ , and plutonium-related  $^{241}\text{Am}$ . These measurements are presented as isopleth plots superimposed on aerial photographs of the islands. Correlations with ground-based radiation measurements and soil sample analysis are discussed in the subsection on Nuclear Instrumentation Systems and Methods.

The photographic data, together with the radiological survey results for the gamma-exposure rates and isotopic concentration for  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ , and plutonium-related  $^{241}\text{Am}$ , are presented in Appendix II. The next subsection of this report gives a description of the photographic instrumentation and methods, while the last subsection describes the nuclear instrumentation systems and methods.

### Photographic Instrumentation and Methods

#### Multispectral Camera System

Hasselblad Camera System – The aerial photographs of the islands compris-

ing the Enewetak Atoll were taken with a four-camera system consisting of 70-mm 500 EL Hasselblad cameras, equipped with 80-mm lenses. The four cameras were arranged along parallel optical paths and imaged identical ground images on the four image planes. The frame size was  $55 \times 55$  mm.

Each of the four cameras recorded a different portion of the visible and near-infrared spectrum. The wavelength region recorded was controlled by the choice of film sensitivity and optical filter combinations. The four film and filter combinations used are shown in Figs. 7 through 10. The four wavelength regions recorded were:

Normal color	4000-7000 Å
Infrared color	5000-9000 Å
Panchromatic/ red filter	6000-7000 Å
Infrared black and white	7000-9000 Å

Camera Mounting – The four Hasselblad cameras were mounted on a rigid plate which subsequently was mounted to the floor of a CH-53 Sea Stallion helicopter, allowing the cameras to view the terrain through a large port in the floor. Since gyrostabilization or shock mounting of the cameras was not used, the system optical axis moved in concert with the aircraft attitude and pitch. The optical axis of the camera system was perpendicular to the floor of the aircraft, which was maintained reasonably level during photographic missions.

#### Operational Considerations –

Photographic missions were flown at altitudes selected to image a single island

on a single frame. On the longer islands, consecutive overlapping frames were taken to provide a mosaic of the individual island. Flight altitudes were selected to

the nearest convenient 300-m (mean sea level) interval in order to simplify the flight plans and allow the acquisition of several islands on a single flight path. Once over the island, the cameras were triggered simultaneously by an operator looking through the floor of the aircraft. Flight altitudes ranged from 300 to 3000 meters.

In addition to the individual island photographs, complete coverage of the Atoll was acquired from an altitude of 3000 m. For this coverage the pilot was directed to fly the center of the visible portion of the Atoll while the camera system was triggered to record overlapping coverage.

The islands were photographed over a span of 8 days from November 12 to 20, 1972, and at diurnal periods between 0955 and 1624 hours, local time. The specific time of day of any photograph in the set presented in Appendix II is available.

Quick-Look Photography – The first missions flown on the island were for the purpose of acquiring photographic

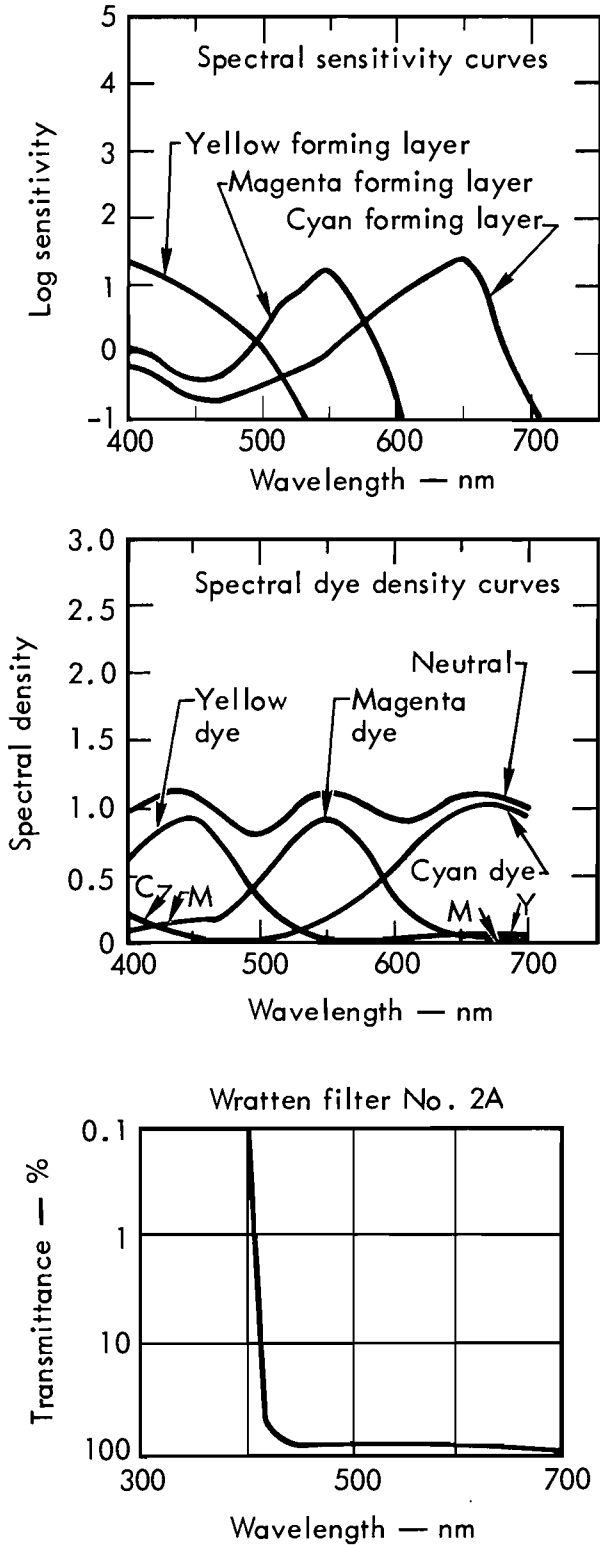


Fig. 7. Kodak Aerocolor Negative Film 2445. This film is a three-layer color film with sensitivity in the visible portion of the spectrum. This film is designed for processing to a color negative and does not have an integral color mask. In this form, the film is suitable for direct visual interpretation or can be readily printed to a positive print. The three layer sensitivities are to blue, green, and red. The film is normally used with a Wratten 2A haze filter, which reduces the recording of unwanted atmospheric haze on the film.

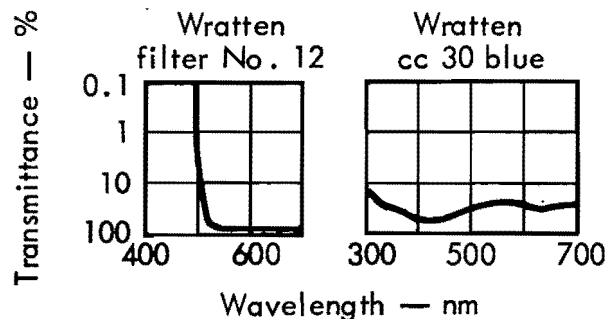
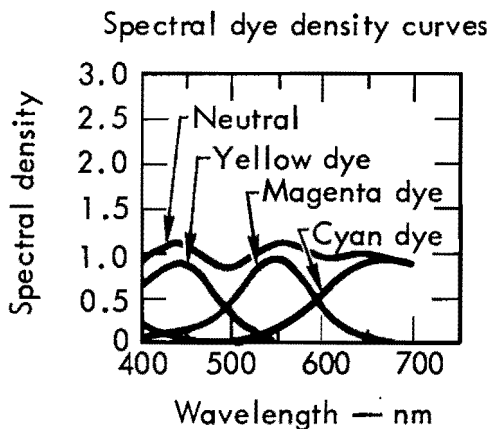
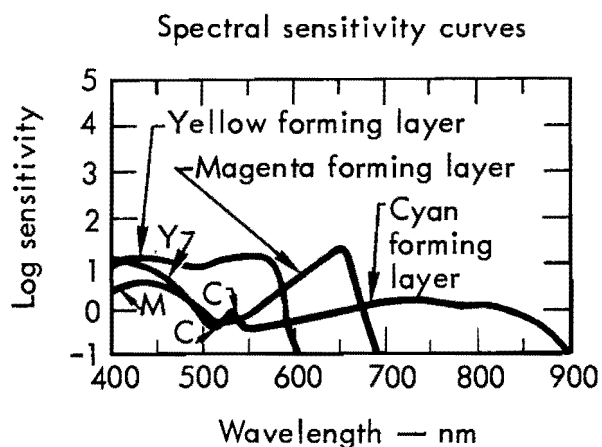


Fig. 8. Kodak Aerochrome Infrared Film 2443. This film is a false-color reversal film designed for use in aerial photography. It differs from ordinary color film in that the three layers are sensitive to green, red, and infrared radiation instead of the usual blue, green, and red. A Wratten 12 yellow filter is always used with this film to absorb blue light, to which all three layers are sensitive. The Wratten CC30 blue filter was used to correct the color balance of this particular emulsion batch and is not normally used with this film.

maps for use by the radiation monitoring personnel. This was accomplished by using the four-camera system equipped with a different film and filter combination than for the multispectral coverage. Kodak Plus-X Aerographic with a Wratten 12 filter was used to provide a photographic record in black and white that closely simulated the tonal relationship

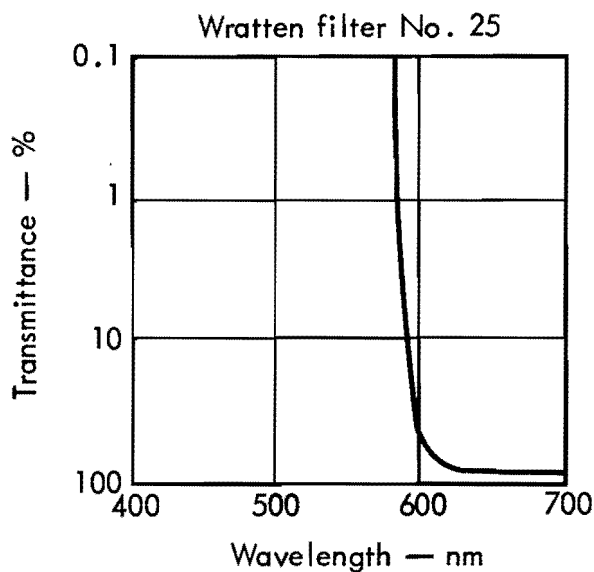
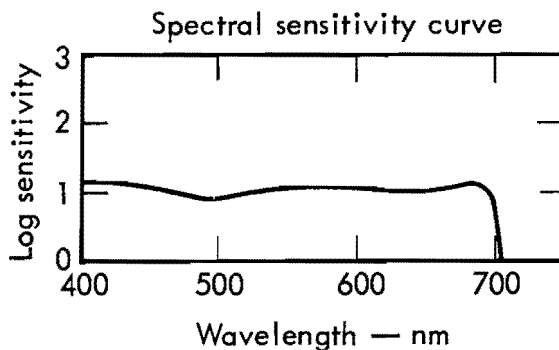


Fig. 9. Kodak Plus-X Aerographic Film 2402. This film is a panchromatic negative material that has extended red sensitivity. When used with a Wratten 25 filter which absorbs blue and green light, only those objects that have reflections in the red portion of the spectrum will be recorded.



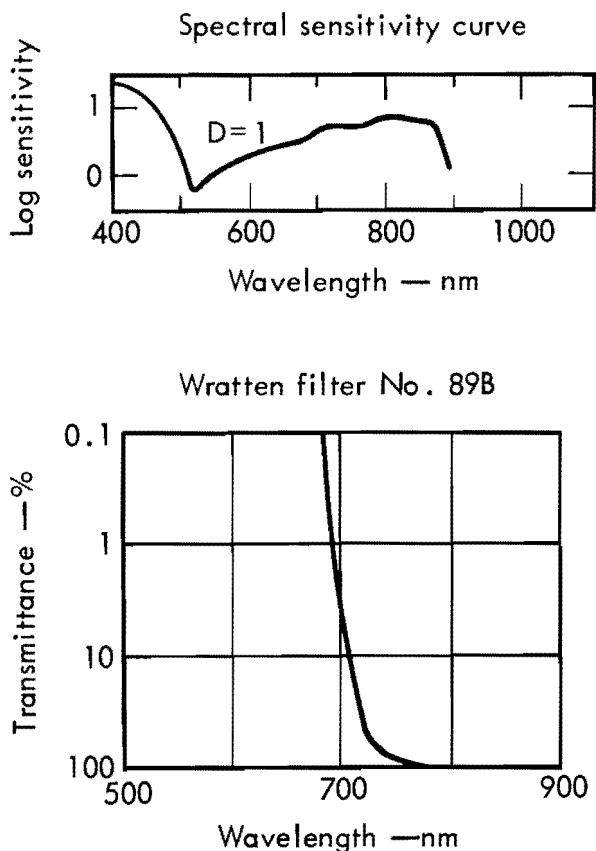


Fig. 10. Kodak Infrared Aerographic Film 2424. This film is a negative material which is sensitive to infrared radiation, as well as to the blue light of the visible spectrum. When used with a Wratten 89B filter, which absorbs all visible radiation, only the infrared radiation from the subject is recorded on the film.

that the human eye sees. The missions were flown similarly to the multispectral missions.

#### Photographic Processing and Printing

##### On-Island Processing and Printing—

The imagery acquired during the quick-look photographic missions was processed and printed on the island, using the Eniwetok Marine Biology Laboratory. Conventional black-and-white developing

and printing were accomplished to provide a 40 × 50-cm photographic map of each island.

Laboratory Processing and Printing — Exposed film from the multispectral camera system was processed in Las Vegas, Nevada. The two black-and-white films were processed by EG&G in a Versamat 5N. Both color-film records were processed commercially in a Kodak Color Versamat.

Photographic enlargements were made by EG&G from all records. The degree of enlargement varied for each island photograph because the island size was imaged to fit the print format with some water surrounding it.

Report Reproductions — The color lithographs in Appendix II were made from the normal color photographic record using four-color separation negatives prepared by EG&G. The color printing was done by EG&G on a model 1250 L&W Multi-lith press. Overprinting of titles and data was accomplished on the same press.

#### Interpretation and Utility of the Photographs

##### Multispectral Imagery Interpretation

— The imagery acquired of each island consists of the four wavelength regions previously described, examples of which are shown in Figs. 11-14. These are film records recorded simultaneously over Japtan Island (DAVID). Each figure shows imagery from a different portion of the spectrum. Figure 11 shows normal wavelengths similar to those seen by the human eye, covering 4000 to 7000 Å. In Fig. 12 all of the colors seen are "false"

with regard to human vision. In this picture, wavelengths between 5000 and 6000 Å (green wavelengths) are recorded as blue, wavelengths between 6000 and 7000 Å (red wavelengths) are recorded as green, and wavelengths between 7000 and 9000 Å (infrared wavelengths) are recorded as red.

Figure 13 is the black-and-white record on panchromatic film and exposed through a Wratten 25 red filter. On this imagery, only wavelengths between 6000 and 7000 Å are recorded. Figure 14 is the black-and-white record recorded on infrared film with a visible absorbing filter. On this imagery only infrared wavelengths between 7000 and 9000 Å are recorded.

While there are many facets to consider when interpreting multispectral photographs, a few general guidelines may be helpful. It is best to spread the four photographs for any one island out on a table when examining them so that the differences can be easily and quickly observed. The normal color record and the black-and-white (red filter) record both penetrate water depths well and show underwater terrain well. However, from the normal color record, it is difficult to determine where the water's edge is located. This can be easily determined by looking at the black-and-white (infrared film) record which shows all water areas as black. The differences between the appearance of the water areas on the normal color and the infrared color record are significant. The normal color record shows colors on the print as they would be seen by the eye. However, on the infrared color record, all the colors are "false." On this record the water still shows as a blue color, even though the film, when used with a yellow filter, has no

sensitivity to blue wavelengths. The blue areas on the print are the direct result of green wavelengths reflected to the camera. In this "false-color" imagery, healthy vegetation and coral areas show as red. This indicates high reflectivity in the near-infrared region of the spectrum. The black-and-white (red filter) record shows green trees very dark and generally causes man-made objects such as concrete, asphalt, and buildings to stand out against the dark background. On the black-and-white (infrared film) record, green healthy trees which have a high reflectance in the infrared region appear very light, indicating again a high reflectance in the infrared region.

Other Interpretations of the Photography – A wealth of information is contained in the photographs. Using a detailed study of one or of a series of photographs and aided by suitable analysis techniques, the photographs could be used for the following:

- Determine the percentage of tree cover for any island.
- Establish vegetation types.
- Determine the waterline at the time of the photograph.
- Locate major areas of debris.
- Determine suitable boat landing areas.
- Determine relative water depths around the islands.

Additionally, because some islands were photographed with overlapping coverage, a stereo presentation is possible. This results in considerably more information about the terrain, surface cover, and man-made structures than is possible with a single photograph.



Fig. 11. Normal color aerial photograph of DAVID covering 4000 to 7000 Å.





Fig. 12. False color aerial photograph of DAVID covering 5000 to 9000 Å.





Fig. 13. Aerial photograph of DAVID covering 6000 to 7000 Å.







Fig. 14. Aerial photograph of DAVID covering 7000 to 9000 Å.





Fig. 15. Single frame of high-altitude photographic coverage.





Fig. 16. Assembled mosaic from JANET to WILMA.



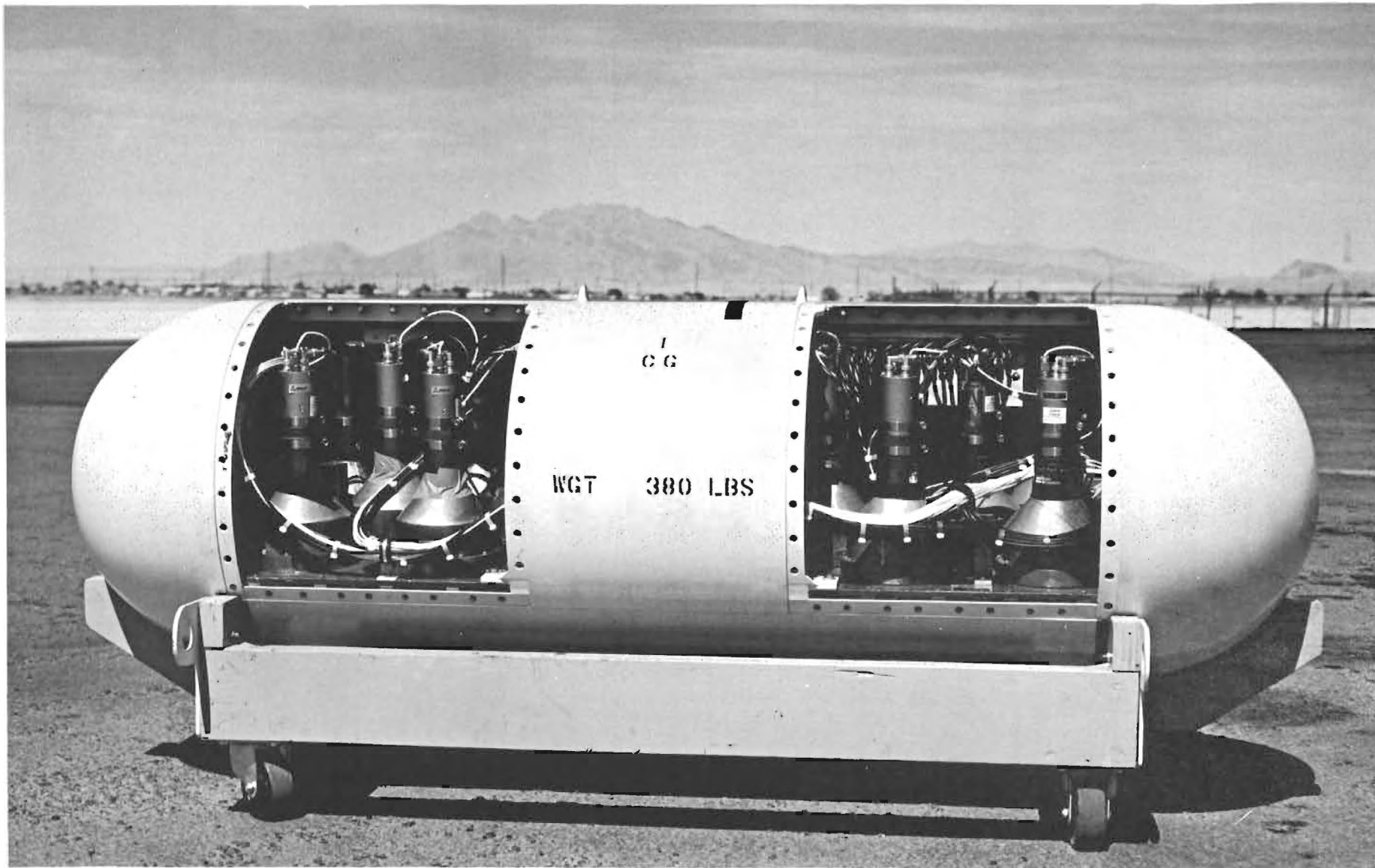


Fig. 17. Single array of NaI detectors.





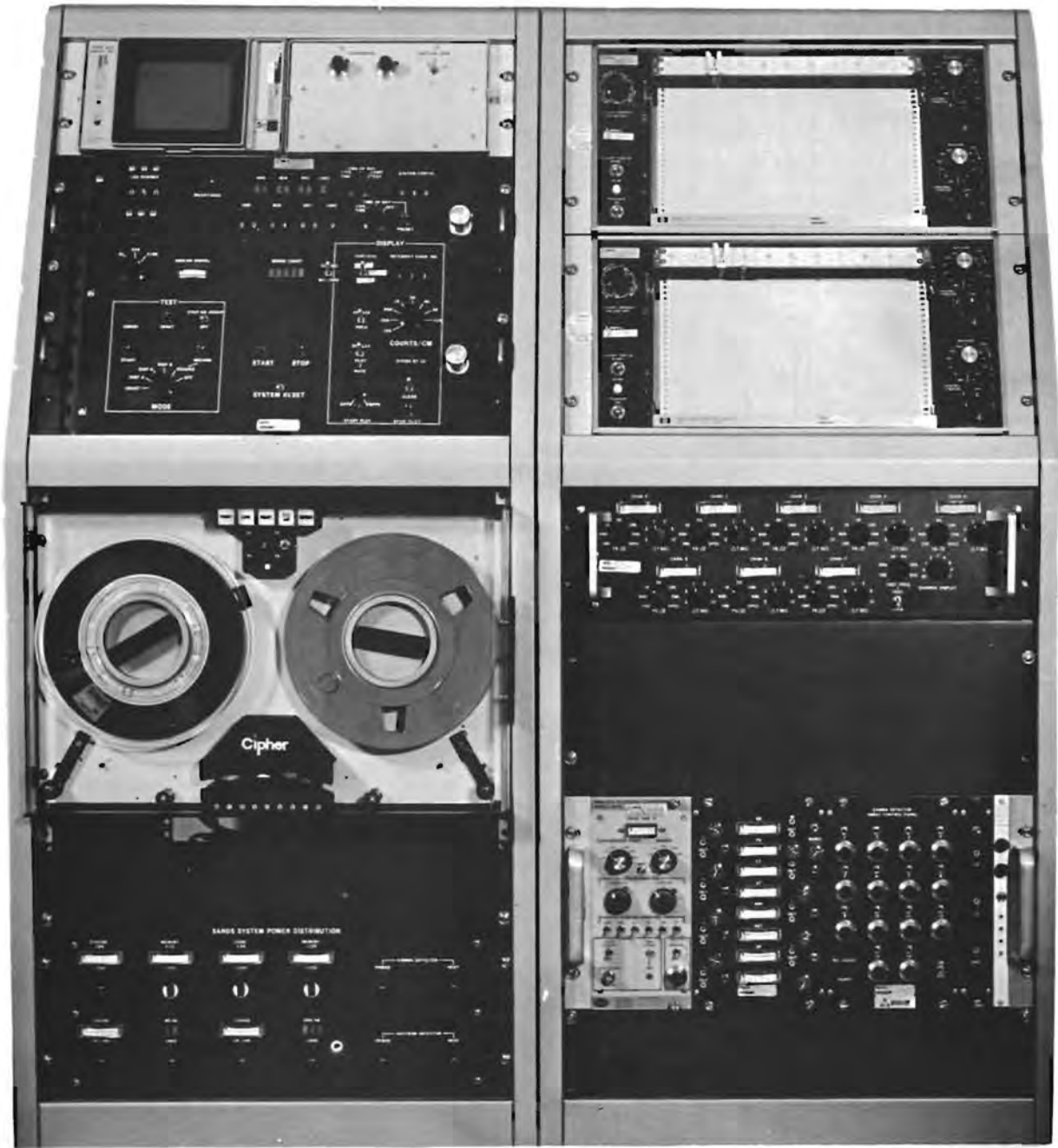


Fig. 18. Data recording system.



High-Altitude Mosaic – The entire Atoll was photographed with the Multi-spectral Camera System from an altitude of 3000 m over a period of several days for the purpose of making a mosaic. A single frame of the high-altitude coverage is shown in Fig. 15. From this altitude the relationship of the islands to one another, as well as the entire reef structure, can be clearly seen. A portion of the assembled mosaic extending from JANET to WILMA is shown in Fig. 16.

## Nuclear Instrumentation Systems and Methods

### Descriptions of Instrument Systems

Detectors – Gamma rays were detected in two arrays of twenty 12.7-cm diam  $\times$  5-cm thick NaI crystal spectrometers. Figure 17 shows one of these arrays. The output from the crystal photomultiplier-preamplifier combinations was summed and fed to the recording system.

Inertial Navigation System – Accurate position data are obtained from a Litton Inertial Navigation System, LTN-51. The actual flight coordinates (latitude and longitude) are recorded on magnetic tape. Special software, prepared by Litton to our specifications, allows these data to be recorded with a minimum detectable distance increment of 15 ft.

When these data are processed, the flight paths are overlaid on a photographic map of the survey area. The end points are matched with the known positions of the start and finish of each line. The position of the aircraft is then known at any point along the flight path with an

uncertainty related to the flying time of  $\pm 1/2$  sec. For a typical survey, conducted at an altitude of 100 ft above terrain and at a speed of 30 m/sec, this implies that the location of the aircraft is known with an uncertainty of  $\pm 15$  m.

Recording System – Summed signals from the separate detectors were split and fed to (1) a 300-channel pulse-height analyzer and (2) a maximum of eight single-channel analyzers with adjustable upper and lower limits. These limits are set to monitor regions of the spectrum pertinent to isotopes of interest. Accumulation time for single-channel data was a minimum of 0.2 sec, while accumulation time for multichannel data was a minimum of 3 sec. Inertial-navigation position data and multi- and single-channel counts occurring in the above time intervals were recorded on magnetic tape. The recording system is shown in Fig. 18.

Data-Processing System – Magnetic tape was processed by a ground-based system, key components of which were two cipher data tape drives, a NOVA computer, and a Cal Comp plotter.

Helicopter – The NaI spectrometer pods and the data-recording system were carried inside a Marine CH53 helicopter. This arrangement resulted in the radiological measurements being made with the terrestrial gamma radiation traveling through the floor of the helicopter to reach the gamma spectrometers. This attenuation effect was taken into account by performing calibrations in a similar geometry. This is discussed in the subsection on Isotopic Concentration.

## Operational Procedures

Survey Measurements – Due to the large difference in photopeak energies and resolution of the recording system, a separate survey was made for plutonium while data for  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  concentrations were accumulated simultaneously. Plutonium was sensed via the 60-keV  $\gamma$  ray from  $^{241}\text{Am}$ , a decay product of  $^{241}\text{Pu}$ . Electronic gain was adjusted for those surveys so that the full-energy scale corresponded to a  $\gamma$ -ray energy of 300 keV. Typical spectra with and without  $^{241}\text{Am}$  are shown in Fig. 19. Shaded areas in this figure define three single channels, the outer two of which were set to monitor changes in background levels. The central window monitors the 60-keV photopeak.

Electronic gain was set to cover a full scale of 3 MeV for the  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  surveys. A typical spectrum is shown in Fig. 20. Shaded areas in this figure again define the single channels set up to monitor background and photopeak regions of the spectra. Gross counts (those between 50 keV and 3 MeV) were also recorded during the high-energy surveys.

A grid of lines spaced 150 ft apart was flown over each island at an altitude of 100 ft and an airspeed of  $\sim 70$  knots. Flight lines were laid out on aerial photographs taken for navigation purposes. An on-top marker was recorded on the magnetic tape when a landmark near the shore was crossed at the start and finish of the flight line. Some individual detectors in the array were turned off, and flight lines were reflown when count rates were high enough to produce spectral distortion due to pulse pileup.

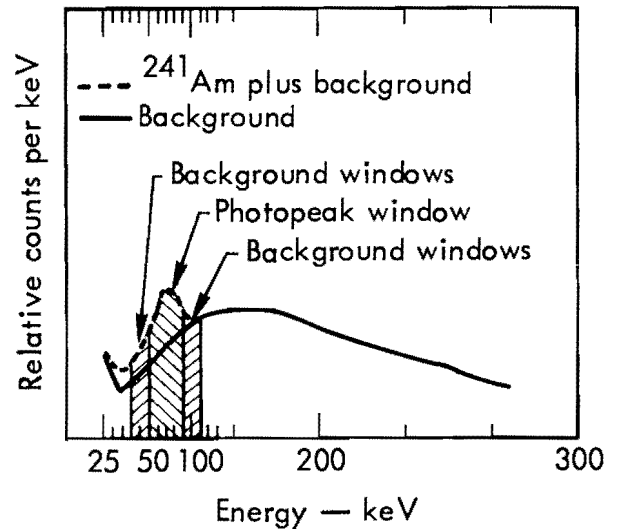


Fig. 19. Gamma spectra with and without the  $^{241}\text{Am}$  contribution.

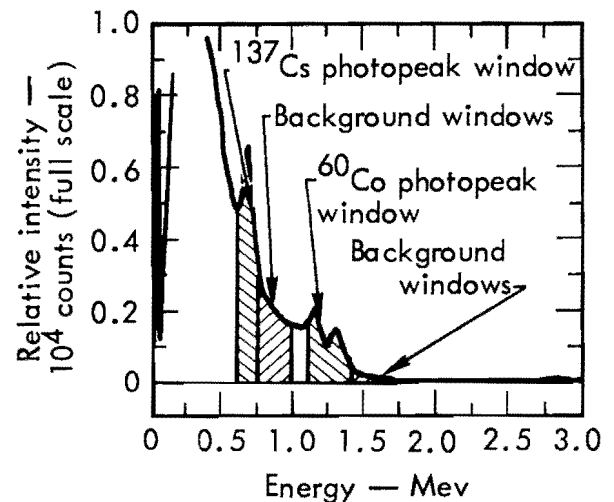


Fig. 20. High-energy gamma spectrum showing contributions from  $^{60}\text{Co}$  and  $^{137}\text{Cs}$ .

Data Processing – The data-processing system converts magnetic tape records to scalar field plots of aircraft position vs count-rate data. Symbols denoting the on-top markers are also printed on the plot. Lines are contracted and expanded in length so that the on-top markers coincide with the photographic landmarks used to annotate the tape.

Contours are drawn after all flight lines have been properly positioned on the photograph of the island.

Computer software has been developed to plot weighted sums of any combination of single-channel data accumulated during 1-sec time intervals. Multichannel data can be processed to give the same type of information, but with a minimum of 3-sec time intervals.

#### Instrumentation Calibration and Conversion Factors

This section describes the method used to convert aerially measured gamma-ray count rates to exposure rates one meter above the ground and to isotopic concentrations in the ground. Count rates in windows previously defined are used to derive isotopic concentrations. The isotopic concentrations can be converted to exposure rates one meter above the ground using previously derived data.\*

General Expressions for Isotopic Concentration—Count rates in pulse-height windows centered on gamma-ray photopeaks of interest are composed of unscattered  $\gamma$  rays from the isotope of interest and background counts from (1) cosmic rays and natural activity in the aircraft and Atoll material and (2) possible contribution from higher-energy contaminants. Background is compensated when the data are processed by subtracting weighted combinations of count rates in appropriate windows. The

\*H. L. Beck, J. DeCampo, and C. Gogolak, In Situ Ge(Li) and NaI(Tl) Gamma-Ray Spectroscopy, HASL, 258, p. 49, 1972.

assumption that only unscattered  $\gamma$  rays remain in the photopeak window after the background is subtracted allows simple expressions to be derived to relate aerial count rates to various source geometries. Good definition of the photopeaks lends credence to this approach.

Conversion factors are developed in the following paragraphs. Detector efficiency is defined in terms of an effective detector area at normal incidence. This area is calculated from gamma-ray count rates measured in helicopter hovers over point radioactive sources of known strength. The change in effective detector area with angle of incidence must be considered for sources distributed over the Atoll. Appropriate or limiting values for angular responses will be assumed according to  $\gamma$ -ray energy. Conversion factors result from eliminating effective detector area between expressions derived for count rates over a point calibration source and the distributed source of interest.

Detector efficiency (effective area) is determined by signal minus background count rates when hovering over  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ , and  $^{241}\text{Am}$  calibration sources of known strength. The photopeak window count rates,  $\text{CR}_P$ , when hovering directly over a calibration source can be written in terms of an effective detector area:

$$\text{CR}_P = \frac{sA}{4\pi d^2} \exp \left[ -\left( \frac{d}{\lambda_a} + \frac{t}{\lambda_s} \right) \right], \quad (1)$$

where

d = distance between point source and the detector,

t = thickness of aircraft skin and floor,

s = source strength,

$\lambda_a$  =  $\gamma$ -ray mean free path in air,

$\lambda_s$  =  $\gamma$ -ray mean free path through aircraft structure,

and

A = effective detector area at normal incidence to the crystal face.

The derivation of the effective detector area includes consideration of the effect of photopeak window efficiency, and the possibility of subtraction of photopeak counts appearing in radiation background windows.

Equation (1) can be combined with an assumed detector angular response to derive expressions for the diameter of the circle that contains ground concentrations that are spatially close enough to the aircraft to contribute to the aerially measured count rates. The count rate when hovering to the side of a point source is:

$$CR'_P = \frac{SA f(\theta)}{4\pi(\ell^2 + d^2)} \exp \left[ - \left( \frac{\sqrt{\ell^2 + d^2}}{\lambda_a} + \frac{t}{\lambda_s} \right) \right], \quad (2)$$

where

$\ell$  = lateral distance between source and detector,

and

$f(\theta)$  = detector angular response.

The diameter of the circle of influence is defined as twice the lateral distance between the source and detector when the signal is equal to half the value measured when the detector is directly over the source. The following equation defines

the diameter,  $\Delta x$ , of the circle of influence:

$$\frac{1}{2} = \left[ \frac{d^2}{\left(\frac{\Delta x}{2}\right)^2 + d^2} \right] \left[ \frac{f(\theta)}{f(0)} \right] \exp \left\{ \left[ \frac{1}{\lambda_a} + \frac{t}{d\lambda_s} \right] \left[ \sqrt{\left(\frac{\Delta x}{2}\right)^2 + d^2} - d \right] \right\}. \quad (3)$$

For a detector with isotropic angular response, this equation becomes:

$$\frac{1}{2} = \left[ \frac{d^2}{\left(\frac{\Delta x}{2}\right)^2 + d^2} \right] \exp \left\{ \left[ \frac{1}{\lambda_a} + \frac{t}{d\lambda_s} \right] \left[ \sqrt{\left(\frac{\Delta x}{2}\right)^2 + d^2} - d \right] \right\}. \quad (4)$$

For a detector with a cosine angular response, this equation becomes:

$$\frac{1}{2} = \left[ \frac{d^2}{\left(\frac{\Delta x}{2}\right)^2 + d^2} \right]^{3/2} \exp \left\{ \left[ \frac{1}{\lambda_a} + \frac{t}{d\lambda_s} \right] \left[ \sqrt{\left(\frac{\Delta x}{2}\right)^2 + d^2} - d \right] \right\}. \quad (5)$$

The diameters calculated from these equations apply to a stationary detector. A moving detector, accumulating data over discrete time intervals, will not be described by a circle of influence, but rather by a figure resembling an ellipse

with the major axis along the direction of motion. The increase in length along this direction is equal to the product of data accumulation time and helicopter speed. This product is  $\sim 100$  ft for all but the  $^{241}\text{Am}$  data.

The form of the expression for count rate at altitude from a distributed source depends upon the vertical distribution of the source in the soil and the angular response of the detector. Due to incomplete knowledge of the form of the source distribution, an exponential decrease with depth will be assumed. It will be shown that factors for converting aerially measured count rates to one-meter-level exposure rates are insensitive to relaxation depth and, therefore, to form of distribution.

Due to the geometrical configuration of the NaI crystals and the detector array, the highest efficiency occurs for photons incident at  $0^\circ$  with respect to the normal to the crystal face. The hypothetical conditions, then, of isotropic angular response and cosine angular response (zero efficiency at  $90^\circ$  incidence) bracket the true angular response.

The differential count rate from a concentration at depth  $z$  uniformly distributed over a volume  $2\pi r dr dz$  of atoll material is given by:

$$dCR = \left[ \frac{\alpha \eta e^{-\alpha z} A}{4\pi(h^2 + r^2)} \right] \exp \left[ -\frac{\sqrt{h^2 + r^2}}{h} \left( \frac{h}{\lambda_a} + \frac{t}{\lambda_s} + \frac{z}{\lambda_m} \right) \right] \times 2\pi r dr dz, \quad (6)$$

where

$\alpha$  = reciprocal relaxation depth of contributing radionuclide,

$\eta$  = total surface concentration or integral of volume concentration to  $\infty$  depth,

$h$  = height above ground,

and

$\lambda_m$  =  $\gamma$ -ray mean free path in the Atoll material.

The above expression can be integrated over the  $\infty$  half space defining the ground to give:

$$CR = \frac{\eta A \alpha}{2} \int_0^\infty E_1 \left( \frac{h}{\lambda_a} + \frac{t}{\lambda_s} + \frac{z}{\lambda_m} \right) e^{-\alpha z} dz, \quad (7)$$

where  $E_1$  is an exponential integral of the first kind. The following equation results from eliminating  $A$  between Eqs. (1) and (7).

$$\eta = \left[ \frac{S \exp \left[ -\left( \frac{d}{\lambda_a} + \frac{t}{\lambda_s} \right) \right]}{2\pi d^2 \alpha \int_0^\infty e^{-\alpha z} E_1 \left( \frac{h}{\lambda_a} + \frac{t}{\lambda_s} + \frac{z}{\lambda_m} \right) dz CR_P} \right] CR. \quad (8)$$

The conversion factor in brackets contains known geometrical parameters, calibration source strengths, and measured count rates.

The expression corresponding to Eq. (6) for a cosine angular response includes an additional factor equal to  $h/\sqrt{h^2 + r^2}$ . The integral of this expression is:

$$CR = \frac{\eta A}{2} \alpha \int_0^\infty e^{-\alpha z} E_2 \left( \frac{h}{\lambda_a} + \frac{t}{\lambda_s} + \frac{z}{\lambda_m} \right) dz. \quad (9)$$

This equation is the same as Eq. (7) with the order of the exponential integral

changed. The conversion factor corresponding to Eq. (8) is, therefore:

$$\eta = \left\{ \frac{S \exp \left[ - \left( \frac{d}{\lambda_a} + \frac{t}{\lambda_s} \right) \right]}{2\pi d^2 \alpha \int_0^\infty e^{-\alpha z} E_2 \left( \frac{h}{\lambda_a} + \frac{t}{\lambda_s} + \frac{z}{\lambda_m} \right) dz CR_P} \right\} CR. \quad (10)$$

### Plutonium Concentrations

Plutonium is sensed via the 60-keV  $\gamma$  ray from  $^{241}\text{Am}$ , which is a decay product of  $^{241}\text{Pu}$ . The pulse-height spectrum from  $\gamma$  rays with energy greater than  $\sim 100$  keV is linear in the energy range between 40 and 80 keV. Therefore, the background count rate in the 20-keV-wide signal window (50-70 keV) is assumed to be equal to the sum of two count rates from 10-keV-wide windows contiguous to both sides of the signal window.

Window count rates can be taken from multichannel data or from single-channel data. Multichannel data have been used, due to electronic problems and the presence of excessive count rates in the single-

channel windows as set up for the plutonium survey. Spatial resolution along the direction of flight is degraded by use of the multichannel data, which have a 3-sec data accumulation time. Part of the expected 300-ft degradation is removed by the manner in which the data are processed. The diameter of the circle of influence is 135 ft, as calculated from Eq. (5).

Due to the presence of the cadmium shielding on the sides of the crystals, the count rate for low-energy photons is proportional to the cosine of the angle of incidence with respect to the normal to the crystal faces. The appropriate conversion factor is therefore given by Eq. (10). The conversion factor as calculated from this equation with an assumed relaxation depth of 10 cm is shown in Table 7.

### Cobalt-60 Concentrations

Background counts in the  $^{60}\text{Co}$  photopeak window (1,095 to 1,395 MeV) are assumed to be proportional to aircraft

Table 7. Photopeak window conversion factors.

Radio-nuclide	Relaxation depth in Atoll material, cm	Conversion factor			Exposure rate at 1 m as calculated from previous column, $\frac{\mu\text{R sec}}{\text{hr cnt}}$
		Isotropic angular response of detector array	Cosine angular response of detector array	Average of previous two columns	
$^{241}\text{Am}$	10		$66 \times 10^{-4}$		
$^{137}\text{Cs}$	1	$8.5 \times 10^{-4}$	$15.2 \times 10^{-4}$	$11.8 \times 10^{-4}$	$74 \times 10^{-4}$
	Average <sup>a</sup> 10	$23.2 \times 10^{-4}$	$36.6 \times 10^{-4}$	$30.0 \times 10^{-4}$	$72 \times 10^{-4}$ $70 \times 10^{-4}$
$^{60}\text{Co}$	1	$4.6 \times 10^{-4}$	$7.2 \times 10^{-4}$	$5.9 \times 10^{-4}$	$155 \times 10^{-4}$
	Average <sup>a</sup> 10	$11.2 \times 10^{-4}$	$19.4 \times 10^{-4}$	$15.3 \times 10^{-4}$	$152 \times 10^{-4}$ $150 \times 10^{-4}$

<sup>a</sup>Average value for two relaxation depths.



background, cosmic rays, and contributions from natural background emitters, all in the energy interval between 1.395 and 3.00 MeV. The ratio is determined by flights at 100 ft over water, which should contain negligible amounts of  $^{60}\text{Co}$ . Data are processed to continuously subtract this background from the photopeak window count rate.

Table 7 compares the factors [(calculated from Eqs. (8) and (10)] for converting the resulting count rate to ground concentration for two relaxation depths. The conversion factor shown in the fifth column is the average of values from the two previous columns. This average represents the best value presently available. Experiments with  $^{137}\text{Cs}$  sources have shown the average to be accurate to within a few percent.

The diameter of the circle of influence lies between 145 and 180 ft, as calculated from Eqs. (4) and (5).

#### Cesium-137 Concentrations

The background count rate in the  $^{137}\text{Cs}$  photopeak window (0.6 to 0.75 MeV) is assumed to be composed of two parts. One of these is proportional to aircraft background, cosmic rays, and contributions from natural background emitters in the energy interval between 1.395 and 3 MeV. The second background component, which is proportional to the  $^{60}\text{Co}$  contribution to the  $^{137}\text{Cs}$  window, was determined from spectral shape when  $^{60}\text{Co}$  was present with negligible amounts of  $^{137}\text{Cs}$ . Backgrounds of both types were subtracted during data processing by summing appropriately weighted single-channel count rates. Table 7 compares the factors [(calculated from Eqs. (8) and (10)] for

converting the resulting count rate to ground concentration for two relaxation depths. Other experiments have shown that the true detector angular response is such that the average conversion factors in the fifth column are accurate to within a few percent.

The diameter of the circle of influence lies between 145 and 180 ft, as calculated from Eqs. (4) and (5).

Exposure Rates – Factors for converting  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  photopeak count rates to 1-meter-level dose rates have been calculated by combining data in the fifth column of Table 7 with data from H. L. Beck *et al.* The result of this combination is given in the last column of the same table. The average value between extremes in angular response is used because experiments show that this average is good to a few percent, at least for  $^{137}\text{Cs}$  sources. The same averaging process is used for  $^{60}\text{Co}$  sources, although similar measurements have not been made.

Note that the factor for converting aerially measured count rates to dose rate is insensitive to large variations in relaxation depth. In most cases the two assumed relaxation depths bracket those measured in soil-sample analyses.

#### Comparison with Ground Data

Aerial data were processed to give 20% increments between contour levels for the islands of JANET, ALICE, BELLE, and DAISY. The sum of Co and Cs contributions to dose rates (using the conversion factors listed in the last column of Table 7) is compared with LiF thermoluminescent dosimetry (TLD) measurements at 37 locations in the chapter on

external dose estimates. Dose rates averaged over these locations were 11% lower for the aerial measurements than for the standard TLD measurements. Two special TLD badges, shielded against  $\beta$  rays, gave a 10% lower exposure rate than the standard unshielded badges at the same location. The aerial measurements do not sense  $\beta$  rays because of the mass of air and structure between the source and NaI. Therefore, the aerial measurements for  $\gamma$  rays only are in excellent agreement with the  $\gamma$ -ray contribution to the TLD measurements. The aerial data have not been normalized to the unshielded TLD data.

It should be mentioned that the excellent agreement between the aerial data and the TLD data is well within the uncertainties in the aerial measurements. In particular, an error of a few feet in the 50-ft hover altitude over the calibration sources would introduce a 10% error in the conversion factor. Oscillations about the point directly over the source effectively increase the average slant range. Use of an excessively small slant range falsely increases quoted concentrations.

The total mass of aircraft structure between the detectors and sources was not known. In particular, the mass of reinforcing material between the two outside plates of the aircraft floor was not known and was excluded in the attenuation calculations. The presence of additional mass lowers the distributed source count rate relative to the count rate from the point calibration source. Neglect of this additional mass has the effect of falsely decreasing quoted concentrations. The two types of errors described above occur in opposite directions and are expected to be partially self-compensating.

## Explanation of Contour Maps

### $^{60}\text{Co}$ and $^{137}\text{Cs}$ Separately –

Contour maps were generated for each island on the basis of photopeak window count rates for  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  separately. All other types of background were subtracted so that the only counts remaining were due to the separate isotopes. Data were processed so that letter symbols denoted a range of values for count rates in the photopeak windows. The fifth and seventh columns in Table 8 relate the contour letter symbols (corresponding to window count rates) to the dose rates delivered by each isotope. This relationship is established from values in the last column of Table 7. Table 8 also relates letter symbols to soil concentration averaged over the two extremes assumed for relaxation depths. The two extremes and the average conversion factor are given in the fifth column of Table 7.  $^{60}\text{Co}$  contours are superimposed on gray prints of the islands (the "m" series of figures in Appendix II);  $^{137}\text{Cs}$  contours are superimposed on green prints of the islands (the "k" series of figures in Appendix II).

These contours were used to tabulate an estimated average dose rate over each island. Results are shown in Table 9.

Average Dose Rates From Gross Counts – Contours superimposed on greenish-gold prints (the "b" series of figures in Appendix II) were constructed from counts in the energy interval between 50 keV and 3 MeV. An average conversion factor must be established to relate these counts to concentration, since this energy interval senses both  $^{60}\text{Co}$  and  $^{137}\text{Cs}$ . This average conversion factor is assumed

Table 8. Contour map key for use with figures in Appendix II.

Sym- bol	<sup>241</sup> Am concentration (assumed 10-cm relaxation depth)		<sup>137</sup> Cs		<sup>60</sup> Co		Gross count exposure rate, μR/hr
	Total μCi/m <sup>2</sup>	pCi/g averaged over top 10 cm	Concentration, μCi/m <sup>2</sup> ± 50% for 1 cm < re- laxation depth < 10 cm	Exposure rate, μR/hr	Concentration, μCi/m <sup>2</sup> ± 50% for 1 cm < re- laxation depth < 10 cm	Exposure rate, μR/hr	
A <sup>-</sup>			0-0.1	0-0.34			
A <sup>-</sup>			0.1-0.2	0.34-0.68	0-0.04	0-0.59	
A	21-30	9-13	0.2-0.4	0.68-1.36	0.04-0.08	0.59-1.14	0-1.0
B	30-45	13-19	0.4-0.6	1.36-2.0	0.08-0.12	1.14-1.7	1.0-1.5
C	45-66	19-28	0.6-0.8	2.0-2.7	0.12-0.16	1.70-2.3	1.5-2.0
D	66-100	28-42	0.8-1.6	2.7-5.4	0.16-0.32	2.3-4.6	2.0-4
E	100-145	42-61	1.6-3.1	5.4-11	0.32-0.64	4.6-9.2	4-8
F	145-210	61-89	3.1-6.2	11-22	0.64-1.3	9.2-18	8-16
G	210-300	89-130	6.2-12	22-44	1.3-2.5	18-36	16-33
H	300-450	130-190	12-25	44-88	2.5-5.0	36-72	33-66
I			25-50	88-170	5-10	72-140	66-130
J			50-100	170-340	10-20	140-290	130-260
K			100-200	340-700	20-40	290-580	260-520
L			200-400	700-1400	40-80	580-1200	520-1050

to be half the sum of the separate conversion factors for <sup>137</sup>Cs and <sup>60</sup>Co. The two separate factors are calculated by multiplying photopeak conversion factors in the sixth column of Table 7 by the ratio of photopeak counts to gross counts in spectra taken at 100 ft over islands that contain predominantly one or the other isotope. Uncertainty as to whether the contaminant is <sup>60</sup>Co or <sup>137</sup>Cs introduces errors of ±10% in the exposure rates derived from gross counts.

The seventh column of Table 8 relates the contour letter symbols to exposure rates for these figures.

Count rates produced by aircraft background and cosmic rays have not been subtracted before application of the conversion factor. The contours, therefore, assume that the conversion factor multiplied by gross count rates over uncontaminated Atoll material equals the dose rate

at the 3-ft level at the same location. The primary contributor in these areas, cosmic rays, are estimated to produce ~3 μR/hr at the 3 ft level. The product of gross counts and conversion factor is 0.9 μR/hr. Therefore, the fractional error is small for dose rates greater than 20 μR/hr and consistent with errors inherent in the average conversion factor concept.

<sup>241</sup>Am Concentration – The island of YVONNE has been contoured for <sup>241</sup>Am concentration. Data were processed so that contour letter symbols denoted a range of counts remaining in the photopeak window after the two contiguous background windows had been subtracted. This letter symbol and range of count rates was related to concentration according to Eq. (10). A 10-cm relaxation depth

Table 114. Summary of average exposure rates for islands in Enewetak Atoll.

Island	Average exposure rate, $\mu\text{R/hr}$ at 1 m <sup>a</sup>			Range <sup>b</sup>
	<sup>137</sup> Cs	<sup>60</sup> Co	Total $\gamma$ (0-3 MeV)	
ALICE	42	36	81	4-170
BELLE	61	50	115	5-200
CLARA	20	19	42	5-100
DAISY	6.8	14.4	21.3	5-140
EDNA	2.8	2.4	6	5-8
IRENE	14	63	80	3-560
JANET	25	13	40	2-150
KATE	11	7	19	3-22
LUCY	6	7	14	1-20
PERCY	2	2	5	2-11
MARY	5.5	4	10	2-12
NANCY	6	5	12	1-50
OLIVE	6.5	4.5	11	1-15
PEARL	12	45	70	1-400
RUBY	2	12	14	1-42
SALLY	3.5	3	7	3-110
TILDA	4	2	6	2-11
URSULA	3	1.8	5	1-7
VERA	2.8	2	5	1-6
WILMA	1	1	2	1-3
YVONNE	5.6	22.4	33	1-750
SAM	<0.3 (0.20)	<0.6 (0.11)	10.9	0-1
TOM	<0.3 (0.18)	<0.6 (0.13)	<0.9	0-1
URIAH	<0.3 (0.06)	<0.6 (0.43)	<0.9	0-1
VAN	<0.3 (0.08)	<0.6 (0.25)	<0.9	0-1
ALVIN	N. D. (0.06)	<0.6 (0.25)	<0.9	0-1
BRUCE	0.4 (0.22)	0.8 (0.34)	1.2	0-1
CLYDE	<0.3 (0.04)	<0.6 (0.11)	<0.9	0-1
DAVID	N. D. (0.21)	N. D. (0.10)	<0.9	0-5
REX	<0.3 (0.28)	<0.6 (0.25)	<0.9	0-1
ELMER	N. D. (0.19)	N. D. (0.12)	<0.09	0-2
WALT	<0.3 (0.08)	<0.6 (0.10)	<0.9	0-1
FRED	N. D. (0.14)	N. D. (0.12)	<0.9	0-1
GLENN	0.4 (0.33)	<0.6 (0.20)	<0.9	0-1
HENRY	<0.3 (0.14)	<0.6 (0.20)	<0.9	0-1
IRWIN	<0.3 (0.08)	<0.6 (0.46)	<0.9	0-1
JAMES	<0.3 (0.05)	2.8	3.0	0-5
KEITH	<0.3 (0.15)	<0.6 (0.49)	<0.9	0-2
LEROY	2.8	4.8	7.6	3-8

<sup>a</sup>Average dose rates given are derived from aerial survey data. On islands where activity levels are at the lower limit of sensitivity of the aerial survey equipment, dose rates derived from the soil sample data are given in parentheses.

<sup>b</sup>As measured with the Baird-Atomic instrument.

was assumed as an average of those measured in soil sample analyses. The resulting conversion factor is given in the fourth column of Table 7. The second column of Table 8 relates contour symbols to  $^{241}\text{Am}$  concentrations as calculated with this conversion factor. The third column of Table 8 lists the corresponding volume concentrations averaged over the top 10 cm.

Concentrations above our minimum detectable level in  $^{241}\text{Am}$  were not present in sufficient quantity to justify plotting exposure rate or material concentration distributions for other islands. The minimum detectable level is controlled by statistical variations in the background count rate from cosmic rays,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$ . The minimum detectable level, thus, changes from island to island and from point to point within a particular island. Soil samples may show concentrations that are not detectable from the air due to high background count rates or to the presence of dense vegetation, which severely attenuates the 60-keV  $\gamma$  rays from  $^{241}\text{Am}$ .

#### TERRESTRIAL SOIL SURVEY

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#### Soil Survey Plan

The Enewetak soil survey, described in this section, had as its objective a thorough evaluation of the present radiological conditions of all islands of the Atoll. Planning of the soil survey was based

upon extensive investigations of the historical aspects of the weapons-testing program, the most recent information gathered during previous radiological surveys of Bikini Atoll, and preliminary surveys of Enewetak Atoll in July 1971 and May 1972.

Laboratories which conducted the experiments provided reports containing data on the original nuclear devices. Actual test information, fallout patterns, radiological safety reports, etc., came from AEC sources. Construction drawings and information on modifications to the topography were made available by the testing support contractor, Holmes and Narver, Inc. (H&N). Other organizations, including those which conducted environmental studies during and after the testing program, supplied their findings. In addition, a wealth of information was available in old reports, records, documents, etc., stored in archives.

Examination of reports from the Lawrence Livermore Laboratory (LLL) and Los Alamos Scientific Laboratory (LASL) enabled us to identify radionuclides most likely to be present, based upon the composition of the nuclear devices and associated experiments. These radionuclides are listed on Table 10. The quantities of "environmental" materials such as structural steel, concrete, wiring, pipe, etc., were also determined for purposes of estimating the types of contaminated debris that should have remained after a shot.

The Test Manager's operations reports contained fallout patterns for nearly every event. From these reports, in a crude effort to estimate residual conditions, the Atoll's islands were graded as

Table 10. Radionuclides expected in Enewetak Atoll soil.

Radio-nuclide	Source	Radio-nuclide	Source
$^{241}\text{Am}$	Unburned weapon fuel	$^{147}\text{Pm}$	Fission product
$^{240}\text{Pu}$	Unburned weapon fuel	$^{137}\text{Cs}$	Fission product
$^{239}\text{Pu}$	Unburned weapon fuel	$^{125}\text{Sb}$	Fission product
$^{238}\text{Pu}$	Unburned weapon fuel	$^{102}\text{Rh}$	Activation product
$^{238}\text{U}$	Unburned weapon fuel	$^{90}\text{Sr}$	Fission product
$^{235}\text{U}$	Unburned weapon fuel	$^{63}\text{Ni}$	Activation product
$^{207}\text{Bi}$	Activation product	$^{60}\text{Co}$	Activation product
$^{155}\text{Eu}$	Fission product	$^{55}\text{Fe}$	Activation product
$^{154}\text{Eu}$	Fission product	$^{14}\text{C}$	Activation product
$^{152}\text{Eu}$	Activation product	$^3\text{H}$	Activation product and fuel
$^{151}\text{Sm}$	Fission product		

a function of the reported fallout contamination corrected to H + 1 hr past detonation. The resulting gradation is shown in Table 11.

Radiological safety reports written during and after the test operations indicated several acute radiological problems which were subsequently corrected, such as serious alpha contamination, radioactive debris, etc. Unfortunately, these reports failed to provide sufficient detail to determine, in all cases, the eventual fate of the radioactivity itself—whether it was disposed of in land, lagoon, or sea, for instance, and how thoroughly.

Interviews with test personnel produced additional information, although somewhat contradictory at times. However, these interviews did confirm that burial and relocation of high-level radioactive contaminated debris was attempted frequently in many places. Verification of these burial activities by documentation has been very difficult and only partially successful. This information,

however, indicates that radioactive debris probably is buried only on islands that had surface ground zeros. A list, shown in Table 12, has been made of suspected or known burial sites, the locations of which are shown in Figs. 21-24.

Two preliminary radiological surveys, conducted in July 1971 and May 1972, confirmed suspected conditions on most of the islands and provided approximate but valuable estimates of the range of radioactivity levels to be expected.

The July 1971 survey was severely limited in time and scope. Even though visits were only made to six islands—IRENE, JANET, SALLY, TILDA, URSULA, and YVONNE—the following information was obtained:

- Many of the islands were still radioactively contaminated.
- Much of the Atoll was heavily re-vegetated and difficult to traverse.
- There were no obvious indicators (signs, posts, fences, etc.) of buried radioactivity in clear sight.

Table 11. Ranking of islands in Enewetak Atoll according to fallout contamination at H + 1 hr.

Island code name	Local name	Total R/hr	Total events <sup>a</sup>	Total SGZ
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 <sup>b</sup>	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	Bijiri	774	17	0
URSULA	Rojoa	651	12	0
CORAL HEAD (MACK)	—	452	10	0
WILMA	Piiraai	294	13	0
VERA	Aaraanbiru	270	11	0
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	Enewetak	2.6	4	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
CLYDE	Chinimi	0	1	0
REX	Jieroru	0	1	0

<sup>a</sup>This includes the events that produced contamination by fallout or surface ground zero location.

<sup>b</sup>Presently part of IRENE.

Table 12. Suspected or known burial sites for radioactive debris.

Island	Contamination	Quantity	Location	Confidence	Source <sup>a</sup>
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 <sup>b</sup>	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
	Contaminated debris	Unknown	West of CACTUS crater	Suspected	6
	Contaminated debris	Unknown	ERIE SGZ	Positive, high	7
	Contaminated soil	Unknown	North of HARDTACK Sta. 1310	Positive, high	8

<sup>a</sup>Sources

1. Interview.
2. 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. 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.

<sup>b</sup>That portion remaining attached to SALLY by a causeway.

- There was significant contaminated radioactive debris on YVONNE (Runit Island) at the CACTUS crater lip and also a plutonium-contaminated soil outcropping on the oceanside beach, mid-island
- There appeared to be a definite pattern to the exposure rates encountered, with the higher rates observed on the northern half of the Atoll.

As a result of this survey, the AEC's 1972 Bikini radiological survey was extended to cover Enewetak Atoll in a very

limited reconnaissance effort during May of that year. Of the 43 islands of the Atoll, 18 were visited in May 1972. These, in addition to three other islands visited in the July 1971 effort, made available recent data regarding soil activity levels and radiation exposure rates on 21 islands, slightly less than half of the total number of islands within the Atoll. The results of this survey also verified the Atoll-wide pattern of contamination suggested by the 1971 survey and the ranking of islands according to fallout levels.



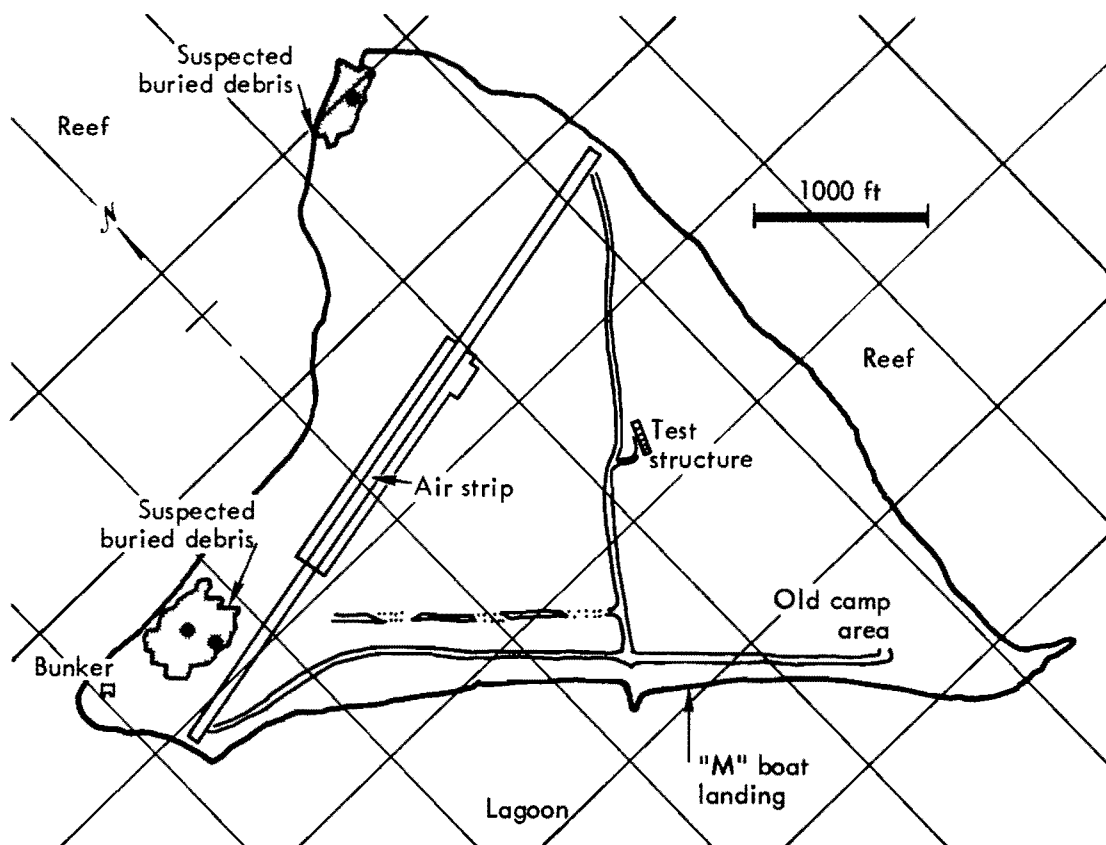


Fig. 21. Suspected or known radioactive material burial sites, JANET.

Since a cleanup effort would require preliminary cost estimates for the disposal of contaminated soil, the sampling plan was designed to provide data that could be used to estimate, at least in a gross manner, the volume of contaminated soil on those islands where it was thought to exist or had a high probability for existence.

The Atoll was stratified into groups of islands, individual islands, or specific areas of islands, according to what was known or suspected about the radiological condition of the area and the type of survey information that was desired. Since  $^{239}\text{Pu}$  is an isotope whose distribution at Enewetak is of particular concern, estimates of its abundance were also used in the stratification process. A summary

of this stratification, and the reasons for each stratification effort are indicated below, by phase, group, island, and fraction of island, as appropriate. Figure 25 shows the location of islands in each classification.

#### Phase I Islands

These islands, all of those on roughly the southern half of the Atoll, from all indications are relatively clean in comparison with the remainder. None of these islands included any surface ground zeros. All, with the exception of LEROY, received little fallout from the nuclear tests. LEROY is included because of its location and the fact that its fallout dosage was small compared to islands on the northern half of the Atoll.

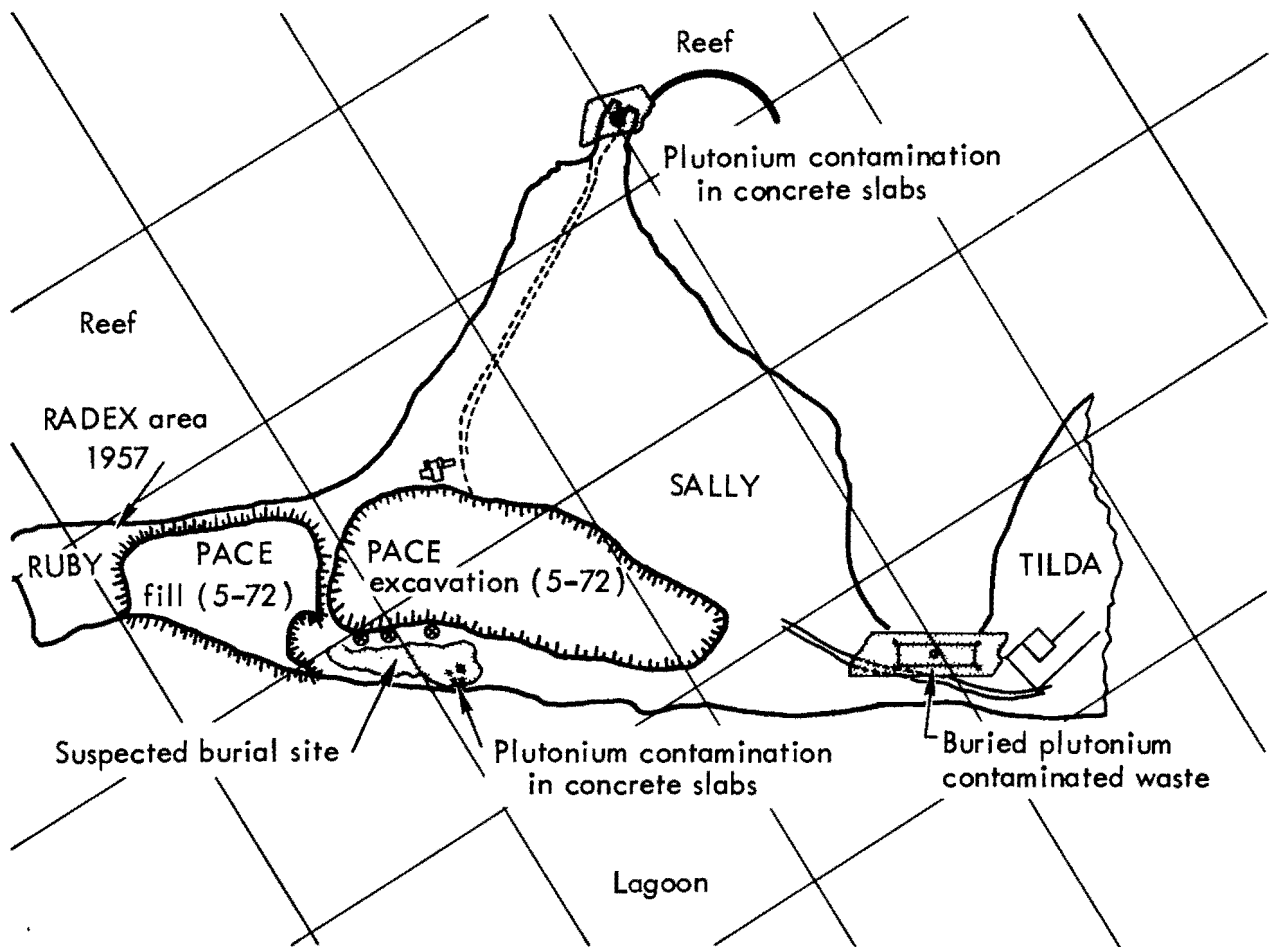


Fig. 22. Suspected or known radioactive material burial sites, SALLY.

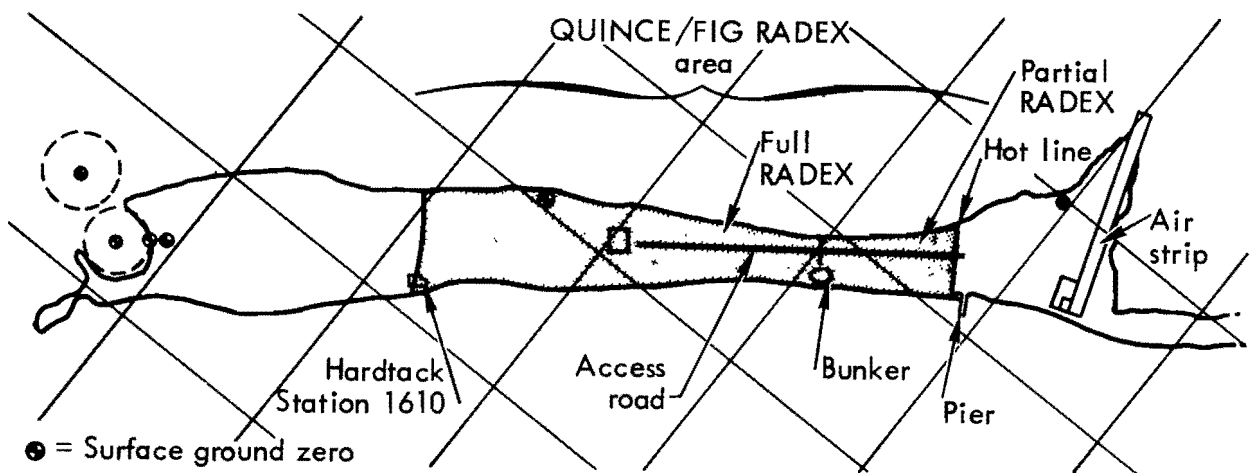


Fig. 23. QUINCE and FIG decontamination operations RADEX area, established 1958, YVONNE.

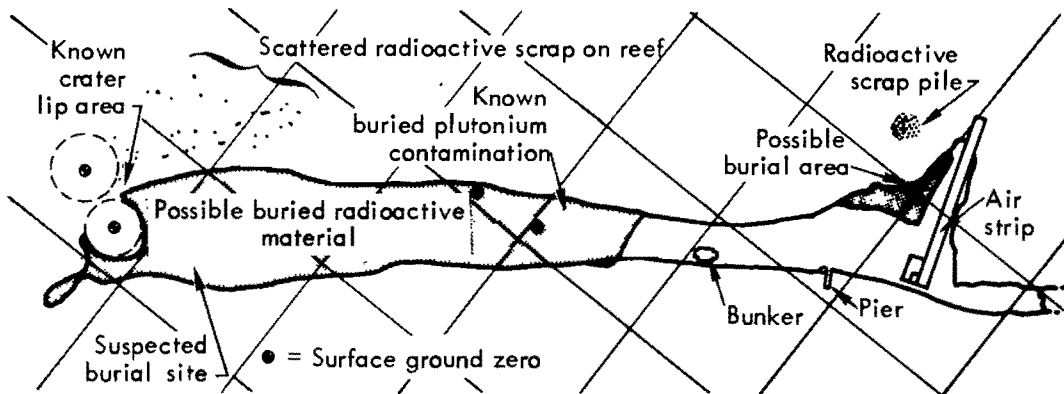


Fig. 24. Suspected or known radioactive material burial sites, YVONNE.

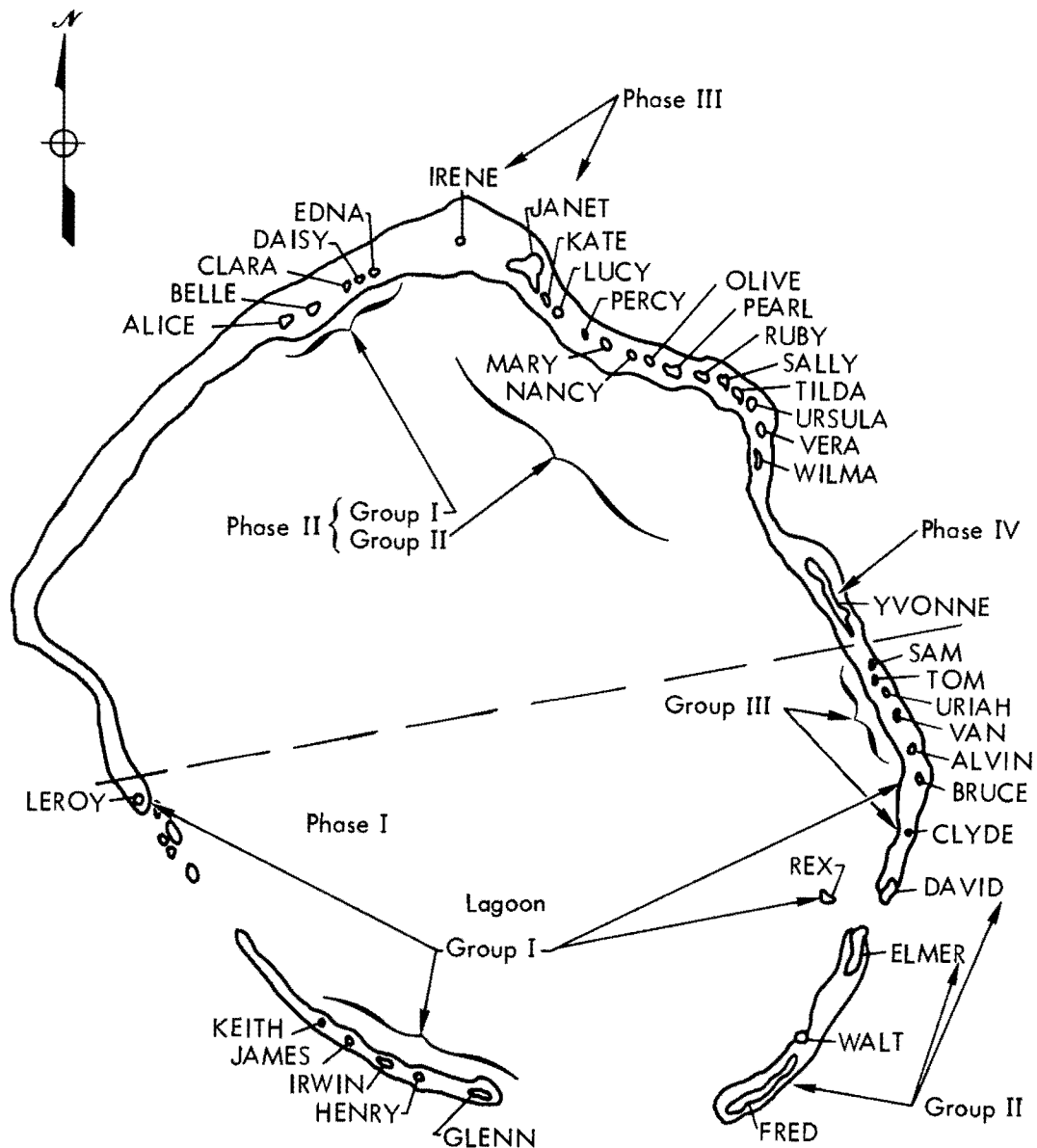


Fig. 25. Stratification of Enewetak Atoll for soil sampling program.

The average contamination of the Phase I islands was about 10 R/hr at H + 1 hr (see Table 11). FRED and ELMER were the sites of the main camps and airfields, and DAVID was used as a rest area.

The islands of Phase I were divided into the following three groups for soil-sampling purposes:

Phase I—Group I

BRUCE (Aniyaanii)	IRWIN (Pokon)
REX (Jieroru)	JAMES (Ribaion)
GLENN (Igurin)	KEITH (Giriinien)
HENRY (Mui)	LEROY (Rigili)

Phase I—Group II

DAVID (Japtan)	FRED (Enewetak)
ELMER (Parry)	

Phase I—Group III

SAM	WALT	ALVIN (Chinicero)
TOM	VAN	CLYDE (Chinimi)
URIAH		

Those in Group I are relatively large islands with fairly heavy vegetation; those in Group II are southern islands which are very likely to be inhabited continuously by the Enewetak people after they return; and those in Group III are sandbars or very small islands with relatively little vegetation or likelihood of heavy use.

Phase II Islands

The Phase II islands were termed to be "lightly contaminated," based upon the historical background, ranking of islands by fallout levels, and previous surveys. The term "lightly contaminated" is, of course, only a relative one. The islands were expected to be significantly more

contaminated than any of the Phase I islands. Using the gamma exposure rates measured on ALICE through EDNA during previous surveys, and the positions of these islands relative to the islands with ground zeros, two groups of islands were developed: Phase II, Group I, those islands which had been visited and for which some radiological information was available, and Phase II, Group II, islands which have not been visited recently (except for limited sampling on TILDA and URSULA), but from all indications were likely to be similar in fallout level and exposure rate to the Phase II, Group I islands. These two Phase II groups consisted of the following islands:

Phase II—Group I  
(visited during previous surveys)

ALICE (Bogallua)	DAISY (Lidilbut)
BELLE (Bogombogo)	EDNA (San- ildefonso)
CLARA (Eybbiyae)	

Phase II—Group II  
(not visited during previous surveys)

KATE (Muzin)	TILDA (Bijjiri) <sup>a</sup>
MARY (Bokonaarappu)	WILMA (Piirai)
PEARL (Rujoru)	PERCY
VERA (Aaraanbiru)	OLIVE (Aitsu)
LUCY (Kirinian)	URSULA (Rojoa) <sup>a</sup>
NANCY (Yeiri)	

<sup>a</sup>Visited July 1971.

Soil samples were available from the May 1972 survey for the islands of ALICE, BELLE, CLARA, DAISY, and EDNA. These samples were very limited in number, and, unfortunately, were combined for each island during collection. However, they did indicate that the

islands were contaminated, and there appeared to be some difference between the lagoon and the ocean sides of the islands. Plutonium-239 activities in soil on these islands 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).

As a general rule, the number of samples to be collected on a particular island by this survey was proportional to the expected mean activity of  $^{239}\text{Pu}$  in the soil on that island. The mean value of 50 pCi/g, listed above, was assumed to be applicable to all Phase II islands. However, the islands that had not been previously visited received an increased sample allocation because of the large uncertainty in their mean activity values.

#### 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. The historical search indicated that there had been considerable impact to the islands from close-in fallout, and some had or were expected to have burial grounds for contaminated debris.

IRENE (Bogon) is a medium-sized island whose single nuclear test left a

sizable crater. Exposure rates of the order of 50-100  $\mu\text{R/hr}$  were observed in the 1971 survey effort. The accumulated H + 1 hr fallout level was about 6184 R/hr from a total of 24 nuclear tests, sound indication of both fallout and probable buried contamination over much of the island's area.

JANET (Engebi) is the second largest island on the Atoll and was the site of three early nuclear tests. Weapons test structures may be found in numerous locations. The island was the site of a large base camp. It was also a primary site of native habitation and would possibly be so again.

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. Large areas of SALLY were excavated by PACE, some adjacent to SGZ's and suspected burial sites. In addition, the excavated material had been deposited on the remaining surface areas of SALLY and between SALLY and what remains of RUBY. Because of this situation, an attempt was made early in the survey to delete these islands from the effort, since PACE was then active and any earth-moving or other land modifications conducted by them would negate any soil-survey results before they could be reported. However, while the survey was in progress, PACE ceased all activities on the Atoll, at which time it was deemed prudent to include the undisturbed portions of these islands in the survey efforts.

#### Phase IV Island

Only one island, YVONNE (Runit) was classified in the Phase IV, "severely contaminated" category. This island, at the top of the list in accumulated fallout, with a total H + 1 hr fallout of 62,849 R/hr is the site of eight SGZ's. The island is the most disturbed testing location on the Atoll. Record searches produce many conflicting reports of the disposal of radioactive materials on or near the island. These records all show considerable construction and reconstruction activity. "Old-timers" indicate that the island was actually plowed in the search for experimental packages dispersed during several nuclear tests. The island is known to have significant amounts of activated or contaminated scrap and 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 heterogeneous conglomeration of radioactive debris. On the northern half of the island, soil samples collected at one location are not necessarily representative of those obtained at other locations within the immediate area.

It was obvious that a random-sampling approach to such a situation was inappropriate. Therefore, a sampling pattern based upon prior knowledge of known surface activity levels, ground-zero locations, construction activities, suspected burial areas, etc., was adopted. In essence, the plan included sampling the area in the vicinity of the QUINCE ground zero to a depth of 120 cm on an approximate 200-ft grid system, and every 200 ft

along a line up the center of the island to the Cactus crater at the north end. It was felt that this approach would be adequate to reveal the extent of seriously contaminated areas in sufficient detail to enable cleanup estimates to be made.

The southern portion of the island (the area south of the bunker) also has a surface ground zero. However, most of the area was subjected to fallout from the nearby tests and could be sampled by a random approach similar to that used on Phase III islands.

#### Soil-Sampling Philosophy

A random-sampling technique was chosen as the primary method for determining soil-sample locations. The actual number of samples that were collected on a particular island was a function of parameters such as total accumulated fallout, number of ground-zero locations, amount of construction activities, and the likelihood of habitation. In general, the sampling frequency increased with contamination level; it was lowest on the Phase I islands and highest on Phase IV. Table 13 lists the actual number of sample locations on an island-by-island basis.

#### Selection of Sample Locations

The random selection of sampling locations was performed in the following manner. A map of each island was divided into relatively small rectangular areas. The grid spacing was generally 50 ft in order to get several thousand squares on the map of a large island. Each of these grid squares was numbered, except for those that would be impossible to sample, such as concrete pads, coral reef, runways, paved roads, etc. The sample

Table 13. Number of sample locations on each island.

Stratification	Island	Approx area, 10 <sup>5</sup> ft <sup>2</sup>	Assumed mean <sup>239</sup> Pu activity, pCi/g	No. of sample locations	
				Surface, 0-15 cm	Profiles
Phase I Group I	BRUCE	9	1	10	3
	REX	2	1	4	3
	GLENN	25	1	28	4
	HENRY	13	1	14	3
	IRWIN	7.5	1	9	3
	JAMES	4.8	1	6	3
	KEITH	11	1	12	3
	LEROY	7	1	8	3
Phase I Group II	DAVID	48	1	53	7
	ELMER	80	1	80	10
	FRED	140	1	64	8
Phase I Group III	SAM	0.25	1	4	1
	TOM	0.25	1	4	1
	URIAH	0.89	1	2	2
	WALT	1.74	1	4	1
	VAN	1.39	1	5	1
	ALVIN	0.61	1	4	1
	CLYDE	1.01	1	3	1
Phase II Group I	ALICE	10	50	22	4
	BELLE	20	50	33	4
	CLARA	2	50	9	3
	DAISY	6	50	15	4
	EDNA	0.3	50	6	2
Phase II Group II	KATE	8	50	22	2
	LUCY	10.5	50	22	4
	PERCY	1	50	5	1
	MARY	6	50	22	3
	NANCY	9	50	22	4
	OLIVE	14	50	23	4
	PEARL	27	50	45	4
	TILDA	15	50	33	5
	URSULA	12	50	27	4
	VERA	10	50	22	3
	WILMA	7	50	22	3
Phase III	IRENE	20	100	20	14
	JANET	120	50	132	12
	SALLY (including SALLY's CHILD)	37	50 (west end) 10 (elsewhere)	34	9
Phase IV	YVONNE (south)	18	50	51	9
	YVONNE (north)	25	Highly variable	0	46

locations were chosen for each island by using random-number tables,\* with an excess of 10% chosen to allow for additional locations which could not be sampled due to unforeseen coral outcroppings, concrete pads, beach erosion, etc. These locations were then replotted on the work maps, drawings, or photographs that were used in the field. Both surface and profile locations were determined in this manner.

The exact location of the sample collection was to be the center of the area chosen by the grid and random-number technique. It was realized that the determination of such a point with any great precision or accuracy in the field was technically difficult in most cases, even though large-scale photographs taken during the aerial radiological survey were used by the field parties. It was most important, however, that the individual collecting the sample make every reasonable effort to locate the position as closely as possible. In particular, the sample was to come from within a 10 × 10-ft area, defined as the center area for the grid point. In the field the sampling site was to be chosen by pacing from a known reference point or other field direction. If there were some obstacle to sampling at this specified location (which had not been eliminated prior to the random-selection process), then that fact was recorded in the field and no samples collected at that point. In this way, bias due to a collector choosing the easiest location to sample, such as a

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\* Handbook of Mathematical Functions, USDC, NBS Applied Mathematics Series 55 (U. S. Government Printing Office, Washington, D. C., 1965), pp. 991-995.

clearing rather than within a dense thicket, was minimized. This protocol was followed rigidly and did, in fact, result in some collection groups going to great effort cutting through jungle and arriving at the designated location, only to find it to be on a large pad of concrete or outcropping of coral. On JANET each sampling point was located accurately by an engineering survey team fielded for that purpose. This additional effort was expended because of the island's large size, dense vegetation cover, and probable rehabilitation.

During November 1972 an aerial radiation survey was made of all islands within the Atoll which identified "hot spots" on a number of islands. Soil samples were taken in all of these locations independently of the random-sampling process.

#### Execution of Soil-Sampling Program

The soil survey was conducted over a period of 8 weeks by roughly 18 people. The islands surveyed ranged from small, bare sandbars to large (31-acre), densely vegetated islands, often infested with wasps and spiders. With the exception of FRED (Enewetak Island), the islands of the Atoll were accessible only by boat. Only five of the islands had usable personnel piers (FRED, ELMER, DAVID, YVONNE, and URSULA). All other islands had to be reached by using a small rubber dinghy or landing craft. Depending on the weather, tides, and location on the Atoll, these landings had to be made in up to Force 4 (11-16 knots) trade winds through surf of various conditions onto sandy beaches or coral reefs.



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. The survey parties had to cut into the dense jungle to reach sample locations, clear areas to make collections, and 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. Soil texture ranged from soft coral sand to rough coral aggregates. These, in turn, were interlaced with plant roots and scrap metal junk. The possibility of encountering 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.

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; it was 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.

#### Soil-Sampling Techniques

Two types of soil samples were taken during the survey—"surface" and "profile."

At "surface" sampling locations, two samples were taken; one a  $30\text{-cm}^2$   $\times$  15-cm-deep core, and the second a composite of two  $30\text{-cm}^2$   $\times$  5-cm-deep cores.

Special tools were used to assure uniformity of sampling and ease of collection. The shallow core (5 cm) was obtained with 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  $30\text{ cm}^2$ . 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 (15 cm) 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,  $30\text{ cm}^2$  in cross section, was driven into the soil. The surrounding soil was then removed, the cutter inserted, and the sample treated in the same manner as the shallow core.

"Profile" samples were obtained using another special tool designed by Wayne Bliss of the Environmental Protection Agency. This consisted of a drawer-like sample collector, with the back of the drawer absent, which was inserted into the side wall of a trench dug to a total profile depth. The drawer was 10  $\times$  10 cm on top and 5 cm deep. After the drawer was inserted into the soil, a cutter (large putty knife) was inserted as the back of the drawer, freeing the sample. The sample was then removed, bagged, and numbered.

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

Profile samples were taken at nominal depth increments of: 0 to 2, 2 to 5, 5 to 10, 10 to 15, 15 to 25, and 25 to 35 cm and at 10-cm increments to total depth. If soil horizons were encountered, an attempt was made to choose the interface lines as additional increments.

Each soil sample collected was placed in a plastic bag; the bag was numbered and 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 had been damaged in transport. Each sample was then gamma-scanned in the field counting laboratory, and placed in storage until it could be shipped to the continental U. S. laboratory.

### Results and Discussion

The soil-sampling locations on each island are shown in the "f" overlay figures of Appendix II. Each location has an identifying number for reference purposes. These locations were chosen primarily by a random-selection technique with a few sites chosen to study specific areas of interest such as hot

spots, decontamination areas, surface ground zeros, etc. The average activities of  $^{239}\text{Pu}$ ,  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$ , exhibited by the core samples collected to a depth of 15 cm, are shown in the "i," "j," "l," and "n" overlays of Appendix II. These activities, expressed in picocuries per gram of dry soil, are displayed at the geographical locations where the respective samples were collected. For those who desire to convert these data into activities per unit area, one may use an approximate dry soil density of  $1.5 \text{ g/cm}^3$ . No attempt was made to measure in situ densities. The meaning of the resulting deposition values, however, is subject to some interpretation since one must realize that an appreciable fraction of the total activity may be situated below the sampling depth, as shown in the profile figures for each island. In these figures the activities of  $^{239}\text{Pu}$ ,  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$  are plotted as a function of depth for the corresponding profile locations. Additionally, the complete records of all radionuclides are reproduced on microfiche at the end of Appendix II.

In general, the activities shown in the figures, when properly grouped, approximate lognormal distributions. This may be illustrated by grouping the activity levels measured in the 15-cm deep core samples collected on JANET into equal class intervals and plotting the resulting frequency distribution curve shown in Fig. 26. Instead of being symmetric about the maximum as a normal distribution, one observes a long "tail" which includes a significant proportion of relatively high activity levels. This distribution can be transformed into the more

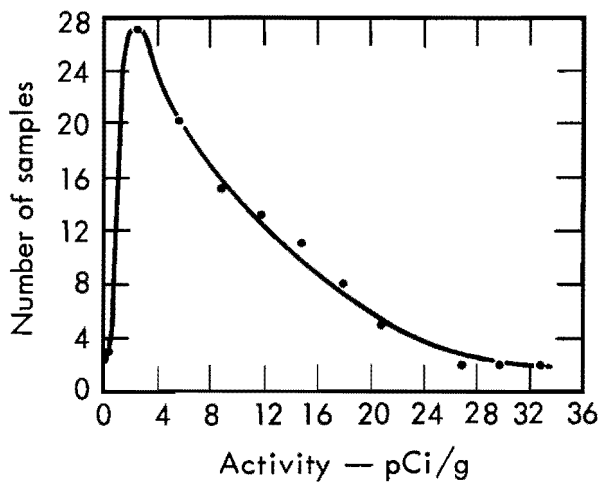


Fig. 26. Frequency distribution of  $^{239}\text{Pu}$  activities in surface samples collected on JANET.

familiar normal (Gaussian) distribution by plotting the frequency distribution of the logarithms of the individual data points. This transformation permits the use of the usual statistical parameters for describing the population. By using a log probability grid, with a logarithmic vertical scale and a horizontal scale marked in cumulative percent, these parameters may be obtained with a minimum number of data points. As an illustration, Fig. 27 shows the  $^{239}\text{Pu}$  activities used to construct Fig. 26, plotted as a function of cumulative frequency on this grid. The plot is approximately linear, indicating an essentially lognormal distribution. The convenience of using this type of plot may be demonstrated readily by the fact that two important parameters—the geometric mean and geometric standard deviation—may be obtained from the plot. The geometric mean is the equivalent of the median for a lognormal distribution. Therefore, the geometric mean (hereafter referred to as the mean) is the activity level corresponding to the 50% intercept on the log proba-

bility plot. Thus, the mean of the  $^{239}\text{Pu}$  activities shown in Fig. 27 is 8.5 pCi/g. The geometric standard deviation (hereafter referred to as the standard deviation) represents a quantitative measure of the dispersion or variability of the activity levels. One standard deviation corresponds to the interval between the mean and the 84% quantile or, because of symmetry, the interval between the mean and the 16% quantile. Thus, one standard deviation on both sides of the mean contains 68% (84 less 16%) of the population values. One may readily observe that a set of data which has a relatively small variability will exhibit a frequency distribution curve of narrow width, and that the slope of the straight line on the log probability plot will be less than that for a more variable set of data, since the slope of the line is a direct measure of the standard deviation. The standard deviation may be calculated by dividing the activity corresponding to the 84% quantile by the mean activity. Thus, from Fig. 27 one may compute the standard deviation to be  $25/8.5$  or 2.9, with the result that 68% of the  $^{239}\text{Pu}$  activities have values between 2.9 and 25 pCi/g ( $8.5/2.9$  and  $8.5 \times 2.9$ ).

A careful review of the activities exhibited by samples collected on any particular island in the northern part of the Atoll shows a reasonably direct correlation with the amount of vegetation present in the area surrounding the sampling locations. This is not surprising in view of the protection that a heavy vegetative cover can provide to minimize the effects of weathering processes (e.g., wind and rain erosion) that may serve to transport the surface activity to other areas of the

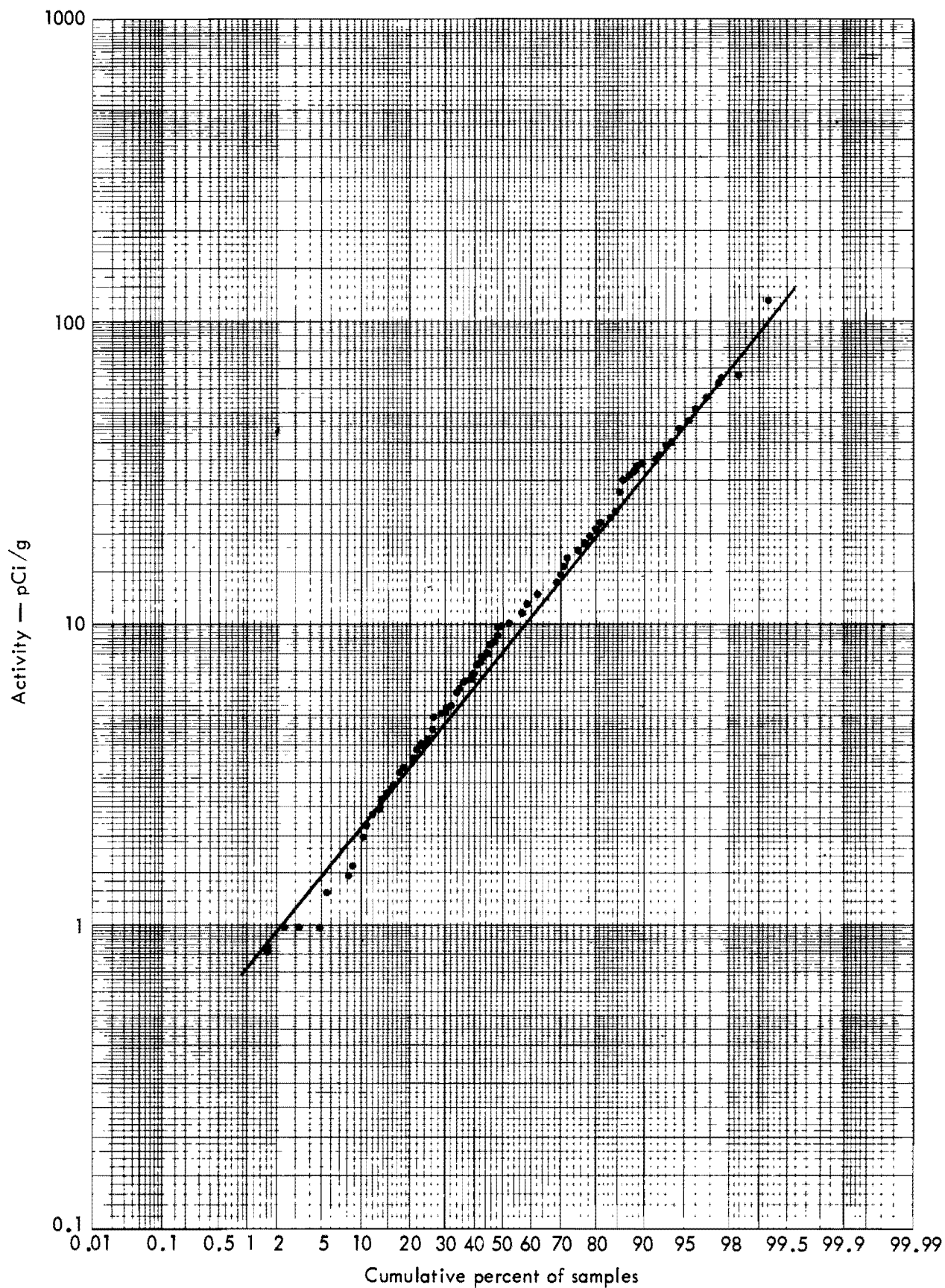


Fig. 27. Distribution of  $^{239}\text{Pu}$  activities in surface samples collected on JANET.

Atoll. This correlation of activity with vegetative cover was also observed at Bikini. Thus, a particular island may show the following distinct areas having significantly different radiological conditions: Densely vegetated areas exhibiting the highest activities; sparsely vegetated areas showing intermediate activity levels; and beach areas displaying the lowest activities. This pattern is occasionally perturbed in "hot-spot" areas where ground-zero locations existed, as well as in areas that have been subjected to extensive construction activities.

The  $^{239}\text{Pu}$ ,  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$  activities shown in the figures in Appendix II were plotted separately on log probability paper on an island-by-island basis. Islands situated in the southern part of the Atoll were combined into groups because to their radiological similarities and low activity levels. Whenever appropriate, an island was divided into "dense vegetation," "light vegetation," and "beach" categories, and if significant radiological differences were noted, a mean value and the standard deviation were obtained for each distinct area on the island. In those cases where the differences in the mean values were less than a factor of two, all of the measurements for a particular radionuclide were combined, and the mean and standard deviations were obtained for the entire island, excluding the beach areas. In most situations, the standard deviations were fairly constant, ranging largely between 1.5 and 2.5, indicating that the degree of variability of the measurements from one island to the next was small.

The distributions of activity with soil depth obtained for the profile samples

show many variations. However, in spite of these variations, some general comments may be made. Excluding beaches and areas subjected to extensive construction activity, the radioactivity generally decreases with depth in some highly variable and nonlinear fashion. Frequently, the activity decreases rapidly within the first few centimeters and then more slowly with increasing depth. A relaxation length of 3-5 cm (the depth at which the activity is  $e^{-1}$  or 37% of the surface activity) is commonly observed within the top 5-8 cm. Below this depth the relaxation length frequently increases to 10 cm or more. Profile samples collected on or near the beaches display a different depth distribution. Surface activities are usually considerably lower than island interior values, and the distributions are essentially uniform or may even increase with depth.

Radionuclides other than  $^{239}\text{Pu}$ ,  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$  appeared in the gamma-ray spectra. A convenient way to evaluate these activity levels is presented in Table 14, which gives the median activity ratios of  $^{241}\text{Am}/^{239}\text{Pu}$ ,  $^{238}\text{Pu}/^{239}\text{Pu}$ ,  $^{125}\text{Sb}/^{137}\text{Cs}$ , and  $^{155}\text{Eu}/^{137}\text{Cs}$  for each island situated within the northern portion of the Atoll. Inspection of the data indicates that the median activity ratios of  $^{241}\text{Am}/^{239}\text{Pu}$ ,  $^{238}\text{Pu}/^{239}\text{Pu}$ , and  $^{125}\text{Sb}/^{137}\text{Cs}$  are essentially constant, with approximate values of 0.40, 0.10, and 0.07, respectively.  $^{155}\text{Eu}/^{137}\text{Cs}$  values exhibit a reasonably constant value of 0.20, except for DAISY, EDNA, and IRENE, where the values rise to a maximum of 2.5.

The following is a description of the current radiological conditions of the

Table 14. Median activity ratios of pertinent radionuclides measured in soil samples.

Island	$^{241}\text{Am}/^{239}\text{Pu}$	$^{238}\text{Pu}/^{239}\text{Pu}^{\text{a}}$	$^{155}\text{Eu}/^{137}\text{Cs}$	$^{125}\text{Sb}/^{137}\text{Cs}$
ALICE	0.39	0.10	0.12	0.05
BELLE	0.33	0.11	0.15	0.07
CLARA	0.26	0.14	0.15	0.04
DAISY	0.36	—	0.72	0.09
EDNA	0.35	0.06	0.81	0.03
IRENE	0.19	—	2.5	0.15
JANET	0.38	—	0.11	0.03
KATE	0.42	—	0.22	0.06
LUCY	0.43	—	0.27	0.07
PERCY	0.41	—	—	0.17
MARY	0.38	—	0.22	0.06
NANCY	0.49	—	0.23	0.08
OLIVE	0.38	—	0.30	0.08
PEARL	0.25	—	0.48	0.08
RUBY	0.11	—	2.6	0.31
SALLY	0.28	—	0.18	0.07
TILDA	0.51	—	0.20	0.08
URSULA	0.41	—	0.14	0.07
VERA	0.44	—	0.17	0.05
WILMA	0.40	—	0.11	0.09

<sup>a</sup> $^{238}\text{Pu}$  activities were measured only in a few samples.

islands within the Atoll. For discussion purposes each island situated within the northern part of the Atoll is treated separately, while those within the southern part of the Atoll are treated in groups because of their radiological similarities. In addition, the mean values and range of observed activities listed for the northern islands do not include the activities of samples collected on the beaches, since it was felt that these low values might unduly distort the description of the islands' radiological condition. This was not considered to be true of islands within the southern part of the Atoll. The

activities listed in the discussions were obtained from the surface samples collected to a depth of 15 cm.

For ease of comparison, the data for the northern islands are summarized in Table 15 and for the southern islands in Table 16.

#### Northern Portion of Atoll (ALICE-YVONNE)

ALICE—This island is densely vegetated over its entire surface. The mean and range of observed activities exhibited by the surface samples for the following radionuclides are:

Radio-nuclide	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	80	14-430
<sup>137</sup> Cs	36	5.6-141
<sup>239</sup> Pu	12	3.9-68
<sup>60</sup> Co	5.9	1.4-33

The radioactivity seems to be fairly homogeneously distributed throughout the island, even though considerable construction activities, such as the building of an airstrip along the center of the island and large-scale earth grading at

Table 15. Enewetak soil data, "northern islands" (pCi/g in top 15 cm).

		<sup>90</sup> Sr		<sup>137</sup> Cs		<sup>239</sup> Pu		<sup>60</sup> Co	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
ALICE		80	14-430	36	5.6-141	12	3.9-68	5.9	1.4-33
BELLE	Dense	123	14-670	48	14-170	26	7.2-130	10	3.1-30
	Sparse	44	35-130	8.6	3.3-44	11	5.8-26	4.6	2.4-9.6
CLARA		65	13-310	26	5.6-110	22	3.5-88	6.4	0.91-20
DAISY	Dense	190	100-380	11	3.4-33	41	22-98	11	6.4-26
	Sparse	32	16-120	3.8	0.86-9.0	15	3.8-33	0.85	0.37-7.4
EDNA		46	30-220	4.2	2.7-6.4	18	13-24	0.43	0.33-0.63
IRENE		30	5.9-570	3.2	0.22-41	11	2.4-280	5.4	0.12-520
JANET		44	1.6-630	16	0.57-180	8.5	0.08-170	1.9	0.02-33
KATE	Dense	67	37-200	24	18-37	17	8.6-50	2.7	1.6-5.8
	Sparse	11	1.6-49	4.8	1.8-16	2.3	0.17-14	0.46	0.03-3.5
LUCY		32	10-83	11	2.2-25	7.7	2.4-22	1.5	0.26-3.8
MARY		29	11-140	9.9	5.6-26	8.0	2.0-35	1.5	0.74-4.8
NANCY		36	16-110	12	6.0-28	9.1	2.3-28	1.6	0.56-5.3
PERCY		13	3.6-73	0.94	0.12-17	3.5	1.5-23	0.47	0.08-2.9
OLIVE	Dense	22	4.6-70	8.5	3.5-28	7.7	2.2-30	1.5	0.65-4.1
	Sparse	4.5	2.0-11	0.16	0.07-11	2.8	1.9-4.1	0.11	0.05-0.31
PEARL	Hot spot	62	35-140	19	7.4-55	51	15-530	12	3.6-70
	Remainder	17	3.2-61	7.6	1.2-34	11	0.85-100	4.1	0.49-49
RUBY		12	7.1-63	1.4	0.71-7.2	7.3	3.0-24	0.93	0.29-16
SALLY		8.4	0.87-140	3.0	0.03-30	4.3	0.21-130	0.54	0.05-69
TILDA	Dense	27	17-54	8.4	3.5-20	7.6	1.4-17	1.2	0.61-1.9
	Sparse	8.7	2.2-47	1.0	0.04-5.3	2.5	1.1-34	0.37	0.21-1.7
URSULA		6.8	2.0-19	1.7	0.13-7.8	1.3	0.26-7.3	0.31	0.05-1.7
VERA		6.3	1.1-68	2.0	0.03-12	2.5	0.60-25	0.30	0.02-2.2
WILMA		3.3	0.26-13	1.3	0.31-7.2	1.1	0.1-5.3	0.12	0.01-0.7
Southern									
YVONNE		1.7	0.09-20	0.40	0.02-3.6	3.2	0.02-50	0.64	0.01-20
Northern									
Beaches		6.4	1.2-30	0.30	0.03-9.0	2.7	0.34-18	0.13	0.03-1.6

YVONNE - Because of the complex distribution of activities on Northern YVONNE no single mean value for an isotope can be used for the island as a whole without being misleading. Readers should consult the YVONNE discussion in this section and the detailed data in Appendix II for information pertinent to their interests.

Table 16. Enewetak soil data, southern islands (pCi/g in top 15 cm).

	$^{90}\text{Sr}$		$^{137}\text{Cs}$		$^{239}\text{Pu}$		$^{60}\text{Co}$	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Group A (DAVID, ELMER, FRED)	0.41	0.02-4.8	0.21	0.01-2.1	0.04	0.004-0.31	0.03	0.01-0.15
Group B (All others except LEROY) <sup>a</sup>	0.52	0.03-3.9	0.14	0.004-1.8	0.07	0.004-1.1	0.06	0.007-63
Group C (LEROY)	11	1.6-34	3.2	0.5-10	0.63	0.02-2.0	0.58	0.04-5.0

<sup>a</sup>SAM, TOM, URIAH, VAN, ALVIN, BRUCE, CLYDE, REX, WALT, GLENN, HENRY, IRWIN, JAMES and KEITH.

the northeastern end, took place during the weapons-testing period. This relative homogeneity is also supported by the results of the aerial survey.

The activities as a function of depth, obtained from Locations 24, 26, and 100 within the island's interior, follow the general rule of a rapid decrease in activity within the first few centimeters of the surface (relaxation lengths of 3-5 cm) and then level off to become almost homogeneous (as demonstrated at Location 100). Profile samples collected at Locations 23 and 25, which are on or near the beaches, display essentially homogeneous activity distributions.

BELLE—As clearly indicated by the photographs, this island is so heavily vegetated that it was almost impossible to penetrate. The only exception is the northeast corner of the island, which is relatively open with sparse vegetation. Most of the soil samples were collected within the densely vegetated areas, with a few obtained within the sparsely vege-

tated northeast corner. The following activities resulted:

Radio-nuclide	Activity, pCi/g	
	Mean	Range
<u>Areas of dense vegetation</u>		
$^{90}\text{Sr}$	123	14-670
$^{137}\text{Cs}$	48	14-170
$^{239}\text{Pu}$	26	7.2-130
$^{60}\text{Co}$	10	3.1-30
<u>Areas of sparse vegetation</u>		
$^{90}\text{Sr}$	44	35-130
$^{137}\text{Cs}$	8.6	3.3-44
$^{239}\text{Pu}$	11	5.8-26
$^{60}\text{Co}$	4.6	2.4-9.6

The mean activities exhibited by the samples from the northeast corner are roughly a factor of three smaller than those from the remainder of the island. Since only a few samples were collected within the corner area, the factor of three may or may not reflect the true difference in the mean values. The aerial survey results do not reflect this difference.



The depth distributions indicate fairly rapid decrease of activity with depth. The activities are highest at Locations 35 and 100 in the interior of the island and considerably lower at Locations 36 and 37, which are situated near the beaches.

CLARA—This is a small, narrow island with reasonably dense vegetation. Thirteen locations were sampled on the island, and the results of the analyses are:

Radionuclides	Activity, pCi/g	
	Mean	Range
$^{90}\text{Sr}$	65	13-310
$^{137}\text{Cs}$	26	5.6-110
$^{239}\text{Pu}$	22	3.5-88
$^{60}\text{Co}$	6.4	0.91-20

These activities are somewhat lower than those measured on ALICE and BELLE. Since the radiological contamination by the weapons tests to CLARA is essentially the same as that for ALICE and BELLE, the lower residual activities are probably due to increased weathering processes.

All of the profile sampling locations are situated within the interior of the island, and the results from these locations show properties similar to those observed for samples collected within the interiors of ALICE and BELLE.

DAISY—The southern (lagoon) and eastern sides of this island consist primarily of a very sparsely vegetated area, and the northwest portion contains considerably denser vegetation. The mean and range of the observed activities in the soil from these two areas are:

Radio-nuclide	Activity, pCi/g	
	Mean	Range
<u>Areas of dense vegetation</u>		
$^{90}\text{Sr}$	190	100-380
$^{137}\text{Cs}$	11	3.4-33
$^{239}\text{Pu}$	41	22-98
$^{60}\text{Co}$	11	6.4-26
<u>Areas of sparse vegetation</u>		
$^{90}\text{Sr}$	32	16-120
$^{137}\text{Cs}$	3.8	0.86-9.0
$^{239}\text{Pu}$	15	3.8-33
$^{60}\text{Co}$	0.85	0.37-7.4

Thus, one observes large differences between the mean values exhibited by samples collected within the densely and sparsely vegetated areas. The highest activity levels were measured in samples obtained slightly toward the northwestern (leeward) side of the island, which is in excellent agreement with the exposure rate contours produced by aerial survey measurements.

The depth distributions measured at Locations 16, 17, and 18 display similar slopes. At Location 100, situated in the midst of the most densely vegetated area, the depth distribution shows a rapid decrease in activity within the top 5 cm (relaxation lengths of 2-4 cm) and then assumes a much slower rate of decrease with depth similar to those at Locations 16, 17, and 18. A homogeneous distribution was measured at Location 19, as would be expected because of its close proximity to the beach.

EDNA—This tiny island really consists of a sandbar with a little vegetation on it. The activities obtained from the eight sampling locations are:

Radionuclide	Activity, pCi/g	
	Mean	Range
$^{90}\text{Sr}$	46	30-220
$^{239}\text{Pu}$	18	13-24
$^{137}\text{Cs}$	4.2	2.7-6.4
$^{60}\text{Co}$	0.43	0.33-0.63

These mean activities are lower than those measured on ALICE, BELLE, CLARA, or DAISY, even though the radiological contamination of EDNA from the weapons tests is a factor of three greater than those given to the other islands in the group. This is, of course, most probably due to the enhanced wind and wave action operating on this tiny island which has diluted and transported the activity. The homogeneous depth distribution at Locations 7 and 8 tends to bear this out.

IRENE—This island played a central role in the weapons-testing program. Highlights of its role include the detonation of the SEMINOLE event, which created a large water-filled crater within the island's central region; its proximity to the MIKE and KOA thermonuclear events, which significantly altered its physical characteristics; and extensive construction activities which involved the erection of test structures and the movement of large amounts of earth. Thus, one would expect the radiological situation on this island to be exceedingly complex and this was certainly borne out by the survey. The geographical distributions of the surface activities are relatively heterogeneous. Elevated  $^{239}\text{Pu}$ ,  $^{90}\text{Sr}$ , and  $^{60}\text{Co}$  activities appear immediately east and north of the crater; however,

$^{137}\text{Cs}$  seems to be most abundant within the central portions of the present land mass. Because of the complex situation, no attempt was made to divide the island into areas of distinct radiological conditions. The activities of various radionuclides distributed over the island to a depth of 15 cm (including the beaches) are:

Radionuclide	Activity, pCi/g	
	Mean	Range
$^{90}\text{Sr}$	30	5.9-570
$^{239}\text{Pu}$	11	2.4-280
$^{60}\text{Co}$	5.4	0.12-520
$^{137}\text{Cs}$	3.2	0.22-41

Profile samples were collected at numerous places throughout the island. The resulting depth distributions of activity also reveal the complexity of the situation. After a careful review of the distributions, one may identify several areas that show  $^{239}\text{Pu}$  activities of about 100 pCi/g to depths as much as one meter beneath the surface. The approximate geographical distribution of these areas is shown in Fig. 28.

JANET— This is the largest island within the northern part of the Atoll. Three nuclear devices were detonated on the island. An enormous amount of construction activity associated with the weapons program and World War II operations took place, as indicated by the significant quantities of radioactive and nonradioactive scrap scattered around the island (refer to Engineering Survey data), the bunkers, test structures, and mounds of soil. In addition, an airstrip was constructed along the northern side

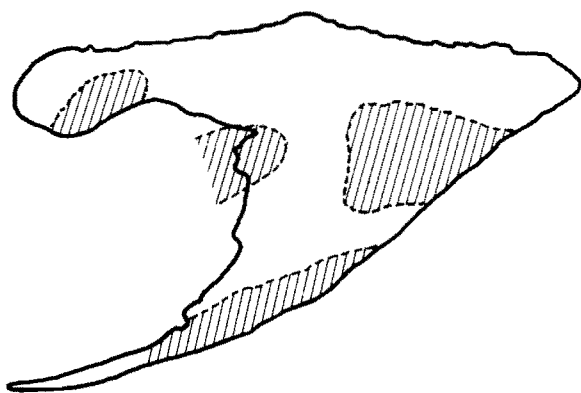


Fig. 28. The shading denotes areas that show elevated levels of subsurface  $^{239}\text{Pu}$  contamination, IRENE.

of the island. A major fraction of the island's surface is covered with dense vegetation; however, other areas, especially along the northern side, are more sparsely vegetated. Even these are covered with some sort of ground cover.

The island was sampled extensively during this survey, partly because of its past history, but principally because it is the most likely site in the northern part of the Atoll for habitation by the returning native population. Surprisingly, in view of man's past activities on the island, the soil radioactivities measured in all of the 15-cm-deep surface samples (excluding beach samples) closely follow a lognormal distribution (as demonstrated in Fig. 27), even though they were collected throughout the island from areas of widely differing vegetation densities. The standard geometric deviations, on the other hand, were somewhat greater than usual (2.8-3.0), indicating increased variability in the measurements in relation to similar measurements made on the other islands. The pertinent activities exhibited by these surface samples are:

Radionuclide	Activity, pCi/g)	
	Mean	Range
$^{90}\text{Sr}$	44	1.6-630
$^{137}\text{Cs}$	16	0.57-180
$^{239}\text{Pu}$	8.5	0.08-170
$^{60}\text{Co}$	1.9	0.02-33

The geographical distribution of  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{239}\text{Pu}$  do not show any particular systematic pattern, but elevated  $^{60}\text{Co}$  levels are observed preferentially within the northeast corner of the island. The area is primarily north of the airstrip, with a long finger extending south across the airstrip and halfway across the island. The mean activity within this area is about a factor of 2-3 greater than that shown above. These elevated activities are probably due to a surface ground zero situated within the open area near the beach, on the northeast corner of the island.

The depth distributions of activity were measured at 12 locations on the island to depths as great as 180 cm. As one would expect, considerable variability exists between the individual distributions. However, some common features do exist. Most of the distributions display a relatively rapid decrease in activity within the top few centimeters (relaxation lengths typically 3-10 cm) and subsequent leveling off in activity with increasing depth. Significant deviations from this behavior, however, are observed at several sites. At Location 147, the distributions reveal a layer of contaminated material situated between 50 and 90 cm below the surface. A similar feature, on a smaller scale, was also noted at Location 140. In addition, the depth

distribution at Location 143 is essentially homogeneous to a depth of 50 cm below the surface.

KATE—This island contains relatively open, sparsely vegetated areas over a considerable portion of its interior and along the lagoon and north sides. The remainder of the island is covered with a dense vegetation cover. The activities of interest with respect to these areas are:

Radio-nuclide	Activity, pCi/G	
	Mean	Range
<u>Areas of dense vegetation</u>		
<sup>90</sup> Sr	67	3.7-200
<sup>137</sup> Cs	24	18-37
<sup>239</sup> Pu	17	8.6-50
<sup>60</sup> Co	2.7	1.6-5.8
<u>Areas of sparse vegetation</u>		
<sup>90</sup> Sr	11	1.6-49
<sup>137</sup> Cs	4.8	1.8-16
<sup>239</sup> Pu	2.3	0.17-14
<sup>60</sup> Co	0.46	0.03-3.5

Again, considerable differences are noted in the mean values corresponding to the sparse and dense vegetated areas. The depth distributions of activity do not show grossly dissimilar characteristics from those obtained from more pristine areas, but they may not be entirely due to environmental factors since earth grading and building construction took place on this island during the weapons-testing program.

LUCY—This island is heavily vegetated over most of its surface, with somewhat lighter vegetation occurring on

its southern end. Since only a few soil samples were obtained from this lightly vegetated area, it was necessary to treat this island as a single entity. The iso-exposure contours developed from the aerial survey measurements, however, reflect lower exposure rates over the lightly vegetated area. The mean and range of activities observed in soil samples collected on this island are:

Radionuclide	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	32	10-83
<sup>137</sup> Cs	11	2.2-25
<sup>239</sup> Pu	7.7	2.4-22
<sup>60</sup> Co	1.5	0.26-3.8

The profile samples generally reflect a sharp decrease in activity within the top 10 cm (relaxation lengths of about 5 cm) and a leveling off below this depth.

MARY—The distribution of radio-activity seems fairly homogeneously distributed throughout the island, with no significant correlation between activity levels and the degree of vegetation in the vicinity of the sampling locations. The mean and range of activities observed over the entire island, excluding the beaches, are:

Radionuclide	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	29	11-140
<sup>137</sup> Cs	9.9	5.6-26
<sup>239</sup> Pu	8.0	2.0-35
<sup>60</sup> Co	1.5	0.74-4.8

Relatively minor construction activity did take place on this island during the

testing period. The effects of this may be reflected in the somewhat homogeneous depth distributions observed.

NANCY—This island is essentially covered with dense vegetation over its entire surface. The radioactivity seems to be fairly homogeneously distributed throughout the island. The activities of the pertinent radionuclides are:

Radionuclide	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	36	16-110
<sup>137</sup> Cs	12	6.0-28
<sup>239</sup> Pu	9.1	2.3-28
<sup>60</sup> Co	1.6	0.56-5.3

The depth distributions display the familiar rapid decrease of activity immediately below the surface (relaxation lengths of 3-5 cm) at Locations 23, 24, and 25 situated within the island's interior. The distribution at Location 22 is essentially homogeneous, as would be expected because of its location on the beach.

PERCY—This island is a small sandbar with no vegetation on it. Samples obtained from six sampling locations show the following activities:

Radionuclide	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	13	3.6-73
<sup>137</sup> Cs	0.94	0.12-17
<sup>239</sup> Pu	3.5	1.5-23
<sup>60</sup> Co	0.47	0.08-2.9

The depth distribution obtained from a single profile indicates that the maximum

activity is situated 3-8 cm below the surface. This may have resulted from weathering processes that have diluted the surface activity levels.

OLIVE—This island contains dense vegetation over most of its surface, with the exception of a relatively sparsely vegetated area toward the south end. The sampling locations were divided into two groups: (1) those within the sparsely vegetated area on the south end and several locations situated on the edge between the vegetated area and the beach, and (2) those within the remainder of the island, where the vegetative cover is reasonably dense. The activities of interest in regard to these areas are:

Radio-nuclide	Activity, pCi/g	
	Mean	Range
<u>Areas of dense vegetation</u>		
<sup>90</sup> Sr	22	4.6-70
<sup>137</sup> Cs	8.5	3.5-28
<sup>239</sup> Pu	7.7	2.2-30
<sup>60</sup> Co	1.5	0.65-4.1
<u>Areas of sparse vegetation</u>		
<sup>90</sup> Sr	4.5	2.0-11
<sup>137</sup> Cs	0.16	0.07-11
<sup>239</sup> Pu	2.8	1.9-4.1
<sup>60</sup> Co	0.11	0.05-0.31

The unusually large difference in the mean values of the two groups of data is probably due to the fact that (1) samples collected on or near the edge of the sparsely vegetated area to some degree reflect the low activities on the beach, and that (2) a significant portion of the samples representing the densely vegetated interior were collected in an

area somewhat toward the ocean side. According to the aerial survey measurements, the latter area had a slightly higher radiation level than the rest of the island.

The depth distributions obtained within the interior of the island, Locations 24, 25, and 26, are quite similar. Relaxation lengths of about 5 cm are typical. The distribution measured at Location 27 is essentially homogeneous as expected.

PEARL—Since this island contains a surface ground zero, the radiological analysis was based entirely upon the measured soil activities without regard to the degree of vegetation. A review of the data reveals a "hot spot" centered around Locations 5, 6, 9, 10, and 11. This is in reasonable agreement with the aerial survey measurements, except for the exact geographical location of the hot spot. The mean and range of observed activities for the hot spot and the remainder of the island are:

Radio-nuclide	Activity, pCi/g	
	Mean	Range
<u>Hot spot</u>		
<sup>90</sup> Sr	62	35-140
<sup>137</sup> Cs	19	7.4-55
<sup>239</sup> Pu	51	15-530
<sup>60</sup> Co	12	3.6-70
<u>Remainder of island</u>		
<sup>90</sup> Sr	17	3.2-61
<sup>137</sup> Cs	7.6	1.2-34
<sup>239</sup> Pu	11	0.85-100
<sup>60</sup> Co	4.1	0.49-49

The depth distributions measured at various locations throughout the island

show relaxation lengths, of the order of 5 cm, except at Location 48 (near the southeast end), where the soil activities seem to be much more homogeneous with depth.

RUBY—This is a tiny island situated immediately north of SALLY. The activities obtained from five sample locations are:

Radionuclide	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	12	7.1-63
<sup>137</sup> Cs	1.4	0.71-7.2
<sup>239</sup> Pu	7.3	3.0-24
<sup>60</sup> Co	0.93	0.29-16

The profile samples collected at Location 2 indicate a homogeneous distribution of activity with depth.

SALLY—This island was the site of several surface detonations. In addition, the PACE Project had excavated extensive areas throughout the island during the past year. Since some of these excavations centered around the surface ground zeros and possible burial sites, it was difficult to devise a meaningful and realistic soil survey. Therefore, a decision was made to include only the undisturbed areas in the sampling plan. The results of this effort should not be regarded as a definitive statement of the radiological conditions on this island, but only as an indication of the activity levels that may be encountered. The pertinent activities obtained from the samples collected within the undisturbed areas on SALLY and SALLY'S CHILD are:

Radionuclides	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	8.4	0.87-140
<sup>137</sup> Cs	3.0	0.03-30
<sup>239</sup> Pu	4.3	0.21-130
<sup>60</sup> Co	0.54	0.05-69

The maximum activities, listed above, were all obtained from a sample collected at Location 30 on the beach at the northern tip of SALLY. These activities are approximately a hundred times greater than expected. Since these elevated levels were not recognized until after the completion of the field portion of the survey, no additional samples were collected to define the extent of the contamination.

The profile samples collected at Locations 34 and 35 indicate increasing activities to a depth of 60-150 cm below the surface, while the distribution at Location 200 is essentially homogeneous to a depth of 40 cm. These unusual distributions may have resulted from mechanical mixing of the soils due to construction activities during the weapons-testing period or, more likely, due to the Project PACE excavations. The depth distributions measured at the remaining sites throughout SALLY and SALLY'S CHILD show the more conventional rapid decrease in activity with depth through the first 10-20 cm with a gradual leveling off in the rate of decrease below 20 cm.

TILDA—The activity that is distributed throughout this island resulted primarily from the devices detonated on SALLY, the adjacent island to the north. This activity seems to be distributed fairly homogeneously throughout the island; however, a direct correlation

may again be made with the density of vegetation present. The island is divided more or less centrally by an old airstrip. Inspection of the aerial photographs of the island reveals that the area north of the airstrip and on the lagoon (west) side of the north-south road is much less densely vegetated than the remainder of the island situated between the airstrip and the road. The following activities reflect this difference in vegetation:

Radio-nuclide	Activity, pCi/g	
	Mean	Range
<u>Areas of dense vegetation</u>		
<sup>90</sup> Sr	27	17-54
<sup>137</sup> Cs	8.4	3.5-20
<sup>239</sup> Pu	7.6	1.4-17
<sup>60</sup> Co	1.2	0.61-1.9
<u>Areas of sparse vegetation</u>		
<sup>90</sup> Sr	8.7	2.2-47
<sup>137</sup> Cs	1.0	0.04-5.3
<sup>239</sup> Pu	2.5	1.1-34
<sup>60</sup> Co	0.37	0.21-1.7

Thus, the mean values vary by factors of nearly three or more between these two areas. This variation is also observed in the aerial survey measurements.

The depth distributions of activity seem to vary considerably throughout the island. The distribution measured at Location 35 reveals a maximum activity value at 10-15 cm below the surface, possibly due to road construction. On the other hand, the profiles obtained at Locations 34 and 36 display the usual rapid decrease in activity within the first few centimeters (relaxation lengths of 3-5 cm), while the activity at Location 38 falls off almost exponentially with a relaxation length of roughly 20 cm.

URSULA—The activities measured on this island were quite low with respect to those measured on the more northern islands. Possibly due to these low activities, no correlation was observed between activity and the degree of vegetation. The mean and range of activities measured in the surface samples collected over the entire island are:

Radionuclides	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	6.8	2.0-19
<sup>137</sup> Cs	1.7	0.13-7.8
<sup>239</sup> Pu	1.3	0.26-7.3
<sup>60</sup> Co	0.31	0.05-1.7

The depth distribution at Location 29, an interior site, shows the typical decrease in activity with depth; however, the distributions measured at Locations 28 and 31 reveal higher activities beneath the surface. This may be due to their proximity to the beaches.

VERA—The radiological contamination of this island from the weapons tests is relatively minor. Consequently, the activities measured in the surface samples collected on this very densely vegetated island are correspondingly low. The pertinent activities are:

Radionuclides	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	6.3	1.1-68
<sup>137</sup> Cs	2.0	0.03-12
<sup>239</sup> Pu	2.5	0.60-25
<sup>60</sup> Co	0.30	0.02-2.2

The depth distributions at Location 24 display relaxation lengths of 2-5 cm,

while those at Locations 23 and 25 are more like 10-15 cm.

WILMA—Since the radiological contamination of this island was similar to that for VERA, one would expect roughly the same activity levels. This was borne out by the following data obtained from the surface samples collected.

Radionuclide	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	3.3	0.26-13
<sup>137</sup> Cs	1.3	0.31-7.2
<sup>239</sup> Pu	1.1	0.1-5.3
<sup>60</sup> Co	0.12	0.01-0.7

The profile samples collected at several sites throughout the island display similar depth distributions, with relaxation lengths of 10-15 cm being the general rule.

Beaches—Since the activities of the samples collected on the beaches are appreciably lower than those measured in samples from the islands' interiors, and since these activities do not vary greatly from one island to another, it is convenient for discussion purposes to combine the beach activities obtained from all of the islands in the northern part of the Atoll, except for IRENE, EDNA, RUBY, and PERCY. The results are:

Radionuclides	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	6.4	1.2-30
<sup>137</sup> Cs	0.30	0.03-9.0
<sup>239</sup> Pu	2.7	0.34-18
<sup>60</sup> Co	0.13	0.03-1.6



YVONNE—Yvonne received the most severe radiological dose of any island within the Atoll. Eight nuclear tests were conducted on the island, and the close-in fallout patterns from an additional 16 events intersected various parts of the island. This fallout history, plus construction and decontamination activities conducted during and after the testing period, have produced a rather heterogeneous and unusual radiological situation on the island.

To facilitate the soil survey, the island was divided into two sections: (1) the southern section consisting of the area south of the bunker complex (approximate center of YVONNE C photograph), and (2) the area situated north of the bunker (YVONNE A and B photographs). This division was based upon a review of historical records, data obtained from the aerial survey, and data from previous ground surveys. Indications were that these two sections were quite distinct in their radiological characteristics; it was expected that the southern section would be only slightly contaminated, while the northern section would probably reveal elevated activity levels with high geographical variability.

Southern YVONNE—A review of the activities measured in the soil samples collected on this section of the island indicates that the geographical distribution of activity within the top 15 cm is rather uniform; however, somewhat higher values appear preferentially within the area immediately north of the runway (see YVONNE figures in Appendix II). The geometric mean and the range of activities of selected radionuclides

measured within the top 15-cm layer are:

Radionuclides	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	1.7	0.09-20
<sup>137</sup> Cs	0.40	0.02-3.6
<sup>239</sup> Pu	3.2	0.02-50
<sup>60</sup> Co	0.64	0.01-20

The distributions of activity with depth at Locations 33 and 34 show some irregular variations with depth but generally indicate reasonably homogeneous characteristics. The distributions at Locations 35 and 37, on the other hand, indicate fairly rapid decreases in activities with depth. This may be contrasted with those at Location 61, where the activities actually increase with depth by about a factor of five over those measured at the surface.

Northern YVONNE—The complexity of the radiological conditions on this section of the island was produced by several nuclear events. Most notable of these is the QUINCE event (see Fig. 23 for approximate SGZ location), which failed to produce a fission yield, with the result that the plutonium within the device was merely dispersed by the high explosives. Some effort was expended shortly after the event to decontaminate the area by soil removal and the placement of clean soil over the decontaminated area. In spite of this decontamination effort, considerable plutonium was still left behind. Subsequently, a second nuclear device was detonated over the same area. Recent radiation surveys reveal that the area is heterogeneously contaminated

with  $^{239}\text{Pu}$  particles of various sizes. Radiation surveys were conducted to evaluate the frequency and geographical distribution of the plutonium-bearing fragments situated on or near the surface within the QUINCE area. The surveys were executed by traversing the area on a 10-ft grid pattern with a Fidler instrument and carefully searching the area for relative "hot spots," or localized high Fidler readings. The Fidler, consisting of a thin NaI detector connected to a rate meter, is a field instrument designed to detect low-energy gamma radiation emitted by the  $^{241}\text{Am}$  associated with the plutonium. The surveys uncovered roughly 60 "hot spots" scattered throughout the area in a highly random fashion. On Fig. B.23.1a (YVONNE B) the area in which "hot spots" have been found is bounded roughly by a line across the island 1 cm from the right-hand border of the figure and a line across the island 2 cm from the left-hand border, the full width of the island. One must be quite cautious in interpreting the meaning of a high Fidler reading since the instrument responds to low-energy scattered radiation produced by high-energy gamma emitters, as well as gamma rays associated with  $^{241}\text{Am}$ . In addition, the instrument's response is a function of the amount of radioactive material, as well as its depth of burial. Thus, the "hot spots" found on YVONNE are local concentrations of radioactivity which, because of the history of the area, are probably, but not certainly, plutonium.

Soil samples were taken on a number of "hot spot" locations and progressively divided into "hot" and "cold" halves on the basis of Fidler readings, resulting in the

isolation of milligram-size pieces of plutonium metal. The "cold" fractions were not amenable to further physical separation of plutonium; they gave Fidler readings but appeared to have plutonium uniformly dispersed through the soil volume.

In addition to the plutonium contamination, the northern tip of YVONNE was the site of several nuclear detonations; the most notable were the CACTUS and LA CROSSE events, which produced large craters now filled with water. The throw-out material from these events, according to the aerial survey results, presently display the highest gamma exposure rates on the Atoll [see Fig. B.22.1b (YVONNE A)].

With this situation in mind, the sampling plan illustrated in Figs. B.22.1f and B.23.1f was developed. In essence, the plan included sampling the QUINCE area to a depth of 120 cm on a systematic grid pattern, as well as every 200 ft along a line running up the center of the island to the CACTUS crater. The program also included sampling along a cross section leading from the crater to the lagoon side of the island. It was realized that this program could not address the complete distribution of the large plutonium fragments within the QUINCE area, but would only reveal the general contamination levels in the soil.

The following discussion of the radiological conditions is simplified for the sake of brevity and clarity. For a detailed analysis of the situation, the reader is referred to the original data shown in YVONNE figures in Appendix II. Analytical data for each of the profile sampling locations is also presented in the

YVONNE A and B sections of Appendix II. To aid in visualizing the three-dimensional distribution of plutonium on the northern half of YVONNE, the plutonium profile data have been plotted in Figs. 29-37, each of which represents a section either across the island or through a portion of its length.

A careful review of the  $^{239}\text{Pu}$  activities measured in soil samples collected within this area reveals that a significant fraction of the activity is situated along the ocean side of the island between Locations 104 and 117. Within this area, the activities generally exceed 100 pCi/g to depths of 30 cm or more. These relatively high contamination levels appear to penetrate furthest inland along the Location 112-116 cross section, as evidenced by activity levels of greater than 100 pCi/g to depths of 50 cm at Location 113 and 10 cm at Location 114. Elevated  $^{239}\text{Pu}$  activities are also observed to a

lesser extent along the lagoon side of the island. Activities exceeding 100 pCi/g were measured to depths of 20 cm within a narrow strip situated along Locations 111, 116, 120, and 125. An additional area of interest may be noted at depths of 60-90 cm beneath the surface within the island's interior. A strip, estimated to be as much as 100-200 ft wide, may be delineated at Locations 110 and intersecting Locations 114 and 115. The  $^{239}\text{Pu}$  activities generally exceed 10 pCi/g within the strip, with an observed maximum of value of 70 pCi/g.

The  $^{239}\text{Pu}$  activities measured in the samples collected along the line running up the center of the island to the CACTUS crater are significantly lower than those measured within the QUINCE area. For instance, activities exceeding 100 pCi/g were measured only on the surface at Location 134. Except for minor variations, the  $^{239}\text{Pu}$  activities range from

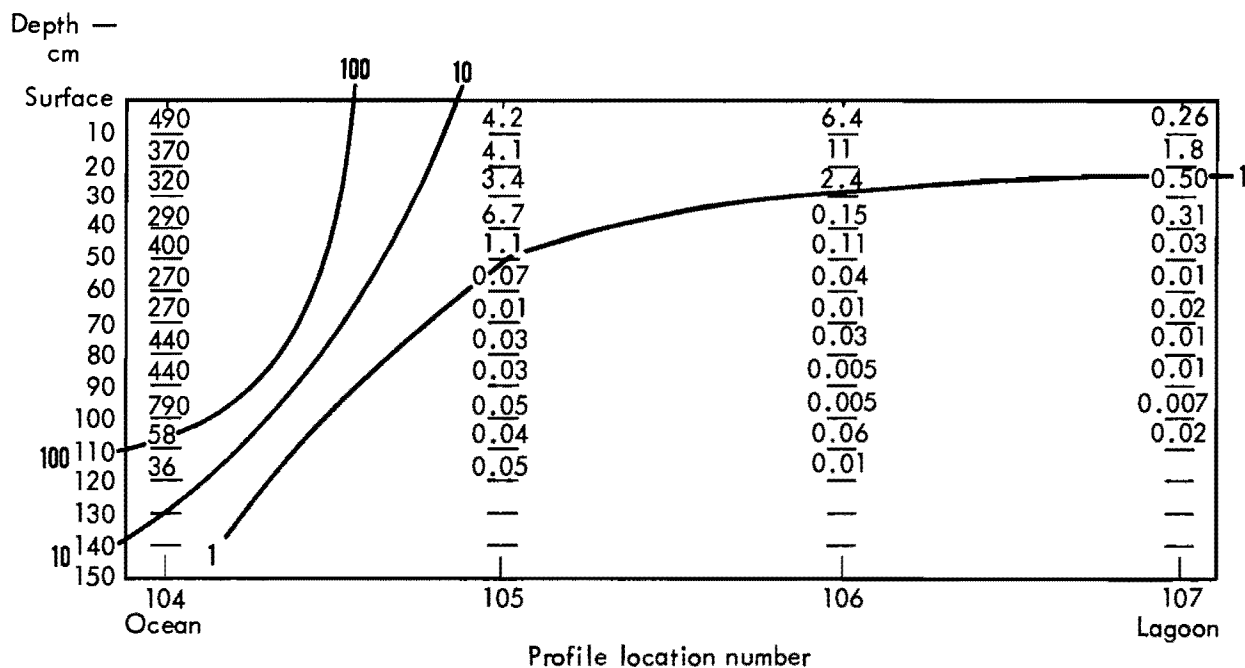


Fig. 29. Plutonium profile data, Locations 104-107, YVONNE.

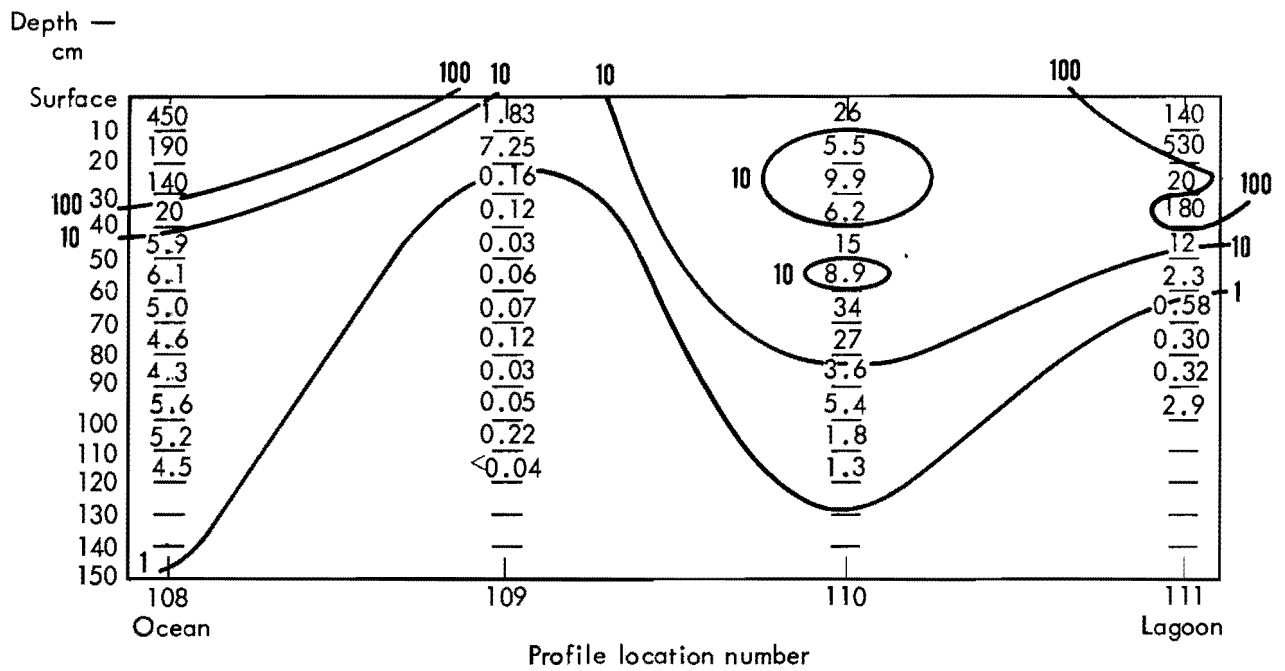


Fig. 30. Plutonium profile data, Locations 108-111, YVONNE.

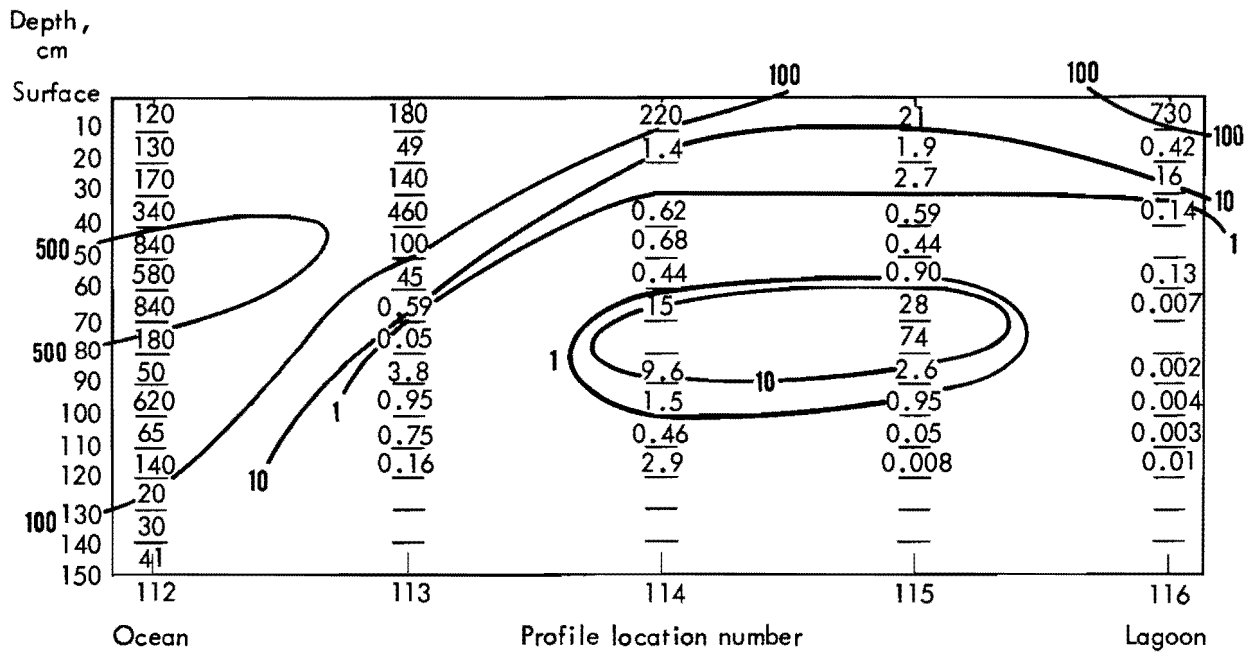


Fig. 31. Plutonium profile data, Locations 112-116, YVONNE.

5 to 30 pCi/g within the top 30 cm between Locations 132 and 142. Slightly higher activities, however, were measured at Locations 143, 144, and 146, along the CACTUS crater-to-lagoon cross section,

where activities range typically between 10 and 150 pCi/g.

With the exception of the CACTUS crater area, the activities of  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$  seem to be fairly evenly distributed

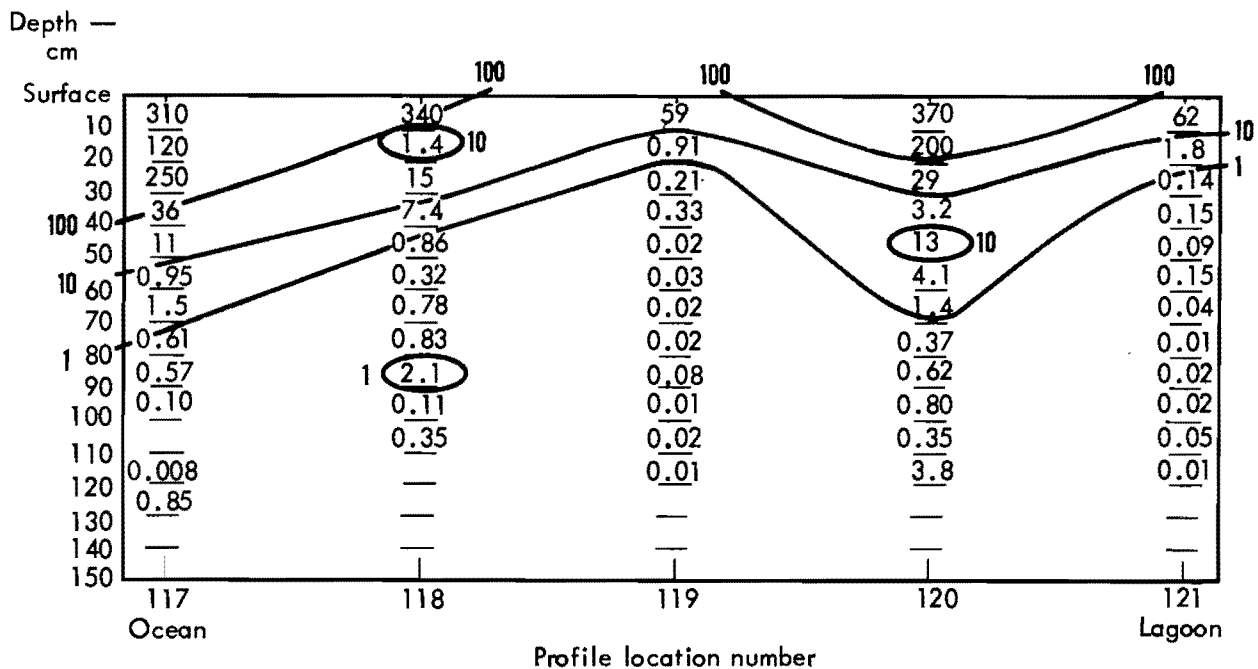


Fig. 32. Plutonium profile data, Locations 117-121, YVONNE.

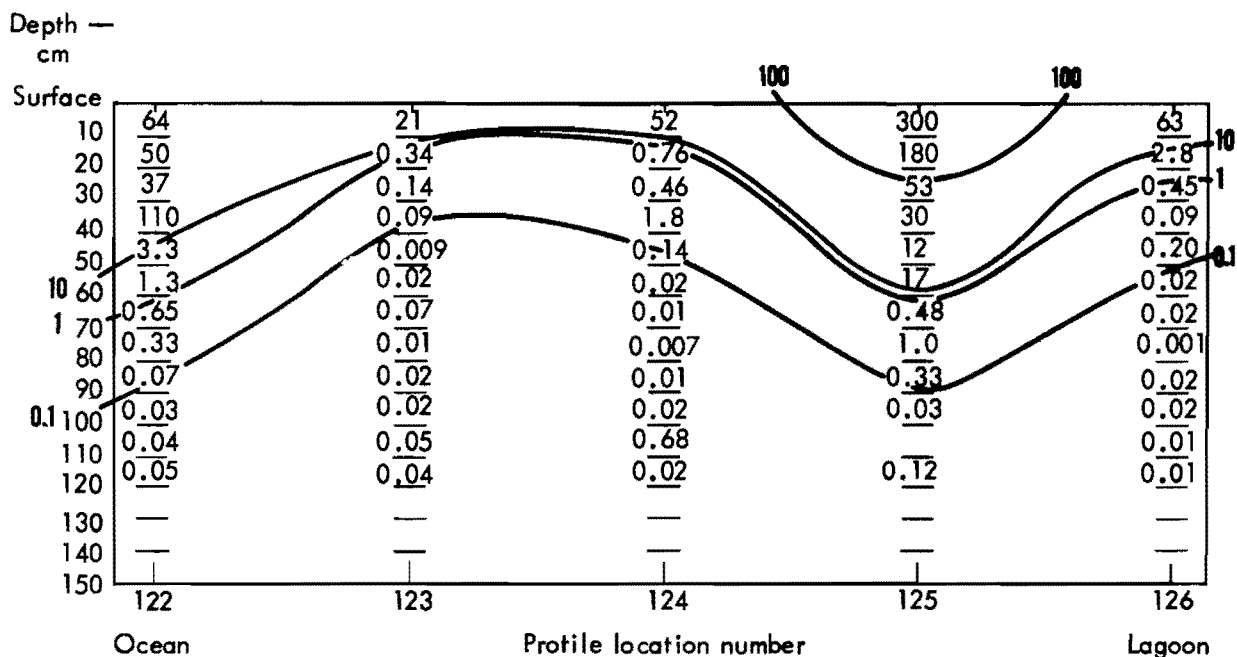


Fig. 33. Plutonium profile data, Locations 122-126, YVONNE.

throughout northern YVONNE. Generally, the  $^{90}\text{Sr}$  activities range between 1 and 5 pCi/g within the top 50 cm and less than 1 pCi/g beneath this depth. The activities of  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  are similar in magni-

tude and usually range between 0.1 and 2 pCi/g.

Within the CACTUS crater area, the mean surface activities of  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$  are generally an order of

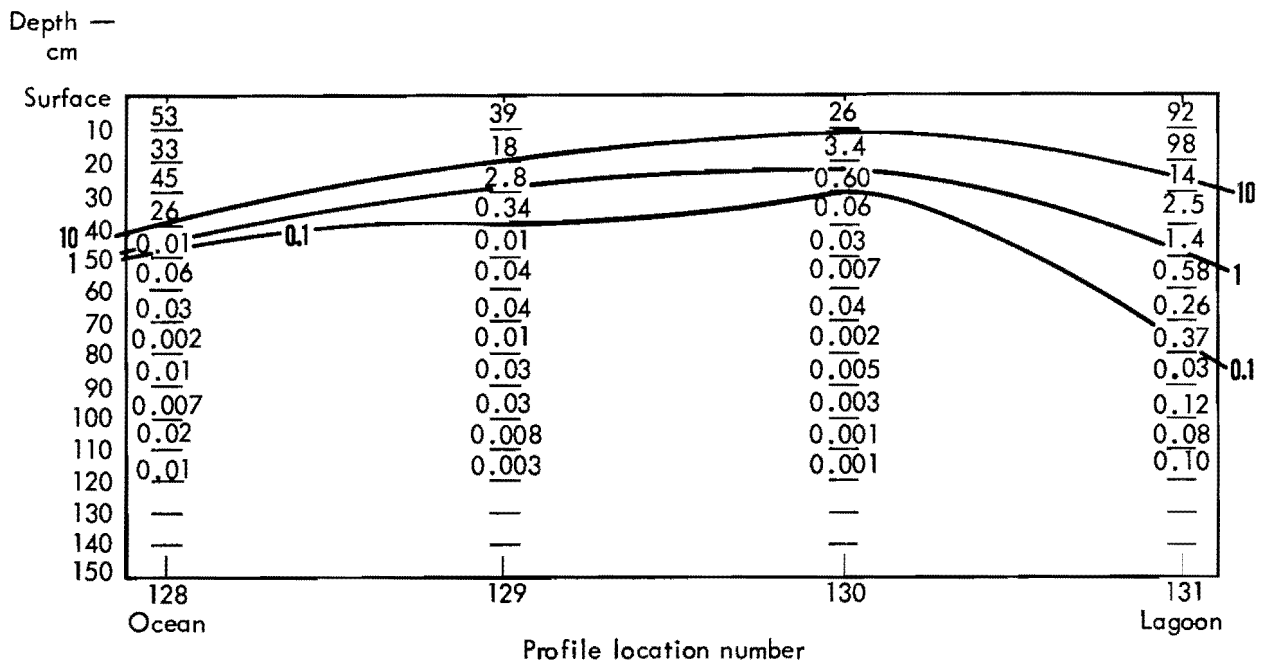


Fig. 34. Plutonium profile data, Locations 128-131, YVONNE.

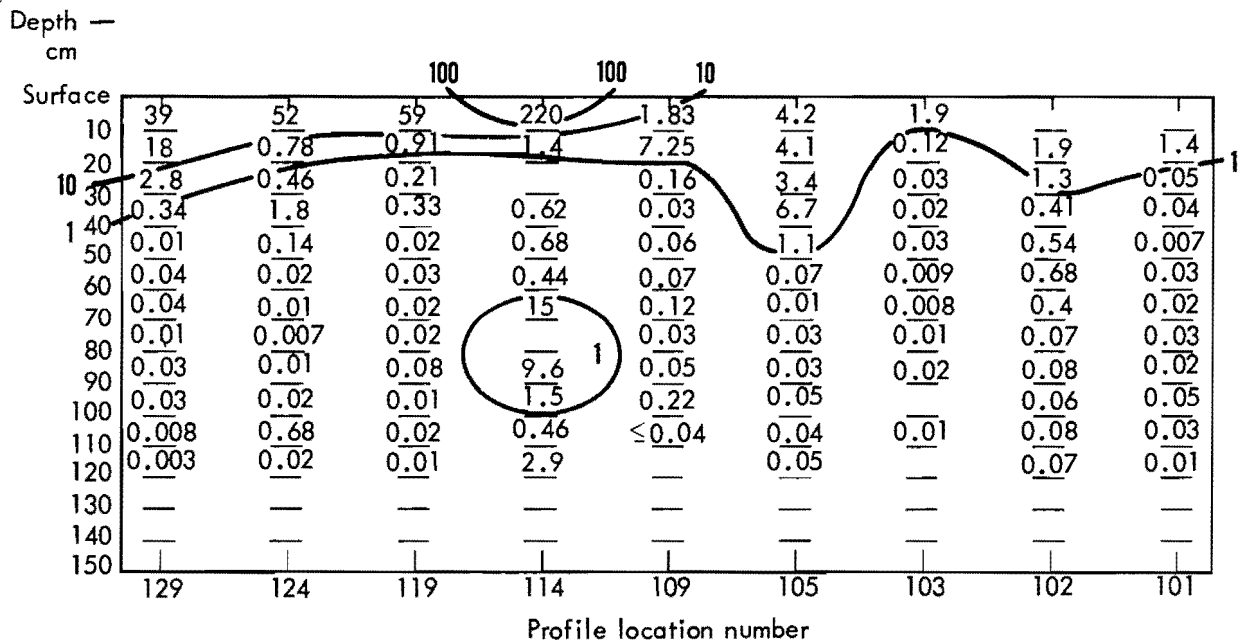


Fig. 35. Plutonium profile data, Locations 101-103, 105, 109, 114, 119, 124, and 129, YVONNE.

magnitude greater than those measured throughout the remainder of Northern YVONNE. Even though the geographical distributions of these radionuclides are highly variable, they do show somewhat

similar characteristics. For instance, if one proceeds outward on the two sample radials leading from Location 142, on the crater lip, one encounters an approximate tenfold increase in activity levels (averaged

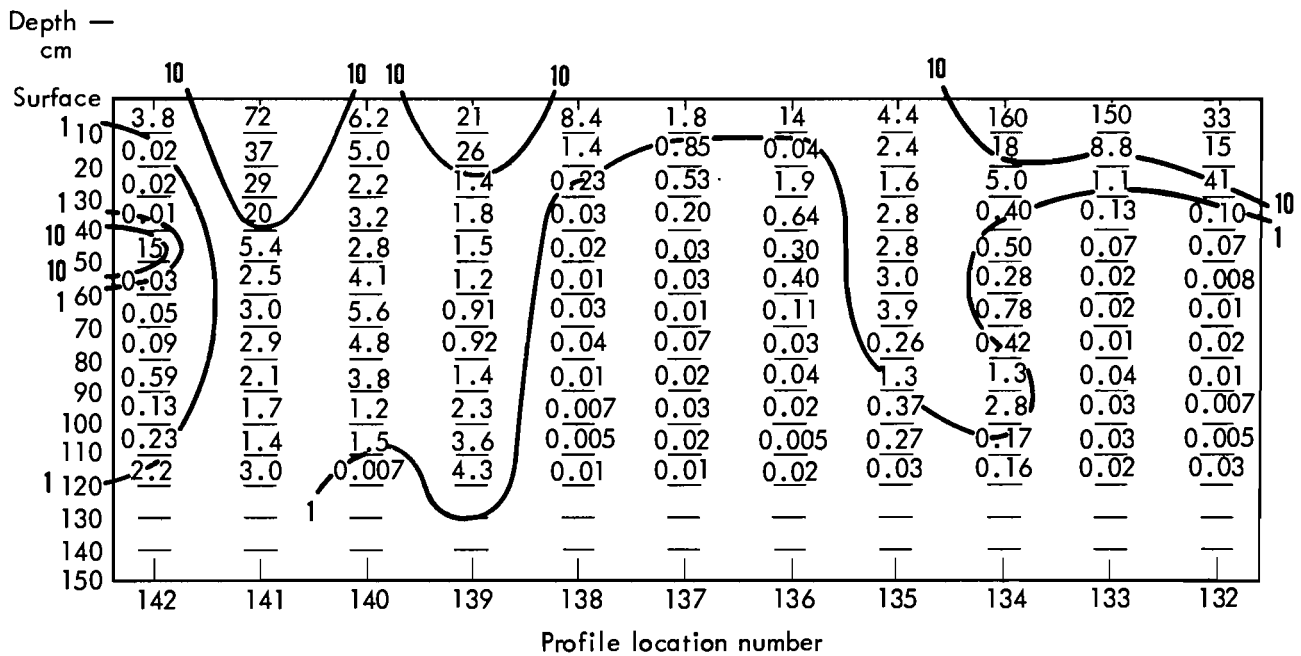


Fig. 36. Plutonium profile data, Locations 132-142, YVONNE.

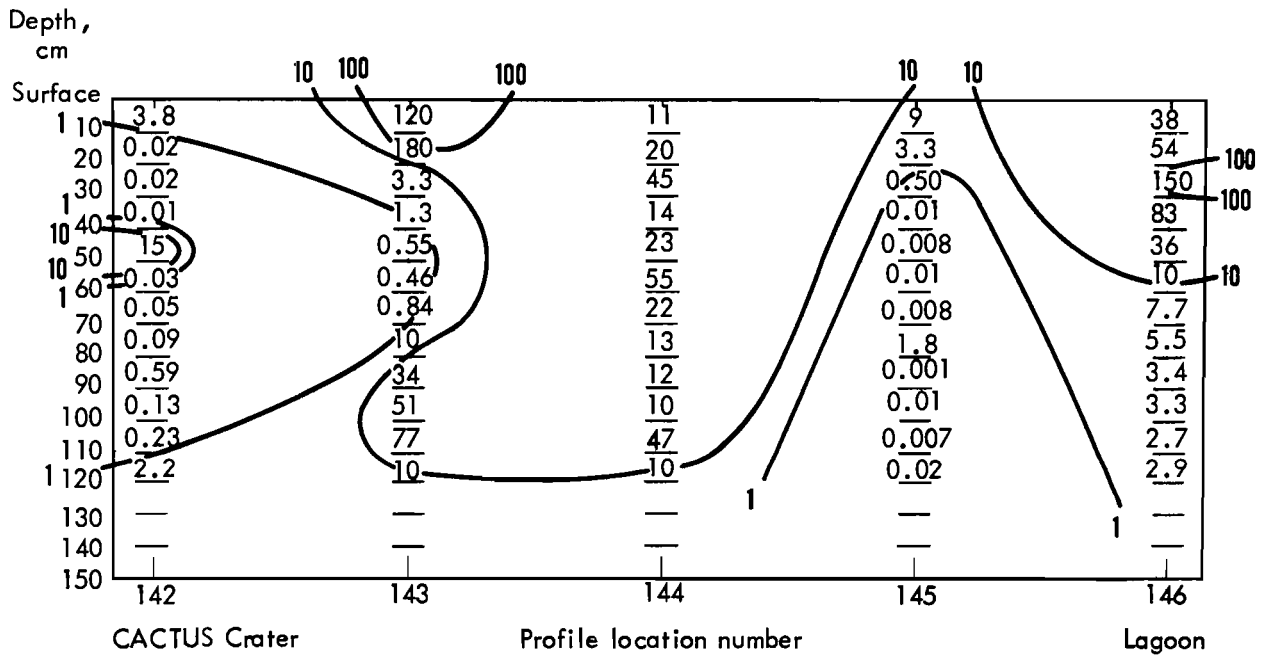


Fig. 37. Plutonium profile data, Locations 142-146, YVONNE.

over 120 cm depth) in the vicinity of Locations 141-140 and Locations 143-144. These activities fall off, however, as one proceeds to Locations 139 and 145.

#### Southern Portion of Atoll (SAM-LEROY)

For discussion purposes, the islands within this portion of the Atoll have been divided into three groups. Group A includes DAVID, ELMER, and FRED

because of their importance as likely sites for habitation by the returning native population. These islands are no different, radiologically speaking, from the remainder of the islands in this part of the Atoll. Group B consists of all of the remaining islands except LEROY, including: SAM, TOM, URIAH, VAN, ALVIN, BRUCE, CLYDE, REX, WALT, GLENN, HENRY, IRWIN, JAMES, and KEITH. LEROY is placed in Group C because its radiological conditions are slightly different from those of the other islands.

Group A—The scientific and military headquarters were situated on ELMER and FRED during the weapons-testing period. DAVID was used mostly for communications and recreational purposes. Relative to the northern islands, radiological contamination of these islands was small. Any observed elevated levels of contamination probably would have resulted from special operations such as equipment decontamination, radiochemical processing, etc. Special samples were collected in those areas suspected of containing contamination from these operations; however, no elevated levels were noted. The mean and range of activities observed on these islands are:

Radionuclide	Activity, pCi/g	
	Mean	Range
<sup>90</sup> Sr	0.41	0.02-4.8
<sup>137</sup> Cs	0.21	0.01-2.1
<sup>239</sup> Pu	0.04	0.004-0.31
<sup>60</sup> Co	0.03	0.01-0.15

The depth distributions generally display a slight decrease in activity immediately below the surface and then become essentially homogeneous with increasing depth.

Group B—Most of the islands in this group are small in area; in fact, SAM, TOM, URIAH, VAN, ALVIN, CLYDE, and WALT are hardly more than small sandbars with some vegetation on them. The mean and range of observed activities obtained from the 15-cm-deep surface samples, including those collected on the beaches, are:

Radionuclide	Activity pCi/g	
	Mean	Range
<sup>90</sup> Sr	0.52	0.03-3.9
<sup>137</sup> Cs	0.14	0.004-1.8
<sup>239</sup> Pu	0.07	0.004-1.1
<sup>60</sup> Co	0.06	0.007-63

The distributions of activity with depth display similar characteristics throughout these islands. In areas of dense vegetation, the activities within the top 20 cm decrease relatively slowly with relaxation lengths of about 8 cm. On the other hand, profile samples collected in open or sparsely vegetated areas exhibited essentially homogeneous distributions.

Group C—LEROY was situated within the fallout patterns from several events that took place on the eastern and northern sides of the Atoll. This, of course, was reflected by the elevated activities measured in soil samples from this island. Furthermore, the island's dense vegetation probably tends to inhibit



dilution of the activities by environmental processes. The activities obtained from the 15-cm-deep surface samples are:

Radionuclide	Activity pCi/g	
	Mean	Range
<sup>90</sup> Sr	11	1.6-34
<sup>137</sup> Cs	3.2	0.5-10
<sup>239</sup> Pu	0.63	0.02-2.0
<sup>60</sup> Co	0.58	0.04-5.0

These mean activities are roughly ten times greater than those observed on the other islands in the southern part of the Atoll. The depth distributions of activity measured at three locations within the interior of the island exhibit very gradual decreases in activity with depth. Relaxation lengths of 10 cm or greater are typical.

#### EXTERNAL DOSE ESTIMATES

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#### Introduction

Our objective was to quantitatively assess the total external dose that the returning native population might receive as a result of the radiological contaminants distributed in the environs of the Enewetak Atoll. Since the external dose is almost entirely due to the gamma-

emitting radionuclides, with only minor contributions from alpha and beta emitters, it was essential to obtain the best possible description of the geographical variability of the gamma exposure rates in air on each island of the Atoll. These data, in conjunction with pertinent population statistics and expected life style, will enable us to make realistic estimates of the external dose to the future inhabitants.

Several independent techniques were used to measure these exposure rates, since each technique has its own set of limitations (i. e. nonlinear energy response, portability of equipment, and extent of geographical coverage). We used results from the following techniques to satisfy the objective: ground measurements made with the use of a portable, hand-held Baird-Atomic NaI scintillation detector, two types of thermoluminescent dosimeters (TLD), and a helicopter-borne NaI detector array (aerial survey). The first two techniques are discussed below, while the details and results of the aerial survey are discussed in a separate chapter of this report. A comparison of the results obtained by these techniques and the use of the results in the population dose computation is included in the following discussions.

#### Measurement Techniques

##### Ground Measurements Made With Baird-Atomic NaI Detector

This instrument is a transistorized, hand-held portable ratemeter sensitive to gamma radiation. It consists of a photomultiplier tube optically coupled with a NaI crystal, electronic circuits, meter, associated range selector, and two "D"

batteries in a sealed container. The detector assembly is a thallium-activated NaI crystal (2.54-cm diam × 3.8-cm long). It is contained in a hermetically sealed can fitted with a glass window which is optically coupled to the photocathode window of the photomultiplier tube. The radiation level indicating meter is calibrated in microroentgens per hour in three ranges corresponding to 0 to 30, 0 to 300, and 0 to 3000  $\mu\text{R/hr}$ . Since the instrument is completely sealed and desiccated, it readily survived the conditions of constant exposure to sunlight, rain, salt water, and general rough handling encountered on the Atoll.

The instruments were carefully calibrated at the primary calibration range of the National Environmental Research Center, Las Vegas. The range, consisting of a horizontal track approximately 10 m long is situated in an air-conditioned concrete block room. Prior to calibration, each instrument was turned on for several hours and thoroughly inspected. The calibration was performed by attaching the detector to a traveling dolly mounted on a horizontal track. This allowed positioning of the instrument at various distances from a 1-mCi  $^{137}\text{Cs}$  source inserted in the source holder at one end of the track. The instrument's response was then recorded at various distances from the source so that all three ranges of the instrument were checked. The response was then compared with the calculated dose rate at the corresponding distances from the source, and, if necessary, appropriate corrections were applied to the instrument.

While the energy response of this instrument is inherently nonlinear, it was

not a serious limitation in this case because of the dominance of  $^{137}\text{Cs}$  in the radiation background on the Atoll. The instrument was expected to overrespond if the gamma flux was due to scattering from a buried area source rather than from a point source as used in the calibration. This will be shown to be of minor consequence when we compare the resulting data with those obtained by other techniques. In addition, the instrument does not respond quantitatively to cosmic radiation, which is essentially the only natural source of radiation on the Atoll.

Practically all of the measurements obtained with this instrument were made by the soil-survey teams. The exposure rate at 1 m above the ground was measured at each of the soil sample locations on every island in the Atoll for possible correlation with the soil activities. The resulting data, which include a rather extensive coverage of islands, are presented in the "d" series of figures in Appendix II. Additional measurements were made at each TLD location for direct correlation with the TLD measurements.

#### Thermoluminescent Dosimeter (TLD) Measurements

We used LiF and  $\text{CaF}_2:\text{Dy}$  TLD chips for measuring the radiation fields at numerous locations on the Atoll. The LiF chip was used as the principal detector due to its energy linearity and its excellent thermal stability. Its response is within approximately 1% of being air equivalent for a typical environmental radiation field that contains appreciable scattered radiation in addition to the primary gamma rays that are present.

Therefore, the results derived from the LiF TLDs were chosen as a reference to which measurements obtained by the other techniques could be compared. The  $\text{CaF}_2$  TLDs have an enhanced energy response at low energies and were used to detect possible low-energy radiation fields. A comparison of their signals with those from the LiF TLDs may provide an indication of the presence of an unsuspected concentration of low-energy radiation. For a typical radiation field, the  $\text{CaF}_2$  TLDs were expected to overestimate the dose rate to air by approximately 30 to 40%.

The LiF and  $\text{CaF}_2$  chips (1/8-in. square  $\times$  0.035-in. and 0.040-in. thick, respectively) were carefully selected by



Fig. 38. Field placement of TLD's with enlarged view of TLD packet.

a process of annealing, followed by irradiation to a common total exposure. Subsequent readout then allowed the extraction of defective chips. The TLDs were transported to Enewetak and annealed on the Atoll immediately prior to being placed on the seven outlying islands that were selected for the TLD program. Two LLL plastic personnel badges containing three LiF and three  $\text{CaF}_2$  chips were placed at each field location. The TLD packets were attached by two nails and a nylon strap to small tree limbs at a height of 1 m above the ground (Fig. 38). Each location was marked with copious quantities of fluorescent tape and paint to facilitate retrieval of the TLDs after the 3-1/2-mo exposure period. The locations were carefully chosen to obtain a representative sampling of the terrain (i. e., densely and sparsely vegetated areas and areas adjacent to sandy beaches).

Upon retrieval each TLD packet was immediately placed in a lead container and handcarried to LLL where it was stored in a lead container in an underground, radiation-counting facility. Each chip was individually read on the LLL, hot-nitrogen, automatic TLD chip reader\* which was interfaced to a PDP-11 computer. In this way a catastrophic reader failure would only reduce the precision of the answer and would not result in the total loss of data from any badge. This technique also eliminated undetected errors due to drift in reader sensitivity.

\*K. F. Petrock and D. E. Jones, "Hot Nitrogen Gas for Heating Thermoluminescent Dosimeters," in Proceedings of the Second International Conference on Luminescent Dosimetry (Gatlinburg, Tenn., 1968).

A number of ancillary experiments were performed for calibration purposes and to insure that no errors were incorporated into the measurements. A separate set of chips was exposed to a  $^{137}\text{Cs}$  point source at convenient times during the field exposure period for calibration and signal-fading studies. The strength of the calibration source was checked before and after field use with NBS-calibrated Radocon chambers and is known to within 3% at one standard deviation. Control TLDs were carried to the outer islands and back to measure the dose received during transit. All of the chips were then stored in the lead containers for the balance of the field measurement period. In addition, another set of control TLDs was stored within and on the periphery of the lead storage containers for environmental background studies.

The background exposure on the control TLDs was essentially all contributed by cosmic radiation during the 3-1/2-mo exposure period on the Atoll and during the aircraft flight to LLL. The average background exposure for the two types of TLDs was subtracted from all field measurements so that the results represent only the terrestrial radiation exposure rates. For verification purposes, the magnitude of the total background exposure was also estimated by using successive differences for each type of TLD on the three sets of calibration exposures and by using the sensitivity in light output per milliroentgen (mR) to estimate exposure for the average control light output. All estimates fell in the range of 10 to 12 mR, which agrees well with our previous experience of measuring cosmic ray exposures.

The TLD-signal-fading data have been carefully analyzed to determine the necessity, if any, of applying a fading correction. Figure 39 shows the net light sums for identical exposures at specified times following the start of the field measurement. The TLDs were exposed at different times during the field measurement, and thus long post-annealing times represent later exposures. Note that early exposures (day 4), have lower light sums than those at the end of the field measurement (day 111), due to thermal fading. In the analysis a constant exposure rate was assumed and the empirical fit of Fig. 39 was assumed to

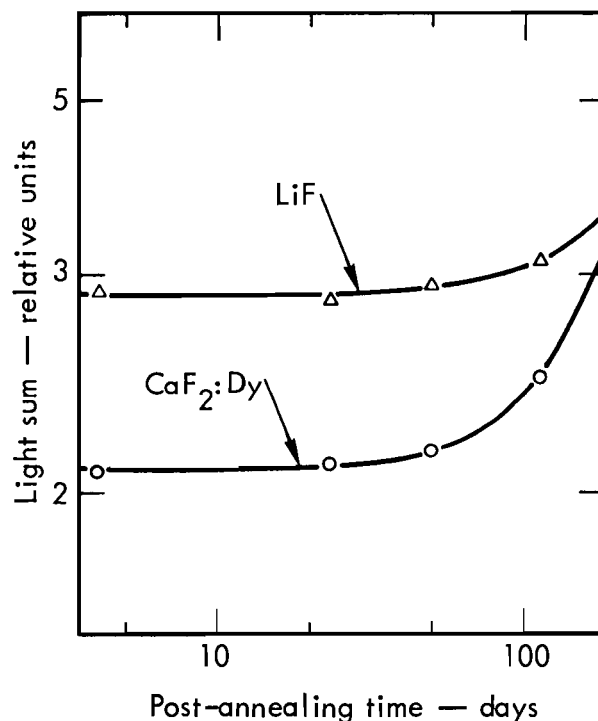


Fig. 39. A plot showing TLD fading characteristics. The TLDs were subjected to equal exposures ( $^{137}\text{Cs}$  source) at various times during the field measurement period. Annealing time was at  $t=0$ , exposures were from  $t=1$  to  $t=111$  days, and the light readings were taken from  $t=130$  to  $t=134$  days.

describe the fading. These assumptions should be quite good for the nearly constant ambient field conditions and the age of the artificial radionuclides present. Corrections of less than 1% for LiF and 3% for CaF<sub>2</sub> were obtained by integration and applied to the calibration data. These fading exposures were performed on the atoll and the TLDs were stored under ambient conditions.

The net light outputs from the calibration exposures are plotted against the calculated exposures in Fig. 40. Second-degree polynomial expressions are fitted to the data. From these curves, one may assign exposures to the light outputs from all the TLDs. These exposures were then separated by island and divided by the number of hours of field exposure to determine the appropriate exposure rates.

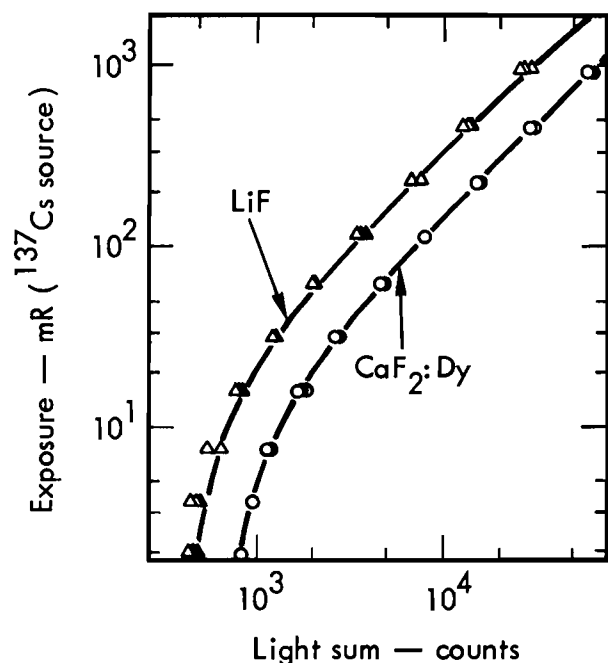


Fig. 40. Calibration curves for LiF and CaF<sub>2</sub>:Dy TLD's. The values for CaF<sub>2</sub> counts have been multiplied by 0.05 to enable presentation of both sets of data in the same figure.

The LiF measurements for the islands of ALICE, BELLE, CLARA, DAISY, IRENE, JANET, AND PEARL are shown in figure overlays at the respective geographical locations where the measurements were made (see Appendix II, series h). Table 17 contains a complete listing of the CaF<sub>2</sub>, LiF, and portable NaI measurements for each TLD location.

Table 17. Listing of exposure rate levels.

TLD location	Exposure rates, $\mu\text{R/hr}$		
	TLD (LiF)	TLD (CaF <sub>2</sub> )	Portable NaI detector
Island: ALICE			
17	48	59	55
18	120	132	120
19	108	120	110
55	0	4	3
56	45	52	45
57	42	50	45
58	109	128	100
59	127	142	130
60	6	10	7
61	26	28	20
Island: BELLE			
14	84	97	80
15	131	151	120
16	121	132	120
21	8	16	12
22	129	133	110
23	118	136	130
24	154	173	140
25	139	173	140
26	138	155	145, 1-m height
27	149	168	145, 0.33-m height
28	140	167	145, 0.67-m height
29	124	153	145, 1.33-m height
38	200	219	200
39	81	92	100
Island: CLARA			
20	67	65	75
41	12	15	8.5
42	58	59	50
43	49	58	50, 1-m height
44	58	66	50, 0.33-m height

Table 17 (continued)

TLD location	Exposure rates, $\mu\text{R/hr}$			TLD location	Exposure rates, $\mu\text{R/hr}$		
	TLD (LiF)	TLD (CaF <sub>2</sub> )	Portable NaI detector		TLD (LiF)	TLD (CaF <sub>2</sub> )	Portable NaI detector
45	55	61	50, 0.67-m height	88	43	58	60
46	52	52	50, 1.33-m height	89	30	42	50
47	54	58	60	310	3	8	7.5
51	104	112	105	311	33	41	45
52	118	144	130	312	110	137	135
Island: DAISY				313	79	104	110
48	11	13	10	314	47	64	75, 1-m height
49	33	35	20	315	46	61	75, 1.5-m height
63	20	28	13	316	55	70	75, 0.5-m height
64	17	21	13	317	66	75	75
65	18	21	11	318	43	61	65
66	8	12	8	319	54	61	65
67	8	11	7, 1-m height	320	36	46	50
68	9	12	7, 0.5-m height	321	28	35	22
69	7	11	7, 1.5-m height	322	1	2	3, 1-m height in bunker
70	7	12	7.5	323	1	2	3.5
75	8	13	10	324	19	19	16
76	106	113	90	327	43	60	75, 1-m height, 0.02-in.-Al cover
77	65	72	65	328	0	1	3, 1-m height, 0.02-in.-Al cover
Island: IRENE				Island: PEARL			
71	92	107	90	1	23	33	21
73	194	215	200	2	159	181	170
74	25	34	45	3	151	178	170
78	72	86	75	4	48	70	70
80	26	34	25	5	52	73	60
Island: JANET				6	44	56	50
301	62	71	70	7	31	44	40
302	65	73	80	8	19	26	25
303	56	73	80	9	19	26	14
304	70	85	90	11	14	19	10
305	30	42	45	12	19	24	12
306	36	48	55	13	14	17	8
307	45	58	65	31	68	74	65
308	36	42	45	32	128	138	65
309	37	44	45	33	80	90	80
81	1	5	5	34	39	49	50
82	19	26	18	35	43	56	50
83	8	16	12	36	67	82	65
84	32	43	27	37	38	44	40
85	50	65	65				
86	46	58	60				
87	54	67	65				

Contiguous locations.

A statistical analysis was performed to determine the accuracy of the TLD results. Within the range of 30 to 50  $\mu\text{R/hr}$ , the accuracy of the exposure rates is conservatively estimated to be 4% for  $\text{CaF}_2$  and 6% for LiF at one standard deviation. For the  $\text{CaF}_2$  results, this estimate does not include the nonrandom error due to the nonlinear energy response. For very low exposure rates the error becomes much larger, especially in regard to the LiF data. This is due to the subtraction of the relatively large background, the increased variability of the data at low exposure rates, and the empirical fitting technique that forces the best fit at the higher exposure rates. For instance, at an exposure rate of 4  $\mu\text{R/hr}$  the LiF results are considered to be accurate to approximately 40%; the relative precision is considerably better.

#### Aerial Radiological Survey

The details of this survey, including results, are provided in a separate chapter of this report. In essence, gamma rays were detected by a helicopter-borne array of 40 NaI detectors flown over each island on a 150-ft grid spacing. An inertial navigation system provided position coordinates. The output from the detectors was analyzed according to pulse height and recorded along with the position data on magnetic tape. The tape was processed on a ground-based computer to produce a very detailed mapping of the iso-exposure rate contours at 1 m above the ground for each island in the Atoll.

#### Comparison of Results

Because the LiF TLD has excellent thermal stability and its response is

essentially air equivalent, the LiF measurements are considered to be the most accurate measure of the gamma exposure rates at the limited number of sites where TLDs were placed, and, therefore are used as the reference to which all the other measurements are compared. However, when making comparisons between results obtained with various techniques, one must be careful to avoid comparing measurements that are entirely different in nature. For instance, the radiation field measured by the TLDs and portable NaI detector is very local in nature (the order of a few square meters), while that measured by the aerial system is of the order of hundreds of square meters. Thus, local radiation gradients are averaged over large areas by the aerial system, and the results obtained from specific areas may be quite different from those obtained by the TLDs and portable survey meters.

The comparison, shown in Table 18, specifically excludes areas exhibiting steep radiation gradients so that the TLD and portable-survey-meter measurements may be considered representative of an area of several hundred square meters. With this in mind the TLD locations in Table 18 were selected from areas of uniform exposure rates in the interiors of ALICE, BELLE, DAISY, and JANET. Inspection of the data in Table 18 reveals that the LiF measurements are approximately 17% less than those of  $\text{CaF}_2$ . This is reasonable in view of the enhanced energy response of  $\text{CaF}_2$  at low energies. This expected relative difference between the results of the two types of TLDs also gives added credence to the LiF measurements. The table also reveals that the aerial survey measurements and the

Table 18. Comparison of the gamma-ray exposure rates ( $\mu\text{R/hr}$ ) obtained at selected locations by the various techniques.

Island	Exposure rate, $\mu\text{R/hr}$							
	Exposure rate, $\mu\text{R/hr}$			TLD (LiF) TLD (CaF <sub>2</sub> )	Portable NaI detector	TLD (LiF)		TLD (LiF) Aerial survey
	TLD location	TLD (LiF)	TLD (CaF <sub>2</sub> )			Portable NaI detector	Aerial survey	
ALICE	17	48	59	0.81	55	0.87	56	0.85
	18	120	132	0.91	120	1.0	81	1.48
	56	45	52	0.87	45	1.0	38	1.21
	58	109	128	0.85	100	1.09	121	0.89
	59	127	142	0.89	130	0.98	121	1.04
BELLE	22	129	133	0.97	110	1.17	101	1.28
	23	118	136	0.87	130	0.91	121	0.97
	24	154	173	0.89	140	1.10	149	1.04
	25	139	173	0.80	140	0.99	149	0.93
	38	200	219	0.91	200	1.00	122	1.64
	39	81	92	0.88	100	0.81	81	1.00
DAISY	49	33	35	0.94	20	1.65	25	1.30
	63	20	28	0.71	13	1.54	25	0.79
	64	17	21	0.81	13	1.31	17	0.99
	65	18	21	0.86	11	1.64	17	1.04
	77	65	72	0.90	65	1.00	56	1.16
JANET	85	50	65	0.77	65	0.77	43	1.17
	86	46	58	0.79	60	0.77	43	1.07
	87	54	67	0.81	65	0.83	43	1.26
	88	43	58	0.74	60	0.72	36	1.21
	89	30	42	0.71	50	0.60	38	0.79
	301	62	71	0.87	70	0.89	43	1.45
	302	65	72	0.89	80	0.81	46	1.41
	303	56	73	0.77	80	0.70	54	1.04
	304	70	85	0.82	90	0.78	52	1.34
	305	30	42	0.71	45	0.67	40	0.75
	306	36	48	0.75	55	0.65	55	0.66
	307	45	58	0.78	65	0.69	52	0.87
	308	36	42	0.86	45	0.80	35	1.04
	309	37	44	0.84	45	0.82	28	1.34
	312	110	137	0.80	135	0.81	87	1.27
	313	79	104	0.76	110	0.76	70	1.13
317	66	75	0.88	75	0.88	43	1.54	
318	43	61	0.70	65	0.66	43	1.00	
319	54	61	0.89	65	0.88	43	1.26	
320	36	46	0.78	50	0.72	40	0.90	
321	28	35	0.80	22	1.27	32	0.88	
Average ratios				$0.83 \pm 0.07$		$0.93 \pm 0.26$		$1.10 \pm 0.28$



portable NaI detector results agree, on the average, within about 10% with the LiF measurements. This is within the accuracy of the measurements and the agreement is considered excellent. On the basis of this comparison and because of the extensive geographical coverage, we feel that the aerial measurements provide the most complete and accurate description of the gamma exposure rates throughout the entire Atoll. Therefore, we feel justified in using these data as a basis for determining the external dose to the returning population.

#### External Dose Determination

In addition to the gamma-ray exposure rates, one needs to consider the expected living patterns of the future inhabitants in order to evaluate the external dose problem. Due to the uncertainties inherent in predicting future living patterns, several cases were chosen for analysis. These are presented in Table 19. The selection of these cases was based upon the most recent information available regarding present population figures, age distributions, and expected life styles (see The Enewetak Atoll People, p. 25). Furthermore, the cases were chosen in such a manner as to bracket the most likely range of doses which could be received by any sizable segment of the population. This will allow any other reasonable pattern to be inferred by proper interpolation of the results obtained for the cases shown in Table 19.

The first four cases are based upon the assumption that some fraction of the population may choose to reside primarily on JANET (the largest island within the northern part of the Atoll), with the re-

mainder residing on FRED, ELMER, or DAVID in the southern group of islands. Each case under consideration allows for visits to other islands. Case I<sub>b</sub> differs from case I<sub>a</sub> in that more time is allotted to temporary occupation of islands other than JANET at the expense of less time being spent in the JANET village area. These cases, or combinations thereof, are considered to represent the most likely living patterns.

Case V, on the other hand, represents a "worst credible" type of living pattern. The village is situated on BELLE, the island with the highest mean gamma-ray exposure rates (excluding YVONNE), and visits are only allowed to the other northern islands. Thus, Case V would most probably lead to upper-limit doses if some reasonable fraction of the population should decide to reside permanently on BELLE. However, such a plan is not being considered at this time. No attempt was made to subdivide the time spent on other islands into specific areas, since it was felt that such a breakdown would unnecessarily complicate the calculations.

Even though wide variations in gamma-ray exposure rates were measured throughout the northern islands, it was necessary, for the purpose of the dose calculation, to derive the most reasonable values of the current mean exposure rates for each specific geographical area under consideration. These values are shown in Table 20. The mean exposure rates for specific areas of JANET were obtained by examination of the <sup>137</sup>Cs and <sup>60</sup>Co iso-exposure-rate contour maps provided by the aerial survey. The village area was assumed to lie along the lagoon

Table 19. Assumed geographical living patterns.

Description	Group	Village	Beach	Interior	Lagoon	Other islands
I <sub>a</sub> Village on JANET, visits to other northern islands only.	Infants	85 <sup>c</sup>	5	0	0	10
	Children	55	10	15	5	15
	Men	50	5	15	10	20
	Women	60	10	10	0	20
I <sub>b</sub> Village on JANET, visits to other northern <sup>a</sup> islands only.	Infants	70	5	5	0	20
	Children	50	5	15	10	20
	Men	40	5	20	10	25
	Women	50	5	15	5	25
II Village on FRED, ELMER, or DAVID, visits to northern <sup>a</sup> islands only (excl. JANET).	Infants		Same as Case I <sub>b</sub>			
	Children					
	Men					
	Women					
III Village on JANET, visits to southern <sup>b</sup> islands only.	Infants		Same as Case I <sub>a</sub>			
	Children					
	Men					
	Women					
IV Village on FRED, ELMER, or DAVID, visits to southern <sup>b</sup> islands only.	Infants		Same as Case I <sub>b</sub>			
	Children					
	Men					
	Women					
V Village on BELLE, visits to other northern islands only.	Infants		Same as Case I <sub>b</sub>			
	Children					
	Men					
	Women					

<sup>a</sup>Northern islands include ALICE, BELLE, CLARA, DAISY, IRENE, JANET, KATE, LUCY, MARY, NANCY, OLIVE, PEARL, SALLY, TILDA, URSULA, VERA, and WILMA.

<sup>b</sup>Southern islands include all islands from TOM through LEROY, proceeding clockwise around the Atoll.

<sup>c</sup>These values represent the percentage of time spent in the various areas.

side of the island. The mean values given for all of the northern islands were obtained by weighting the mean exposure rates for each individual island with the area of each island. Since the minor contamination of the southern islands is relatively uniform, the mean <sup>137</sup>Cs and <sup>60</sup>Co exposure rates were chosen by inspection of the individual aerial-survey contour maps. The cosmic-ray contribution was estimated to be 3.3  $\mu$ R/hr at this latitude and the naturally occurring

radionuclides in the soil and sea water were expected to contribute an additional 0.2  $\mu$ R/hr.

The relative gamma-ray exposure rate contributions from <sup>60</sup>Co and <sup>137</sup>Cs obtained from the aerial survey agrees well with values independently inferred from the soil activity-depth profile measurements. Although the soil measurements indicate trace amounts of other gamma emitters, such as <sup>125</sup>Sb, <sup>155</sup>Eu, and <sup>241</sup>Am, calculations of exposure

Table 20. Estimated mean exposure rates ( $\mu\text{R/hr}$ ) used for dose calculations.<sup>a</sup>

Major geographical area	Source	Exposure rate, $\mu\text{R/hr}$		
		Village	Interior	Beach
JANET	$^{137}\text{Cs}$	9.0	33	1.0
	$^{60}\text{Co}$	5.0	14	0.5
	Cosmic and natural	3.5	3.5	3.5
BELLE	$^{137}\text{Cs}$	61	61	1.0
	$^{60}\text{Co}$	50	50	0.5
	Cosmic and natural	3.5	3.5	3.5
FRED, ELMER, or DAVID	$^{137}\text{Cs}$	0.2	0.2	0.2
	$^{60}\text{Co}$	0.1	0.1	0.1
	Cosmic and natural	3.5	3.5	3.5
Lagoon	Cosmic and natural	3.5	3.5	3.5
<u>Area-weighted mean exposure rates, <math>\mu\text{R/hr}</math></u>				
Northern islands (ALICE-WILMA, but excluding JANET)	$^{137}\text{Cs}$	14		
	$^{60}\text{Co}$	21		
Northern islands (ALICE-WILMA, but excluding BELLE)	$^{137}\text{Cs}$	15		
	$^{60}\text{Co}$	16		
Southern islands (TOM-LEROY)	$^{137}\text{Cs}$	0.2		
	$^{60}\text{Co}$	0.1		

<sup>a</sup>Based upon the mean values reported in the aerial survey section.

rates based upon the observed soil activities indicate that these radionuclides contribute at most an additional 3 to 5% of the total exposure rate. The contribution due to these radionuclides was therefore neglected. Thus, the mean exposure rates shown in Table 20 are felt to be the most reasonable values available for computing integrated dose values. In fact, these mean values may be somewhat high (conservative), even though the aerial survey data agree well with the TLD data, because the latter may have slightly overestimated the exposure rates due to the minimal beta-ray shielding afforded by the TLD badges.

Integral 5-, 10-, 30-, and 70-yr gamma-ray doses for each age group were calculated for each case or living pattern

described in Table 19. The results were then combined by "folding" in the present population distribution shown in Table 21. Corrections were made for radioactive decay but not for possible weathering and subsequent deeper penetration of the radionuclides in the soil. The results of these calculations are given in Table 22 and are labeled "unmodified." Additional calculations were made to ascertain the effect of reasonable attempts to reduce the exposure rates on the Atoll.

The first modification, labeled "village graveled" in Table 22, reflects the effect of covering the village areas with about 2 in. of coral gravel — a common practice throughout Micronesia.\* This action can

\*J. A. Tobin, private communication, 1973.

Table 21. Population distribution of Enewetak.

Age groups	Percentage of total population
Infants (0-5 yr)	
Male	12
Female	10
Children (6-18 yr)	
Male	21
Female	21
Adults (19-50 yr)	
Male	18
Female	14
Adults (over 50)	
Male	2
Female	2
Total population	432
On Ujilang now	340

be expected to reduce the gamma exposure rates in the village area by approximately a factor of two. The second and third modifications are based upon the assumption that clearing the islands for agricultural use and housing will result in some mixing of the top soil. It appears that it would be practical during this period to also plow many of the more contaminated islands to a depth of 1 ft. Assuming that plowing results in mixing rather than burying the topsoil, an average reduction in exposure rates of about a factor of three may be obtained. This reduction factor is based upon the present 3- to 5-cm relaxation lengths (the depth at which the activity is  $e^{-1}$ , or 37%, of the surface activity) for activity depth distribution in the uppermost soil layers of the more contaminated areas. This value, however, is highly variable from site to site. In Table 22 modification (2) indicates the effect of plowing only JANET or BELLE,

while modification (3) reflects the additional effect of plowing all the northern islands. Deeper plowing or turning over the soil rather than mixing would, of course, result in even greater exposure-rate reductions. For example, mixing to a depth of 2 ft would reduce the exposure rates by an additional factor of two, while covering the sources with approximately 1 ft of uncontaminated soil would essentially reduce the exposure rates to negligible values similar to those observed on the southern islands. Removing the top 6 in. of soil, which often contains about two-thirds of the activity, would result in a threefold reduction in the exposure rates. The advantages of plowing or removing the topsoil should, however, be considered on a case-by-case basis because of the highly variable distributions of activity with depth. In fact, plowing IRENE could possibly increase the exposure rates in specific areas due to the elevated activity levels beneath the surface.

A review of Table 22 reveals that extensive modifications may not be required in order to reduce the dose levels to values comparable to typical U.S. values. Keeping in mind that Cases I-IV represent approximations to the most likely living patterns, one observes that even for Cases I<sub>a</sub> and I<sub>b</sub>, the unmodified 70-yr integral doses are comparable to the U.S. Values,\* while Cases II and IV lead to considerably lower doses. The mean integrated doses to the entire population, shown in Table 22, were derived

\*H. L. Beck, W. J. Lowder, B. G. Bennett, and W. J. Condon, Further Studies of External Environmental Radiation, USAEC, Rept. HASL-170 (1966).

Table 22. Estimated integral external free air gamma doses (rads).

	Time interval, yr			
	5	10	30	70
<b>I<sub>a</sub></b>				
Unmodified	<u>0.76</u>	<u>1.37</u>	<u>3.12</u>	<u>5.33</u>
(1) Village graveled	<u>(0.62)</u>	<u>(1.12)</u>	<u>(2.58)</u>	<u>(4.51)</u>
(2) + JANET plowed	(0.41)	(0.75)	(1.77)	(3.27)
(3) + Northern islands plowed	(0.30)	(0.56)	(1.40)	(2.76)
<b>I<sub>b</sub></b>				
Unmodified	8.83	1.49	3.35	5.65
(1) Village graveled	<u>(0.71)</u>	<u>(1.28)</u>	<u>(2.89)</u>	<u>(4.96)</u>
(2) + JANET plowed	(0.49)	(0.87)	(2.01)	(3.62)
(3) + Northern islands plowed	(0.33)	(0.61)	(1.50)	(2.90)
<b>II</b>				
Unmodified	<u>0.38</u>	<u>0.68</u>	<u>1.59</u>	<u>2.97</u>
(3) Northern islands plowed	<u>(0.22)</u>	<u>(0.41)</u>	<u>(1.08)</u>	<u>(2.26)</u>
<b>III</b>				
Unmodified	<u>0.60</u>	<u>1.10</u>	<u>2.60</u>	<u>4.60</u>
(1) Village graveled	<u>(0.48)</u>	<u>(0.88)</u>	<u>(2.14)</u>	<u>(3.90)</u>
(2) + JANET plowed	(0.25)	(0.48)	(1.26)	(2.56)
<b>IV</b>				
Unmodified	<u>0.14</u>	<u>0.28</u>	<u>0.83</u>	<u>1.92</u>
<b>V</b>				
Unmodified	2.72	4.78	10.06	15.50
(1) Village graveled	<u>(1.78)</u>	<u>(3.14)</u>	<u>(6.69)</u>	<u>(10.53)</u>
(2) + BELLE plowed	(0.83)	(1.47)	(3.26)	(5.47)
(3) + Northern islands plowed	(0.68)	(1.23)	(2.77)	(4.76)
Mean population dose (average of cases I <sub>b</sub> -IV)				
Unmodified	<u>0.49</u>	<u>0.89</u>	<u>2.09</u>	<u>3.79</u>
(1) Village graveled	<u>(0.43)</u>	<u>(0.78)</u>	<u>(1.86)</u>	<u>(3.44)</u>
(2) + JANET plowed	(0.32)	(0.58)	(1.42)	(2.77)
(3) + All northern islands plowed	(0.24)	(0.45)	(1.17)	(2.41)
Sea level U. S. A. (80 mrad/yr) <u>Typical</u>	<u>0.40</u>	<u>0.80</u>	<u>2.40</u>	<u>5.60</u>

by averaging those for Cases I<sub>b</sub>, II, III, and IV. This implies that half of the returning population live on JANET and the other half live on FRED, ELMER, or DAVID and that trips to the northern or

southern islands are equally likely for both groups. The unmodified mean population doses are all quite comparable to U. S. values. At most, implementation of modifications 1 and 2 should be sufficient

Table 23. Illustration of dose breakdown among population groups (Case I<sub>a</sub> - unmodified).

Group	Total integrated dose, rad			
	5 yr	10 yr	30 yr	70 yr
Infants	0.64	1.15	2.66	4.53
Children	0.79	1.43	3.24	5.52
Men	0.82	1.47	3.32	5.61
Women	0.79	1.42	3.20	5.42

to assure mean population exposures well below the U.S. levels. Case V represents a "worst credible" type of living pattern which, of course, leads to appreciably higher doses. However, even in this situation, the modifications can bring the levels down to the range of U.S. values.

Because of the low amount of natural radioactivity normally present in the coral atolls, the external dose levels calculated for Cases I-III and V are still appreciably higher than corresponding levels found elsewhere in the Marshall Islands (essentially Case IV). The results for Cases II and IV indicate that restricting the permanent villages to "clean" southern islands at least temporarily would result in lower exposures. Note that for Case I<sub>b</sub> almost as much exposure is accumulated in the first 10 years as in the succeeding 20 years.

As illustrated in Table 23 for Case I<sub>a</sub>, the differences in radiation exposure of the various population groups are minor, particularly for the longer time periods. Similar results were obtained for the other cases, indicating that the exact breakdown among age groups is not highly important. The fact that the doses for Cases I<sub>a</sub> and I<sub>b</sub> do not differ substantially indicates that the exact time breakdown among geographical areas is also not critical. Table 24 illustrates the distribution of dose with respect to geographical area for Cases I-IV. The large fraction received while working in the interior or on other islands reflects, of course, the higher exposure rates present in these areas.

All of the doses discussed so far are due to free-air gamma plus cosmic-ray exposures. The effect of shielding by structures or the body itself on gonadal

Table 24. Percentage of unmodified exposure received from various locales.<sup>a</sup>

Case	Village	Beach	Interior	Lagoon	Other islands
I <sub>a</sub>	47	2	27	1	23
I <sub>b</sub>	36	1	33	2	28
II	22	2	8	4	64
III	58	2	33	1	5
IV	50	5	17	8	20

<sup>a</sup>For 30-yr intervals averaged over population distribution. Percentages for other time periods are similar.

or bone doses has been ignored. To convert from free-air dose (rads) to gonadal dose (rem), a body-shielding factor of 0.8 may be used.\*

The free-air dose will be additionally enhanced by the presence of beta rays, originating primarily from  $^{90}\text{Sr}$ - $^{90}\text{Y}$  in the soil. In radiation fields produced by global fallout, where the  $^{90}\text{Sr}/^{137}\text{Cs}$  activity ratio in the soil is normally about 0.67, the free-air beta dose at 1 m above the ground is expected to be about four times that due to the  $^{137}\text{Cs}$  gamma rays. At Enewetak, however, the  $^{90}\text{Sr}/^{137}\text{Cs}$  activity ratios in the soil samples showed a wide range of values with an average ratio of about three. Thus, the free-air beta dose rates may average about  $600 \mu\text{rad/hr}$  in the interior of JANET and about  $200 \mu\text{rad/hr}$  in the village area. The resulting beta-ray doses to the skin, eye lenses, and gonads will be about 50, 25 and 1%, respectively, of the free-air values.† Thus, appreciable increases in skin and eye-lens doses due to the beta contribution could be expected. The gonadal dose, on the other hand, would be insignificant.

Very little information is available to verify these calculated beta-ray air doses, but indications are that they may be unrealistically high. This is based upon data obtained from two LiF TLD badges that were equipped with aluminum shields, one of which was situated within the

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\* Report of the United Nations Scientific Committee on The Effects of Atomic Radiation, 27th Session, Vol. 1, Supplement No. 25 (1975).

† K. O'Brien, Health and Safety Laboratory, USAEC, New York, private communication (1973).

interior of JANET. These shielded badges only showed an approximate 10% reduction in exposure rates from those measured by the unshielded badges at the same location, thus leading one to suspect that the beta air doses are considerably less than the calculated values.

## MARINE PROGRAM

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### Purpose

The mission of the aquatic survey was to collect enough sufficiently representative samples to define and quantify the contributing radioactivities in the lagoon and reef areas of the Atoll. The radiological data are needed to assess both the exposure pathways to persons utilizing the aquatic environment and to determine the distribution of selected radionuclides in the Enewetak marine environment. Fish, invertebrates, plankton, and water and marine sediment were collected and other marine observations conducted during October, November, and December, 1972. This section of the report describes the kinds and quantities of samples obtained, the methods of collecting and processing, and the details pertinent to each kind of sample or program.

### General Program Description

#### Ships and Capabilities

A 17-ft Boston Whaler was flown from LLL to Enewetak for the survey of the

lagoon. It was powered by a 65-hp outboard engine and carried a 7.5-hp outboard for emergency use. It was equipped with a depth sounder and davit with a hand-operated winch and 500 ft of 3/32-in. steel cable, sufficient to reach any depth in the lagoon.

This boat was used chiefly for sampling near the shore; its range was limited because it was necessary to remain within sight of land to fix the station locations, which was done with a sighting compass. We sampled the lagoon between FRED and PEARL, no more than 6 km from shore; additional collections were made between LEROY and FRED, including stations in the Wide Passage.

Sampling by the Whaler crew included water collection, sediment collection, plankton-tow and mid-lagoon trolling with rod and reel. This small boat proved very satisfactory for these collections. In all, 43 of the 126 sediment grabs, 21 water samples, many open lagoon fish, and several plankton samples were collected by the whaler during the survey in spite of bad weather which seriously hampered its operation in the lagoon. On a number of days, operations were curtailed because of wind and sea conditions.

A landing craft utility (LCU) was provided for the survey and used to support all survey programs. Its use for the marine program was on an availability basis, but the time allotted was sufficient to complete the program. A portable winch powered by a gasoline engine was mounted on the stern of the vehicle deck. The winch contained 1000 ft of 3/32-in. stainless steel hydrographic cable which passed through a metering sheave secured to the port-side davit of the ves-

sel. All sampling operations were conducted from the port side with equipment attached to the hydrowire.

The bridge-height of the LCU was sufficient to sight on land from any location in the lagoon and the Navy crew provided all fixes necessary for locating station positions. Sample depths were determined from the wire-out readings recorded on the sheave. Water samples, sediment samples, and fish and plankton samples were obtained. Bad weather limited many operations from the LCU.

A 24-ft launch belonging to the USAEC has been stored and used at Enewetak since May 1972. It is powered by two 120-hp inboard-outboard engines and is equipped with a depth sounder.

This boat was used for transportation between sampling locations during all portions of the Enewetak Survey and for the in situ gamma probe work. The boat was adequate for both purposes, since it was large enough to handle the normal wind and wave conditions found in the lagoon, yet maneuverable enough to work in the shallow near-shore waters.

#### Equipment and Other Facilities

Both the Whaler and the LCU had complete pumping systems aboard. Surface and subsurface water samples were collected with battery-operated pumps through a weighted hose-line which was lowered to the desired depth. Each sampling operation was preceded by pumping for at least 10 min to flush out the entire system. The 55 liter black (Deldrum) polyethylene collection barrels were first rinsed with the sample water and then filled at the rate of 8 liters per min.



Sediment grab samples were collected with either Shipek, Ponar, or Ekman samplers. Plankton were collected in No. 6 or No. 10 nets, 1 m in diam. Fish were collected by trolling with rod and reel in the lagoon or with nets in the shallow near-shore areas. Invertebrates were hand collected. Crater sediments in MIKE and KOA craters were sampled with

a "Benthos" model 3-in.-diam gravity corer.

Every precaution was taken to ensure against contamination of the samples. All samples were placed in plastic bags, jars, or barrels, immediately after collection. After each day's cruise, all decks and equipment were washed to remove any sediment debris accidentally spilled and overlooked.

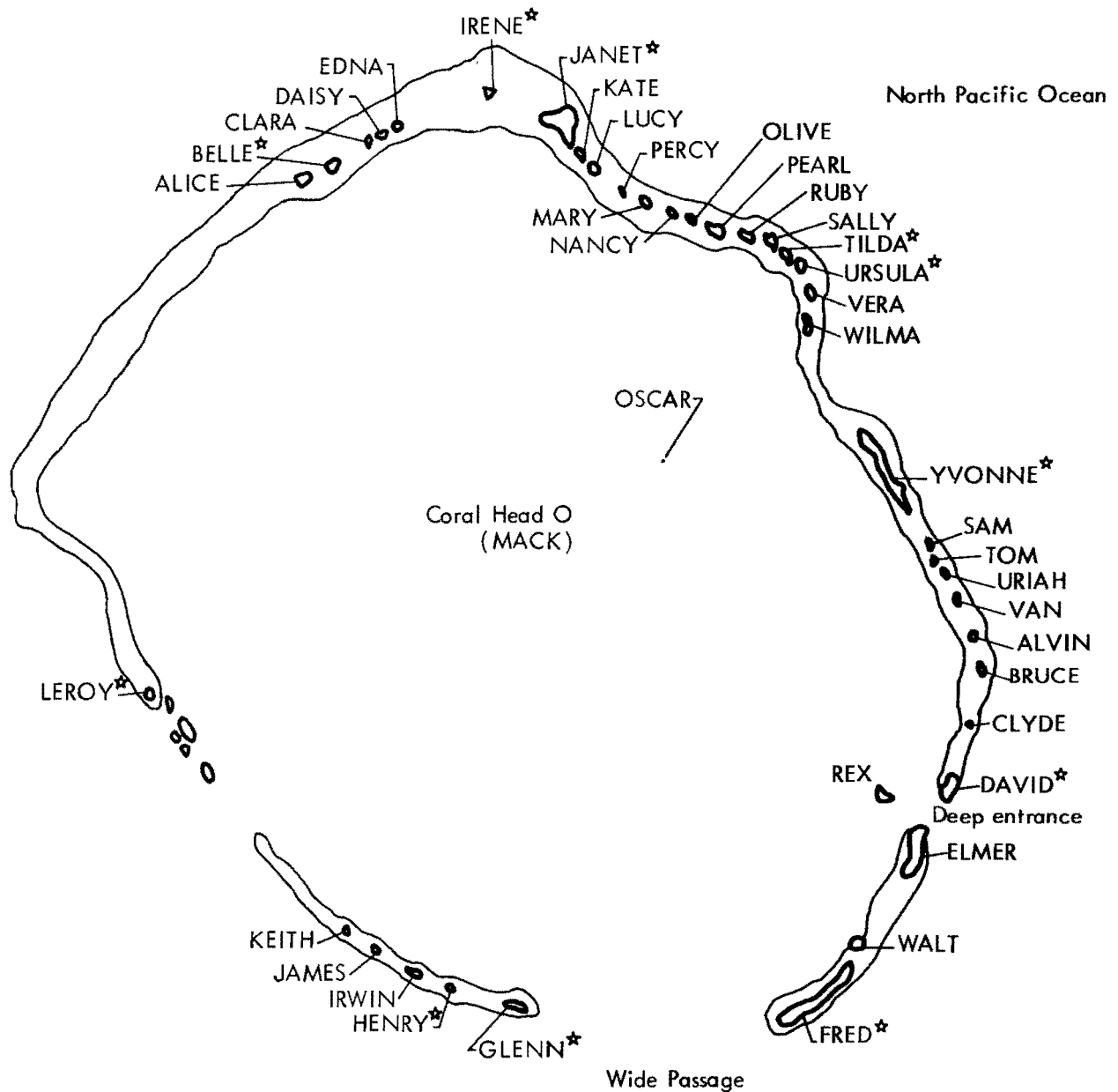


Fig. 41. Major collection locations (starred) of marine biological samples at Enewetak Atoll, October to December, 1972.

## Fish

### Introduction

There are more than 700 species of fish at Enewetak Atoll, but only a few species of reef, benthic, and pelagic fishes were selected for use in this study. The common anglicized names of the fishes are used in the text, but the scientific names and the Enewetakese common names, when known, are listed in Table 25. The Enewetakese names were those used by Smith Gideon, Enewetak magistrate, in his conversations with Victor Nelson at Enewetak in July 1973, and from Goo and Banner (1963).

The species selected were chosen for one or more of the following reasons:

(1) they are commonly eaten by the Marshallese; (2) they are relatively abundant at most of the collection sites; (3) they are representative of a feeding habit; or (4) there is previous relevant radiometric information about the species. The species of reef fishes selected as being representative of feeding habits include the mullet (a plankton and detritus feeder), convict surgeon (a grazing herbivore), goatfish (a bottom-feeding carnivore) and parrot-fish (a coral eater). The tunas, jacks, and dolphins – pelagic fish – and the snappers and groupers – benthic fish – are carnivores of high order in the food chain leading to man. Information about the radioactivity in Enewetak fish during the last 25 yr, including the species selected for this study, can be found in the reports of the University of Washington, Laboratory of Radiation Ecology, which include the following: Held, 1973<sup>a</sup>; Beasley and Held, 1972<sup>b</sup>; Held, 1971<sup>c</sup>; Welander, 1967<sup>d</sup>; Welander

et al., 1967<sup>e</sup>; Seymour, 1963<sup>f</sup>; Held, 1963<sup>g</sup>; Lowman, 1960<sup>h</sup>.

### Sample Collections

Reef Fishes—The nine major collection stations are shown in Fig. 41. They are listed in clockwise order around the Atoll, and beginning with the most northern station are as follows: BELLE, IRENE, JANET, TILDA-URSULA, YVONNE,

<sup>a</sup>E. E. Held "Fallout Radionuclides in Pacific Ocean Tuna," in Proc. Third National Symposium on Radioecology, 10-12 May 1971 (Oak Ridge, Tennessee) CONF 710501, p. 689.

<sup>b</sup>T. M. Beasley and E. E. Held, "Silver-108m in Biota and Sediments at Bikini and Eniwetok Atolls," Nature 230(5294), 450 (1971).

<sup>c</sup>E. E. Held, Radiological Resurvey of Animals, Soils and Groundwater at Bikini Atoll 1969-1970, U.S. Atomic Energy Commission, Rept. NVO-269-8 (1971).

<sup>d</sup>A. D. Welander, "Distribution of Radionuclides in the Environment of Eniwetok and Bikini Atolls, August 1964," in Symposium on Radioecology, Proc. Second National Symposium, 15-17 May 1967 (Ann Arbor, Michigan) CONF-670503, p. 346 (1969).

<sup>e</sup>A. D. Welander et al., Bikini-Eniwetok Studies, 1964: Part II. Radiobiological Studies, U.S. Atomic Energy Commission, Rept. UWFL-93 (Pt. II) (1967).

<sup>f</sup>A. H. Seymour "Radioactivity of Marine Organisms from Guam, Palau, and the Gulf of Siam, 1958-1959," in Radioecology, V. Schultz and A. W. Klement Jr., Eds. (Reinhold, New York, and Amer. Inst. Biol. Sci., Washington, D. C., 1963) p. 151.

<sup>g</sup>E. E. Held "Qualitative Distribution of Radionuclides at Rongelap Atoll," in Radioecology, V. Schultz and A. W. Klement, Jr. Eds. (Reinhold, New York, 1963) p. 167.

<sup>h</sup>F. G. Lowman, "Marine Biological Investigations at the Eniwetok Test Site," in Proc. Conference on Disposal of Radioactive Wastes, Monaco, Nov. 16-21, 1959 (IAEA, Vienna, 1960) p. 105.

Table 25. Common, scientific, and Marshallese names and wet weight to dry weight ratios of tissues from aquatic organisms collected at Enewetak and Kwajalein Atolls, October to December 1972.

Common name	Scientific name	Marshallese <sup>a</sup> name	Tissue	Number of samples	Wet/dry ratio
<u>Fishes</u>					
Barracuda	<u>Sphyraena</u> <u>barracuda</u>	Nidwa	Muscle	1	4.36
			Bone	1	
Bonefish	<u>Albula vulpes</u>		Muscle	1	3.38
			Viscera	1	1.57
			(solids and lipids)		
Skipjack	<u>Euthynnus yaito</u>	Loj	Light muscle	9	3.51
			Dark muscle	9	3.58
			Liver	9	3.60
			Bone	9	
Butterflyfish	<u>Chaetodon auriga</u>	Dribob	Evisc. whole	1	3.06
			Viscera	1	4.38
Convict surgeon	<u>Acanthurus</u> <u>triolestegus</u>	Kuban	Evisc. whole	30	3.54
			Viscera	28	5.26
Damselfish	<u>Abudefduf</u> sp.		Entire	1	3.09
Dolphin	<u>Coryphaena</u> <u>hippurus</u>		Muscle	2	4.01
			Liver	2	3.47
Flagtail	<u>Kuhlia taeniura</u>	Jerot	Evis. whole	1	2.76
			Viscera	1	3.09
			Entire	2	3.29
Goatfish	<u>Mulloidichthys</u> <u>auriflamma</u>	Jome	Evisc. whole	1	3.26
			Viscera	1	3.65
Goatfish	<u>Mulloidichthys</u> <u>samoensis</u>	Jo	Evisc. whole	13	3.38
			Viscera	13	3.50
Goatfish	<u>Parapeneus</u> <u>barberinus</u>	Jerrobe	Evisc. whole	4	3.78
			Viscera	3	4.31
Goatfish	<u>Parapeneus</u> <u>cyclostomus</u>	Jerrobe	Evisc. whole	2	3.29
			Viscera	2	4.03
Goatfish	<u>M. samoensis</u> & <u>M. auriflamma</u>		Evisc. whole	1	3.24
			Viscera	1	3.82
Grouper	<u>Epinephelus</u> <u>merra</u>	Momo	Evisc. whole	1	3.28
			Viscera	2	3.63
			Muscle	1	4.98
			Entire	1	3.37
			Bone	1	
Grouper	<u>Epinephelus</u> <u>spilotoceps</u>	Momo	Muscle	1	4.03
			Liver	1	2.16
Grouper	<u>Epinephelus</u> sp.	Momo	Evisc. whole	1	3.50
			Viscera	1	3.52
Grouper	<u>Variola louti</u>	Kaikbet	Muscle	1	4.76
			Liver	1	3.04
			Bone	1	
Halfbeak	<u>Hemirhamphus</u> <u>laticeps</u>	Kibu	Entire	1	4.57

Table 25 (continued).

Common name	Scientific name	Marshallese <sup>a</sup> name	Tissue	Number of samples	Wet/dry ratio
<u>Fishes (continued)</u>					
Jack	<u>Caranx</u> <u>melampygus</u>	Deltokrok	Muscle	4	4.36
			Viscera	4	3.73
			Bone	2	
Jack	<u>Caranx</u> <u>sexfasciatus</u>		Evisc. whole	1	3.88
			Viscera	1	4.26
Mackerel	<u>Grammatorcynus</u> <u>bilineatus</u>		Muscle	3	4.10
			Viscera	2	3.72
			Bone	1	
Mullet	<u>Crenimugil</u> <u>crenilabis</u>	Iōl	Evisc. whole	3	2.88
			Viscera	4	2.68
			Muscle	1	3.94
			Remainder	1	2.40
Mullet	<u>Plicomugil</u> <u>labiosus</u>	Ikari	Evisc. whole	1	3.25
			Viscera	1	3.06
Mullett	<u>Mugil</u> sp.	Jomou	Evisc. whole	3	3.76
			Viscera	3	2.32
Mullet	<u>Neomyxus</u> <u>chaptalii</u>	Ikari	Evisc. whole	13	2.97
			Viscera	13	2.83
			Muscle	6	3.86
Needlefish	<u>Strongylura</u> <u>incisa</u>	Tak	Muscle	1	4.41
			Viscera	1	3.67
Parrotfish	<u>Scarus</u> <u>sordidus</u>	Mao	Evisc. whole	2	3.85
			Viscera	10	2.95
			Muscle	9	4.92
			Bone	9	
Rabbitfish	<u>Siganus</u> <u>rostratus</u>	Elik	Evisc. whole	1	3.91
Rudderfish	<u>Kyphosus</u> <u>cinerascens</u>	Bagrok	Muscle	1	4.95
			Viscera	1	5.69
			Remainder	1	3.15
Skipjack tuna	<u>Euthynnus</u> <u>pelamis</u>	Chilu	Light muscle	2	3.51
			Dark muscle	2	3.55
			Liver	2	3.52
			Bone	1	
Snapper	<u>Aphaerus</u> <u>furcatus</u>		Muscle	1	4.62
			Viscera	1	3.69
Snapper	<u>Aprion</u> <u>virescens</u>	Eowae	Muscle	1	4.34
			Viscera	1	4.18
Snapper	<u>Lethrinus</u> <u>kallopterus</u>	Jalia	Muscle	2	4.78
			Liver	1	3.38
			Viscera	1	3.71
			Bone	1	
Snapper	<u>Lutjanus</u> <u>monostigmus</u>	Ban	Muscle	2	4.34
			Viscera	2	3.20
			Liver	1	3.09
			Skin	1	1.91
			Remainder	1	2.90
			Bone	1	

Table 25 (continued).

Common name	Scientific name	Marshallese <sup>a</sup> name	Tissue	Number of samples	Wet/dry ratio
<u>Fishes (continued)</u>					
Snapper	<u>Lutjanus</u> <u>vaigiensis</u>	Ban	Evisc. whole	1	3.41
Snapper	<u>L. monostogmus</u> & <u>L. vaigiensis</u>		Muscle	1	4.71
			Remainder	1	3.05
Surgeonfish	<u>Ctenochaetus</u> <u>striatus</u>		Evisc. whole	1	3.97
			Viscera	1	3.16
Surgeonfish	<u>Naso lituratus</u>	Balak	Muscle	1	4.70
			Viscera	1	5.97
			Remainder	1	2.42
Wahoo	<u>Acanthocybium</u> <u>solanderi</u>		Muscle	3	3.88
			Liver	3	2.97
Wrasse	<u>Goris</u> sp.		Muscle	1	4.83
			Viscera	1	3.22
			Bone	1	
Yellowfin tuna	<u>Thunnus</u> <u>albacares</u>	Pwepwe	Light muscle	5	3.78
			Dark muscle	4	3.75
			Liver	5	3.80
			Bone	3	
<u>Invertebrates</u>					
Pencil urchin			Soft parts	1	2.92
			Hard parts	1	
Sea cucumber	<u>Actinopygia</u> <u>mauritiana</u>		Evisc. whole	2	6.49
			Viscera	2	5.51
Sea cucumber	<u>Holothuria atra</u>		Evisc. whole	2	8.21
			Viscera	2	2.92
Sea cucumber	<u>Holothuria</u> <u>leucospilota</u>		Evisc. whole	3	9.02
			Viscera	3	3.32
Sea cucumber	<u>Holothuria</u> sp.		Evisc. whole	5	7.56
			Viscera	5	5.31
Sea cucumber	Unidentified		Entire	1	2.26
Spiny lobster	<u>Panulirus</u> <u>penicillatus</u>		Muscle	1	4.32
			Hepatopancreas	1	2.94
			Exoskeleton	1	7.61
Top snail	<u>Trochus</u> sp.		Soft parts	1	4.57
Tridacna	<u>Tridacna gigas</u>	Kabwur	Muscle	2	4.29
			Mantle	2	7.43
			Muscle & mantle	4	6.44
			Kidney	5	3.36
			Viscera	5	6.79
			Kidney & viscera	1	4.78
			Gills	1	7.82

Table 25 (continued).

Common name	Scientific name	Marshallese <sup>a</sup> name	Tissue	Number of samples	Wet/dry ratio
<u>Invertebrates (continued)</u>					
Tridacna	<u>Tridacna</u> sp.		Muscle & mantle	11	6.17
			Viscera & kidney	4	5.02
			Viscera	7	6.85
			Kidney	6	4.37
			Entire	3	5.03
<u>Algae</u>					
Calcareous algae	<u>Halimeda</u>		Entire	2	2.59
<u>Turtle</u>					
Sea turtle	<u>Chelonia</u> sp.		Muscle	1	7.43
			Liver	1	4.33
			Kidney	1	6.64
			Lungs	1	8.85
			Heart	1	6.49
			Mesenteries	1	24.37

<sup>a</sup>Marshallese names from the 1963 unpublished manuscript, "A preliminary compilation of Marshallese animal and plant names," by F. C. Goo and A. H. Banner, Hawaii Marine Laboratory, University of Hawaii, Honolulu, and from personal communications with Smith Gideon, Ujilang Magistrate in 1973.

DAVID, FRED, GLENN-HENRY and LEROY. These areas were selected because they are potential resettlement sites and/or were previous collection sites. In addition, "control" fish from a noncontaminated area were obtained from Enewetak, Kwajalein, and Meck Islands in Kwajalein Atoll.

Most of the reef fish were caught in variable mesh monofilament gillnets 25 to 125 ft in length and 6 ft deep. Gillnets were watched closely and unwanted fish were usually released alive. Thrownets were also used in some instances. In most cases, these methods of capture allowed us to collect only fish which were needed for analysis.

The total catch was about 200 mullet (4 species), 100 goatfish (4 species), 40 convict surgeon (1 species), 40 parrotfish

(1 species), and 40 other reef fish (12 species). The miscellaneous species included flagtail, rabbitfish, wrasse, surgeon, butterflyfish, damselfish, and bonefish. The catch of reef fish by species and location is given in Table 26.

Pelagic and Benthic Fishes – Large pelagic fishes (tuna, jacks, dolphins) and benthic fishes (snapper, grouper) were collected, since they will presumably be captured and eaten by the Enewetak people and they represent carnivores of high order in the food chain leading to man. They were collected primarily on sport-fishing gear, using feathered jigs and spoons as lures while trolling in the lagoon and in the passes leading to the ocean. Most of the large yellowfin tuna and dolphins were caught in the passes between the

Table 26. Number of organisms collected at Enewetak Atoll and Kwajalein Atoll near-shore sites, October to December 1972.

Collection site	Organism								Approx total
	Mullet	Goatfish	Convict surgeon	Parrot-fish	Other reef fish	Tridacna	Sea cucumber <sup>a</sup>	Other invertebrates	
Enewetak Atoll									
GLENN-HENRY	~ 25	11	~ 50	2	10	6	4	6 <sup>b</sup>	114
LEROY	~ 50	9	34	3	1	1	0	~ 10 <sup>c</sup>	108
FRED	0	~ 20	~ 50	9	7	3	2		91
DAVID	0	25	~ 50	12	2	4	1		94
BELLE	~ 50	3	30	1	3	10	0		97
IRENE	2	3	12	0	8	0	0		25
JANET	~ 50	3	~ 40	1	0	4	0		98
TILDA-URSULA	~ 35	11	~ 50	2	3	3	3		107
YVONNE	10	~ 15	~ 55	10	3	0	3	9 <sup>d</sup>	105
Kwajalein Atoll									
	-	-	~ 30	1	5	5			41
Approximate Total	~ 220	~ 100	~ 400	41	42	36	13	25	870

<sup>a</sup>The number given is the number of collections from a given site.

<sup>b</sup>Pencil urchins.

<sup>c</sup>Top snails.

<sup>d</sup>Spiny lobster.

lagoon and the ocean, while the smaller skipjack, mackerel, and ulua were caught in the lagoon proper. The snappers and groupers were caught in both the shallow water of the reef and the deep lagoon waters. The number of large carnivorous fish caught is given in Table 27.

#### Sample Analyses

Field Processing – After capture, fish were segregated by type (e. g., goatfish, mullet, etc.), placed in plastic bags, and transferred to ice chests containing dry ice as soon as practical (1 to 4 hr after collection). At the main camp, most fish were frozen, either in dry ice or in freezer units. Occasionally, fish were dissected fresh, the tissue dried, and then frozen.

Originally, it was planned that most of the marine biological samples would

be processed at Enewetak by people from the Laboratory of Radiation Ecology. However, the disruption to the program caused by Typhoon Olga made sample processing at Enewetak impractical; therefore, the majority of the samples were processed at the home laboratory in Seattle, Washington.

Laboratory Preparation – The samples were frozen at Enewetak and remained frozen until processed at the Seattle laboratory. To begin preparation of the samples for analyses, the fish were partially thawed and dissected into the tissue types shown in Table 25. Tissue types chosen were those most useful for estimation of the radiation dose and were of sufficient size to yield a dried sample of adequate size for gamma spectroscopy or radiochemical analyses. After

Table 27. Number of carnivorous fish collected from the Enewetak and Kwajalein off-shore lagoon sites, October to December 1972.

Collection site	Yellowfin tuna	Organism						Total
		Skipjack	Mackerel	Dolphin	Snapper	Grouper	Ulua	
Enewetak	2	9	3	2	8	8	8	40
Kwajalein	3	1				2		6
Total	5	10	3	2	8	10	8	46

dissection, the tissues were dried at about 80°C until a constant dry weight was reached. Two to three days were usually required for this process; oily samples (viscera, liver) took longer.

The dried samples were then ground in a food blender and packaged in standard-size containers for gamma counting. Packages were of two basic types. Dried samples larger than 25 g were packaged in containers made from sections of polyvinyl chloride (PVC) pipe. The PVC sample holders were of two sizes – 2-in. diam by 1/2-in. high for 25-g samples and 2 in. by 1 in. for 50-g samples. Dried samples were placed in the sample holder and then compacted with a press to conform to the dimensions of the container. The amount of sample used was the amount required to yield a sample density within the container of 1.1. Dried samples less than 25 g were packaged in plastic petri dishes of two sizes (23 cm<sup>3</sup> and 6 cm<sup>3</sup>). These samples were not compacted and, therefore, the sample weight was not constant; however, sample density was calculated from the weight and volume.

Counting Methods – Packaged samples were shipped to Lawrence Livermore Laboratory for gamma spectroscopic

analyses. After gamma analysis, most marine biological samples were analyzed for <sup>55</sup>Fe, <sup>90</sup>Sr, and <sup>239</sup>Pu. These analyses were done at the Laboratory of Radiation Ecology (LRE), Lawrence Livermore Laboratory (LLL), McClellan Central Laboratory (MCL), and LFE Environmental Laboratory (LFE). A limited number of samples were analyzed for <sup>113m</sup>Cd, <sup>129</sup>I, <sup>14</sup>C, <sup>151</sup>Sm, <sup>147</sup>Pm, <sup>63</sup>Ni, and <sup>3</sup>H. Detailed descriptions of methods used for these analyses are given in the section on the Analysis Program.

#### Results and Discussion

The fish samples have been analyzed for gamma-emitting radionuclides, <sup>55</sup>Fe, <sup>90</sup>Sr, and <sup>239</sup>Pu. The gamma-emitting radionuclides detected by the Ge(Li) diode system included naturally occurring <sup>40</sup>K and <sup>228</sup>Th and fission and activation products – <sup>60</sup>Co, <sup>65</sup>Zn, <sup>101</sup>Rh, <sup>102m</sup>Rh, <sup>108m</sup>Ag, <sup>125</sup>Sb, <sup>137</sup>Cs, <sup>152</sup>Eu, <sup>155</sup>Eu, <sup>207</sup>Bi, and <sup>241</sup>Am. It should be noted that the radioactivity values for the fish are given as of the date of collection in terms of dry sample weight but can be converted to wet weight values by use of the conversion factors given in Table 25 for all samples except bone. The results



of the analyses are usually in terms of picocuries per gram of dry tissue because the true wet weight of some samples is difficult to determine.

The Kwajalein data are presented in only two tables since the number of samples is relatively small, but the Enewetak data have been grouped into separate tables by species.

Kwajalein Atoll – Kwajalein is environmentally similar to Enewetak, but has not been contaminated by radionuclides from local fallout. Naturally occurring radionuclides and radionuclides from worldwide fallout are present in Kwajalein fish and similar quantities would be expected in Enewetak fish. Hence, the Kwajalein fish can be considered as "control" fish and the difference in the radioactivity of the Kwajalein and Enewetak fish of similar type is an estimate of the contribution of the nuclear testing program at Enewetak Atoll to the radioactivity in the Enewetak fish.

Not all of the species of fish collected at Enewetak were collected at Kwajalein. The catch at Kwajalein included convict surgeon, parrotfish, yellowfin tuna, bonito, and groupers, but not mullet, goatfish or snappers (Tables 26 and 27). The results of the analyses are tabulated in Tables 28 and 29.

Reef fish – Reef fish from Kwajalein Atoll had tissue concentrations of naturally occurring  $^{40}\text{K}$  which averaged 15 pCi/g, dry, and ranged from 7.3 to 52 pCi/g, dry (Table 28). These concentrations are slightly higher than values found in fish from Enewetak Atoll. In addition, 2 of 16 fish from Kwajalein Atoll had  $^{125}\text{Sb}$  (0.21

and 0.25 pCi/g in kuhlia and convict surgeon) and one rabbitfish had 0.11 pCi of  $^{137}\text{Cs}$  per gram of dry tissue. Similar or higher concentrations of  $^{125}\text{Sb}$  and  $^{137}\text{Cs}$  were found in Enewetak fish samples. Levels of  $^{125}\text{Sb}$  are not included in the tables of the radionuclide concentrations in the Enewetak fish because they appear on such a sporadic basis.

Cobalt-60, one of the most abundant gamma-emitters found in the Enewetak fish, was not detected in fish from Kwajalein. Europium-155 and  $^{207}\text{Bi}$ , both commonly present in Enewetak fish, were also absent in fish from Kwajalein.

In the samples analyzed, the average  $^{55}\text{Fe}$  value was less than 1 pCi/g, dry, while the highest  $^{55}\text{Fe}$  value was about 13 pCi/g, dry, in the reef fish and 83 pCi/g, dry, in the light muscle of a wahoo. These  $^{55}\text{Fe}$  levels are at or below  $^{55}\text{Fe}$  concentrations found in similar species from the southern sector of Enewetak Atoll.

Strontium-90 levels were all less than 0.5 pCi/g, dry. Plutonium-239, 240 concentrations ranged up to 0.5 pCi/g, dry, in a halfbeak from Kwajalein Island, but most other samples had less than 0.1 pCi/g, dry.

Lagoon fish – The background levels of  $^{40}\text{K}$  in tissues of lagoon fish from Kwajalein (Table 29) tissues averaged 14 pCi/g, dry (range, 3.1 to 23 pCi/g, dry). Eight of 26 samples had detectable levels of  $^{137}\text{Cs}$ , averaging 0.17 pCi/g, dry (range of 0.12 to 0.22 pCi/g, dry), which was slightly above the mean limit of detection, 0.13 pCi/g, dry, found for the other 18 samples. Two skipjack and

Table 28. Radionuclides in reef fish and tridacna clams collected at Kwajalein Atoll, December 1972.

Sample number	Island	Organism	Tissue	Radionuclides (pCi/g, dry) <sup>a</sup>					
				<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>125</sup> Sb	<sup>90</sup> Sr	<sup>239,240</sup> Pu
8007	Enewetak	Convict	E. whole <sup>b</sup>	9.0 ± 1.1	0.18 ± 0.08	< 0.17	0.21 ± 0.10	0.03 ± 0.01	0.96 ± 0.08
8006	Enewetak	surgeon	Viscera	52 ± 6.8	1.9 ± 0.9	< 0.05	< 1.5	0.41 ± 0.13	0.43 ± 0.03
8008	Enewetak	Damselfish	Entire	15 ± 1.8	0.68 ± 0.14	< 0.14	< 0.39	0.37 ± 0.04	0.23 ± 0.12
8011	Enewetak	Parrotfish	E. whole	15 ± 1.3	0.16 ± 0.08	< 0.18	< 0.23	< 0.02	—
8010	Enewetak	Parrotfish	Viscera	NC <sup>c</sup>	0.86 ± 0.30	< 0.40	< 0.79	< 0.01	0.41 ± 0.02
0485	Kwajalein	Convict	E. whole	7.7 ± 1.3	0.12 ± 0.03	< 0.14	< 0.26	< 0.05	0.010 ± 0.001
0487	Kwajalein	surgeon	E. whole	13 ± 1.0	1.4 ± 0.2	< 0.13	< 0.15	0.04 ± 0.03	0.011 ± 0.005
0486	Kwajalein		Viscera	16 ± 1.4	0.58 ± 0.09	< 0.20	< 0.30	0.25 ± 0.08	0.009 ± 0.001
8013	Kwajalein	Convict	E. whole	16 ± 2.6	—	< 0.19	< 0.48	—	—
8012	Kwajalein	surgeon	Viscera	NC	13 ± 0.5	< 0.37	< 0.79	0.06 ± 0.03	0.11 ± 0.01
0763	Kwajalein	Grouper ( <i>E. merra</i> )	Entire	7.3 ± 1.0	0.36 ± 0.09	< 0.04	< 0.11	< 0.01	0.009 ± 0.001
0766	Kwajalein	Snapper ( <i>L. vaigiensis</i> )	E. whole	14 ± 1.1	1.9 ± 0.3	< 0.07	< 0.18	< 0.02	0.08 ± 0.005
0764	Kwajalein	Halfbeak	Entire	9.2 ± 1.1	—	< 0.05	< 0.12	< 0.01	0.54 ± 0.01
8003	Kwajalein	Kuhlia	Entire	9.8 ± 1.1	—	< 0.16	0.25 ± 0.10	0.02 ± 0.01	0.13 ± 0.01
8004	Kwajalein	Kuhlia	Entire	NC	0.50 ± 0.31	< 0.03	< 0.09	< 0.01	0.72 ± 0.02
0765	Kwajalein	Rabbitfish	E. whole <sup>d</sup>	13 ± 1.6	—	< 0.07	< 0.13	< 0.01	0.004 ± 0.001
0767	Kwajalein	Tridacna	Muscle and mantle	12 ± 2.3	—	0.22 ± 0.09	< 0.17	0.02 ± 0.001	0.23 ± 0.01
0768	Kwajalein	Tridacna	Viscera and kidney	13 ± 1.6	1.3 ± 0.1	2.3 ± 0.20	< 0.32	0.04 ± 0.03	0.14 ± 0.01

<sup>a</sup>Error values are one-sigma, counting errors.<sup>b</sup>Eviscerated whole is the entire fish, less the viscera.

NC = not computed.

<sup>d</sup>This sample also contained <sup>137</sup>Cs (0.11 ± 0.05 pCi/g, dry).

Table 29. Radionuclides in lagoon fish collected at Kwajalein Atoll, December 1972.

Sample number	Island	Common name	Tissue	Radionuclides (pCi/g, dry) <sup>a</sup>					
				<sup>40</sup> K	<sup>55</sup> Fe	<sup>65</sup> Zn	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>239,240</sup> Pu
0741	Kwajalein	Skipjack	Light muscle	11 ± 1.3	2.8 ± 0.1	NC <sup>b</sup>	0.11 ± 0.04	0.026 ± 0.013	< 0.014
0742	Kwajalein	Skipjack	Dark muscle	14 ± 2.0	12 ± 0.1	NC	0.21 ± 0.08	0.07 ± 0.05	0.03 ± 0.005
0740	Kwajalein	Skipjack	Liver	NC	—	NC	< 0.19	0.40 ± 0.03	
0773	Kwajalein	Skipjack	Bone	NC	2.6 ± 0.2	NC	< 0.15	< 0.11	< 0.77
0779	Kwajalein	Skipjack	Light muscle	9.1 ± 1.5	2.0 ± 0.1	NC	< 0.12	< 0.011	0.005 ± 0.001
0780	Kwajalein	Skipjack	Dark muscle	12 ± 1.0	12 ± 0.6	NC	< 0.11	< 0.015	0.15 ± 0.12
0778	Kwajalein	Skipjack	Liver	7.7 ± 1.4	0.7 ± 0.1	1.8 ± 0.3	< 0.08	< 0.022	0.005 ± 0.001
0777	Kwajalein	Skipjack	Bone	NC	4.7 ± 0.4	NC	< 0.21	< 0.015	0.15 ± 0.01
0595	Meck	Skipjack	Light muscle	12 ± 1.7	7.2 ± 0.5	NC	< 0.09	0.029 ± 0.002	0.009 ± 0.003
0594	Meck	Skipjack	Dark muscle	11 ± 1.3	30 ± 0.9	NC	< 0.10	< 0.02	0.018 ± 0.001
0595	Meck	Skipjack	Liver	12 ± 1.7	13 ± 1.3	0.5 ± 0.2	< 0.08	< 0.011	0.006 ± 0.002
0583	Meck	Wahoo	Light muscle	17 ± 1.2	83 ± 0.8	NC	0.12 ± 0.04	0.008 ± 0.002	0.012 ± 0.003
0584	Meck	Wahoo	Liver	14 ± 1.4	11 ± 1.0	NC	0.19 ± 0.07	< 0.026	0.006 ± 0.003
0585	Meck	Wahoo	Light muscle	18 ± 1.5	—	NC	0.18 ± 0.05	< 0.006	< 0.004
0586	Meck	Wahoo	Liver	23 ± 6.2	—	NC	< 0.28	0.039 ± 0.020	0.16 ± 0.003
0771	Meck	Wahoo	Muscle	13 ± 1.4	0.24 ± 0.04	NC	< 0.09	0.011 ± 0.055	0.05 ± 0.004
0772	Meck	Wahoo	Liver	3.1 ± 1.0	26 ± 0.8	0.4 ± 0.1	< 0.05	0.004 ± 0.002	0.034 ± 0.002
0542	Kwajalein	Yellowfin	Light muscle	18 ± 1.2	< 0.01	NC	0.22 ± 0.06	< 0.01	0.007 ± 0.002
0462	Kwajalein	Yellowfin	Liver	20 ± 3.8	7.2 ± 0.4	NC	< 0.19	0.11 ± 0.03	0.10 ± 0.02
0463	Kwajalein	Yellowfin	Bone	NC	1.7 ± 0.3	NC	< 0.16	0.07 ± 0.04	0.024 ± 0.005
0587	Meck	Yellowfin	Light muscle	14 ± 1.0	1.2 ± 0.1	NC	0.16 ± 0.04	< 0.009	< 0.003
0588	Meck	Yellowfin	Dark muscle	11 ± 1.2	—	NC	0.19 ± 0.05	< 0.009	0.006 ± 0.001
0589	Meck	Yellowfin	Liver	18 ± 2.2	18 ± 0.9	NC	< 0.12	< 0.011	0.013 ± 0.003
0591	Meck	Yellowfin	Light muscle	12 ± 1.8	1.0 ± 0.1	NC	< 0.09	< 0.004	0.014 ± 0.002
0590	Meck	Yellowfin	Dark muscle	20 ± 1.5	1.8 ± 0.9	NC	< 0.10	0.014 ± 0.008	0.11 ± 0.01
0592	Meck	Yellowfin	Liver	19 ± 5.1	—	NC	< 0.24	< 0.12	0.10 ± 0.01

<sup>a</sup>Error values are one-sigma, counting errors.<sup>b</sup>NC = not computed.

one wahoo had  $^{65}\text{Zn}$  concentrations in their liver tissue of 1.8, 0.5, and 0.4 pCi/g, dry, respectively. Zinc-65 levels were not computed in the other 23 samples because the levels were below the limits of detection. As for the Kwajalein reef fish, no  $^{60}\text{Co}$ ,  $^{155}\text{Eu}$ , or  $^{207}\text{Bi}$  was detected in any of the 26 lagoon fish samples analyzed. The highest  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$  levels in Kwajalein fish appear to be similar to average levels found in fish from the southern portion of Enewetak Atoll.

Enewetak Atoll – The results of the gamma-spectrum analyses grouped by

species – goatfish, convict surgeon, mullet, parrotfish, snapper, grouper, ulua, and tuna – are given in Tables 30 to 36. When some samples in a group of samples which were averaged did not have detectable levels of a radionuclide, the limit of detection value was used. For example, in a group of four samples of eviscerated goatfish from DAVID, three samples had net  $^{60}\text{Co}$  values greater than the one standard deviation propagated counting error (0.98, 0.65, and 0.48 pCi/g, dry) and the other sample had a limit of detection of 0.16 pCi/g, dry. For this group of four samples, the mean value was 0.57 pCi/g.

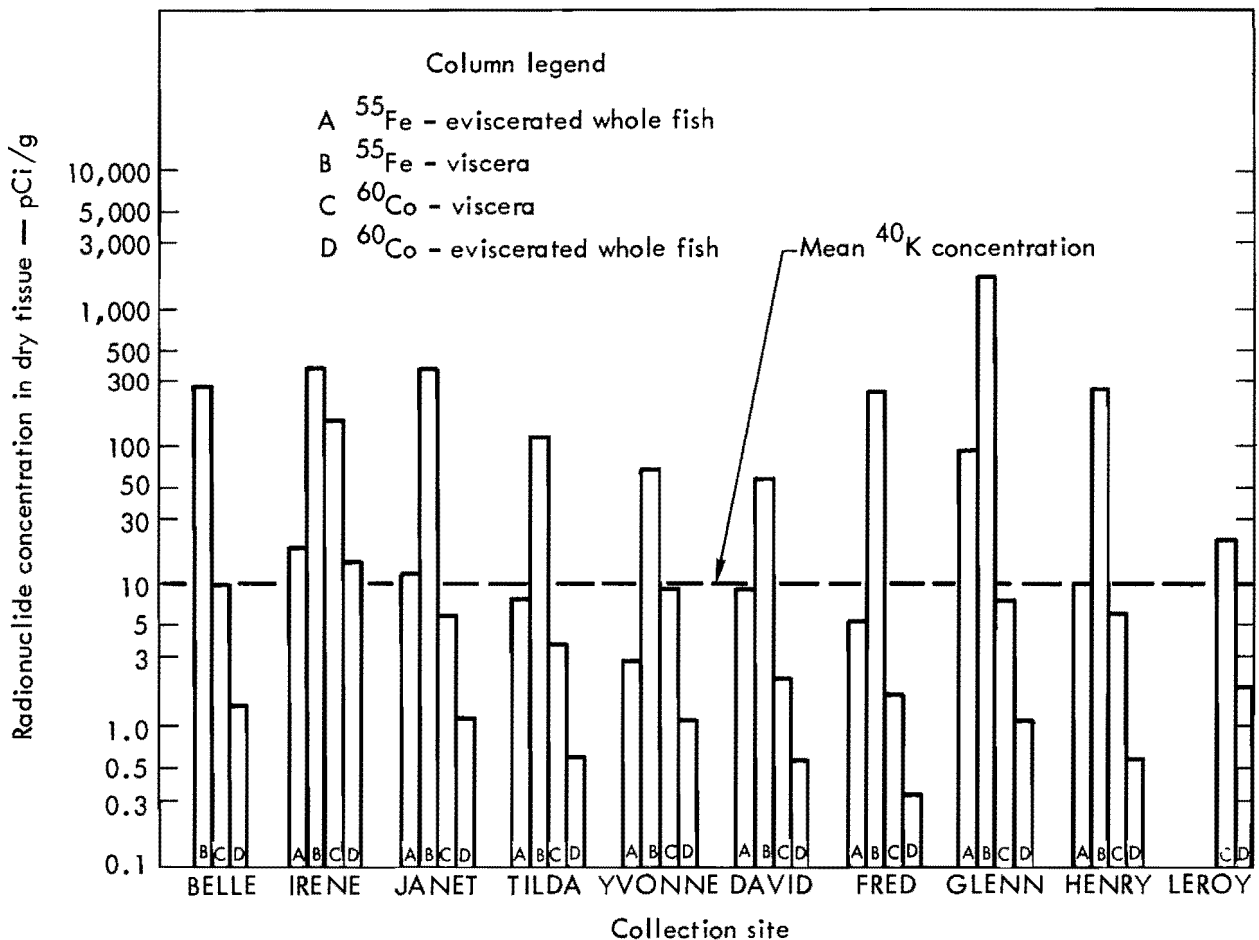


Fig. 42. Average  $^{55}\text{Fe}$  and  $^{60}\text{Co}$  concentration in goatfish from Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean from all goatfish samples.

Table 30. Predominant radionuclides in viscera and eviscerated whole goatfish collected at Enewetak Atoll, October to December 1972.

Island	Tissue <sup>b</sup>	samples	Radionuclide average $\pm$ standard deviation <sup>a</sup> in pCi/g, dry							
			<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu
BELLE	E. whole	1	13 $\pm$ 0.8		1.4 $\pm$ 0.1	0.12 $\pm$ 0.04	<0.06	0.39 $\pm$ 0.03	0.31 $\pm$ 0.03	0.008 $\pm$ 0.001
	Viscera <sup>c</sup>	1	NC <sup>d</sup>	270 $\pm$ 7	10 $\pm$ 1	<0.34	2.6 $\pm$ 0.4	24 $\pm$ 5	7 $\pm$ 0.3	5 $\pm$ 0.4
IRENE	E. whole	1	8.0 $\pm$ 0.8	18 $\pm$ 0.2	14 $\pm$ 0.2	0.98 $\pm$ 0.09	0.05	1.4 $\pm$ 0.1	0.70 $\pm$ 0.03	0.010 $\pm$ 0.003
	Viscera	1	16 $\pm$ 3.8	390 $\pm$ 1.3	160 $\pm$ 2	<0.41	<0.46	2.4 $\pm$ 0.3	1.5 $\pm$ 0.1	1.2 $\pm$ 0.04
JANET	E. whole	1	9.4 $\pm$ 1.1	12 $\pm$ 0.1	1.1 $\pm$ 0.1	<0.11	<0.10	0.18 $\pm$ 0.05	0.46 $\pm$ 0.04	0.02 $\pm$ 0.01
	Viscera	1	NC	390 $\pm$ 4	6.0 $\pm$ 0.6	<0.23	<0.35	0.76 $\pm$ 0.19	0.12 $\pm$ 0.06	0.03 $\pm$ 0.01
TILDA	E. whole	2	10 $\pm$ 0.9	8.0 $\pm$ 1.3	0.59 $\pm$ 0.17	<0.12 $\pm$ 0.01	<0.11 $\pm$ 0.01	0.57 $\pm$ 0.28	0.15 $\pm$ 0.14	0.033 $\pm$ 0.024
	Viscera	2	12 $\pm$ 2.8	130 $\pm$ 14	3.8 $\pm$ 2.7	<0.11 $\pm$ 0.01	<0.17 $\pm$ 0.01	0.42 $\pm$ 0.18	0.40 $\pm$ 0.01	0.45 $\pm$ 0.03
YVONNE	E. whole	2	7.8 $\pm$ 2.1	3.0 $\pm$ 0.2	1.1 $\pm$ 0.4	0.21 $\pm$ 0.08	<0.05 $\pm$ 0.01	0.34 $\pm$ 0.01	0.14 $\pm$ 0.17	0.047 $\pm$ 0.010
	Viscera	2	7.8 $\pm$ 0.4	73 $\pm$ 13	9.5 $\pm$ 3.6	0.32 $\pm$ 0.23	0.80 $\pm$ 0.99	0.56 $\pm$ 0.16	0.57	2.0 $\pm$ 1.2
DAVID	E. whole	4	11 $\pm$ 1.1	9.8 $\pm$ 12	0.57 $\pm$ 0.34	<0.11 $\pm$ 0.02	<0.10 $\pm$ 0.02	0.80 $\pm$ 0.70	0.06 $\pm$ 0.07	0.004 $\pm$ 0.001
	Viscera	4	13 $\pm$ 4.1	62 $\pm$ 53	2.3 $\pm$ 2.3	<0.20 $\pm$ 0.03	<0.23 $\pm$ 0.17	1.4 $\pm$ 1.5	0.61 $\pm$ 0.79	0.018 $\pm$ 0.002
FRED	E. whole	4	11 $\pm$ 3.6	9.6 $\pm$ 6.7	0.34 $\pm$ 0.03	0.12 $\pm$ 0.07	0.13 $\pm$ 0.08	0.62 $\pm$ 0.53	0.13 $\pm$ 0.09	0.022 $\pm$ 0.017
	Viscera	4	9.5 $\pm$ 7.6	260 $\pm$ 280	1.7 $\pm$ 0.5	<0.11 $\pm$ 0.06	<0.21 $\pm$ 0.12	0.79 $\pm$ 0.56	0.07 $\pm$ 0.05	0.026 $\pm$ 0.004
GLENN	E. whole	3	12 $\pm$ 0.8	110 $\pm$ 170	1.2 $\pm$ 0.4	<0.12 $\pm$ 0.07	0.22 $\pm$ 0.11	0.60 $\pm$ 0.33	0.56 $\pm$ 0.81	0.005 $\pm$ 0.001
	Viscera	2	8.3 $\pm$ 1.4	1700 $\pm$ 2200	8.1 $\pm$ 2.5	<0.29 $\pm$ 0.29	0.69 $\pm$ 0.28	2.6 $\pm$ 0.5	0.64	0.37 $\pm$ 0.37
HENRY	E. whole	2	8.6 $\pm$ 0.4	11 $\pm$ 7.8	0.59 $\pm$ 0.27	0.20 $\pm$ 0.13	<0.12 $\pm$ 0.04	1.4 $\pm$ 0.4	0.08 $\pm$ 0.07	0.004 $\pm$ 0.001
	Viscera	1	9.7 $\pm$ 1.5	270 $\pm$ 3.7	5.4 $\pm$ 0.3	0.22 $\pm$ 0.08	<0.15	2.5 $\pm$ 0.1	0.20	0.012 $\pm$ 0.003
LEROY	E. whole	1	9.0 $\pm$ 1.1	20 $\pm$ 1.4	1.9 $\pm$ 0.2	<0.07	0.21 $\pm$ 0.04	1.6 $\pm$ 0.1	0.09 $\pm$ 0.001	0.002 $\pm$ 0.001
	Viscera	1	9.8 $\pm$ 1.3	700 $\pm$ 7	23 $\pm$ 2	<0.14	0.62 $\pm$ 0.30	5.1 $\pm$ 0.2	0.04 $\pm$ 0.01	0.032 $\pm$ 0.008

<sup>a</sup>Single sample error values are one-sigma counting errors, while error values for two or more samples are one sample standard deviation without consideration of counting error.

<sup>b</sup>Eviscerated whole is the entire fish, less the viscera.

<sup>c</sup>This sample also contained <sup>241</sup>Am (3.8 pCi/g, dry). Two other samples of viscera from goatfish collected at Yvonne had 0.54 pCi of <sup>241</sup>Am/g, dry.

<sup>d</sup>NC = not computed.

Table 31. Predominant radionuclides in convict surgeon collected at Enewetak Atoll, October to December 1972.

Island	Tissue	No. of samples	Radionuclide average $\pm$ deviation <sup>a</sup> in pCi/g, dry								
			<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu	
BELLE	E. whole	3	11 $\pm$ 3.1	12 $\pm$ 0.6	2.3 $\pm$ 0.4	1.1 $\pm$ 0.2	< 0.09	0.11 $\pm$ 0.05	0.51 $\pm$ 0.03	0.07 $\pm$ 0.08	
	Viscera	3 <sup>b</sup>	14 $\pm$ 11	150 $\pm$ 50	16 $\pm$ 2.4	1.0 $\pm$ 0.8	0.49 $\pm$ 0.09	2.0 $\pm$ 1.6	1.9 $\pm$ 0.7	1.9 $\pm$ 0.4	
IRENE	E. whole	1	13 $\pm$ 1.1	10 $\pm$ 0.1	28 $\pm$ 0.4	6.7 $\pm$ 0.2	< 0.14	< 0.15	1.2 $\pm$ 0.06	0.11 $\pm$ 0.01	
	Viscera	1	14 $\pm$ 2.0	160 $\pm$ 12	210 $\pm$ 3	6.0 $\pm$ 0.4	5.8 $\pm$ 0.3	1.1 $\pm$ 0.2	17 $\pm$ 1	15 $\pm$ 1.5	
JANET	E. whole	2	9.6 $\pm$ 0.7	5.4 $\pm$ 2.0	0.22 $\pm$ 0.02	0.23 $\pm$ 0.03	< 0.04 $\pm$ 0.01	0.03 $\pm$ 0.01	0.31 $\pm$ 0.01	0.03 $\pm$ 0.03	
	Viscera	2	10 $\pm$ 0.8	28 $\pm$ 4.2	0.96 $\pm$ 0.20	0.16 $\pm$ 0.12	0.17 $\pm$ 0.10	0.20 $\pm$ 0.01	0.17 $\pm$ 0.04	0.36 $\pm$ 0.25	
URSULA	E. whole	3	8.9 $\pm$ 1.2	3.0 $\pm$ 0.9	0.22 $\pm$ 0.08	0.17 $\pm$ 0.07	< 0.04 $\pm$ 0.01	< 0.02 $\pm$ 0.01	0.25 $\pm$ 0.28	0.071 $\pm$ 0.064	
	Viscera	3	14 $\pm$ 4.8	19 $\pm$ 7.8	0.98 $\pm$ 0.37	0.19 $\pm$ 0.10	0.18 $\pm$ 0.15	0.17 $\pm$ 0.09	0.23 $\pm$ 0.06	0.81 $\pm$ 0.02 <sup>a</sup>	
YVONNE	E. whole	3	8.2 $\pm$ 0.7	1.9 $\pm$ 0.8	1.2 $\pm$ 0.6	0.58 $\pm$ 0.24	< 0.04 $\pm$ 0.01	< 0.02 $\pm$ 0.01	0.18 $\pm$ 0.22	0.022 $\pm$ 0.016	
	Viscera	3	10 $\pm$ 3.3	2.8 $\pm$ 6.4	5.2 $\pm$ 1.6	0.72 $\pm$ 0.25	0.20 $\pm$ 0.09	0.33 $\pm$ 0.24	0.17 $\pm$ 0.04	0.60 $\pm$ 0.43	
DAVID	E. whole	4	10 $\pm$ 3.4	1.6 $\pm$ 0.7	0.21 $\pm$ 0.09	0.13 $\pm$ 0.05	< 0.13 $\pm$ 0.08	< 0.08 $\pm$ 0.05	0.08 $\pm$ 0.10	0.026 $\pm$ 0.018	
	Viscera	4	17 $\pm$ 3.4	17 $\pm$ 4.3	2.1 $\pm$ 2.1	0.14 $\pm$ 0.08	< 0.16 $\pm$ 0.13	0.21 $\pm$ 0.04	0.42 $\pm$ 0.23	0.031 $\pm$ 0.010	
FRED	E. whole	3	11 $\pm$ 2.9	0.33 $\pm$ 0.2	< 0.10 $\pm$ 0.05	0.11 $\pm$ 0.04	< 0.09 $\pm$ 0.05	< 0.05 $\pm$ 0.03	0.02 $\pm$ 0.01	0.08 $\pm$ 0.09	
	Viscera	3	12 $\pm$ 3.8	3.1 $\pm$ 0.8	0.57 $\pm$ 0.19	0.09 $\pm$ 0.04	< 0.10 $\pm$ 0.05	< 0.10 $\pm$ 0.05	0.05 $\pm$ 0.02	0.031 $\pm$ 0.034	
GLENN	E. whole	1	11 $\pm$ 1.2	—	0.4 $\pm$ 0.40	0.18 $\pm$ 0.03	< 0.17	0.06 $\pm$ 0.02	< 0.01	0.90 $\pm$ 0.02	
	Viscera	1	16 $\pm$ 0.7	12 $\pm$ 0.7	3.3 $\pm$ 0.08	0.15 $\pm$ 0.04	< 0.06	0.74 $\pm$ 0.04	< 0.20	0.05 $\pm$ 0.01	
HENRY	E. whole	3	8.9 $\pm$ 0.7	8.2 $\pm$ 0.5	0.47 $\pm$ 0.32	0.10 $\pm$ 0.05	< 0.09 $\pm$ 0.07	< 0.15 $\pm$ 0.09	0.02 $\pm$ 0.01	0.074 $\pm$ 0.12	
	Viscera	2	11 $\pm$ 1.3	78 $\pm$ 3.5	2.0 $\pm$ 2.6	0.15 $\pm$ 0.09	< 0.13 $\pm$ 0.02	0.96 $\pm$ 0.02	0.02 $\pm$ 0.01	0.045 $\pm$ 0.004	
LEROY	E. whole	3	10 $\pm$ 3.5	16 $\pm$ 6.0	1.0 $\pm$ 0.3	0.16 $\pm$ 0.05	< 0.08 $\pm$ 0.06	0.25 $\pm$ 0.07	0.14 $\pm$ 0.07	0.008 $\pm$ 0.002	
	Viscera	2	13 > 1	160 $\pm$ 40	3.4 $\pm$ 4.2	0.26 $\pm$ 0.20	< 0.13	3.1 $\pm$ 1.7	0.24 $\pm$ 0.03	0.27 $\pm$ 0.15	

<sup>a</sup>Single sample error values are one-sigma counting errors, while error values for two or more samples are one sample standard deviation without consideration of counting error.

<sup>b</sup>Two samples of viscera from convict surgeon collected at BELLE had an average <sup>241</sup>Am level of 0.74 pCi/g, dry. Americium-241 was also found in two samples of viscera from URSULA (average, 0.34 pCi/g, dry) and one sample of viscera from YVONNE (3.7 pCi/g, dry).

Table 32. Predominant radionuclides in mullet collected at Enewetak Atoll, October to December 1972.

Island	Tissue	No. of samples	Radionuclide, average $\pm$ standard deviation <sup>a</sup> in pCi/g, dry							
			<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu
BELLE	Muscle	1	15 $\pm$ 1.2	6.8 $\pm$ 0.2	3.7 $\pm$ 0.2	0.63 $\pm$ 0.09	< 0.10	0.13 $\pm$ 0.05	—	0.006 $\pm$ 0.001
	E. whole	3	6.9 $\pm$ 2.3	7.1 $\pm$ 0.6	2.8 $\pm$ 0.3	0.34 $\pm$ 0.10	< 0.05 $\pm$ 0.01	< 0.05 $\pm$ 0.03	0.16 $\pm$ 0.04	0.04 $\pm$ 0.03
	Viscera <sup>b</sup>	3	4.5 $\pm$ 0.4	100 $\pm$ 60	9.4 $\pm$ 2.3	1.5 $\pm$ 0.4	3.0 $\pm$ 0.2	0.61 $\pm$ 0.16	6.1 $\pm$ 1.8	8.0 $\pm$ 2.6
IRENE	Muscle	1	15 $\pm$ 1.3	14 $\pm$ 0.56	20 $\pm$ 0.5	4.3 $\pm$ 0.2	< 0.14	0.20 $\pm$ 0.09	0.01	0.020 $\pm$ 0.003
	E. whole	1	5.2 $\pm$ 1.0	13 $\pm$ 0.4	18 $\pm$ 0.5	1.8 $\pm$ 0.2	< 0.14	< 0.14	0.06 $\pm$ 0.01	0.19 $\pm$ 0.01
	Viscera	1	3.5 $\pm$ 1.6	220 $\pm$ 0.1	90 $\pm$ 1.1	9.8 $\pm$ 0.5	22 $\pm$ 0.3	2.2 $\pm$ 0.2	< 0.02	24 $\pm$ 0.5
JANET	Muscle	2	10 $\pm$ 1.5	1.3 $\pm$ 0.4	0.44 $\pm$ 0.40	0.13 $\pm$ 0.03	< 0.11 $\pm$ 0.06	< 0.05 $\pm$ 0.03	0.05 $\pm$ 0.01	0.001 $\pm$ 0.001
	E. whole	2	3.9 $\pm$ 1.3	1.4 $\pm$ 0.4	0.23 $\pm$ 0.11	0.15 $\pm$ 0.08	< 0.10 $\pm$ 0.07	< 0.05 $\pm$ 0.03	0.03 $\pm$ 0.03	0.017 $\pm$ 0.018
	Viscera	2	3.9 $\pm$ 0.1	19 $\pm$ 0.7	1.1 $\pm$ 0.6	0.06 $\pm$ 0.04	< 0.09 $\pm$ 0.06	< 0.04 $\pm$ 0.01	0.46 $\pm$ 0.47	0.29 $\pm$ 0.30
TILDA	Muscle	1	17 $\pm$ 2	1.9 $\pm$ 0.3	< 0.19	< 0.12	< 0.15	< 0.08	< 0.03	< 0.027
	E. whole	2	7.4 $\pm$ 3.4	1.3 $\pm$ 0.5	< 0.17 $\pm$ 0.02	< 0.10 $\pm$ 0.01	< 0.15 $\pm$ 0.01	< 0.07 $\pm$ 0.02	0.05 $\pm$ 0.05	5.8 $\pm$ 11
	Viscera	2	4.7 $\pm$ 0.9	13 $\pm$ 16	0.79 $\pm$ 0.13	0.08 $\pm$ 0.02	0.18 $\pm$ 0.03	0.06 $\pm$ 0.01	0.56 $\pm$ 0.16	0.63 $\pm$ 0.29
YVONNE	E. whole	3	6.6 $\pm$ 1.8	0.95 $\pm$ 0.82	0.95 $\pm$ 0.61	0.26 $\pm$ 0.28	< 0.13 $\pm$ 0.04	< 0.07 $\pm$ 0.01	0.03 $\pm$ 0.02	0.016 $\pm$ 0.016
	Viscera	3	5.2 $\pm$ 1.9	11 $\pm$ 8.6	4.9 $\pm$ 2.0	0.54 $\pm$ 0.70	2.2 $\pm$ 1.8	0.12 $\pm$ 0.04	0.70 $\pm$ 0.27	3.8 $\pm$ 4.7
GLENN	E. whole	1	7.2 $\pm$ 1.6	—	0.85 $\pm$ 0.09	< 0.10	< 0.16	< 0.08	< 0.01	0.63 $\pm$ 0.01
	Viscera	1	5.5 $\pm$ 1.2	28 $\pm$ 1.1	3.3 $\pm$ 0.2	0.16 $\pm$ 0.05	0.17 $\pm$ 0.03	1.8 $\pm$ 0.1	0.26 $\pm$ 0.02	0.30 $\pm$ 0.02
HENRY	E. whole	4	6.3 $\pm$ 1.1	2.7 $\pm$ 0.8	0.73 $\pm$ 0.11	0.04 $\pm$ 0.02	0.10 $\pm$ 0.06	< 0.04 $\pm$ 0.01	0.07 $\pm$ 0.07	0.011 $\pm$ 0.010
	Viscera	4	4.2 $\pm$ 0.5	21	2.9 $\pm$ 0.6	< 0.07 $\pm$ 0.05	< 0.11 $\pm$ 0.07	0.13 $\pm$ 0.05	0.01 $\pm$ 0.01	0.58 $\pm$ 0.88
LEROY	Muscle	2	11 $\pm$ 1.6	4.1 $\pm$ 0.8	1.1 $\pm$ 0.2	0.12 $\pm$ 0.02	< 0.11 $\pm$ 0.08	< 0.06 $\pm$ 0.04	0.07 $\pm$ 0.04	0.34 $\pm$ 0.48
	E. whole	3	6.6 $\pm$ 2.9	32 $\pm$ 48	1.2 $\pm$ 0.9	0.09 $\pm$ 0.04	< 0.10 $\pm$ 0.04	< 0.05 $\pm$ 0.03	0.04 $\pm$ 0.02	0.004 $\pm$ 0.001
	Viscera	3	3.6 $\pm$ 0.0	92 $\pm$ 63	3.4 $\pm$ 1.0	< 0.11 $\pm$ 0.01	0.20 $\pm$ 0.05	0.73 $\pm$ 0.18	0.38 $\pm$ 0.22	0.33 $\pm$ 0.14

<sup>a</sup>Single sample error values are one-sigma counting errors, while error values for two or more samples are one sample standard deviation without consideration of counting error.

<sup>b</sup>The viscera samples from BELLE also had an average <sup>241</sup>Am level of 4.0 pCi/g, dry. One viscera sample from TILDA and three from YVONNE also had <sup>241</sup>Am levels of 0.22 and 1.6 pCi/g, dry, respectively.

Table 33. Predominant radionuclides in parrotfish collected at Enewetak Atoll, October to December 1972.

Island	Tissue	No. of samples	Radionuclide, average $\pm$ standard deviation <sup>a</sup> in pCi/g, dry								
			<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu	
BELLE	E. whole <sup>b</sup>	1	12 $\pm$ 1.1	13 $\pm$ 0.4	4.4 $\pm$ 0.1	3.0 $\pm$ 0.1	<0.06	<0.04	0.75 $\pm$ 0.05	0.02 $\pm$ 0.002	
	Viscera <sup>b</sup>	1	21 $\pm$ 5.3	150 $\pm$ 5.0	13 $\pm$ 1.0	2.5 $\pm$ 0.5	1.2 $\pm$ 0.6	<0.25	5.3 $\pm$ 0.30	2.9 $\pm$ 0.30	
JANET	Muscle	1	22 $\pm$ 1.6	0.36 $\pm$ 0.04	<0.23	0.98 $\pm$ 0.09	<0.12	<0.07	<0.08	0.14 $\pm$ 0.12	
	Viscera	1	5.8 $\pm$ 1.0	14 $\pm$ 0.5	0.39 $\pm$ 0.12	0.25 $\pm$ 0.07	0.17 $\pm$ 0.08	<0.07	1.3 $\pm$ 0.1	0.24 $\pm$ 0.01	
	Bone	1	NC <sup>c</sup>	1.3 $\pm$ 0.8	<0.34	<0.28	<0.44	<0.18	0.27 $\pm$ 0.12	<0.22	
TILDA	Muscle	1	22 $\pm$ 1.6	0.12 $\pm$ 0.07	<0.20	0.42 $\pm$ 0.07	<0.10	<0.02	<0.03	0.05 $\pm$ 0.01	
	Viscera	1	6.7 $\pm$ 0.8	4.9 $\pm$ 0.1	0.38 $\pm$ 0.10	0.12 $\pm$ 0.01	0.20 $\pm$ 0.06	<0.05	<0.18	0.45 $\pm$ 0.01	
	Bone	1	NC	0.76 $\pm$ 0.20	<0.18	<0.13	<0.02	<0.11	<0.12	0.018 $\pm$ 0.003	
YVONNE	Muscle	2	19 $\pm$ 6.4	0.15 $\pm$ 0.04	<0.16 $\pm$ 0.03	0.49 $\pm$ 0.30	<0.10 $\pm$ 0.05	<0.06 $\pm$ 0.01	0.02 $\pm$ 0.01	0.026 $\pm$ 0.021	
	Viscera	2	6.7 $\pm$ 0.8	7.5 $\pm$ 3.2	2.5 $\pm$ 2.9	0.20 $\pm$ 0.16	0.88 $\pm$ 0.88	0.69 $\pm$ 0.87	0.42 $\pm$ 0.39	1.8 $\pm$ 2.0	
	Bone	2	8.1 $\pm$ 0.7	2.0 $\pm$ 2.2	0.30 $\pm$ 0.16	<0.12 $\pm$ 0.01	<0.07 $\pm$ 0.01	<0.08 $\pm$ 0.01	0.07 $\pm$ 0.03	2.5	
DAVID	Muscle	2	14 $\pm$ 5.7	<1.7	<0.05 $\pm$ 0.02	0.07 $\pm$ 0.06	<0.04 $\pm$ 0.01	<0.03 $\pm$ 0.01	<0.18	<0.01	
	Viscera	2	9.4 $\pm$ 3.7	4.6 $\pm$ 3.6	0.33 $\pm$ 0.22	<0.09 $\pm$ 0.04	<0.10 $\pm$ 0.03	0.10 $\pm$ 0.02	0.17 $\pm$ 0.21	0.19 $\pm$ 0.21	
	Bone	2	11 $\pm$ 1.4	<5.5	<0.22 $\pm$ 0.13	<0.16 $\pm$ 0.10	<0.28 $\pm$ 0.18	<0.11 $\pm$ 0.06	2.2 $\pm$ 2.4	0.033 $\pm$ 0.008	
FRED	Muscle	1	22 $\pm$ 1.5	2.7 $\pm$ 0.7	<0.23	1.8 $\pm$ 0.1	<0.11	<0.07	<0.01	<0.019	
	Viscera	1	3.8 $\pm$ 0.9	170 $\pm$ 12	0.47 $\pm$ 0.12	<0.11	<0.11	1.4 $\pm$ 0.1	0.07 $\pm$ 0.05	0.18 $\pm$ 0.02	
	Bone	1	14 $\pm$ 22	2.4 $\pm$ 0.1	<0.23	<0.23	<0.21	<0.14	0.15 $\pm$ 0.05	0.004 $\pm$ 0.002	
HENRY	Muscle	1	27 $\pm$ 2.2	5.0 $\pm$ 0.3	<0.20	0.40 $\pm$ 0.10	<0.24	<0.11	<0.01	—	
	Bone	1	NC	—	0.20 $\pm$ 0.03	0.07 $\pm$ 0.02	<0.05	<0.02	0.07 $\pm$ 0.01	<0.004	
LEROY	Muscle	1	23 $\pm$ 1.4	10 $\pm$ 0.9	<0.09	0.28 $\pm$ 0.05	<0.08	<0.04	<0.019	<0.005	
	Viscera	1	3.9 $\pm$ 1.0	300 $\pm$ 3.2	1.9 $\pm$ 0.2	<0.07	0.35 $\pm$ 0.11	1.3 $\pm$ 0.1	1.5 $\pm$ 0.1	0.45 $\pm$ 0.30	

<sup>a</sup>Single sample error values are one-sigma counting errors, while error values for two or more samples are one sample standard deviation without consideration of counting error.

<sup>b</sup>This sample also had an <sup>241</sup>Am level of 1.4 pCi/g, dry. Americium-241 was also detected in a viscera sample from TILDA (0.21 pCi/g, dry) and one viscera sample from YVONNE (0.58 pCi/g, dry).

<sup>c</sup>NC = not computed.



Table 34. Predominant radionuclides in single, pooled samples of snappers collected at Enewetak Atoll, October to December 1972.

Sample number	Island	Tissue	No. of fish	Species (size in mm)	Radionuclide, average $\pm$ standard deviation <sup>a</sup> in pCi/g, dry						
					<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>137</sup> Cs	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu
0447	IRENE	Muscle	4	<u>L. monostigmus</u>	21 $\pm$ 2.5	7.2 $\pm$ 1.0	11 $\pm$ 0.4	2.1 $\pm$ 0.17	< 0.14	< 0.84	0.063
0448		Remainder	4	(140-240)	8.1 $\pm$ 1.0	36 $\pm$ 0.3	35 $\pm$ 0.5	0.72 $\pm$ 0.17	0.22 $\pm$ 0.10	0.79 $\pm$ 0.03	0.068 $\pm$ 0.006
0488	TILDA	Muscle	2	<u>L. monostigmus</u>	17 $\pm$ 1.7	6.5 $\pm$ 0.6	< 0.28	0.32 $\pm$ 0.09	< 0.09	0.23	< 0.059
0489		Viscera	2	(220, 225)	13 $\pm$ 1.4	120 $\pm$ 4.9	< 0.45	< 0.28	0.20	—	0.59 $\pm$ 0.02
0490		Remainder	2		9.8 $\pm$ 1.1	6.5	< 0.17	< 0.11	< 0.06	1.4 $\pm$ 0.1	< 0.002
0575	TILDA	Muscle	4	<u>L. monostigmus</u>	NC <sup>b</sup>	4.7 $\pm$ 0.3	< 0.15	< 0.17	< 0.15	0.11	—
0576		Liver	4	(195-333)	19 $\pm$ 5.7	640 $\pm$ 13	3.1 $\pm$ 0.4	< 0.32	< 0.23	2.9 $\pm$ 0.12	0.045 $\pm$ 0.006
0577		Bone	4		3.4 $\pm$ 0.9	2.6 $\pm$ 0.5	< 0.07	0.10 $\pm$ 0.03	< 0.03	0.25	< 0.013
0578		Viscera	4		4.5 $\pm$ 0.8	37 $\pm$ 0.8	0.28 $\pm$ 0.05	< 0.05	< 0.04	0.004 $\pm$ 0.002	0.023 $\pm$ 0.001
0579		Skin	4		4.6 $\pm$ 1.2	4.3 $\pm$ 0.6	< 0.07	< 0.05	< 0.03	< 0.23	0.44 $\pm$ 0.03
0580	TILDA	Muscle	1	<u>L. kallopterus</u>	18 $\pm$ 1.3	0.50 $\pm$ 0.06	0.06 $\pm$ 0.06	0.14 $\pm$ 0.03	0.12 $\pm$ 0.03	0.01 $\pm$ 0.004	0.005 $\pm$ 0.001
0581		Viscera	1	(290)	19 $\pm$ 3.2	19 $\pm$ 2.3	0.98 $\pm$ 0.22	< 0.16	< 0.14	0.29 $\pm$ 0.06	0.10 $\pm$ 0.01
0582		Bone	1		NC	< 0.33	< 0.39	< 0.28	< 0.21	< 0.92	< 0.042
0437	ELMER	Muscle	1	<u>A. virescens</u>	20 $\pm$ 1.2	2.8 $\pm$ 0.3	0.36 $\pm$ 0.05	0.13 $\pm$ 0.05	0.34 $\pm$ 0.04	< 0.10	< 0.003
0438		Viscera	1	(360)	16 $\pm$ 3.0	310 $\pm$ 7.0	4.9 $\pm$ 0.3	< 0.15	0.42 $\pm$ 0.11	< 1.0	—
0400	FRED	Muscle	1	<u>L. kallopterus</u>	16 $\pm$ 1.4	3.1 $\pm$ 0.1	< 0.15	< 0.10	< 0.07	0.01 $\pm$ 0.001	< 0.001
0401		Liver	1	(300)	NC	—	5.8 $\pm$ 0.8	< 0.49	1.5 $\pm$ 0.4	0.44 $\pm$ 0.28	0.09 $\pm$ 0.04
0398	GLENN	Muscle	1	<u>A. furcatus</u>	25 $\pm$ 2.3	8.3 $\pm$ 0.2	0.68 $\pm$ 0.11	0.31 $\pm$ 0.13	1.9 $\pm$ 0.1	0.011 $\pm$ 0.004	0.006 $\pm$ 0.001
0397		Viscera	1	(302)	NC	360 $\pm$ 8.0	22 $\pm$ 0.51	< 0.25	2.0 $\pm$ 0.2	< 1.3	< 0.07

<sup>a</sup>Single sample error values are one-sigma counting errors, while error values for two or more samples are one sample standard deviation without consideration of counting error.

<sup>b</sup>NC = not computed.

Table 35. Predominant radionuclides in single, pooled samples of groupers<sup>a</sup> collected at Enewetak Atoll, October to December 1972.

Sample number	Island	Tissue	No. of fish	Radionuclide, average $\pm$ standard deviation <sup>b</sup> in pCi/g, dry						
				<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>137</sup> Cs	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu
0543	TILDA	E. whole	2	NC <sup>c</sup>	1.3 $\pm$ 0.3	< 0.17	< 0.11	< 0.09	< 0.08	< 0.003
0544		Viscera	2	14 $\pm$ 3.8	94 $\pm$ 3.5	1.1 $\pm$ 0.3	< 0.19	< 0.17	< 0.70	< 0.043
8022	YVONNE	Muscle	1	18 $\pm$ 1.4	5.6 $\pm$ 0.1	< 0.74 $\pm$ 0.12	0.33 $\pm$ 0.09	2.5 $\pm$ 0.1	< 0.03	< 0.001
8023		Viscera	1	19 $\pm$ 2.7	430 $\pm$ 1.3	36 $\pm$ 0.6	< 0.24	4.6 $\pm$ 0.2	0.10 $\pm$ 0.07	0.036 $\pm$ 0.019
8024		Bone	1	NC	3.1 $\pm$ 0.2	< 0.23	< 0.15	< 0.13	< 0.04	0.50 $\pm$ 0.04
0403	FRED	Muscle	1	15 $\pm$ 1.1	0.47 $\pm$ 0.05	< 0.14	0.53 $\pm$ 0.07	2.1 $\pm$ 0.1	< 0.03	< 0.014
0404		Liver	1	3.1 $\pm$ 0.8	160 $\pm$ 0.5	2.1 $\pm$ 0.1	< 0.05	1.1 $\pm$ 0.1	0.14 $\pm$ 0.01	0.11 $\pm$ 0.04
0405	FRED	Muscle	1	15 $\pm$ 1.5	13 $\pm$ 0.3	< 0.43 $\pm$ 0.11	0.51 $\pm$ 0.09	0.63 $\pm$ 0.07	< 0.01	0.007 $\pm$ 0.001
0406		Liver	1	NC	4900 $\pm$ 50	94 $\pm$ 2	< 0.53	< 0.40	< 0.22	0.038 $\pm$ 0.007
0407		Bone	1	9.7 $\pm$ 3.1	13	2.0 $\pm$ 0.3	< 0.18	< 0.13	0.09 $\pm$ 0.04	0.034 $\pm$ 0.003
0369	FRED	E. whole	3	8.4 $\pm$ 1.2	1.1 $\pm$ 0.1	< 0.10	< 0.06	< 0.06	< 0.02	0.003 $\pm$ 0.001
0370		Viscera	3	NC	—	1.3 $\pm$ 0.2	< 0.12	< 0.10	0.05 $\pm$ 0.01	0.13 $\pm$ 0.01

<sup>a</sup>All groupers were Epinephelus sp. except one grouper from FRED (0405-0407) which was variola louti.

<sup>b</sup>Error values are one-sigma, counting errors.

<sup>c</sup>NC = not computed.

Table 36. Predominant radionuclides in single, pooled samples of ulua<sup>a</sup> collected at Enewetak Atoll, October to December 1972.

Sample number	Island	Tissue	No. of fish	Radionuclide, average ± standard deviation <sup>b</sup> in pCi/g, dry						
				<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>137</sup> Cs	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu
0545	TILDA	Muscle	1	15 ± 1.0	5.8 ± 0.2	0.06	0.24 ± 0.05	0.25 ± 0.04	< 0.11	< 0.001
0546		Viscera	1	9.6 ± 1.1	—	0.68 ± 0.08	< 0.08	11 ± 0.2	0.11 ± 0.01	0.011 ± 0.001
0547		Bone	1	3.2 ± 1.1	4.0 ± 0.2	< 0.05	0.13 ± 0.05	3.0 ± 0.11	0.37 ± 0.05	0.59 ± 0.01
8032	YVONNE	Muscle	2	18 ± 1.6	10 ± 0.1	1.3 ± 0.12	0.46 ± 0.1	0.33 ± 0.11	< 0.04	—
8033		Viscera	2	15 ± 1.8	350 ± 1	13 ± 2.1	< 0.15	2.5 ± 0.15	< 0.07	0.032 ± 0.006
8034		Bone	2	NC <sup>c</sup>	3.3 ± 0.2	< 0.20	< 0.20	0.62 ± 0.19	0.10 ± 0.04	< 0.016
0457	ELMER	Muscle	1	19 ± 1.2	25 ± 0.3	1.5 ± 0.15	0.54 ± 0.08	0.92 ± 0.06	< 0.11	< 0.002
0456		Viscera	1	NC	33 ± 1.8	7.5 ± 0.75	< 0.27	2.8 ± 0.27	< 1.5	< 0.002 ± 0.001
0434	FRED	Muscle	1	21 ± 1.4	150 ± 0.6	2.2 ± 0.19	0.36 ± 0.10	5.7 ± 0.13	0.05 ± 0.01	0.003 ± 0.001
0435		Viscera	1	NC	510 ± 3	8.9 ± 0.52	< 0.64	206 ± 6.0	0.24 ± 0.05	15 ± 0.3
0266	HENRY	E. whole	2	16 ± 2.6	20 ± 0.6	3.0 ± 0.39	1.0 ± 0.29	248 ± 1.5	0.48 ± 0.02	0.004 ± 0.001

<sup>a</sup>All ulua were Caranx melampygus except fish from HENRY, which were C. sexfasciatus.

<sup>b</sup>Error values are one-sigma counting errors.

<sup>c</sup>NC = not computed.

Goatfish – The results of the radiological analyses of the goatfish tissues are given in Table 30. Each sample was made up of the tissues from an average pool of five fish. Although four species of goatfish of various size classes were present in the samples, no apparent species or size differences in radionuclide content were noted and samples from all species and sizes were pooled to form the data in Table 30. Seventy-five percent of the goatfish collected for samples were Mulloidichthys samoensis.

The two most prevalent radionuclides found in the goatfish were  $^{55}\text{Fe}$  and  $^{60}\text{Co}$ , followed by  $^{40}\text{K}$ ,  $^{207}\text{Bi}$ ,  $^{137}\text{Cs}$ , and

$^{155}\text{Eu}$ . Americium-241 was found in 3 of 19 viscera samples, 1 from BELLE and 2 from YVONNE, while  $^{90}\text{Sr}$ ,  $^{55}\text{Fe}$ , and  $^{239,240}\text{Pu}$  were found in most samples.

Potassium-40 levels showed little variability between sampling locations or between eviscerated whole fish and viscera samples. The  $^{40}\text{K}$  values for all areas and the two tissue types averaged 9.8 pCi/g, dry. These levels are similar to  $^{40}\text{K}$  levels found in goatfish collected from other areas and times in the Central Pacific and indicate the natural levels of  $^{40}\text{K}$  in goatfish from that area.

Iron-55 and  $^{60}\text{Co}$  were the predominant man-produced radionuclides in the

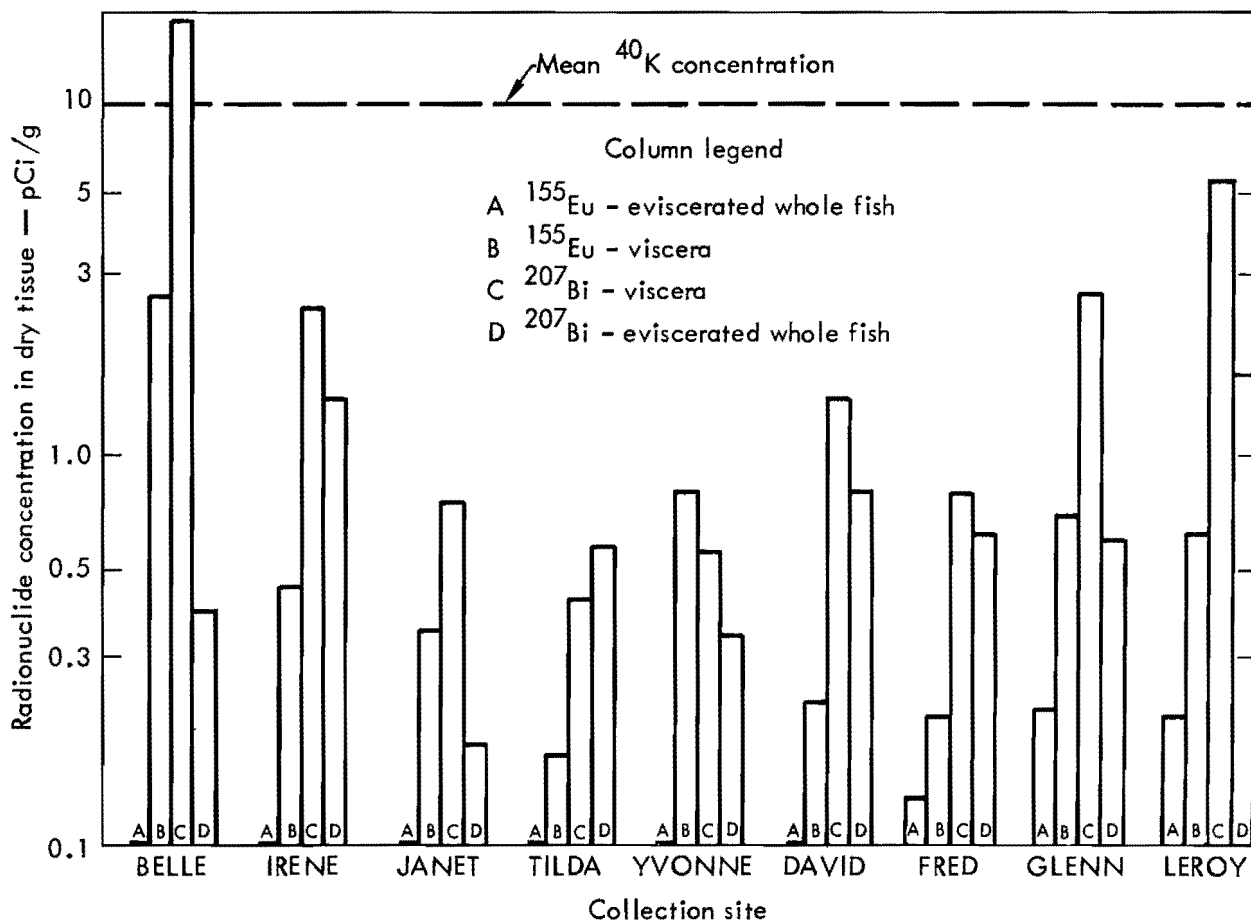


Fig. 43. Average  $^{40}\text{K}$ ,  $^{155}\text{Eu}$ , and  $^{207}\text{Bi}$  concentration in goatfish from Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean of all goatfish samples.

goatfish. A comparison of the amounts of  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ , and  $^{60}\text{Co}$  in goatfish is shown in Fig. 42. Iron-55 and  $^{60}\text{Co}$  were higher in the viscera than in the eviscerated whole fish by a factor of about 20 for  $^{55}\text{Fe}$  and 7 for  $^{60}\text{Co}$ . The viscera sample from goatfish collected at IRENE had the highest levels of  $^{60}\text{Co}$  (160 pCi/g, dry),

while the goatfish viscera from GLENN had the highest  $^{55}\text{Fe}$  level (1700 pCi/g, dry). Goatfish from LEROY, JANET, and YVONNE also had comparatively high levels of  $^{55}\text{Fe}$ , while goatfish from LEROY, BELLE, YVONNE, and GLENN had higher than average levels of  $^{60}\text{Co}$  for goatfish collected at Enewetak.

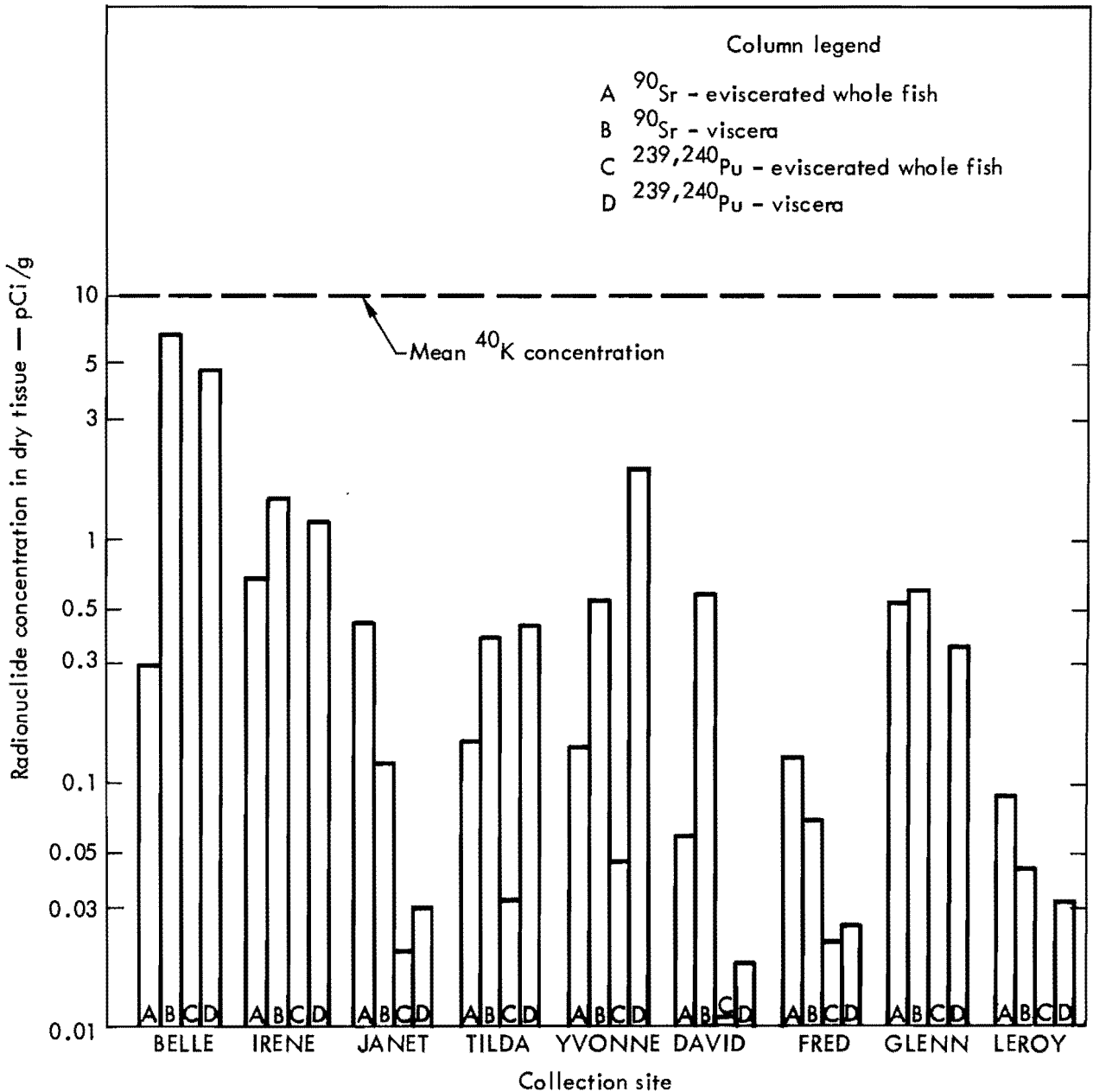


Fig. 43a. Average  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  concentration in goatfish from Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all goatfish samples.

Bismuth-207 was detected in most samples, but  $^{137}\text{Cs}$  and  $^{155}\text{Eu}$  were detected in less than 50% of the samples. A comparison between  $^{155}\text{Eu}$  and  $^{207}\text{Bi}$  levels in the goatfish is shown in Fig. 43. Levels of  $^{207}\text{Bi}$ ,  $^{155}\text{Eu}$ , and  $^{137}\text{Cs}$  were generally less than 3, 0.8, and 0.4 pCi/g, dry, respectively. The viscera samples from goatfish collected at BELLE had the highest levels of  $^{207}\text{Bi}$  (24 pCi/g, dry) and  $^{155}\text{Eu}$  (2.6 pCi/g, dry). Cesium-137 was highest in eviscerated whole goatfish from IRENE (0.98 pCi/g, dry). Europium-155 and  $^{207}\text{Bi}$  concentrations were higher in the viscera of the goatfish than in the eviscerated whole fish by factors of up to 43 for  $^{155}\text{Eu}$  and 62 for  $^{207}\text{Bi}$ , but the average ratio was less than 5 for  $^{155}\text{Eu}$  and 5 for  $^{207}\text{Bi}$ . Cesium-137 levels were similar in the two tissue types analyzed.

Strontium-90 and Pu data indicate that higher levels are found in the viscera than in the eviscerated whole fish. The highest level of these radionuclides is found in the viscera of goatfish from BELLE ( $^{90}\text{Sr} = 7.0$  pCi/g), ( $^{239,240}\text{Pu} = 5.0$  pCi/g). Goatfish from the north-east sector (BELLE to YVONNE) of the Atoll generally had higher levels of these two radionuclides than fish from the southwest sector (DAVID to LEROY). Strontium-90 and  $^{239,240}\text{Pu}$  (viscera samples) concentrations averaged less than 0.5 and 0.05 pCi/g, dry, in the northern and southern sectors of the atoll, respectively.

Convict Surgeon – The results of the radiological analyses of the convict surgeon samples are given in Table 31. Each sample was made up of the tissues

from an average pool of 15 fish, and all stations except IRENE and GLENN had 2 or more samples of both eviscerated whole fish and viscera. All fish were one species, Acanthurus triostegus. No differences due to size of fish pooled for a sample were noted and samples from all size classes were pooled to form the data in Table 31.

Naturally occurring  $^{40}\text{K}$  and man-made  $^{55}\text{Fe}$  and  $^{60}\text{Co}$  were the predominant radionuclides in the convict surgeon. Cesium-137,  $^{155}\text{Eu}$ , and  $^{207}\text{Bi}$  were also present in the samples from 50% or more of the collection sites. Americium-241 was found in 5 of 24 viscera samples, 2 each from BELLE and YVONNE and 1 from IRENE, while  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$  were found in most samples. Potassium-40 levels showed little variability between sampling sites. The viscera samples, however, had a greater  $^{40}\text{K}$  concentration (13 pCi/g, dry) than did the eviscerated whole fish sample (9.9 pCi/g, dry). Iron-55 concentrations were about 10 times higher in the viscera than in the eviscerated whole fish and were highest in the viscera of convict surgeon from LEROY and IRENE (160 pCi/g, dry). Viscera samples from convict surgeon collected from YVONNE to GLENN averaged < 10 pCi/g, dry. The viscera and eviscerated whole fish samples from convict surgeon collected from the Seminole Crater area of IRENE had the highest  $^{60}\text{Co}$  content (210 and 28 pCi/g, dry, respectively) of any of the convict surgeon samples. The viscera of convict surgeon from BELLE had 16 pCi of  $^{60}\text{Co}$ /g, dry, and all other samples had < 5.2 pCi/g, dry. The levels of  $^{60}\text{Co}$ ,  $^{55}\text{Fe}$ , and  $^{40}\text{K}$  in the convict surgeon are compared in Fig. 44.

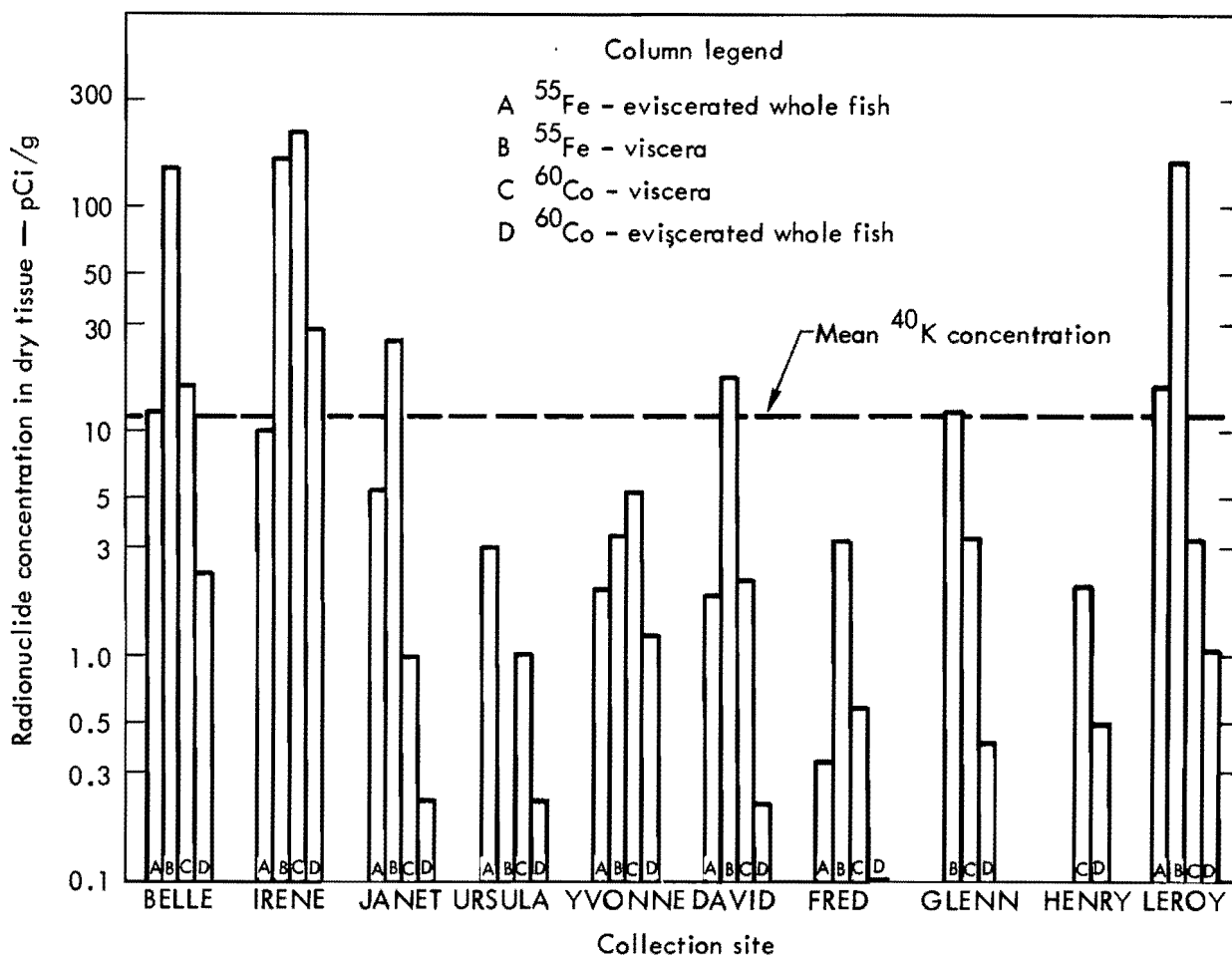


Fig. 44. Average  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ ,  $^{60}\text{Co}$  concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all convict surgeon samples.

Cesium-137,  $^{155}\text{Eu}$ , and  $^{207}\text{Bi}$  concentrations were less than 7 pCi/g, dry, in all samples and averaged less than 1 pCi/g, dry. The highest levels of  $^{137}\text{Cs}$  and  $^{155}\text{Eu}$  were found in convict surgeon collected from IRENE, while  $^{207}\text{Bi}$  was highest in convict surgeon from LEROY. A comparison of  $^{137}\text{Cs}$ ,  $^{155}\text{Eu}$ , and  $^{207}\text{Bi}$  levels in the convict surgeon is shown in Fig. 45.

Iron-55,  $^{60}\text{Co}$ ,  $^{155}\text{Eu}$ , and  $^{207}\text{Bi}$  levels were generally higher in the viscera of the convict surgeon than in the eviscerated whole fish. Differences between tissues were similar to those found

in the goatfish. Cesium-137 was equally distributed in the viscera and eviscerated whole fish.

Data on  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  concentrations in the convict surgeon indicate that the viscera of convict surgeon from IRENE has the highest concentration of both  $^{90}\text{Sr}$  (17 pCi/g, dry) and  $^{239,240}\text{Pu}$  (15 pCi/g, dry) of any of the convict surgeon samples analyzed so far. Convict surgeon from BELLE also have higher than average concentrations of these radionuclides. Convict surgeon collected from DAVID to HENRY had  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  tissue concentrations of <0.1 pCi/g, dry.

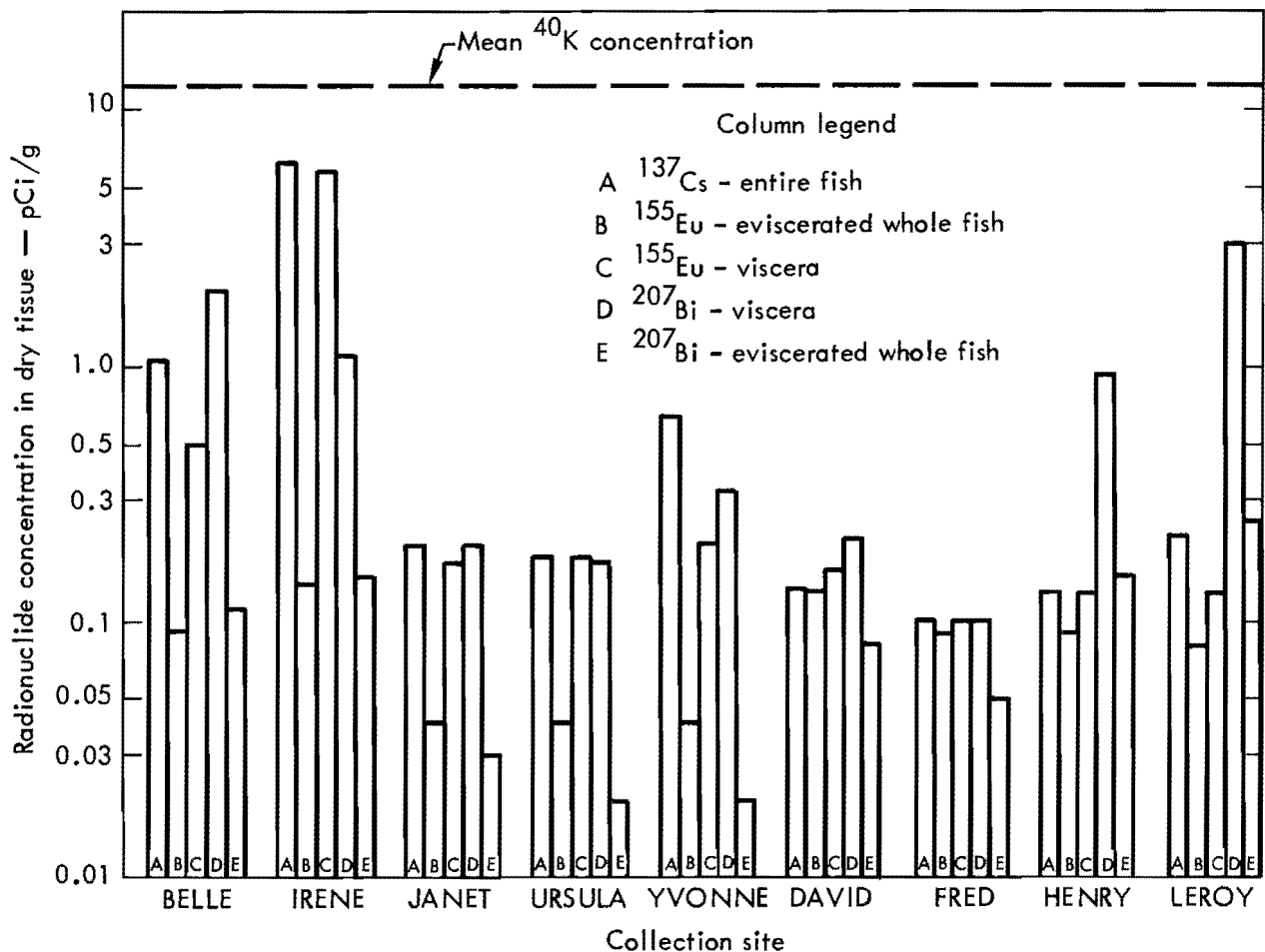


Fig. 45. Average  $^{137}\text{Cs}$ ,  $^{155}\text{Eu}$ , and  $^{207}\text{Bi}$  concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all convict surgeon samples.

Mullet – The results of the radiological analyses of the mullet tissues are given in Table 32. Each sample was made up of the tissues from an average pool of 10 fish. Although four species of mullet of various size classes were present in the samples, no correlation of radionuclide concentration with species or size was noted and samples from all species and sizes were pooled to form the data in Table 32. Sixty percent of the mullet collected for samples were Neomyxus chaptalii.

Of the three commonest radionuclides found in the mullet,  $^{40}\text{K}$  and  $^{55}\text{Fe}$  were

found in all samples, while  $^{60}\text{Co}$  was found in over 90% of the samples. Cesium-137,  $^{155}\text{Eu}$ , and  $^{207}\text{Bi}$  were found in 44%, 26%, and 26% of the samples, respectively. Americium-241 was found in all the viscera samples from BELLE and YVONNE and in one of two viscera samples from TILDA. Plutonium-239,240 and  $^{90}\text{Sr}$  were found in most samples.

Variability of  $^{40}\text{K}$  levels between sampling locations was within the normal range of expected values. Muscle tissue had the highest average  $^{40}\text{K}$  concentration, 13 pCi/g, dry, of the three tissue types analyzed. Eviscerated whole fish and



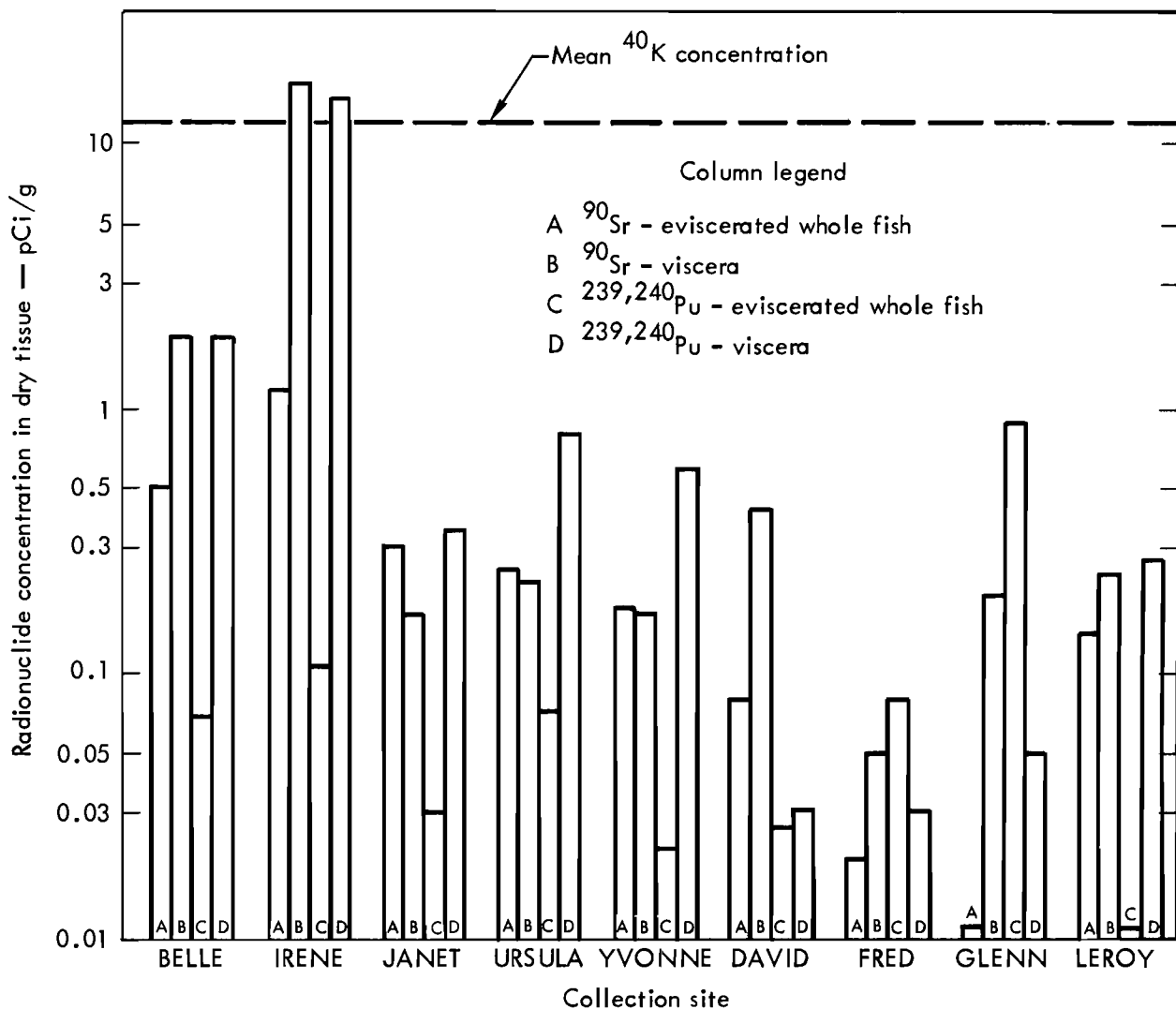


Fig. 45a. Average  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all convict surgeon samples.

viscera averaged 6.3 and 4.3 pCi/g, dry, respectively. A comparison of  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ , and  $^{60}\text{Co}$  in the mullet is shown in Fig. 46. Concentrations of  $^{55}\text{Fe}$  and  $^{60}\text{Co}$ , the most abundant man-produced radionuclides in the mullet, were higher in the viscera than in the muscle or eviscerated whole fish, two tissues which had similar concentrations. Cesium-137,  $^{155}\text{Eu}$ , and  $^{207}\text{Bi}$  were also present in the viscera in higher concentrations than in the other two tissues. Where  $^{155}\text{Eu}$

was detected, it was present in higher concentrations than either  $^{137}\text{Cs}$  or  $^{207}\text{Bi}$ .

The highest concentration of each of the predominant man-made radionuclides was found in the viscera samples taken from mullet collected at IRENE. These concentrations in pCi/g, dry, are as follows:  $^{55}\text{Fe}$  (220),  $^{60}\text{Co}$  (90),  $^{137}\text{Cs}$  (9.8),  $^{155}\text{Eu}$  (22), and  $^{207}\text{Bi}$  (2.2). Viscera samples from mullet collected at BELLE and YVONNE also had higher than average man-made radionuclide levels, but the

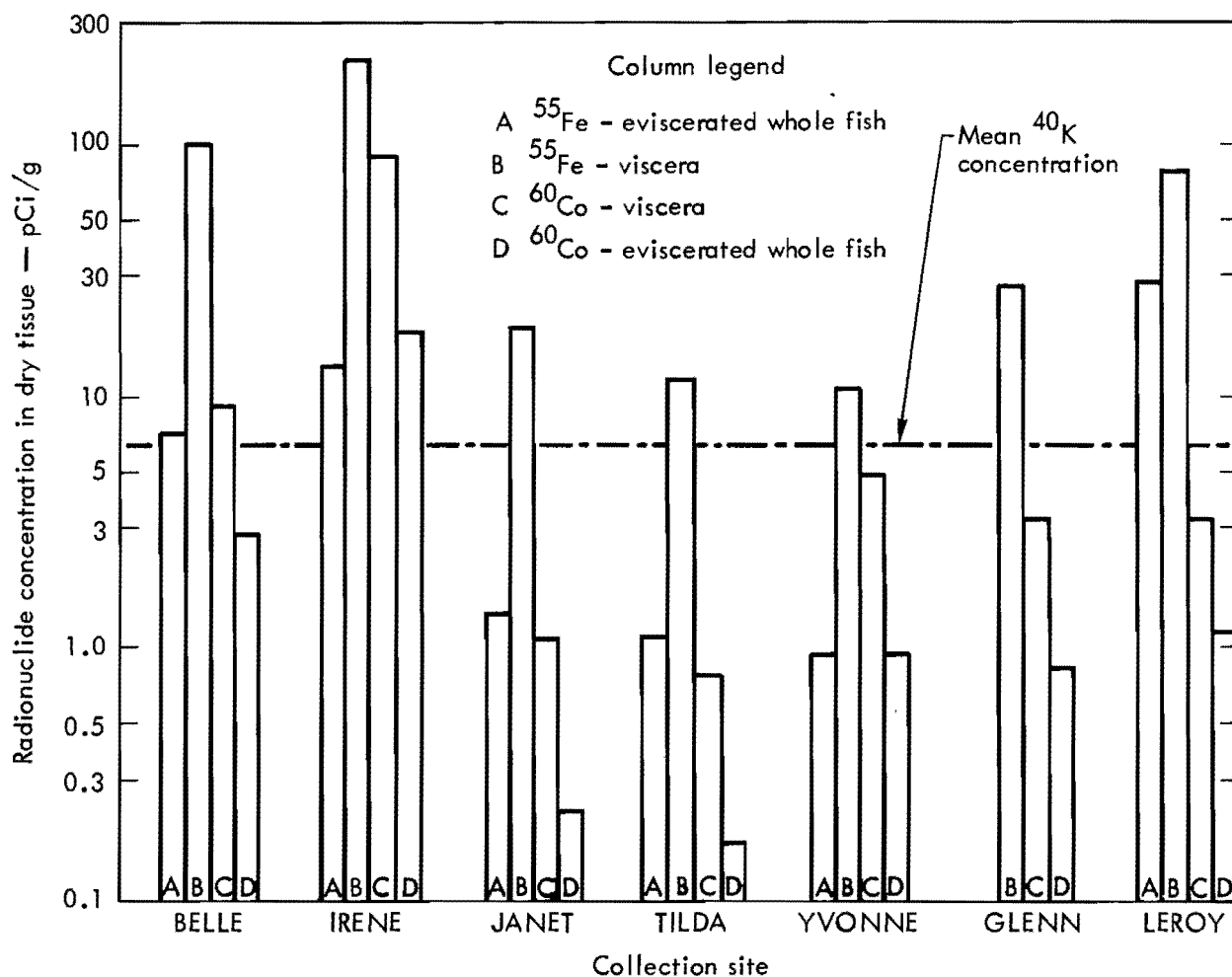


Fig. 46. Average  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ , and  $^{60}\text{Co}$  concentration in mullet collected at Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean from all mullet samples.

levels were lower than those in IRENE fish by factors of roughly 8 (BELLE) and 20 (YVONNE). Generally, levels of the man-made radionuclides in fish from GLENN, HENRY, and LEROY were slightly lower than levels of the same radionuclide in YVONNE mullet; however, one viscera sample from mullet collected from GLENN had 1.8 pCi/g, dry, of  $^{207}\text{Bi}$ , which was only slightly lower than the  $^{207}\text{Bi}$  content in the viscera sample from IRENE mullet. Mullet from JANET had the lowest man-made gamma-emitting radionuclide content.

The highest  $^{90}\text{Sr}$  level (6.1 pCi/g, dry) in the mullet was found in the viscera of mullet from BELLE, while the viscera of mullet from IRENE have the highest  $^{239,240}\text{Pu}$  content (24 pCi/g, dry). Concentrations of  $^{239,240}\text{Pu}$  in the viscera of mullet from BELLE were also higher (8.0 pCi/g, dry) than the average  $^{239,240}\text{Pu}$  concentration of < 1 pCi/g, dry.

Parrotfish - The results of the radiological analyses of the parrotfish tissues are given in Table 33. Each sample was made up of the tissues from an average pool of four fish. All fish were a single

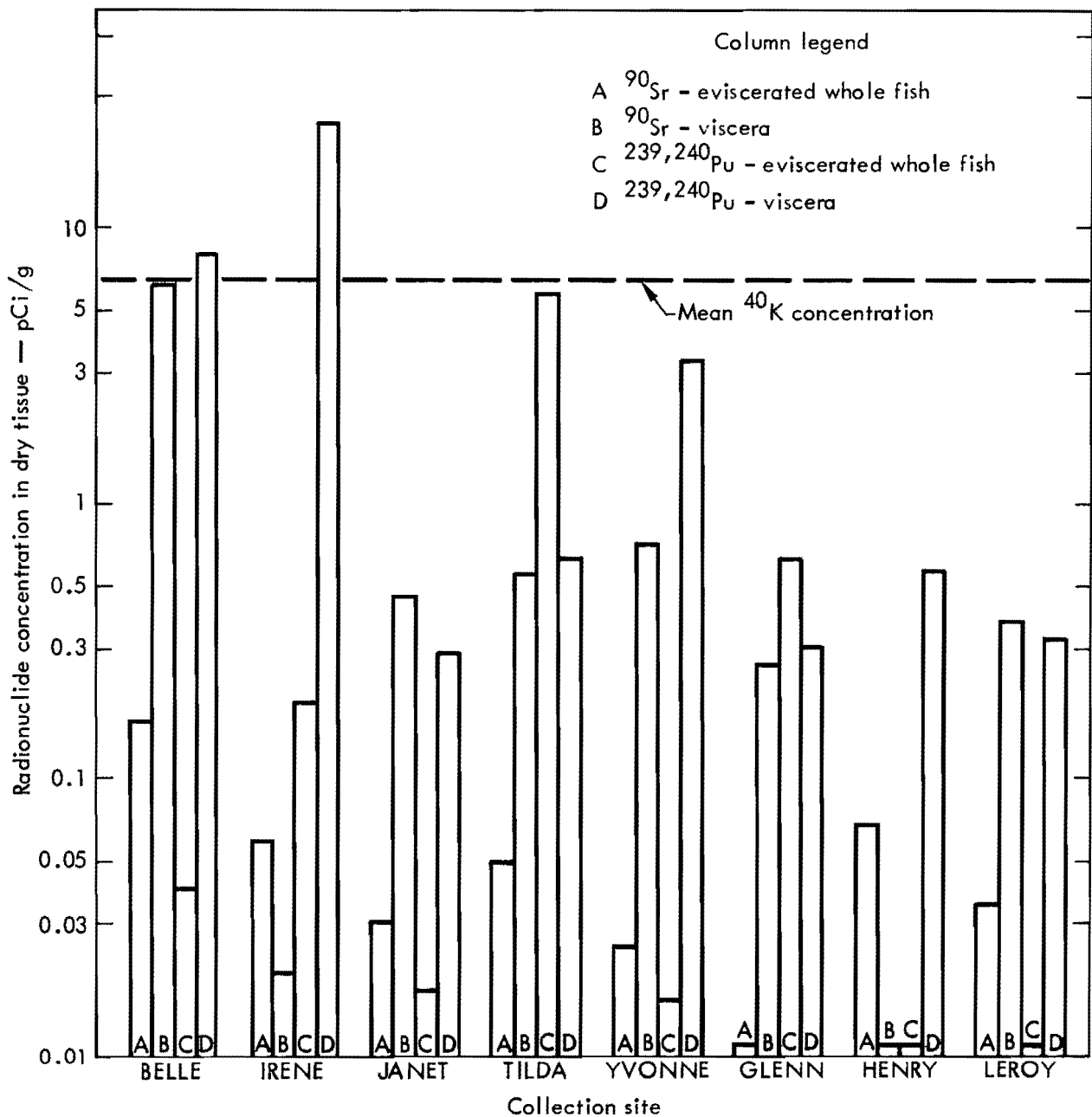


Fig. 46a. Average  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  concentration in mullet collected at Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all mullet samples.

species, Scarus sordidus, and most were of the same size class (24 to 36 cm).

Potassium-40 was the most abundant naturally occurring radionuclide and was detected in all of the parrotfish samples. Of the man-produced radionuclides, only  $^{55}\text{Fe}$  and  $^{137}\text{Cs}$  were present in

more than 50% of the samples.

Cobalt-60,  $^{155}\text{Eu}$ , and  $^{207}\text{Bi}$  were detected in 44%, 22%, and 15% of the samples, respectively. Americium-241 was detected in three viscera samples, one each from BELLE (1.4 pCi/g, dry), TILDA (0.21 pCi/g, dry), and YVONNE

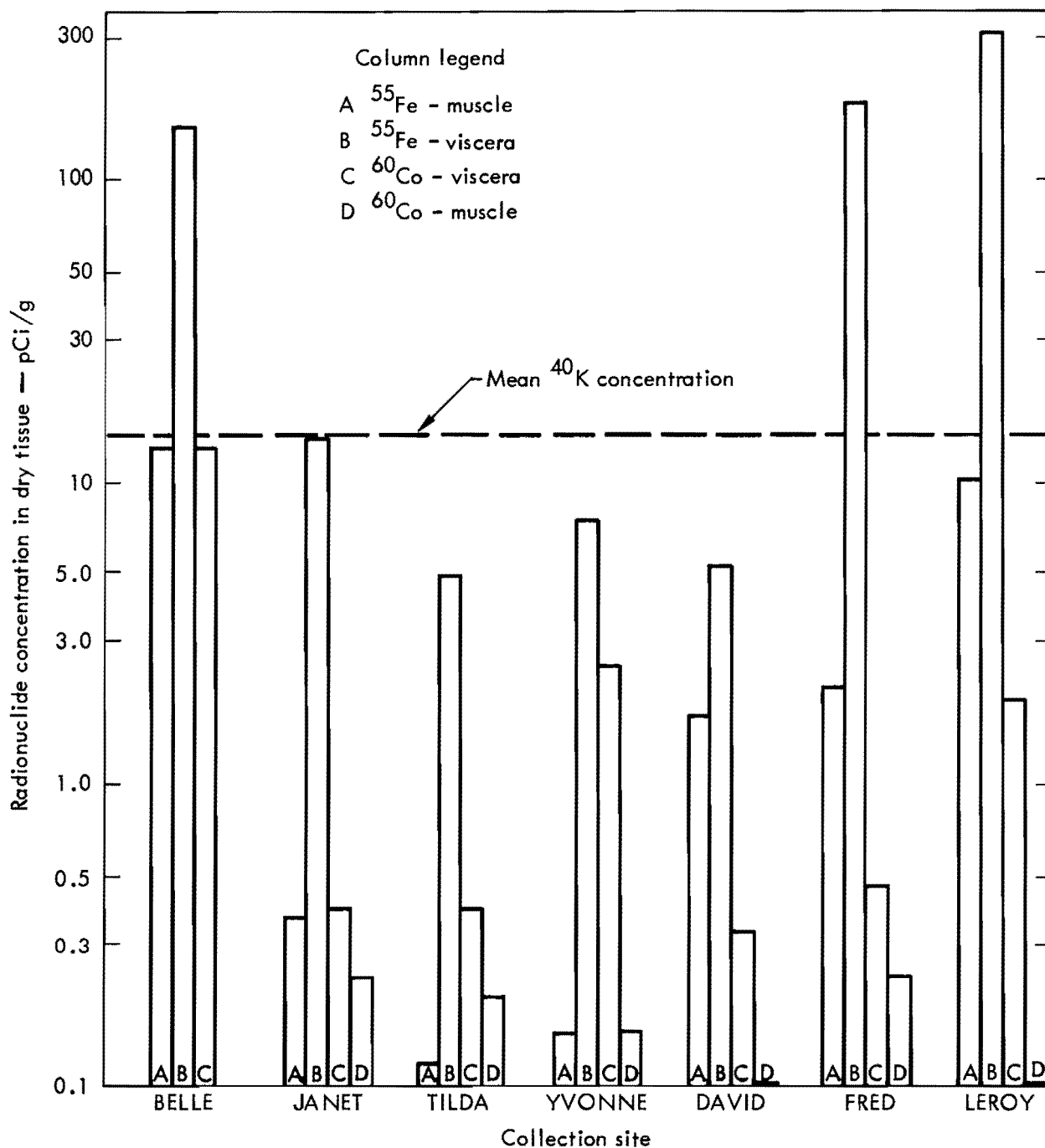


Fig. 47. Average  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ , and  $^{60}\text{Co}$  concentration in muscle and viscera samples from parrotfish collected at Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all parrotfish muscle and viscera samples.

(0.58 pCi/g, dry). Plutonium-239,240 and  $^{90}\text{Sr}$  were detected in most samples.

Potassium-40 levels showed little variability between sampling locations, except for one viscera sample from fish collected at BELLE, which had a  $^{40}\text{K}$

concentration of 21 pCi/g, dry, which was about three times greater than the average value for parrotfish viscera. All samples had  $^{40}\text{K}$  values within the expected range of natural levels, with muscle and viscera averaging 18 and 6.5 pCi/g, dry, respectively.

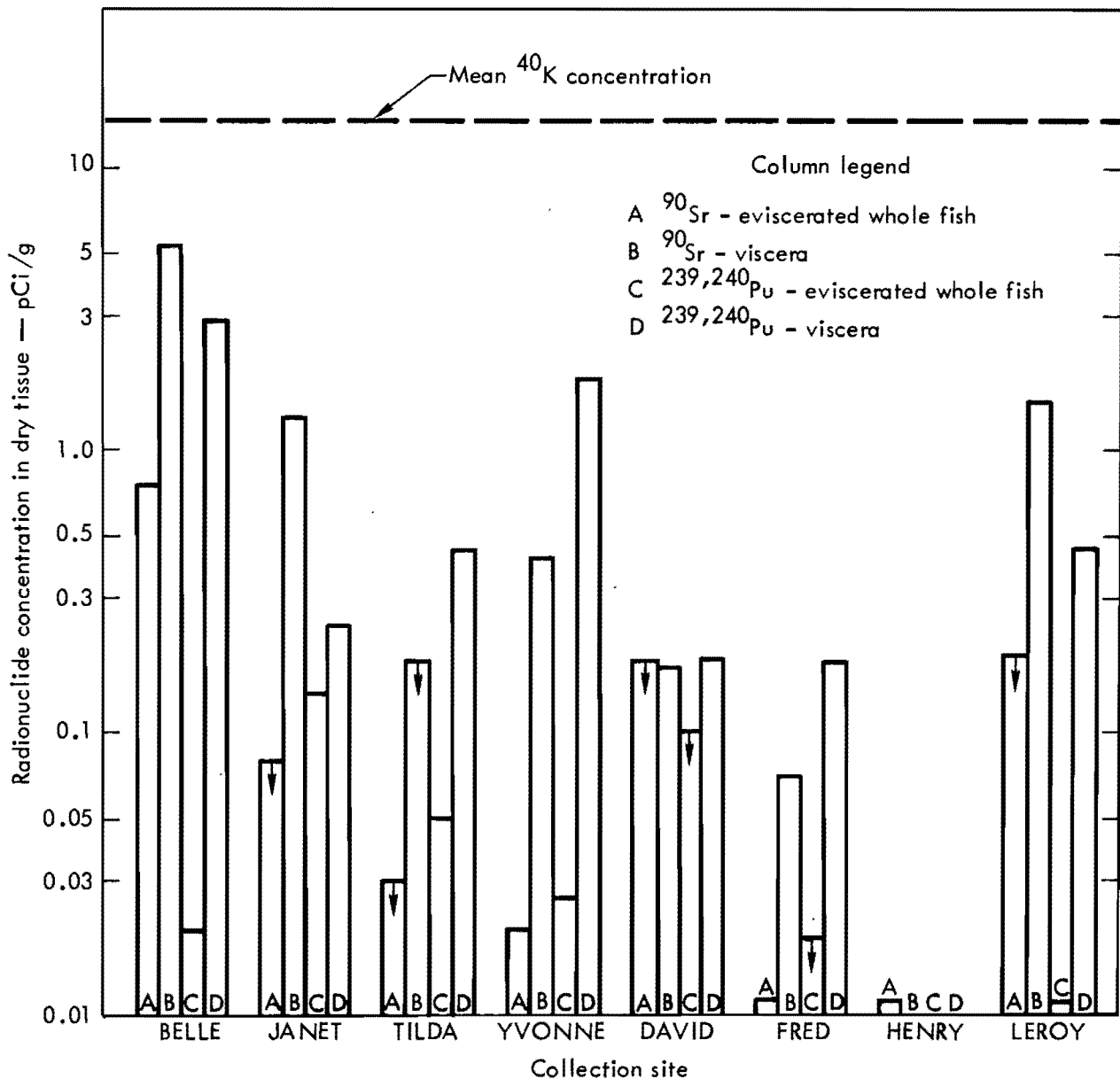


Fig. 47a. Average  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  concentration in muscle and viscera samples from parrotfish collected at Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all parrotfish muscle and viscera samples.

A comparison of  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ , and  $^{60}\text{Co}$  levels in the parrotfish is shown in Fig. 47.

Iron-55 was the most abundant man-produced radionuclide detected in the parrotfish samples. The highest  $^{55}\text{Fe}$  levels were found in the viscera (300 pCi/g, dry) and muscle of parrotfish from LEROY, while the average level was

2.6 pCi/g, dry, in muscle and 82 pCi/g, dry, in viscera.

The other two common man-made gamma-emitting radionuclides detected in the parrotfish were  $^{60}\text{Co}$  and  $^{137}\text{Cs}$ . Cesium was detected in more samples (55%) than  $^{60}\text{Co}$  (44%), but the highest  $^{60}\text{Co}$  level (13 pCi/g, dry) in viscera from BELLE parrotfish was higher than the

highest  $^{137}\text{Cs}$  level (3.0 pCi/g, dry) in eviscerated whole fish from BELLE. In addition to the samples from BELLE,  $^{60}\text{Co}$  was high in viscera from YVONNE (2.5 pCi/g, dry) and LEROY (1.9 pCi/g, dry), and  $^{137}\text{Cs}$  was high in muscle from FRED (1.8 pCi/g, dry). Other  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  concentrations averaged less than 0.40 pCi/g, dry.

Europium-155 and  $^{207}\text{Bi}$  were present in only a few samples. Europium-155 was high in viscera from BELLE (1.2 pCi/g, dry) and YVONNE (0.88 pCi/g, dry), while  $^{207}\text{Bi}$  was high in viscera from FRED (1.4 pCi/g, dry) and LEROY (1.3 pCi/g, dry).

Of the five man-produced radionuclides discussed above, only  $^{137}\text{Cs}$  was present in higher amounts in the muscle than in the viscera. Iron-55,  $^{60}\text{Co}$ ,  $^{155}\text{Eu}$ , and  $^{204}\text{Bi}$  levels were greater in the viscera than in the muscle of parrotfish.

The highest  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  concentrations in the parrotfish were found in the viscera sample from BELLE ( $^{90}\text{Sr}$  = 5.3 pCi/g, dry;  $^{239,240}\text{Pu}$  = 2.9 pCi/g, dry). Plutonium was also high in parrotfish from YVONNE (1.8 pCi/g in the viscera). Other samples had <1 pCi/g, dry, of these radionuclides. Strontium-90 and  $^{239,240}\text{Pu}$  levels were higher in the viscera than in the muscle by factors of 8 and 10, respectively.

Snappers and Groupers – The results of the radiological analyses of the snappers and groupers are given in Tables 34 and 35. These fish will be considered together because of the similarity in the results of the radiological analyses,

which probably is a consequence of the similarity in their feeding habits.

The three most abundant radionuclides found in the snappers and groupers were  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ , and  $^{60}\text{Co}$ . Cesium-137 and  $^{207}\text{Bi}$  in lesser amounts were found in about one-third of the samples. A small amount of  $^{155}\text{Eu}$  (0.13 pCi/g, dry) was found in one liver sample from a grouper collected at FRED, while  $^{241}\text{Am}$  (1.4 pCi/g, dry) was found in one bone sample from a grouper collected from YVONNE. Strontium-90 and  $^{239}\text{Pu}$  were detected in about 50% of the samples. Naturally occurring  $^{40}\text{K}$  levels were similar at all collection sites. Muscle and viscera tissue samples averaged 19 and 14 pCi/g, dry, respectively.

Iron-55 and  $^{60}\text{Co}$  were the predominant man-produced radionuclides found in the snappers and groupers. These two radionuclides were present in the viscera or liver in concentrations over 10 times higher than those found in the muscle. The highest  $^{55}\text{Fe}$  level, by a factor of 8, (4900 pCi/g, dry) was in a liver sample from a grouper collected at FRED. Several snapper and grouper viscera or liver samples from GLENN, ELMER, TILDA, and YVONNE also had  $^{55}\text{Fe}$  concentrations from 310 to 640 pCi/g, dry. Cobalt-60 levels were highest in grouper liver from FRED (94 pCi/g, dry), grouper viscera from YVONNE (36 pCi/g, dry), and snapper remainder (including viscera) from GLENN (22 pCi/g, dry). Only the muscle from the snapper sample from IRENE had a  $^{60}\text{Co}$  concentration above 1 pCi/g, dry (11 pCi/g, dry). Cobalt-60 concentrations in muscle samples averaged 1.4 pCi/g, dry, while  $^{60}\text{Co}$  in viscera or liver samples averaged 16 pCi/g, dry.

Bismuth-207 concentrations were lower than  $^{55}\text{Fe}$  and  $^{60}\text{Co}$  concentrations, but like those radionuclides,  $^{207}\text{Bi}$  levels were higher in the viscera or liver than in the muscle. The degree of difference between the  $^{207}\text{Bi}$  concentrations in the two types of tissue was less than twofold and was not nearly as great as it was for  $^{60}\text{Co}$  and  $^{55}\text{Fe}$ . The highest  $^{207}\text{Bi}$  concentration was found in the viscera (4.6 pCi/g, dry) and muscle (2.5 pCi/g, dry) of a grouper collected at YVONNE. A grouper and a snapper from FRED and a snapper from GLENN also had  $^{207}\text{Bi}$  levels of between one and two pCi/g, dry, in their tissues. Other  $^{207}\text{Bi}$  levels averaged less than 0.17 pCi/g, dry.

Cesium-137 levels in the groupers generally were less than 0.5 and averaged 0.25 pCi/g, dry, while one snapper muscle sample from IRENE had a  $^{137}\text{Cs}$  level of 2.1 pCi/g, dry, and the remainder of the samples averaged less than 0.22 pCi/g, dry.

The highest  $^{90}\text{Sr}$  concentration (2.9 pCi/g, dry) was found in the liver of a snapper collected off TILDA. Most other  $^{90}\text{Sr}$  levels were  $< 1$  pCi/g, dry. The highest  $^{239,240}\text{Pu}$  concentration (0.6 pCi/g, dry) was detected in the viscera of a snapper collected off TILDA. Most other  $^{239,240}\text{Pu}$  levels were  $< 0.1$  pCi/g, dry, with most of the Pu concentrated in the viscera.

Ulua – The results of the radiological analyses of the ulua tissues are given in Table 36. Potassium-40 was present in all tissues at an average concentration of 15 pCi/g, dry. Iron-55 and  $^{207}\text{Bi}$  were the most abundant man-made radionuclides and they were detected in all the ulua

samples. Cobalt-60 and  $^{137}\text{Cs}$  were found in over 50% of the samples, but at lower levels than  $^{55}\text{Fe}$  and  $^{207}\text{Bi}$ . Europium-155 and  $^{241}\text{Am}$  were not detected in any of the ulua samples analyzed. Strontium-90 and  $^{239,240}\text{Pu}$  were found in 50 and 75% of the samples, respectively.

Iron-55 was the most abundant man-made radionuclide found in the ulua. Iron-55 concentrations of up to 510 pCi/g, dry, were found in the viscera of a ulua from FRED. Viscera concentrations in ulua from YVONNE and ELMER were 350 and 33 pCi/g, dry, respectively, while muscle averaged 60 pCi/g, dry, in four samples, including the FRED ulua which had 150 pCi/g, dry, in its muscle tissue.

Bismuth-207 concentrations were quite variable between collection sites. One ulua from FRED had a  $^{207}\text{Bi}$  concentration in its viscera of 206 pCi/g, dry, and a sample of two eviscerated whole ulua from HENRY had a  $^{207}\text{Bi}$  concentration of 248 pCi/g, dry. The  $^{207}\text{Bi}$  concentrations averaged 3.0 pCi/g, dry, in the other nine samples of muscle and viscera.

Cobalt-60 levels were 8 times higher in the viscera samples than in the muscle samples. The greatest amount (13 pCi/g, dry) was in the viscera of two ulua collected at YVONNE. Cobalt-60 averaged 1.3 pCi/g in the muscle samples and 7.5 pCi/g in the viscera samples.

Cesium-137 levels ranged from 1.0 pCi/g, dry (HENRY – eviscerated whole) to less than 0.08 pCi/g, dry, with an average concentration of less than 0.37 pCi/g, dry. Cesium-137 concentrations were higher in the muscle than in the viscera. An exact factor of the tissue difference could not be determined, since

all the  $^{137}\text{Cs}$  levels in the viscera were below the limits of detection.

The highest  $^{90}\text{Sr}$  concentration (0.5 pCi/g, dry) was found in an eviscerated whole ulua collected off HENRY. Other ulua samples analyzed for  $^{90}\text{Sr}$  averaged <0.2 pCi/g, dry. Plutonium-239,240 levels were below 1.0 pCi/g, dry, except for the viscera sample from ulua collected at FRED which contained 15 pCi/g, dry.

Tuna and Other Large Pelagic Lagoon Fish – The results of the radiological analyses of large pelagic lagoon fish are given in Table 37. These fish include skipjack, yellowfin tuna, mackerel, dolphin, and barracuda. Of these fish the yellowfin tuna and the dolphin are likely to be resident in the lagoon on a more temporary basis than the skipjack, mackerel, or barracuda. Each tissue sample was from an individual fish except for mackerel sample No. 0440, which was a composite sample from two fish.

The results indicate that naturally occurring  $^{40}\text{K}$  is present in background amounts. All samples averaged 14 pCi/g, dry, with light muscle, dark muscle, and liver or viscera averaging 16, 12, and 11 pCi/g, dry, respectively. These levels are similar to those found at Kwajalein Atoll where pelagic lagoon fish had an average  $^{40}\text{K}$  tissue concentration of 14 pCi/g, dry.

Of the man-produced radionuclides found in these fish,  $^{55}\text{Fe}$  was by far the most abundant (Fig. 48). Iron-55 levels in the large pelagic fish were generally higher than levels found in other fish types, with the liver of the skipjack having the highest concentrations (maximum - 2500 pCi/g, dry; average - 840 pCi/g, dry) of

the tissues analyzed. Iron-55 in the skipjack was less in the light muscle than in the liver or dark muscle by factors of 18 and 7, respectively.

Cobalt-60 was found in most samples of lagoon fish, but at lower levels than  $^{55}\text{Fe}$ . The highest  $^{60}\text{Co}$  concentration in the pelagic lagoon fish was 36 pCi/g, dry, in the liver of a skipjack captured near YVONNE. Light muscle of tuna and muscle of the other fish averaged 0.58 pCi/g, dry, while dark muscle of tuna and liver or viscera of all these pelagic lagoon fish averaged 8.4 and 11 pCi/g, dry, respectively. There was considerable variation in the amount of  $^{60}\text{Co}$  present in tissue samples from the same species of fish. For instance, a yellowfin tuna taken from the Deep Channel had  $^{60}\text{Co}$  concentrations of 8.4 and 2.1 pCi/g, dry, in the dark muscle and liver, while a yellowfin taken off the ocean side of GLENN, had 0.55 pCi/g, dry, in its dark muscle and less than 0.61 pCi/g, dry, in its liver. The two dolphin exhibited similar differences. This indicates that the residence time of some of these fish near or in the lagoon, which is the major source of the  $^{60}\text{Co}$  and other man-produced radionuclides in their tissues, is quite variable. Fish (i.e., skipjack) which tend to stay within the atoll had a more consistent distribution of radionuclides among individuals, although there is still a wide variability between individuals and the average radionuclide concentration of the total group of fish. For instance, livers from three skipjack taken off YVONNE averaged 23 pCi/g, dry, and had a range from 5.2 to 36 pCi/g, dry, while liver tissue from five skipjack taken from the southern end of the atoll averaged 12 pCi/g, dry, with a range of <0.68 to



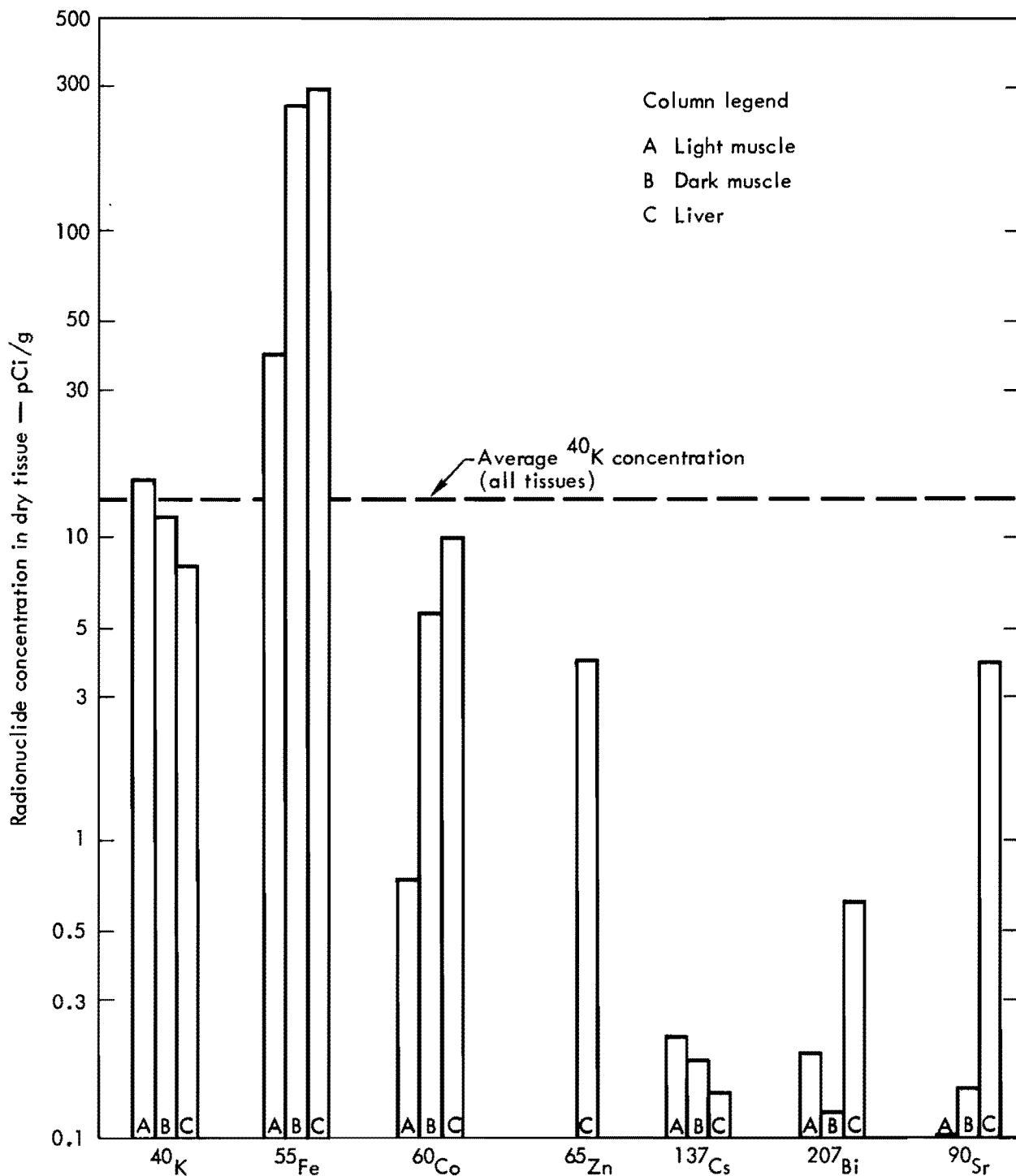


Fig. 48. Average concentration of seven radionuclides in the light muscle (A), dark muscle (B), and liver (C) of three skipjack from Enewetak Atoll, October to December, 1972.

19 pCi/g, dry. This difference between skipjack from the portions of the atoll was found to be not significant when tested with analysis of variance methods. Dark

and light muscle tissue from all skipjack taken at Enewetak had average <sup>60</sup>Co concentrations of 9.4 and 9.8 pCi/g, dry, respectively. There was no significant

Table 37. Predominant radionuclides in large pelagic lagoon fish collected at Enewetak Atoll, October to December 1972.

Sample No.	Collection site	Common name (size in cm)	Tissue <sup>b</sup>	Radionuclide, average $\pm$ standard deviation <sup>a</sup> in pCi/g. dry								
				<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>65</sup> Zn	<sup>137</sup> Cs	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu	
0229	Wide Pass	Skipjack (49)	Light muscle	19 $\pm$ 1.0	37 $\pm$ 0.3	0.98 $\pm$ 0.13	NC <sup>c</sup>	0.22 $\pm$ 0.05	0.13 $\pm$ 0.04	< 0.04	< 0.001	
0240			Dark muscle	16 $\pm$ 2.4	280 $\pm$ 2	5.9 $\pm$ 0.3	NC	0.21 $\pm$ 0.10	0.19 $\pm$ 0.08	< 0.18	< 0.002	
0264			Liver	9.6 $\pm$ 0.9	280 $\pm$ 2	13 $\pm$ 0.2	6.6 $\pm$ 0.4	< 0.07	0.86 $\pm$ 0.06	< 0.06	0.010 $\pm$ 0.001	
0253			Bone	10 $\pm$ 1.3	19 $\pm$ 0.4	0.17 $\pm$ 0.13	NC	0.22 $\pm$ 0.09	0.15 $\pm$ 0.05	0.14 $\pm$ 0.05	< 0.023	
0273	Wide Pass	Skipjack (46)	Light muscle	12 $\pm$ 1.4	39 $\pm$ 0.8	0.52 $\pm$ 0.08	NC	< 0.10	< 0.08	0.04 $\pm$ 0.02	1.2 $\pm$ 0.01	
0268			Dark muscle	9.3 $\pm$ 1.0	—	8.4 $\pm$ 0.2	NC	0.18 $\pm$ 0.08	< 0.08	< 0.01	0.032 $\pm$ 0.001	
0237			Liver	11 $\pm$ 2.1	650 $\pm$ 6.5	< 0.68	1.8 $\pm$ 0.5	0.48 $\pm$ 0.18	0.56 $\pm$ 0.13	0.06 $\pm$ 0.02	0.009 $\pm$ 0.001	
0252			Bone	NC	33 $\pm$ 0.4	< 0.36	NC	< 0.21	< 0.19	< 0.18	< 1.2	
0235	Wide Pass	Skipjack (48)	Light muscle	17 $\pm$ 1.4	47 $\pm$ 1.1	0.87 $\pm$ 0.14	NC	0.28 $\pm$ 0.05	0.21 $\pm$ 0.04	< 0.10	< 0.009	
0274			Dark muscle	9.9 $\pm$ 1.4	270 $\pm$ 2.7	5.8 $\pm$ 0.20	NC	< 0.13	< 0.10	< 0.10	< 0.011	
0269			Liver	8.4 $\pm$ 0.9	410 $\pm$ 4.1	12 $\pm$ 0.4	2.9 $\pm$ 0.3	0.26 $\pm$ 0.08	0.55 $\pm$ 0.05	< 0.23	0.009 $\pm$ 0.001	
0254			Bone	12 $\pm$ 3.5	—	< 0.29	NC	< 0.17	< 0.14	< 0.08	< 0.014 $\pm$ 0.005	
0481	WALT	Skipjack (54)	Light muscle	17 $\pm$ 1.2	73 $\pm$ 1.1	1.2 $\pm$ 0.2	NC	0.67 $\pm$ 0.09	6.1 $\pm$ 0.1	< 0.10	< 0.004	
0482			Dark muscle	14 $\pm$ 1.0	460 $\pm$ 4.6	15 $\pm$ 0.3	NC	0.76 $\pm$ 0.09	3.7 $\pm$ 0.1	< 0.10	< 0.005	
0483			Liver	21 $\pm$ 2.0	2 500 $\pm$ 25	19 $\pm$ 0.4	NC	2.7 $\pm$ 0.2	1.7 $\pm$ 0.2	< 0.02	0.022 $\pm$ 0.007	
0324	DAVID	Skipjack (45)	Light muscle	14 $\pm$ 0.9	29 $\pm$ 0.6	0.62 $\pm$ 0.03	NC	0.16 $\pm$ 0.02	< 0.02	< 0.01	0.005 $\pm$ 0.001	
0325			Dark muscle	13 $\pm$ 1.6	330 $\pm$ 4.4	11 $\pm$ 0.4	NC	0.31 $\pm$ 0.11	< 0.07	< 0.44	—	
0326			Liver	8.7 $\pm$ 2.1	520 $\pm$ 1.0	13 $\pm$ 0.6	2.5 $\pm$ 0.8	0.60 $\pm$ 0.20	0.44 $\pm$ 0.13	< 0.04	< 0.012	
0327			Bone	NC	5.0 $\pm$ 3.3	< 0.36	NC	< 0.23	< 0.21	< 1.1	< 0.039	
0524	YVONNE	Skipjack (58)	Light muscle	17 $\pm$ 1.1	58 $\pm$ 1.2	1.1 $\pm$ 0.1	NC	0.44 $\pm$ 0.05	1.1 $\pm$ 0.1	< 0.01	0.036 $\pm$ 0.002	
0523			Dark muscle	14 $\pm$ 1.0	400 $\pm$ 4.1	12 $\pm$ 0.2	NC	0.39 $\pm$ 0.07	0.82 $\pm$ 0.06	0.004 $\pm$ 0.003	0.005 $\pm$ 0.001	
0525			Liver	14 $\pm$ 2.7	1300 $\pm$ 13	36 $\pm$ 0.6	1.5 $\pm$ 0.6	< 0.22	2.2 $\pm$ 1.8	0.022 $\pm$ 0.009	0.023 $\pm$ 0.002	
0526			Bone	3.4 $\pm$ 1.0	14 $\pm$ 0.14	0.33 $\pm$ 0.06	NC	0.15 $\pm$ 0.06	0.13 $\pm$ 0.06	0.05 $\pm$ 0.005	0.002 $\pm$ 0.001	
0528	YVONNE	Skipjack (57)	Light muscle	10 $\pm$ 1.2	42 $\pm$ 1.5	0.80 $\pm$ 0.08	NC	0.28 $\pm$ 0.06	0.87 $\pm$ 0.08	< 0.009	0.009 $\pm$ 0.002	
0527			Dark muscle	13 $\pm$ 2.2	38 $\pm$ 0.8	11 $\pm$ 0.07	NC	< 0.22	0.89 $\pm$ 0.15	0.007 $\pm$ 0.002	0.72 $\pm$ 0.014	
0534			Liver	9.7 $\pm$ 1.6	—	28 $\pm$ 0.5	2.8 $\pm$ 0.9	< 0.16	3.2 $\pm$ 0.2	0.010 $\pm$ 0.005	0.014 $\pm$ 0.002	
0529			Bone	6.5 $\pm$ 0.9	19 $\pm$ 0.37	0.28 $\pm$ 0.06	NC	< 0.07	0.24 $\pm$ 0.04	0.024 $\pm$ 0.02	0.006 $\pm$ 0.003	
0531	YVONNE	Skipjack (53)	Light muscle	13 $\pm$ 1.3	54 $\pm$ 1.5	0.37 $\pm$ 0.05	NC	0.15 $\pm$ 0.05	0.24 $\pm$ 0.04	< 0.05	0.007 $\pm$ 0.002	
0530			Dark muscle	11 $\pm$ 1.0	240 $\pm$ 1.1	5.0 $\pm$ 0.20	NC	0.19 $\pm$ 0.08	< 0.07	< 0.035	0.002 $\pm$ 0.001	
0532			Liver	6.3 $\pm$ 1.7	200 $\pm$ 0.6	5.2 $\pm$ 0.3	2.2 $\pm$ 0.5	< 0.09	0.43 $\pm$ 0.09	< 0.062	0.004 $\pm$ 0.001	
0533			Bone	8.9 $\pm$ 1.3	5.8 $\pm$ 0.3	< 0.13	NC	< 0.09	< 0.07	< 0.05	< 0.07	
0552	GLENN	Yellow-fin (~100)	Light muscle	16 $\pm$ 1.0	0.17 $\pm$ 0.03	< 0.07	NC	0.10 $\pm$ 0.03	< 0.03	< 0.02	0.006 $\pm$ 0.001	
0553			Dark muscle	12 $\pm$ 1.7	50 $\pm$ 1.5	0.55 $\pm$ 0.10	NC	0.21 $\pm$ 0.07	< 0.04	0.023 $\pm$ 0.003	0.02 $\pm$ 0.003	
0554			Liver	NC	66 $\pm$ 1.3	< 0.61	NC	< 0.33	< 0.27	0.11 $\pm$ 0.05	4.6 $\pm$ 0.14	
0555			Bone	NC	13 $\pm$ 0.6	0.20	NC	< 0.19	< 0.15	< 0.09	0.20 $\pm$ 0.02	

0693	Deep Channel	Yellow-fin (~100)	Light muscle	15 ± 1.1	3.1 ± 0.1	<0.14	NC	<0.09	<0.06	<0.04	<0.028
0694			Dark muscle	9.7 ± 1.2	49 ± 0.4	8.4 ± 1.3	NC	<0.12	<0.07	<0.16	—
0695			Liver	NC	99 ± 1.1	2.1 ± 0.3	NC	<0.30	<0.24	<0.08	<0.001
0696			Bone	2.5 ± 0.6	<0.06	<0.04	NC	<0.03	0.02	<0.02	0.01 ± 0.005
0440	ELMER	Mackerel (47,41)	Viscera	9.7 ± 1.6	240 ± 2.9	2.7 ± 0.25	NC	<0.20	0.98 ± 0.10	<0.34	<0.011
0442			Muscle	20 ± 1.4	6.5 ± 0.3	<0.23	NC	0.17 ± 0.07	0.09 ± 0.04	0.097	<0.002
0443			Muscle	20 ± 1.4	10 ± 0.4	0.68 ± 0.15	NC	0.21 ± 0.07	<0.06	<0.10	<0.006
0572	GLENN	Mackerel (~45)	Muscle	18 ± 1.5	11 ± 0.3	0.37 ± 0.07	NC	0.24 ± 0.06	<0.05	<0.20	<0.009
0574			Viscera	NC	210 ± 6.4	5.3 ± 1.6	NC	0.36	0.34	<1.3	0.002 ± 0.001
0573			Bone	18 ± 4.1	580 ± 10	0.61 ± 0.18	NC	<0.20	<0.17	<1.1	0.014 ± 0.002
0706	Wide Pass	Dolphin (~100)	Muscle	15 ± 1.3	—	0.67 ± 0.18	NC	0.20 ± 0.07	0.09 ± 0.04	0.005 ± 0.003	0.016 ± 0.001
0707			Liver	10 ± 1.7	45 ± 1.3	13 ± 0.5	NC	<0.16	<0.13	<0.02	0.035 ± 0.003
0540	ELMER	Dolphin (80)	Muscle	19 ± 1.7	<0.9	<0.14	NC	<0.09	<0.07	<0.10	0.003
0541			Liver	15 ± 1.6	30 ± 5.9	0.98 ± 0.37	NC	<0.30	<0.67	—	0.07 ± 0.02
0769	MIKE	Barra-cuda (~60)	Muscle	16 ± 1.3	—	0.55 ± 0.07	NC	1.6 ± 0.10	28 ± 0.5	0.05 ± 0.01	—
0770	Crater		Bone	6.3 ± 0.9	—	0.38 ± 0.06	NC	0.48 ± 0.07	2.7 ± 0.1	0.15 ± 0.01	0.24 ± 0.02

<sup>a</sup>Error values are one-sigma, counting errors.

<sup>b</sup>Each tissue sample is from an individual fish except for No. 0440 which is a composite sample from two fish.

<sup>c</sup>NC = not computed.

difference in the  $^{60}\text{Co}$  concentration in muscle tissue of skipjack captured near YVONNE as compared to those captured near the southern end of the atoll.

Zinc-65, was found only in the liver of the skipjack. Seven ( $^{65}\text{Zn}$  in one liver was not computed) skipjack livers had detectable levels of  $^{65}\text{Zn}$  ranging from 1.5 to 6.6 pCi/g, dry, and averaged 2.9 pCi/g, dry. Two skipjack and one wahoo from Kwajalein Atoll also had average  $^{65}\text{Zn}$  concentrations of 0.9 pCi/g, dry, in their livers, indicating that at least a part of the  $^{65}\text{Zn}$  present in the Enewetak skipjack is from worldwide fallout.

Cesium-137 and  $^{207}\text{Bi}$  were found in about 50% of the samples, usually at levels below 1 pCi/g, dry. Cesium-137 was found mainly in the muscle tissue and was evenly distributed between light and dark muscle. However, the highest  $^{137}\text{Cs}$  level was found in the liver of a skipjack from the lagoon off WALT Island. Bismuth-207 was also at its highest level (6.1 pCi/g, dry) in the dark muscle tissue of this skipjack. However,  $^{207}\text{Bi}$  was generally higher in the liver or viscera of a fish than in the muscle.

The only  $^{241}\text{Am}$  detected in the offshore lagoon fish was also found in the above-mentioned skipjack from WALT. This fish had an  $^{241}\text{Am}$  concentration of 0.35 pCi/g, dry, in its light muscle and 0.83 pCi/g, dry, in its liver.

Strontium-90 and  $^{239,240}\text{Pu}$  analyses indicate that these radionuclides are generally found in concentrations < 0.1 pCi/g, dry. The highest  $^{90}\text{Sr}$  levels in the pelagic fish are found in barracuda bone (0.15 pCi/g, dry), while the highest  $^{239,240}\text{Pu}$  concentration (1.2 pCi/g, dry)

was in the light muscle of a skipjack collected in the Wide Pass.

#### Summary and Conclusions

Of the man-made radionuclides,  $^{60}\text{Co}$  and  $^{55}\text{Fe}$  are found in the greatest abundance in the nearshore fish, followed by  $^{207}\text{Bi}$ ,  $^{155}\text{Eu}$ ,  $^{137}\text{Cs}$ , and  $^{241}\text{Am}$  in order of decreasing abundance. All these radionuclides except  $^{137}\text{Cs}$  are present in greater concentrations in the viscera as compared to eviscerated whole fish. Cesium-137 is about equally distributed in the viscera and eviscerated whole fish.

In general, nearshore fish collected from IRENE had the highest levels of  $^{55}\text{Fe}$ ,  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ ,  $^{155}\text{Eu}$ , and  $^{241}\text{Am}$ , while  $^{207}\text{Bi}$  was highest in an ulua from HENRY.

Iron-55 concentrations were generally highest in the liver or dark muscle of the tuna and in the viscera of goatfish, however, a grouper liver from FRED had the highest individual value, 4900 pCi/g, dry, of any sample analyzed. Iron-55 concentrations were higher by a factor of 10 or more in liver or viscera than in light muscle or eviscerated whole fish.

Cobalt-60 concentrations in the nearshore fish ranged from non-detectable amounts to 400 pCi/g, dry, in the viscera of butterfly fish from IRENE. Most  $^{60}\text{Co}$  values for these fish were less than 5 pCi/g, dry.

Cobalt-60 concentrations in Enewetak lagoon fish ranged up to 36 pCi/g, dry, in the liver of a skipjack from near YVONNE. Although the average  $^{60}\text{Co}$  concentration in the tissue samples of three skipjack captured near YVONNE was higher than that found in samples from skipjack in the southern part of the atoll, there was no

significant difference between the two areas due to the high variability within samples from the same area.

Cobalt-60 concentrations in the liver and muscle of the other lagoon fish was less than it was in the skipjack. No  $^{60}\text{Co}$  was detected in lagoon fish from Kwajalein.

Bismuth-207,  $^{155}\text{Eu}$ , and  $^{137}\text{Cs}$  were the next most abundant radionuclides. Bismuth-207 concentrations in the small nearshore fish and in snappers and groupers ranged from non-detectable levels up to 24 pCi/g, dry, in the viscera of goatfish from BELLE, and most concentrations were less than 5 pCi/g, dry; however, one ulua from HENRY had a  $^{207}\text{Bi}$  concentration of 240 pCi/g, dry. Europium-155 concentrations in all nearshore fish ranged up to 22 pCi/g, dry, found in the viscera of mullet from IRENE, while average values were less than 1 pCi/g, dry. Cesium-137 concentrations ranged up to 9.6 pCi/g, dry, in mullet viscera from IRENE, but most concentrations were less than 0.5 pCi/g, dry.

Cesium-137 was found in muscle tissue of offshore lagoon fish from Enewetak and Kwajalein Atolls in about the same concentrations (less than 0.5 pCi/g, dry) except for one barracuda captured in MIKE Crater and a skipjack taken off WALT. The barracuda had a  $^{137}\text{Cs}$  concentration of 16 pCi/g, dry, in its muscle tissue, while the skipjack had 2.7 pCi/g, dry, in its liver.

The muscle tissue of the barracuda from MIKE Crater also had the highest  $^{207}\text{Bi}$  level (28 pCi/g, dry) of any offshore lagoon fish from Enewetak Atoll. Bismuth-207 was detected in 14 or 20 samples of skipjack muscle in concentrations up to 6.1 pCi/g, dry, and averaged 1.5 pCi/g,

dry. All eight skipjack from Enewetak had detectable  $^{207}\text{Bi}$  in their livers in concentrations up to 2.3 pCi/g, dry, and averaged 0.9 pCi/g, dry. No significant differences between  $^{207}\text{Bi}$  content in the tissues of three skipjack from the YVONNE area and five skipjack from the southern end of the Atoll were noted. Yellowfin tuna had no detectable  $^{207}\text{Bi}$  in their tissues, while mackerel and dolphin had low levels in the muscle.

Europium-155 was detected in only one offshore fish sample.

Zinc-65 was found in the liver of skipjack from Enewetak Atoll in concentrations up to 6.6 pCi/g, dry, and averaged 2.9 pCi/g, dry, in the seven skipjack which had detectable levels. Two skipjack livers and one wahoo liver from Kwajalein Atoll also had detectable  $^{65}\text{Zn}$  concentrations which averaged 0.9 pCi/g, dry, tissue. Zinc-65 was detected only in liver tissue.

Other gamma-emitting radionuclides were present in small amounts on a sporadic basis.

Americium-241 was found almost exclusively in the viscera of fish from BELLE, IRENE, TILDA-URSULA, and YVONNE. Concentrations ranged up to 11 pCi/g, dry, in mullet viscera from IRENE, but averaged less than 1 pCi/g, dry. Plutonium-239, 240 and  $^{90}\text{Sr}$  concentrations were also high in the viscera of fish from these areas, with the highest concentrations being in the fish from IRENE and BELLE. Large pelagic lagoon fish had lower concentrations of these radionuclides than did the smaller nearshore fish.

There are some differences in radionuclide content of nearshore fish

Table 38. Comparison of  $^{60}\text{Co}$  and  $^{207}\text{Bi}$  in the viscera of convict surgeon collected in 1964 and 1972.

Island	$^{60}\text{Co}$ in pCi/g, dry			$^{207}\text{Bi}$ in pCi/g, dry		
	1964	1972	Fraction remaining	1964	1972	Fraction remaining
BELLE	120	16	0.13	8.0	2.0	0.25
JANET	8.3	0.96	0.12	1.2	0.2	0.17
GLENN	19	3.3	0.17	2.6	0.7	0.27
LEROY	56	3.4	0.06	5.2	3.1	0.59
YVONNE	64	5.2	0.08	-	-	-
Average			0.11			0.32

associated with feeding habits. The goatfish, a bottom-feeding carnivore, usually contains more  $^{55}\text{Fe}$ ,  $^{60}\text{Co}$ , and  $^{207}\text{Bi}$  than the convict surgeon, a grazing herbivore, or the mullet, a detritus feeder. Convict surgeon from BELLE and IRENE did contain more  $^{60}\text{Co}$  than goatfish from IRENE, but goatfish from all other areas had higher  $^{60}\text{Co}$  concentrations than did the convict surgeon from the same area.

A comparison of the present  $^{60}\text{Co}$  and  $^{207}\text{Bi}$  levels in the fish to those found in the 1964 collections (Welander, *et al.*, 1967\*) gives some indication of the loss rate of those two radionuclides. From the data presented in Table 38, a rough estimate of the effective half-life for  $^{60}\text{Co}$  (2.7 years) and  $^{207}\text{Bi}$  (5 years) can be deduced. Using these values in the equation,  $e = PE/P - E$ , where  $e$  = ecological half-life,  $P$  = physical half-life, and  $E$  = effective half-life, the length of the ecological half-life can be calculated. Ecological half-life is the time required for one-half of the radionuclide in the

organism to be lost by processes other than physical decay of the radionuclide during a period when there can be both uptake and loss of the radionuclide but loss is greater than uptake. Thus, the ecological half-life of both  $^{60}\text{Co}$  and  $^{207}\text{Bi}$  in the convict surgeon at Enewetak between 1964 and 1972 is about 6 yr.

Comparisons of similar samples of mullet and goatfish give a similar value. Hence, these two radionuclides are being eliminated from these fish at a higher rate than would result from physical decay alone.

In conclusion, fish from the northern portion of the Atoll (BELLE to IRENE) had the highest levels of most radionuclides, fish from the southern portion (DAVID to HENRY) had the lowest activity levels, and fish from intermediate areas (JANET to YVONNE, plus LEROY) had intermediate levels of radioactivity. These activity levels generally correspond to the geographical distribution of activity found in the lagoon sediments.

#### Invertebrates

##### Introduction

Selected invertebrates were collected for analysis. *Tridacna* clams were

\* A. D. Welander, *et al.*, Bikini-Eniwetok Studies, 1964: Part II. Radiobiological Studies, USAEC, Rept. UWFL-93 (Pt. II) (1967).

sampled, since they are both a food item and an indicator organism for  $^{60}\text{Co}$ . Spiny lobster and top snails are food items, while sea cucumbers might be an indicator organism for plutonium. The invertebrate organisms were not abundant in all locations, but a fair number of *Tridacna* clams and sea cucumbers were collected from most sampling areas (Table 26). The invertebrates were processed, packaged, gamma-counted, and radiochemically analyzed in the same manner as the fish.

### Results and Discussion

The invertebrate samples have been analyzed for gamma-emitting radionuclides,  $^{55}\text{Fe}$ ,  $^{90}\text{Sr}$ , and  $^{238,239,240}\text{Pu}$ . The gamma-emitting radionuclides detected by the Ge(Li) diode system included naturally occurring  $^{40}\text{K}$  and  $^{226}\text{Ra}$  and 13 fallout radionuclides –  $^{54}\text{Mn}$ ,  $^{60}\text{Co}$ ,  $^{65}\text{Zn}$ ,  $^{101}\text{Ru}$ ,  $^{102}\text{Mn}$ ,  $^{108}\text{Ag}$ ,  $^{125}\text{Sb}$ ,  $^{134}\text{Cs}$ ,  $^{137}\text{Cs}$ ,  $^{152}\text{Eu}$ ,  $^{155}\text{Eu}$ ,  $^{207}\text{Bi}$ , and  $^{241}\text{Am}$ .

Radioactivity values are given as of the date of collection in terms of dry sample weight. Dry weight values may be converted to wet weight values by use of the conversion factors given in Table 25. The Kwajalein invertebrate samples consist of six pooled *Tridacna* clams, and the data are presented in Table 28. The Enewetak data are presented in Tables 39 (*Tridacna*), 40 (Sea cucumbers) and 41 (Miscellaneous).

Tridacna Clams – The results of the radiological analyses of the *tridacna* clams are given in Tables 28 (Kwajalein) and 39 (Enewetak). The large "killer" clam, *Tridacna gigas*, and the smaller

clam, *Tridacna crocea* were the two types collected. All of the clams from JANET, KATE, TILDA, REX, WALT, and LEROY were *T. gigas*. Clams from ALICE and BELLE were a mixture of the two types of clams, while clams from DAVID, GLENN, HENRY, and Kwajalein were the smaller *Tridacna crocea*. Although there are known differences in the radionuclide content of a clam, due to age and species, it appeared that collection location was the most important of these three variables. This is probably because most of the clams collected were living during the period of testing and have been accumulating radionuclides for about the same period of time. Where two or more clams of the same species were available from the same area, size was used as a measure of age and the data compared. Although the larger and presumably older clams in some cases had higher radionuclide concentrations, the opposite situation was often true and, on the average, no significant differences were evident. Comparisons between species from the same area were too few to draw any conclusions.

Naturally occurring  $^{40}\text{K}$  was present at normal levels. Samples averaged 10 pCi/g, dry. The most abundant radionuclide accumulated by the *tridacna* clams was  $^{60}\text{Co}$ . This radionuclide was found in all samples and was present in high concentrations in the kidney samples from most collection areas. Bismuth-207 and  $^{55}\text{Fe}$  were also detected in most samples, but at lower levels than  $^{60}\text{Co}$ . Europium-155 was found at low levels in less than one-third of the samples. Strontium-90 was found in most samples. Americium-241 was detected only in the

Table 39. Predominant radionuclides in Tridacna clams collected from Enewetak Atoll, October to December 1972.

Island	Tissue	No. of samples	No. of clams	Radionuclide, average $\pm$ standard deviation <sup>a</sup> in pCi/g, dry						
				<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>155</sup> Eu	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu
ALICE	Mantle and muscle	2	2	10 $\pm$ 5.2	3.3 $\pm$ 4.5	3.9 $\pm$ 0.9	0.08 $\pm$ 0.01	0.38 $\pm$ 0.01	0.10 $\pm$ 0.13	0.05 $\pm$ 0.01
	Viscera <sup>b</sup>	2	2	9.5 $\pm$ 0.2	23 $\pm$ 11	8.5 $\pm$ 0.6	0.69 $\pm$ 0.06	3.9 $\pm$ 0.6	1.10 $\pm$ 0.4	4.7 $\pm$ 0.4
	Kidney	1	2	4.9 $\pm$ 1.9	68 $\pm$ 1.1	460 $\pm$ 3	<0.48	18 $\pm$ 0.6	1.1 $\pm$ 0.2	0.28 $\pm$ 0.04
	Entire	1	1	8.9 $\pm$ 1.3	8.3 $\pm$ 0.6	34 $\pm$ 0.5	0.44 $\pm$ 0.10	1.7 $\pm$ 0.1	0.62 $\pm$ 0.05	1.2 $\pm$ 0.1
BELLE	Mantle and muscle	3	8	11 $\pm$ 4	9.7 $\pm$ 3.0	18 $\pm$ 19	0.15 $\pm$ 0.13	0.82 $\pm$ 0.36	<0.5	0.24 $\pm$ 0.2
	Viscera and kidney	2	7	8.8 $\pm$ 4.6	34 $\pm$ 3.0	150 $\pm$ 72	0.60 $\pm$ 0.26	7.9 $\pm$ 1.6	1.9 $\pm$ 1.7	1.8 $\pm$ 0.1
	Viscera	1	1	5.5 $\pm$ 1.4		12 $\pm$ 0.2	1.0 $\pm$ 0.1	4.5 $\pm$ 0.1		
	Kidney	1	1	9.5 $\pm$ 3.2	86 $\pm$ 3.2	420 $\pm$ 5	<2.4	20 $\pm$ 0.6	0.53 $\pm$ 0.10	0.42 $\pm$ 0.03
JANET	Mantle and muscle	1	1	14 $\pm$ 1.1	7.2 $\pm$ 0.1	20 $\pm$ 0.4	0.18 $\pm$ 0.08	1.6 $\pm$ 0.1	0.02 $\pm$ 0.01	0.094 $\pm$ 0.003
	Mantle	1	1	7 $\pm$ 0.8	1.7 $\pm$ 0.1	6.4 $\pm$ 0.5	<0.04	0.44 $\pm$ 0.04	0.07 $\pm$ 0.02	0.06 $\pm$ 0.01
	Muscle	1	1	9.4 $\pm$ 1.3	0.58 $\pm$ 0.03	1.4 $\pm$ 0.1	<0.15	<0.09	0.26 $\pm$ 0.003	—
	Viscera	2	2	9.4 $\pm$ 4.8	21 $\pm$ 0.4	26 $\pm$ 26	1.5 $\pm$ 1.2	31 $\pm$ 36	0.014 $\pm$ 0.007	0.72 $\pm$ 0.02
	Kidney	2	2	NC <sup>c</sup>	11 $\pm$ 0.1	2100 $\pm$ 1500	3.7 $\pm$ 0.8	64 $\pm$ 52	0.28 $\pm$ 0.02	0.30 $\pm$ 0.01
	Gills	1	1	7.3 $\pm$ 1.2	4.7 $\pm$ 0.1	34 $\pm$ 0.9	<0.09	1.4 $\pm$ 0.2	0.11 $\pm$ 0.01	0.27 $\pm$ 0.03
KATE	Mantle and muscle	1	1	14 $\pm$ 2.8	1.9 $\pm$ 0.4	0.5 $\pm$ 0.3	<0.21	<0.12	0.01 $\pm$ 0.003	0.50 $\pm$ 0.02
	Mantle	1	1	13 $\pm$ 2.5	2.3 $\pm$ 0.5	2.4 $\pm$ 0.3	<0.22	<0.15	0.010 $\pm$ 0.003	—
	Muscle	1	1	9.8 $\pm$ 1.1	0.83 $\pm$ 0.07	2.3 $\pm$ 0.1	<0.05	<0.04	<0.006	0.016 $\pm$ 0.005
	Viscera	2	2	5.9 $\pm$ 0.6	4.0 $\pm$ 0.7	4 $\pm$ 4	0.08 $\pm$ 0.01	1.7 $\pm$ 1.9	<0.28	0.043 $\pm$ 0.003
	Kidney	2	2	6.6 $\pm$ 0.9 <sup>d</sup>	1.0 $\pm$ 0.2	280 $\pm$ 240	<0.53 $\pm$ 0.54	5.3 $\pm$ 5.9	0.25 $\pm$ 0.04	0.06 $\pm$ 0.002
TILDA	Mantle and muscle	1	1	6.8 $\pm$ 1.0	0.97 $\pm$ 0.08	1.3 $\pm$ 0.1	<0.05	<0.05	0.009 $\pm$ 0.003	0.49 $\pm$ 0.01
	Viscera and kidney	1	1	4.9 $\pm$ 1.0	7.2 $\pm$ 0.1	19 $\pm$ 0.2	0.30 $\pm$ 0.05	1.5 $\pm$ 0.1	0.27 $\pm$ 0.01	2.3 $\pm$ 0.1
	Entire	1	1	15 $\pm$ 2.0	5.4 $\pm$ 0.9	3.4 $\pm$ 0.2	<0.18	<0.11	2.5 $\pm$ 0.2	0.17 $\pm$ 0.04
DAVID	Entire	1	3	15 $\pm$ 1.3	<2.6	7.3 $\pm$ 0.3	<0.14	<0.09	<0.7	0.005 $\pm$ 0.001
REX	Mantle and muscle	1	1	11 $\pm$ 1.2	—	22 $\pm$ 0.5	<0.52	0.54 $\pm$ 0.11	0.013 $\pm$ 0.005	0.015 $\pm$ 0.001
	Viscera and kidney	1	1	10 $\pm$ 2.5	3.0 $\pm$ 0.1	780 $\pm$ 2	<0.15	26 $\pm$ 0.5	0.018 $\pm$ 0.002	2.4 $\pm$ 0.1
WALT	Mantle and muscle	1	3	12 $\pm$ 1.2	0.70 $\pm$ 0.04	2.5 $\pm$ 0.2	<0.10	0.14 $\pm$ 0.05	<0.018	0.06 $\pm$ 0.01
	Viscera	1	3	14 $\pm$ 1.3	6 $\pm$ 0.5	11 $\pm$ 0.2	<0.13	2.6 $\pm$ 0.1	<0.10	0.17 $\pm$ 0.08
	Kidney	1	3	17 $\pm$ 5.6	22 $\pm$ 0.5	420 $\pm$ 4	<0.81	8.0 $\pm$ 0.6	0.06 $\pm$ 0.04	<0.16



GLENN	Mantle and muscle	1	3	1.3 ± 0.4	50 ± 1.1	7.6 ± 0.2	< 0.05	0.38 ± 0.02	< 0.21	0.016 ± 0.003
	Viscera	1	3	12 ± 1.3	18 ± 1.1	47 ± 0.8	0.76 ± 0.40	10 ± 0.2	< 0.7	0.28 ± 0.01
	Kidney	1	3	NC	40 ± 3.0	1250 ± 8	3.5 ± 1.1	33 ± 1.9	< 3.0	< 0.11
HENRY	Mantle and muscle	2	3	6.8 ± 2.8	5.4 ± 0.5	13 ± 9	< 0.11 ± 0.05	0.19 ± 0.09	0.02 ± 0.01	0.90 ± 0.02
	Viscera	2	3	8.6 ± 1.6	11 ± 0.2	43 ± 3	< 0.18 ± 0.02	4.8 ± 3.7	< 0.018	0.28 ± 0.01
	Kidney	2	3	22 ± 5 <sup>d</sup>	—	1000 ± 540	< 0.93 ± 0.04	20 ± 3.5	0.16 ± 0.05	0.22 ± 0.01
LEROY	Mantle and muscle	1	1	13 ± 1.7	4.8 ± 0.3	4.5 ± 0.2	< 0.09	6.7 ± 0.6	< 0.01	0.014 ± 0.001
	Viscera	1	1	8.2 ± 1.4	16 ± 0.3	25 ± 0.4	NC	13 ± 0.2	0.053 ± 0.02	0.86 ± 0.02
	Kidney	1	1	NC	68 ± 0.8	470 ± 3	< 0.56	22 ± 0.6	0.14 ± 0.02	0.18 ± 0.01

<sup>a</sup>Single sample error values are one-sigma counting errors, while error values for two or more samples are one sample standard deviation without consideration of counting error.

<sup>b</sup>0.79 pCi/g, dry, of <sup>241</sup>Am was also present in these samples. Americium-241 concentrations of 1.0 and 0.5 pCi/g, dry, were also present in the viscera samples from BELLE and TILDA, respectively.

<sup>c</sup>NC = not computed.

<sup>d</sup>Potassium-40 was computed for only one of two samples; hence the error is a one-sigma counting error.

viscera samples from ALICE, BELLE, and TILDA, while plutonium-239,240, was detected in most samples. Cobalt-60 concentrations in the kidney samples ranged from 280 to 2100 pCi/g, dry, and averaged 800 pCi/g, dry. The degree of  $^{60}\text{Co}$  concentration in the other tissues decreased in the following order: viscera (including kidney), viscera (less kidney), mantle, and muscle (Figs. 49 and 50). Cobalt-60 levels were 100 times higher in the kidney than in the mantle and muscle. Viscera concentrations were also much lower than kidney, although not as low as mantle or muscle tissue.

Tridacna collected from the lagoon off JANET had the highest average  $^{60}\text{Co}$  concentration in their kidneys (2100 pCi/g, dry). Kidney samples from Tridacna collected on the seaward reef in the GLENN-HENRY area also had a higher than average  $^{60}\text{Co}$  concentration of about 1100 pCi/g, dry. Other kidney samples averaged 410 pCi/g, dry.

The viscera (including kidney) sample from REX had a very high  $^{60}\text{Co}$  concentration compared to the other viscera plus kidney samples. Considering that most of the  $^{60}\text{Co}$  present in this sample was from the kidney portion, which is about 30% of the sample, the  $^{60}\text{Co}$  concentration in the kidney of this clam, if measured alone, would probably be near that found in the kidney from the JANET clams.

Clams collected at Enewetak Atoll from the reef off DAVID and on the seaward side of TILDA had the lowest concentrations of any of the radionuclides detected in the clams, including  $^{60}\text{Co}$ . This is undoubtedly due to their constant exposure to relatively uncontaminated

ocean water passing over the reef on the east side of the atoll.

Tridacna collected from Kwajalein Atoll had a  $^{60}\text{Co}$  concentration of 2.3 pCi/g, dry, in the viscera plus kidney sample and 0.22 pCi/g, dry, in the mantle plus muscle sample. These levels are below the lowest levels found at Enewetak Atoll.

Iron-55 levels were highest in the kidney, ranging up to 86 pCi/g, dry, in the kidney from a Tridacna collected off BELLE. Kidney samples averaged 33 pCi/g, dry. Viscera and mantle plus muscle samples had lower  $^{55}\text{Fe}$  levels by factors of 3 and 5, respectively.

Bismuth-207 and  $^{155}\text{Eu}$  concentrations were also highest in the kidney samples, but were much lower than  $^{60}\text{Co}$  concentrations. Bismuth-207 in the kidney samples was lower than  $^{60}\text{Co}$  by a factor of about 40, while  $^{155}\text{Eu}$  was lower by a factor of over 600. The highest  $^{207}\text{Bi}$  and  $^{155}\text{Eu}$  concentrations were also found in Tridacna samples from JANET, GLENN, and HENRY, while low levels were found in Tridacna from DAVID and TILDA.

Strontium-90 concentrations were highest in the kidney and viscera, ranging up to 1.9 pCi/g, dry, in a viscera + kidney sample from BELLE. Most tissue samples had concentrations of < 1.0 pCi/g, dry.

Plutonium-239,240 concentrations averaged < 0.5 pCi/g, dry. The maximum value was 4.7 pCi/g, dry, in the viscera of two clams. Viscera plus kidney samples from BELLE and TILDA also had high Pu levels, plus detectable  $^{241}\text{Am}$ .

Sea Cucumbers – The results of the radiological analyses of the sea cucumbers are given in Table 40. The two genera collected were Actinopygia mauritiana

Table 40. Predominant radionuclides in sea cucumbers collected from Enewetak Atoll, October to December 1972.

Island	Tissue	No. of samples	Radionuclide, average $\pm$ standard deviation <sup>a</sup> in pCi/g, dry						
			<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>155</sup> Eu	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu
TILDA	E. whole <sup>b</sup>	2	5.4 $\pm$ 0.1	—	<0.07	0.17 $\pm$ 0.04	<0.07	0.03 $\pm$ 0.03	0.033 $\pm$ 0.018
	Viscera <sup>c,d</sup>	2	1.4 $\pm$ 0.1	0.52 $\pm$ 0.17	0.10 $\pm$ 0.02	0.32 $\pm$ 0.02	<0.04	1.4 $\pm$ 0.5	0.56 $\pm$ 0.10
URSULA	E. whole	1	5.3 $\pm$ 1.0	—	<0.08	0.20 $\pm$ 0.04	<0.06	0.03 $\pm$ 0.01	0.09 $\pm$ 0.01
	Viscera	1	NC <sup>e</sup>		<0.13	<0.17	<0.07	0.27 $\pm$ 0.01	0.044 $\pm$ 0.004
YVONNE	E. whole	2	7.7 $\pm$ 1.3	0.35 $\pm$ 0.17	0.29 $\pm$ 0.21	0.19 $\pm$ 0.11	<0.06	0.03 $\pm$ 0.01	0.051 $\pm$ 0.55
	Viscera	2	4.3 $\pm$ 0.6	0.81 $\pm$ 0.56	0.41 $\pm$ 0.26	0.53 $\pm$ 0.06	<0.08	0.15 $\pm$ 0.01	0.95 $\pm$ 0.50
	Entire	1	3.4 $\pm$ 0.85	2.5 $\pm$ 0.8	<0.18	0.21 $\pm$ 0.07	0.12 $\pm$ 0.4	0.15 $\pm$ 0.01	0.28 $\pm$ 0.01
DAVID	E. whole	1	3.6 $\pm$ 1.0	0.32 $\pm$ 0.05	<0.15	0.37 $\pm$ 0.11	<0.07	0.04 $\pm$ 0.01	0.007 $\pm$ 0.001
	Viscera	1	NC	<2.0	<0.15	<1.7	4.1 $\pm$ 1.0	0.16 $\pm$ 0.12	0.05 $\pm$ 0.006
WALT	E. whole	1	6.1 $\pm$ 1.3	<1.7	<0.23	<0.15	<0.09	<0.42	<0.018
FRED	W. whole	1	7.0 $\pm$ 0.77	0.28 $\pm$ 0.03	<0.07	0.16 $\pm$ 0.04	<0.04	0.03 $\pm$ 0.01	0.003 $\pm$ 0.001
	Viscera	1	2.1 $\pm$ 0.74	0.69 $\pm$ 0.19	<0.15	0.10 $\pm$ 0.04	<0.12	—	<0.5
GLENN	E. whole	4	5.3 $\pm$ 2.2	—	6.8 $\pm$ 11	0.12 $\pm$ 0.03	1.3 $\pm$ 1.7	0.05 $\pm$ 0.04	0.74 $\pm$ 1.2
	Viscera	4	1.1	6.0 $\pm$ 5.2	0.29 $\pm$ 0.13	<0.11 $\pm$ 0.06	0.54 $\pm$ 0.46	0.20 $\pm$ 0.10	0.66 $\pm$ 1.1

<sup>a</sup>Single sample error values are one-sigma counting errors, while error values for two or more samples are one sample standard deviation without consideration of counting error.

<sup>b</sup>E. whole = eviscerated whole, the outer body covering of the sea cucumber.

<sup>c</sup>Viscera includes the gut contents, usually coral sand and fragments.

<sup>d</sup>These viscera samples also had an average <sup>241</sup>Am concentration of 0.30 pCi/g, dry. One of two viscera samples from YVONNE also had a <sup>241</sup>Am concentration of 0.23 pCi/g, dry.

<sup>e</sup>NC = not computed.

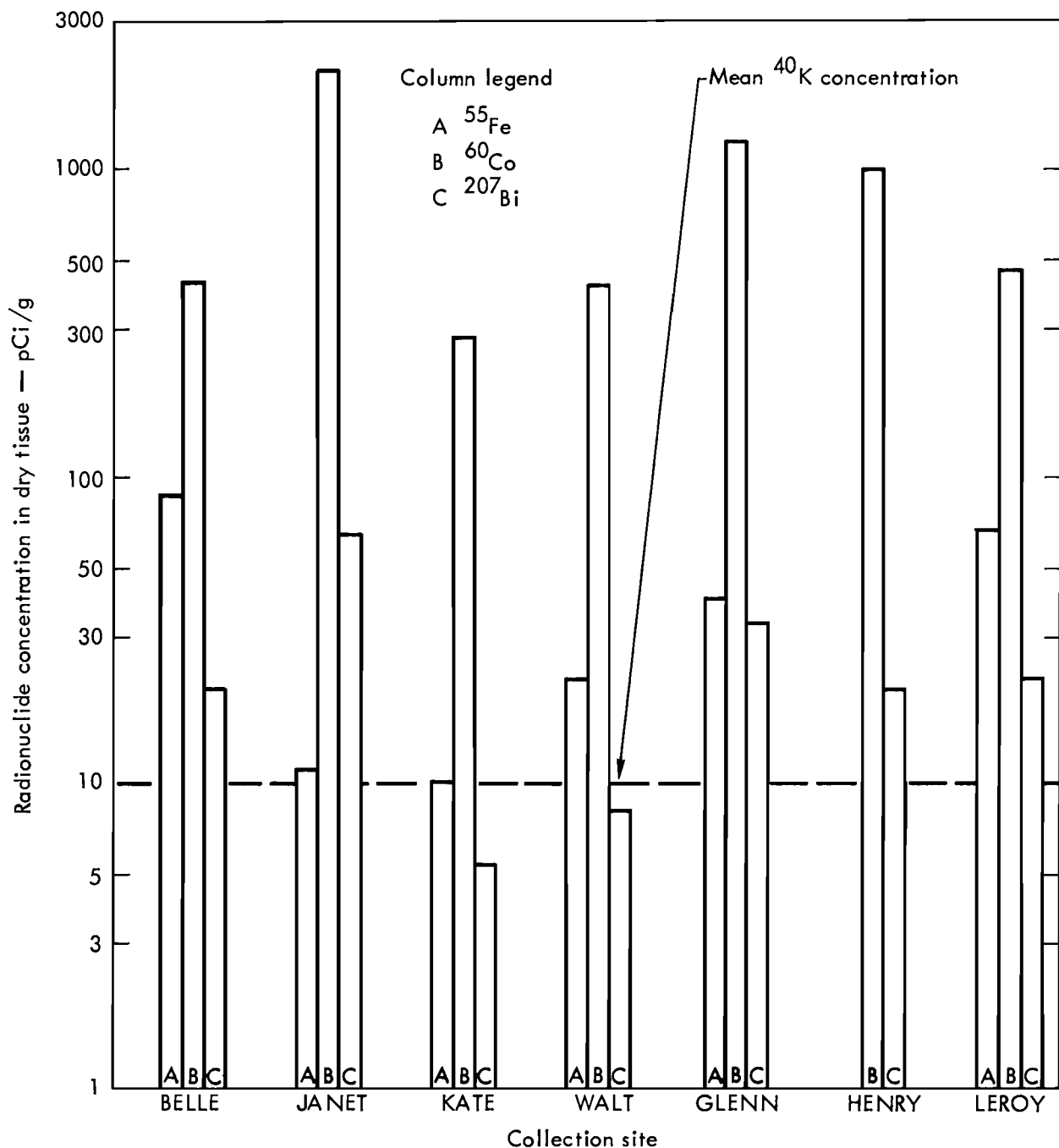


Fig. 49. Average <sup>40</sup>K, <sup>55</sup>Fe, <sup>60</sup>Co, and <sup>207</sup>Bi concentration in the kidney of *Tridacna* clams collected at Enewetak Atoll, October to December, 1972. The <sup>40</sup>K value is the mean of all *Tridacna* samples.

(2 samples) and *Holothuria* sp. (11 samples). Samples of *Actinopygia* and of *Holothuria* were made up from an average pool of 5 and 20 individuals, respectively.

Naturally occurring <sup>40</sup>K was the most abundant radionuclide detected in most of

the sea cucumber samples. It averaged 2.0 and 5.7 pCi/g, dry, in viscera and eviscerated whole sea cucumber samples, respectively. Of the man-produced, radionuclides, <sup>55</sup>Fe and <sup>155</sup>Eu were present in most samples, while <sup>60</sup>Co and <sup>207</sup>Bi were

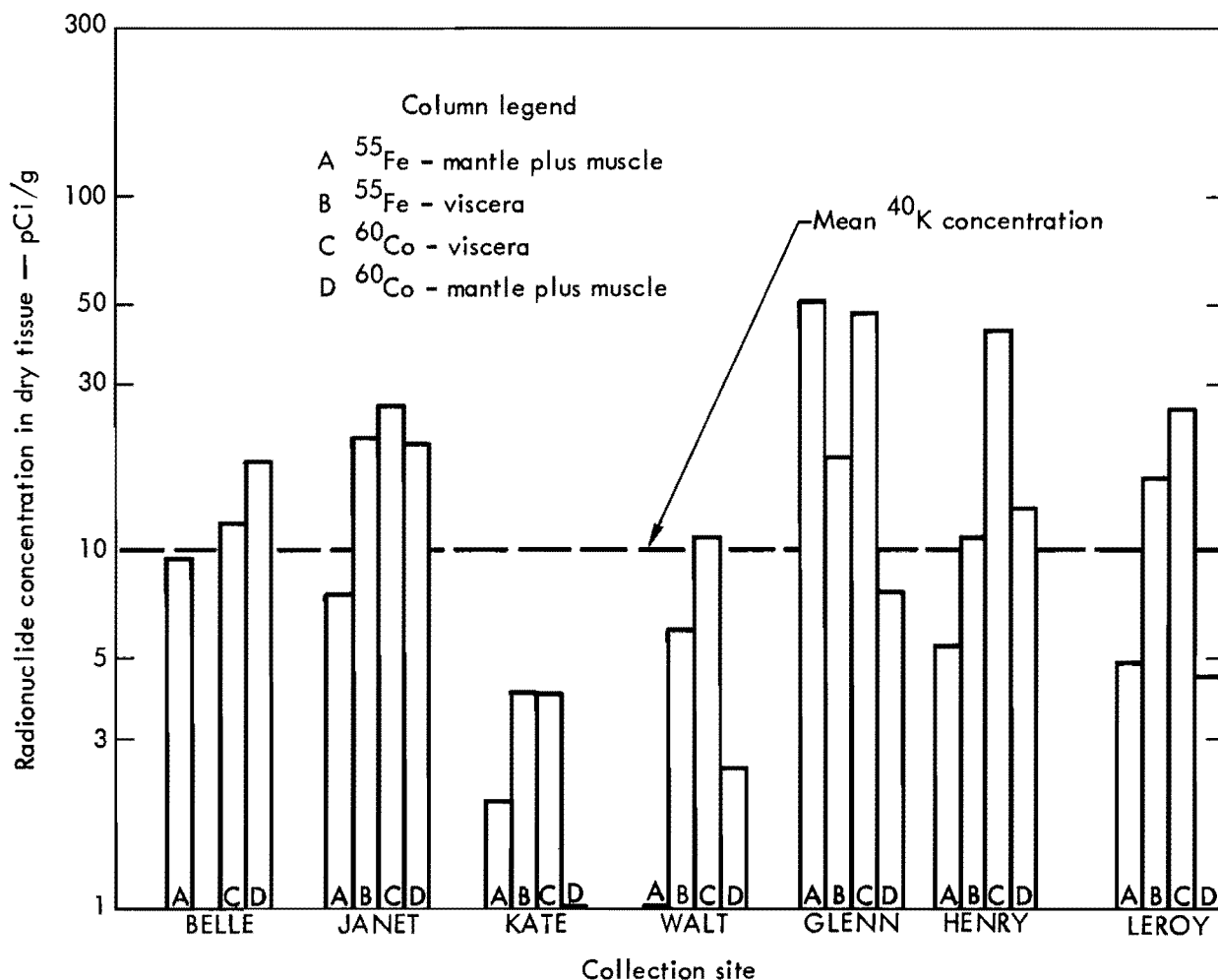


Fig. 50. Average  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ , and  $^{60}\text{Co}$  concentration in the viscera, mantle, and muscle of *Tridacna* clams collected at Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean of all *Tridacna* samples.

detected in some samples. Three of 11 viscera samples had detectable  $^{241}\text{Am}$ . Plutonium-239, 240 and  $^{90}\text{Sr}$  were detected in most samples. Iron-55 was present at low levels ( $< 6.0$  pCi/g, dry). Europium-155 was present at low levels ( $< 0.5$  pCi/g, dry) in most samples, with slightly higher levels present in the viscera samples.

Cobalt-60 and  $^{207}\text{Bi}$  were present in only a few samples. The highest  $^{60}\text{Co}$  levels were in the eviscerated whole samples from GLENN (6.8 pCi/g, dry) and in the viscera samples from YVONNE (0.4 pCi/g, dry). All other samples had  $^{60}\text{Co}$  levels of less than 0.30 pCi/g, dry.

The highest  $^{207}\text{Bi}$  levels were in the viscera samples from DAVID (4.1 pCi/g, dry) and in the GLENN samples (eviscerated whole = 1.3 pCi/g, dry; viscera = 0.54 pCi/g, dry). All other samples had  $^{207}\text{Bi}$  levels less than 0.12 pCi/g, dry.

Americium-241 was detected in only three samples. The two viscera samples from TILDA had an average  $^{241}\text{Am}$  concentration of 0.30 pCi/g, dry, and one of two viscera samples from YVONNE had 0.23 pCi/g, dry. Plutonium-239, 240 was present in the viscera samples at an average concentration of 0.6 pCi/g, dry. The Pu concentration was at least tenfold

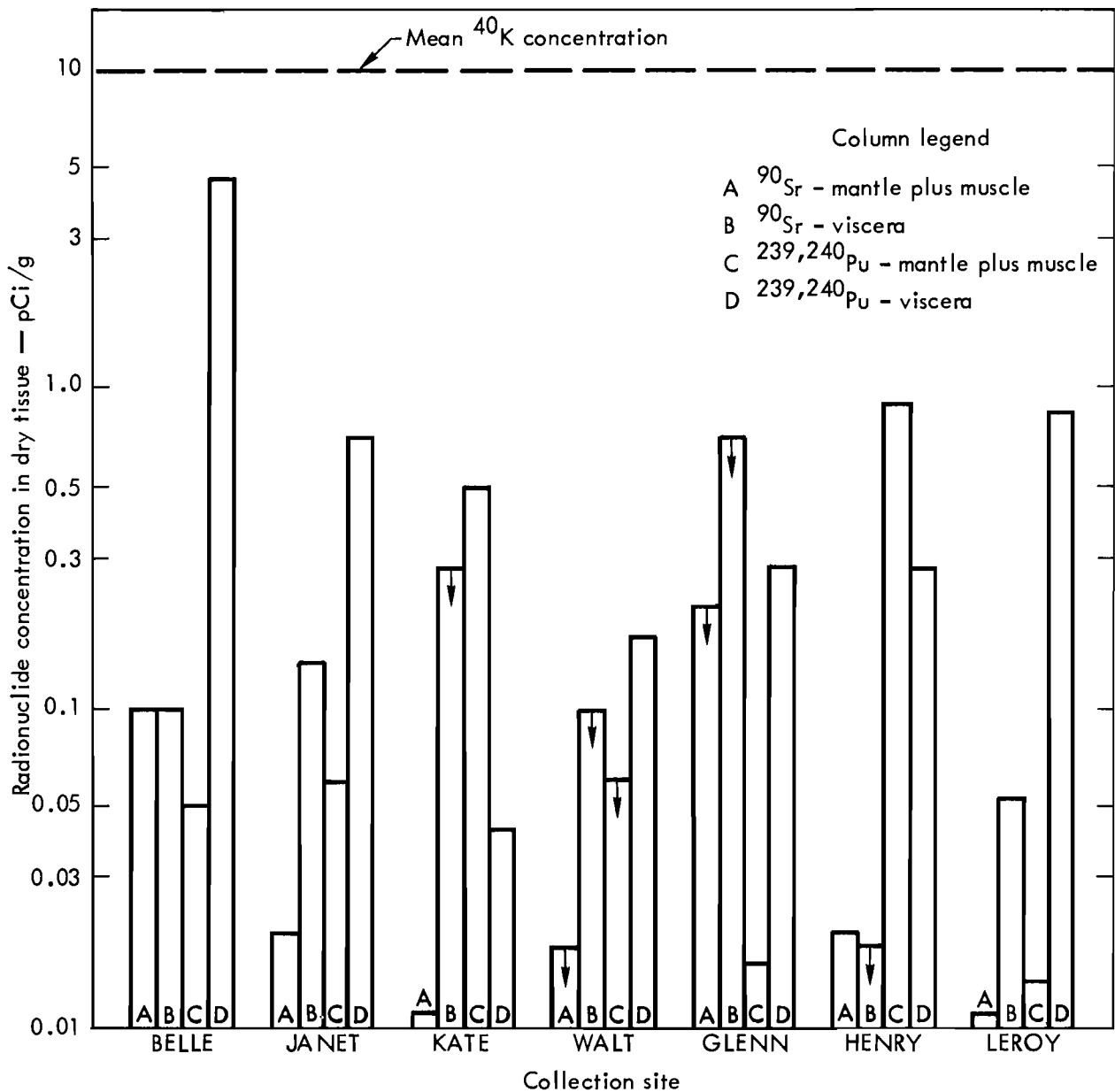


Fig. 50a. Average  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  concentration in the viscera, mantle, and muscle of *Tridacna* clams collected at Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all *Tridacna* samples.

lower in the eviscerated whole sea cucumbers. Strontium-90 was highest in the viscera samples from TILDA (1.4 pCi/g, dry), but was less than 0.3 pCi/g, dry in other viscera samples.

Miscellaneous Invertebrates - The results of the radiological analyses of the

miscellaneous invertebrate samples are given in Table 41. In the miscellaneous invertebrate category were eight spiny lobsters from YVONNE, nine top snails from LEROY, and six pencil urchins from HENRY. More of these types of samples were not collected because adverse weather conditions (high wind and

Table 41. Predominant radionuclides in miscellaneous invertebrates collected from Enewetak Atoll, October to December 1972.

Common name	Island	Tissue	Radionuclide, average $\pm$ standard deviation <sup>a</sup> in pCi/g, dry					
			<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>207</sup> Bi	<sup>90</sup> Sr	<sup>239,240</sup> Pu
Spiny lobster	YVONNE	Muscle	12 $\pm$ 1.2	0.16 $\pm$ 0.06	0.29 $\pm$ 0.14	< 0.06	< 0.02	0.006 $\pm$ 0.001
		Hepatopancreas	6 $\pm$ 0.8	5.3 $\pm$ 0.2	18 $\pm$ 0.3	0.16 $\pm$ 0.08	0.013 $\pm$ 0.002	0.081 $\pm$ 0.004
		Exoskeleton	1.8 $\pm$ 0.6	0.09 $\pm$ 0.04	< 0.14	< 0.05	0.053 $\pm$ 0.01	0.014 $\pm$ 0.001
Pencil urchin	HENRY	Soft parts	2.9 $\pm$ 0.8	7.6 $\pm$ 0.4	4.6 $\pm$ 0.2	0.59 $\pm$ 0.06	< 0.20 $\pm$ 0.01	< 0.022
		Hard parts	NC <sup>b</sup>	1.0 $\pm$ 0.1	< 0.12	< 0.07	0.09 $\pm$ 0.01	0.007 $\pm$ 0.001
Top snail	LEROY	Soft parts	7.9 $\pm$ 1.0	—	4.8 $\pm$ 0.1	6.3 $\pm$ 0.1	0.14 $\pm$ 0.01	0.02 $\pm$ 0.002

<sup>a</sup>Single sample error values are one-sigma counting errors, while error values for two or more samples are one sample standard deviation without consideration of counting error.

<sup>b</sup>NC = not computed.

waves) during the October to December sampling period made collecting on the seaward edge of the reef, where these organisms live, nearly impossible.

Of the gamma-emitting radionuclides only  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ ,  $^{60}\text{Co}$ , and  $^{207}\text{Bi}$  were detected in 50% or more of the samples. Potassium-40 was present at background levels. Iron-55 was one abundant man-produced radionuclide detected in the samples. Concentration ranged up to 7.6 pCi/g, dry, in the soft parts of the pencil urchin and 5.3 pCi/g, dry, in the hepatopancreas of the spiny lobster. The highest  $^{60}\text{Co}$  level (18 pCi/g, dry) was also in the hepatopancreas of the spiny lobster. The soft parts of the pencil urchin and the top snail had similar  $^{60}\text{Co}$  concentrations at 4.6 and 4.8 pCi/g, dry, respectively. Comparing all miscellaneous samples for  $^{207}\text{Bi}$ , it was found that  $^{207}\text{Bi}$  was highest, by a factor of 10, in the soft parts of the top snail with a concentration of 6.3 pCi/g, dry.

The highest  $^{90}\text{Sr}$  concentration was 0.14 pCi/g, dry, in the top snail. All other  $^{90}\text{Sr}$  and Pu concentrations were less than 0.1 pCi/g, dry.

### Plankton

#### Purpose of Collections

Since plankton tend to move with the surface waters and to equilibrate rapidly with them, they can often be used as biological monitors of the radioactivity in their environment. Plankton are also an integral part of the marine food chain, and, because of their ability to very quickly concentrate significant quantities of many radionuclides, they are very useful as indicator species. The radio-

nuclides concentrated by plankton are representative, both in kind and quantity, of those available to other pelagic species of the lagoon.

#### Sampling and Analysis

All tows were made at the water surface. They varied in duration, but none was less than 15 min or longer than 30 min. Figure 51 shows the site of collection of each sample. Samples 04119747 and 04120447 were collected with a 1-m, No. 6 (243-micron mesh) net; all other tows were made with a 1-m No. 10 (160-micron mesh) net. The collected sample was washed from the net into a glass jar containing formalin.

The samples in formalin were returned to Lawrence Livermore Laboratory (LLL) where they were drained wet and weighed.

Table 42. Enewetak plankton collections - 1972.

Sample No.	Wet wt (g)	Dry wt (g)	Ash wt (g)
04 069710	27.9	2.77	0.96
04 091253	6.0	0.66	0.39
04 091053	15.7	1.48	0.81
04 091153	8.5	0.94	0.51
04 069854	33.4	4.34	3.27
04 069954	27.1	2.91	1.88
04 070054	17.9	2.01	1.66
04 114646	11.0	3.17	1.43
04 114524	13.3	1.28	0.77
04 116324	6.9	0.84	0.49
04 116524	23.6	2.33	1.65
04 116247	23.2	2.05	1.24
04 116447	28.7	2.88	1.65
04 119747	9.37	1.56	0.98
04 119847	18.8	1.82	1.48
04 120447	16.6	1.68	1.18



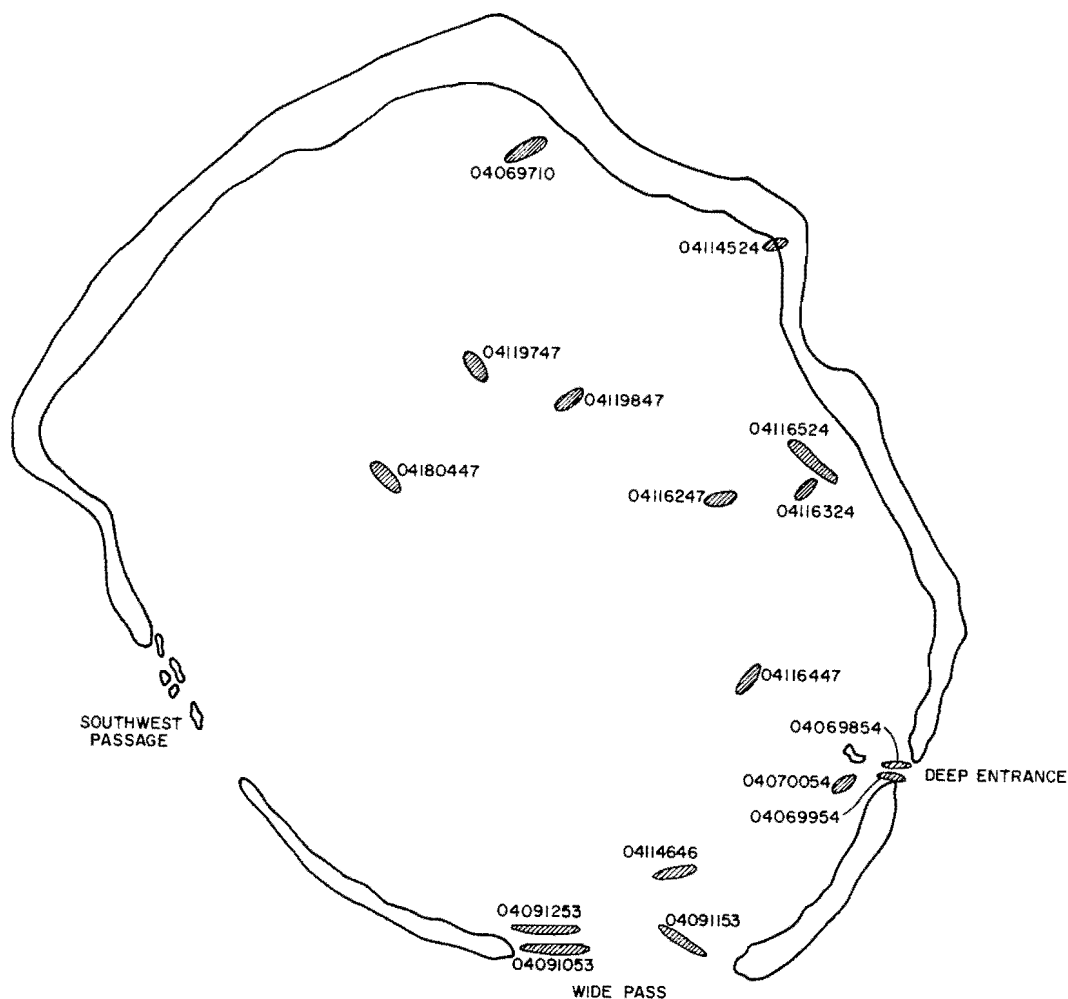


Fig. 51. Location and sample identification of plankton collections at Enewetak Lagoon, 1972.

The samples were dried at 110°C, weighed, ashed at 450°C, and reweighed. Table 42 lists wet, dry, and ash weights of all samples.

The gamma-emitting radionuclides in the plankton were identified by gamma spectrometry at LLL. Samples were processed by wet chemical methods for  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$ . Only  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ ,  $^{155}\text{Eu}$ ,  $^{207}\text{Bi}$ , and  $^{241}\text{Am}$  were positively identified by gamma spectrometry, and these were not detected in all 1972 Enewetak plankton collections. The following radionuclides were undetectable in the plankton at the indicated limits of

detection:  $^{106}\text{Ru}$  (1.0 pCi/g wet weight);  $^{102}\text{Rh}$  (0.1 pCi/g);  $^{125}\text{Sb}$  (0.2 pCi/g);  $^{152}\text{Eu}$  (0.1 pCi/g);  $^{235}\text{U}$  (0.1 pCi/g).

Table 43 lists the radionuclide concentrations found in the plankton samples. All data are as of time of collection. The mean level of activity of each radionuclide was determined by averaging the 16 values. The most abundant were  $^{90}\text{Sr}$  and  $^{207}\text{Bi}$  followed, in order of decreasing concentration, by  $^{60}\text{Co}$ ,  $^{239,240}\text{Pu}$ ,  $^{155}\text{Eu}$ ,  $^{241}\text{Am}$ , and  $^{137}\text{Cs}$ . These, the principal gamma-emitting radionuclides found in the 1972 plankton collections, should be those found in all species that

Table 43. Radionuclide concentrations in Enewetak marine plankton in pCi/g (wet weight) at time of collection.

Sample No.	$^{60}\text{Co}$	$^{137}\text{Cs}$	$^{155}\text{Eu}$	$^{207}\text{Bi}$	$^{241}\text{Am}$	$^{239,240}\text{Pu}$	$^{90}\text{Sr}$
04 069710	1.83	<0.03	0.06	1.06	<0.1	0.06	<0.2
04 091253	<0.18	<0.12	<0.14	0.21	<0.3	<0.05	<0.8
04 091053	0.27	<0.06	<0.07	0.20	<0.1	0.04	<0.3
04 091153	<0.18	<0.03	<0.14	0.22	<0.3	<0.12	<2.0
04 069854	0.18	<0.03	<0.07	0.03	<0.1	0.16	<0.2
04 069954	0.09	<0.03	<0.07	<0.03	<0.1	<0.02	<0.4
04 070054	0.27	<0.05	<0.07	0.27	<0.1	0.05	<0.3
04 114646	1.14	<0.12	0.22	1.21	<0.3	0.11	<0.8
04 114524	<0.09	<0.05	<0.07	<0.05	<0.1	0.04	1.98
04 116324	1.01	0.09	<0.14	1.36	<0.2	0.70	<0.7
04 116524	1.42	<0.06	0.66	2.25	0.41	1.69	0.54
04 116247	0.89	0.11	0.62	1.41	0.25	1.31	0.68
04 116447	0.76	<0.06	0.46	1.45	0.28	0.43	0.24
04 119747	1.33	<0.11	<0.21	0.83	<0.3	0.24	2.97
04 119847	0.79	<0.08	0.55	1.62	0.43	0.59	1.05
04 120447	0.50	<0.05	0.41	0.93	0.25	0.59	0.79
Average <sup>a</sup>	0.68	0.07	0.24	0.83	0.23	0.39	0.86
Average <sup>b</sup>	0.65	0.01	0.19	0.83	0.10	0.37	0.52

<sup>a</sup>Counting upper limit values as a real signal.

<sup>b</sup>Counting upper limit values as zero.

derive trace elements and radioelements from the pelagic environment of the lagoon.

The plankton proved to be sensitive indicators of the environmental radioactivities in the lagoon. High concentrations of  $^{207}\text{Bi}$  and  $^{60}\text{Co}$ , for example, were found in samples taken near YVONNE and IRENE and from mid-lagoon, while the lowest levels were detected near passes, channels, or reef openings where the atoll is exposed to currents from the open ocean. It is noteworthy that the distributions of some radionuclides in the water coincide with those found for the

plankton (see the subsection on lagoon water samples).

It is a useful exercise to compare the present mean activity levels to those found in the 1964 collections. During the 1964 survey of Enewetak (Welander, *et al.*, 1967)\* five plankton collections from the lagoon were reported, data for which are shown in Table 44.

Allowing for radioactive decay from August 1964 to December 1972, and

\*A. D. Welander, *et al.*, Bikini-Enewetak Studies, 1964: Part II. Radiobiological Studies, USAEC, Rept. UWFL-93 (Part II) (1967).

Table 44. Gamma-emitting radionuclides in plankton from Enewetak Atoll, August 1964. Values expressed as picocuries per gram of dry weight at time of collection.

Location	<sup>60</sup> Co	<sup>125</sup> Sb	<sup>137</sup> Cs	<sup>207</sup> Bi
<u>Enewetak Atoll</u>				
Runit, lagoon side <sup>a</sup>	68	0	0	0
Runit, lagoon side	200	50	0	14
Rigili, lagoon side	130	2.7	0	19
MIKE Crater	58	—	2.2	4.6
<u>Engebi,</u>				
lagoon side	47	0	0	5.6
Average	100	13	0.44	4.8
				(sic)
			(arith av	8.6)

<sup>a</sup>No. 20 mesh net; all other catches with No. 6 mesh net.

assuming no other processes operating to affect the activity levels in plankton, we should have seen average concentrations of 34 pCi/g (<sup>60</sup>Co), 1.5 pCi/g (<sup>125</sup>Sb), 0.36 pCi/g (<sup>137</sup>Cs), and 7.1 pCi/g (<sup>207</sup>Bi). The average dry weight concentrations found in December 1972 were 5.9 pCi/g (<sup>60</sup>Co), 0.6 (<sup>137</sup>Cs), and 7.3 pCi/g (<sup>207</sup>Bi) if upper-limit values in Table 43 are considered positive signals. If the upper-limit values are considered to be zero, as was done by Welander, the average dry weight concentrations found in December 1972 are 5.7 pCi/g (<sup>60</sup>Co), 0.09 pCi/g (<sup>137</sup>Cs), and 7.3 pCi/g (<sup>207</sup>Bi).

Each radionuclide found in plankton was reduced in concentration between 1964 and 1972. The values for <sup>207</sup>Bi are about those expected if the loss was due mostly to radioactive decay. The <sup>125</sup>Sb

is below detection limits (~ 2 pCi/g dry) in 1972 collections; its loss could be due mostly to radioactive decay. For <sup>137</sup>Cs and <sup>60</sup>Co, on the other hand, the values for the 1972 collections are significantly less than can be accounted for on the basis of decay alone. Thus, <sup>60</sup>Co and <sup>137</sup>Cs are being lost from the lagoon by removal processes, as well as by physical decay. From the data for 1964 and 1972, it is possible to compute a mean residence half-time, or ecological half-life, for <sup>60</sup>Co and <sup>137</sup>Cs, assuming an exponential loss rate. The equation used to compute the residence time is

$$A_{1972} = A_{1964} e^{-(\tau_1 + \tau_2)t}$$

where  $\tau_1$  is the radiological disintegration constant and equals  $0.693/t_1$ ,  $\tau_2$  is the environmental loss constant and equals  $0.693/t_x$ , and  $t_1$  and  $t_x$  are the physical and ecological half-lives, respectively. The observed activity levels in the respective years are  $A_{1972}$  and  $A_{1964}$ . The time,  $t$ , is the elapsed time between August 1964 and December 1972, or 8.33 yr. In addition to physical decay, <sup>60</sup>Co and <sup>137</sup>Cs are being lost from the lagoon with mean residence half-times of 3.3 and 4.1 yr, respectively.

If the computed mean loss continues at the same rate, the mean <sup>60</sup>Co levels in the water and pelagic biota of the lagoon will be reduced with an effective half-life of approximately 2 yr, and the <sup>137</sup>Cs concentrations will be reduced by one half every 4 yr. The effective half-life for <sup>60</sup>Co deduced from plankton data agrees well with the effective half-life computed from the comparison of fish activity levels in 1964 and 1972.

Comparison of the decreases in activity for  $^{207}\text{Bi}$  with those for  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  indicates clearly that the rate of radionuclide removal, other than by physical decay, is unique for each radionuclide and is controlled by complicated biogeochemical processes occurring within the lagoon environment. In the future, assessments such as the above should be attempted for all long-lived radionuclides, and meaningful sampling programs should be established to verify the predicted losses. Since many processes influence the fate of the radionuclides in each environment phase of the Atoll, the rate of loss of radioactivity may accelerate or decline in the future, depending on the time constants of the controlling mechanisms.

#### Enewetak Lagoon Sediments

##### Purposes of Collections

In all, 133 grab samples, 8 dredge samples, and 37 cores providing 127 subsamples were processed. The number of samples was large enough so that, for the first time, we can assess the quantity and distribution of selected radionuclides in the benthic environment of Enewetak Atoll.

This assessment is an integral part of the Enewetak survey; the radionuclides present in sedimentary deposits are potential contaminants of the atoll environment and thus could contribute to the hazard to man. Marine sediments are usually thought of as the ultimate link for quickly sorbed radionuclides, but in reality there are a number of biological and nonbiological paths through which the radionuclides can be recycled into man's food chain.

In addition, individuals can be exposed directly to external gamma radiation from some surface-bound radionuclides when shallow areas are used for fishing and/or recreation. Near-shore cores were obtained to provide radiological data for assessment of this exposure route.

##### Sampling Locations

Figure 52 gives the locations of all sediment samples obtained from Enewetak lagoon; Fig. 53 is a separate chart of the area sampled near MIKE and KOA Craters. The entire lagoon was adequately covered, and more detailed coverage was devoted to the area off YVONNE. Duplicate samples were obtained at several locations to determine the degree of variability of radiological data at an individual sampling site.

Sampling locations were predetermined before each day's cruise. Because weather conditions often made it impossible to sample the designated area, especially the western side of the lagoon, alternate cruise plans were usually available as well. Upon reaching the designated location, the vessel was anchored, and sightings were made with a sighting compass on at least two, but usually three or four, fixed landmarks (tips of islands or recognizable structures). The bearings were replotted on a master chart to locate accurately the site of collection of each sample, which was identified with a field number and a sample number.

All position plottings were made on A. M. S. Series W861, Type C (AMS1), 1947 charts of the Marshall Islands prepared under the direction of the Chief of Engineers by the Army Map Service (LUAM), War Department, Washington,

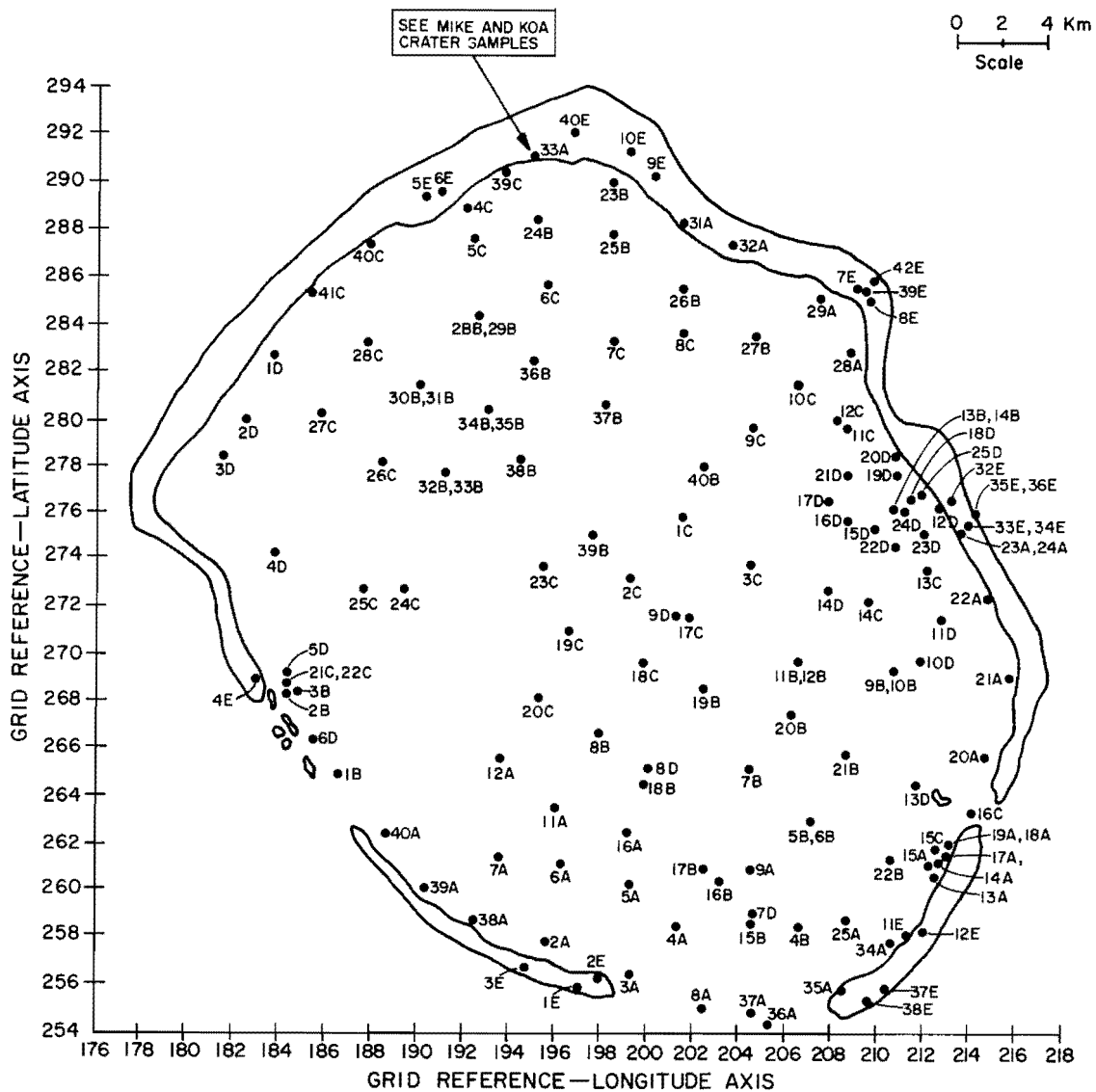


Fig. 52. Location and sample identification of sediment samples at Enewetak Lagoon.

D. C. These charts are provided with a 1000-m universal transverse mercator grid; the horizontal control is based on Enewetak Astro Pier, 11°33'28.48" North, 162°21'10.25" East of Greenwich. The average mercator position or grid position of each sample location was determined by triangulation and provided for reference with the output data. All fixes used to provide these reference points are accurate to within 100 m on the AMS Series W861 charts.

Besides the geographical location, the recorded data usually included the depth of overlying water: Lagoon samples were obtained from depths ranging from 20 to 214 ft.

Thus, the master output of radiological data for marine sediments includes the assigned sample number, the corresponding chart identification number, and the measured depth of water at the sampling location.

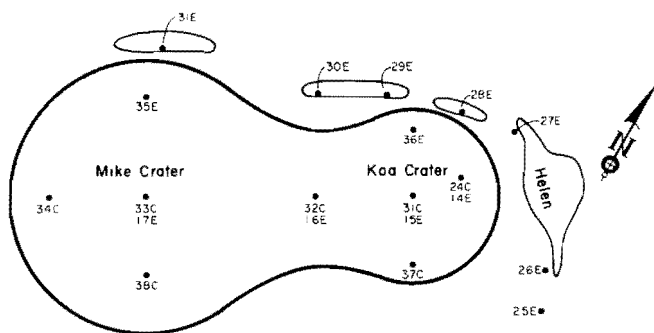


Fig. 53. Location and identification of sediment samples at the MIKE and KOA crater area (crater dimensions are not to scale).

### Collection Methods and Sample Types

The original purpose of the program was to provide both grab and core samples in sufficient numbers for assessment of both the horizontal and vertical distributions of radionuclides in the lagoon sediments. Coring was attempted with both 8- and 5-cm-diam gravity corers fitted with positive-action closing valves and core catchers. Several of the participants in this marine program had had considerable experience with these devices in near-shore and off-shore areas of the Atlantic and Pacific Oceans, where it was usual to obtain the top 60- to 90-cm section of an undisturbed sediment column. In Enewetak lagoon, however, coring was almost a complete failure. Because of the characteristics of the sedimentary deposits, it was usually impossible to penetrate to depths of more than a few centimeters, even with a weight stand exceeding 80 kg. More often than not, coral or shell fragments entrapped in the core catcher allowed the collected sediment to drain from the liner before the sampler could be retrieved. Several times, the plastic core liners returned to the surface bent at 90 deg angles, attesting to

the presence of numerous coral heads on the lagoon floor. Because of the poor penetration of the corer and the difficulty of retrieving a usable core, it was decided to discontinue the coring attempts and instead to concentrate on grab sampling as the method of collecting sediments. Excellent cores were obtained in both MIKE and KOA craters; here however, the deposit was of uniform consistency and free from shell fragments and coral. Coring was successful also in the near-shore areas, where good visibility permitted positioning of a hand coring device without impaction on submerged objects.

The major objective of defining the levels and distributions of selected radionuclides in the lagoon sediments was realized by analyzing the material collected by the grab samplers. This was not accomplished, however, without difficulties similar to those attending the core sampling. The usual problems were pretriggering of the device on submerged coral knolls and trapping of coral or shells in the closing jaws with resultant loss of collected sediment before the surface was reached. At many locations, the samplers usually had to be lowered several times before an adequate sample was obtained. Field comparisons with the corers showed that the grab samplers not only provided sediment samples of larger surface area but penetrated to equivalent depths in the lagoon floor.

A weighted Ekman grab sampler was used from the Boston Whaler only. It collected a surface sample of 232 cm<sup>2</sup> surface area and 2.0 cm mean thickness. The penetration depth was uncontrolled on this as well as on the other grab

samplers used. A Ponar grab sampler, used from both the Whaler and the LCU, collected a surface sample 523 cm<sup>2</sup> in area and 2.8 cm in mean thickness. A Shipek grab was used from the LCU only. The sampled area depended on the depth of penetration and varied from 250 to 400 cm<sup>2</sup> and the mean sediment sample thickness was 4.3 cm.

The mean depth sampled by all three devices was 3.2 cm (1.25 in.). Penetration of the grab was dependent on the composition of the sediment. Penetration was poorest in areas containing high percentages of coarse sediments, shell fragments, and Halimeda, and deepest in areas in which the bottom sediment consisted of fine-grained material. For 83 of the samples, the composition was described qualitatively by the field observers: 34 contained dead Halimeda debris in amounts ranging from 5 to 85% of the sample. The sediment composition was dependent on location and depth of water and included different percentages of fine, coarse, and dark-grained sands, shell fragments, coral pieces, Halimeda, and Foramenifera debris.

Only levels of radioactivity were determined in the entire sediment sample collection; it was not an objective of this

program to assess the quantity of each sedimentary phase or the concentration of radionuclides in each phase.

For comparative purposes, all sediment concentration data is expressed as activity per unit area (mCi/km<sup>2</sup>). Since some samples are diluted in weight with relatively uncontaminated quantities of coral, Halimeda and Forams, this unit better describes the radiological data for relative comparison. There is also evidence that most of the radionuclides are concentrated in the open lagoon sediment surface layers. For example, at several locations, dredge samples were obtained from the anchor of the LCU and provided samples for comparative radiological data with the grab sampler. These two collection methods gave considerably different concentrations of radionuclides per gram, as shown in Table 45. The dredge samples contained less activity per unit weight than the grab samples. This observation supports the idea that radionuclides in those samples from the open lagoon are probably restricted to surface layers of the sediments; the lower activity per unit weight in the dredge samples probably results from sample dilution by relatively uncontaminated subsurface material.

Table 45. Grab and dredge sample comparative data for selected radionuclides.

Sample	pCi/g ± % error					
	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>207</sup> Bi	<sup>239</sup> Pu
34B-Grab	1.83 ± 4	17.1 ± 4	1.02 ± 7	5.98 ± 3	4.5 ± 3	15.7 ± 2
35B-Dredge	2.53 ± 3	12.7 ± 6	0.81 ± 7	5.88 ± 6	4.4 ± 2	6.2 ± 3
30B-Grab	1.6 ± 3	15.3 ± 8	1.14 ± 5	7.28 ± 3	4.04 ± 2	14.2 ± 9
31B-Dredge	1.88 ± 4	7.78 ± 10	0.65 ± 10	3.89 ± 6	2.65 ± 9	7.79 ± 4
29B-Grab	2.68 ± 2	21.9 ± 10	1.53 ± 4	10.0 ± 4	7.4 ± 2	22.4 ± 9
29B-Dredge	0.83 ± 7	2.32 ± 17	0.15 ± 27	1.2 ± 7	1.2 ± 5	2.2 ± 5

It should, however, be kept in mind that each grab sample collected penetrated the sediment layer to different depths. The activity per unit area is reported only to the depth sampled. The mean depth sampled by all devices has already been reported as 3.2 cm. Since comparative dredge and grab and/or core data is not available for all areas of the lagoon floor, there may be some areas, especially in the northeast section, where significant levels of activity could be present below the sampling depths indicated.

For each sample, the radionuclide data (in pCi/g) is accompanied by all relevant data including cross-sectional area sampled, thickness or surface layer sampled, and total weight of the sample. With these data, the results can be converted to any unit of activity per unit weight, volume, or area.

#### Processing (Field and Laboratory)

As each grab or dredge sample was recovered, it was transferred to a polyethylene bag and labeled with a field identification number. At the field laboratory, each sample was double-bagged and labeled with a sample number.

At LLL the volume of each sample was determined, and the penetration depth was calculated from the cross-sectional area of the sampler used. The entire sample was dried at 110°C, ground, and mixed in a ball mill. No attempt was made to separate the sediment into its components. The entire dried sample was weighed and fractions of the sediment were prepared for gamma spectrometry and for radiochemical separation and analysis of <sup>90</sup>Sr and plutonium radionuclides. The sediments were not analyzed

for any other radionuclides than those identified by gamma spectrometry and <sup>90</sup>Sr and some plutonium radionuclides. Processing was done by members of the Radiochemistry Division, LLL. Gamma spectrometry results were obtained from Ge(Li) detector outputs in both the Bio-Medical and the Radiochemistry Divisions of LLL. Plutonium and <sup>90</sup>Sr were separated and analyzed by contractor laboratories.

A selected number of samples (listed in Table 46) were analyzed in duplicate at one laboratory for <sup>239,240</sup>Pu. It is difficult to assess the accuracy of sets of measurements such as these, but the body of data speaks to the question of sample uniformity. In general, the results are in good agreement, suggesting

Table 46. Plutonium-239,240 analyses of replicate sediment samples

Sample	<sup>239,240</sup> Pu (pCi/g, dry) ± % error
35A (a)	<0.72 (upper limit)
(b)	0.13 ± 13
39A (a)	0.38 ± 21
(b)	0.46 ± 9
7B (a)	1.09 ± 8
(b)	0.94 ± 23
22B (a)	0.36 ± 9
(b)	0.44 ± 10
29B (a)	2.25 ± 5
(b)	2.15 ± 3
1C (a)	4.78 ± 4
(b)	4.78 ± 5
13C (a)	5.81 ± 6
(b)	7.88 ± 24
8D (a)	0.77 ± 8
(b)	0.60 ± 19
19D (a)	39.2 ± 4
(b)	53.2 ± 22



that at least the processing produced uniformly well-mixed samples. The duplicate set of samples address the precision of analysis; in general the results in Table 46 are in satisfactory agreement. The calibration data affecting the accuracy of the results is discussed in detail in the Analysis Program section of this report.

Cores collected from the craters and near-shore areas were identified by numbers in the field. At the field laboratory, the cores were logged in and stored in an upright freezer chest. The frozen cores were returned to LLL, where they were sectioned in known depth increments and processed by the same procedure used for the grab samples.

### Analysis and Results

Lagoon Sediment—The radionuclides identified in some, but not necessarily all, processed sediments from the lagoon include  $^{238}\text{Pu}$ ,  $^{239,240}\text{Pu}$ ,  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ ,  $^{241}\text{Am}$ ,  $^{155}\text{Eu}$ ,  $^{60}\text{Co}$ ,  $^{152}\text{Eu}$ ,  $^{154}\text{Eu}$ ,  $^{102\text{m}}\text{Rh}$ ,  $^{207}\text{Bi}$ ,  $^{125}\text{Sb}$ ,  $^{101}\text{Rh}$ , and  $^{106}\text{Ru}$ . In some samples the natural potassium radioisotope,  $^{40}\text{K}$ , and daughter products of the uranium decay series were detected by gamma spectrometry.

The identification of gamma-emitting radionuclides in any sample was dependent on sample size, detector characteristics including background, and the sample counting time. Because of these variables, the lowest limit of positive detection of any gamma-emitting radionuclide was necessarily different for each sample analyzed. Americium-241 was positively identified by spectrometry in marine sediments when the level of activ-

ity generally exceeded  $3 \text{ mCi/km}^2$  or, approximately,  $0.1 \text{ pCi/g}$ . Examples of other averaged lower limits are  $1 \text{ mCi/km}^2$  for  $^{207}\text{Bi}$ ;  $1.5 \text{ mCi/km}^2$  for  $^{155}\text{Eu}$ ;  $2 \text{ mCi/km}^2$  for  $^{60}\text{Co}$ ;  $1 \text{ mCi/km}^2$  for  $^{137}\text{Cs}$ ;  $0.5 \text{ mCi/km}^2$  for  $^{152}\text{Eu}$ ; and  $1 \text{ mCi/km}^2$  for  $^{102\text{m}}\text{Rh}$ . Ruthenium-106 was positively identified by spectrometry in only three samples. The levels of activity were all less than  $1.3 \text{ pCi/g}$ . For all practical purposes, therefore, gamma-emitting fission products with half-lives less than 1 yr and fission yields comparable to  $^{106}\text{Ru}$  should no longer be detectable in the lagoon environment. Ruthenium-106 was measured in surface sediments collected from MIKE Crater during the 1964 survey.\* The average  $^{106}\text{Ru}$  concentration reported was  $100 \text{ pCi/g}$  (range— $29\text{--}170 \text{ pCi/g}$ ). By 1972 this level has decayed to an average of  $0.6 \text{ pCi/g}$ . Three 1972 surface sediments from MIKE Crater were found to contain less than  $0.5 \text{ pCi/g}$  of  $^{106}\text{Ru}$ . This assessment is additional verification that this radionuclide is nearly depleted from the marine environment. The radionuclides,  $^{54}\text{Mn}$  and  $^{57}\text{Co}$ , also reported in marine samples collected during the 1964 survey, were not detected in any 1972 sediment collection.

Europium-154 was identified in only seven bottom sediment samples. The computed mean value of  $^{154}\text{Eu}$  found in the seven samples was  $0.5 \pm 0.6 \text{ pCi/g}$ . Four of the samples were from KOA Crater and the remaining samples were

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\*A. D. Welander, et al., Bikini-Eniwetok Studies, 1964: Part II. Radiobiological Studies, USAEC, Rept. UWFL-93 (Part II) (1967).

from stations 33A, 24B, and 23B. The three lagoon stations are located in the northeast sector of the lagoon, 1 to 5 km from KOA Crater.

For all other radionuclides identified in the sediments, the deposited activity levels determined at each station were plotted on lagoon charts. Isopleths were constructed and the resulting distributions of  $^{90}\text{Sr}$ ,  $^{239,240}\text{Pu}$ ,  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ ,  $^{102\text{m}}\text{Rh}$ ,  $^{241}\text{Am}$ ,  $^{207}\text{Bi}$ ,  $^{155}\text{Eu}$ ,  $^{152}\text{Eu}$ ,  $^{125}\text{Sb}$ , and  $^{101}\text{Rh}$  in the lagoon sediments are shown in Figs. 54 to 64.

The activity levels in the cross hatched area of each figure were, for the most part, below detection limits. It was impossible to construct isopleths in this region of the lagoon because of the scatter in the data points. Therefore, deposition upper limits were determined for this region and are shown in the boxes enclosed in each figure. Some mean values of the activities in the cross hatched region were computed and are also shown in the enclosed box.

Each radionuclide is nonuniformly distributed over the lagoon floor. The most contaminated area of the lagoon can be roughly separated from a relatively uncontaminated area by an imaginary line extending from the Southwest Passage to the island of TOM on the eastern rim of the Atoll. The sediments in the region north of this line are much more burdened with fission and activation products than the area south of this division. Cobalt-60,  $^{207}\text{Bi}$ ,  $^{102\text{m}}\text{Rh}$ , and  $^{152}\text{Eu}$ , all activation products, are most intense in deposits off the shore of the IRENE-JANET area, while  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ ,  $^{155}\text{Eu}$ ,  $^{241}\text{Am}$ , and  $^{239,240}\text{Pu}$  are most concentrated in north-south oriented elliptical

areas, roughly 2 to 3 km east of the islands of ALICE and BELLE. The highest concentration of  $^{125}\text{Sb}$  is found in sediments a few kilometers south of this area. The sediment burdens decrease in a southwesterly direction from the northwest towards the center of the lagoon. A secondary region of contamination, but with significantly lower activity levels than the northwest region, is noted off the shore of YVONNE. The offshore distribution of relatively high activity sediment in this area is restricted to a smaller region than found in the northwest. The concentration levels decrease in all directions from YVONNE but appear to decrease more rapidly toward the south and north than toward the center of the lagoon. Isolated pockets of relatively high concentration levels of some radionuclides are evident in otherwise lesser contaminated areas of the lagoon.

The mean lagoon sediment activity per unit area of each radionuclide was determined from Figs. 54 to 64. These results are tabulated in Table 47 and ranked in order of decreasing mean activity. The most abundant radionuclide detected was  $^{90}\text{Sr}$ , followed by  $^{239,240}\text{Pu}$ ,  $^{155}\text{Eu}$ ,  $^{241}\text{Am}$ ,  $^{207}\text{Bi}$ ,  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ ,  $^{125}\text{Sb}$ ,  $^{102\text{m}}\text{Rh}$ ,  $^{152}\text{Eu}$ ,  $^{101}\text{Rh}$ ,  $^{154}\text{Eu}$ , and  $^{106}\text{Ru}$ .

The percent of the lagoon floor containing radionuclides at or above several levels of activity was determined from Figs. 54 to 64. This data is tabulated in Table 48. Approximately 15% to 20% of the area of the lagoon contains  $^{90}\text{Sr}$ ,  $^{239,240}\text{Pu}$ ,  $^{155}\text{Eu}$ ,  $^{241}\text{Am}$ , and  $^{125}\text{Sb}$  at concentrations which exceed their respective computed mean level. Only 11% of the area of the lagoon is contaminated

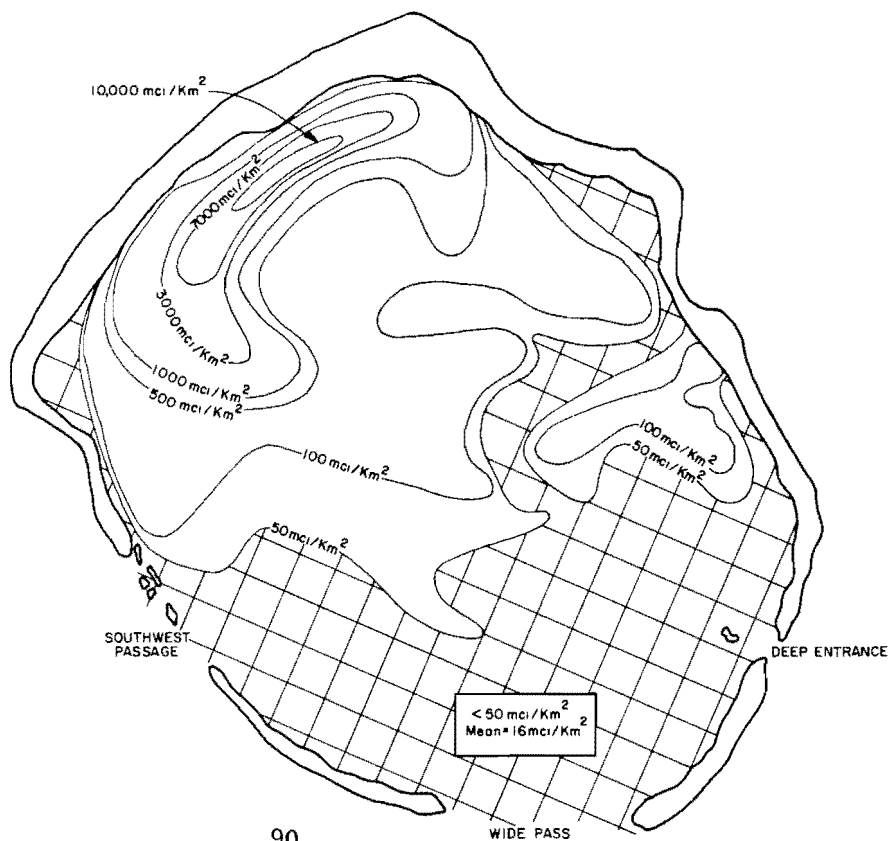


Fig. 54. Activity levels of  $^{90}\text{Sr}$  deposited in the sediments of Enewetak Lagoon.

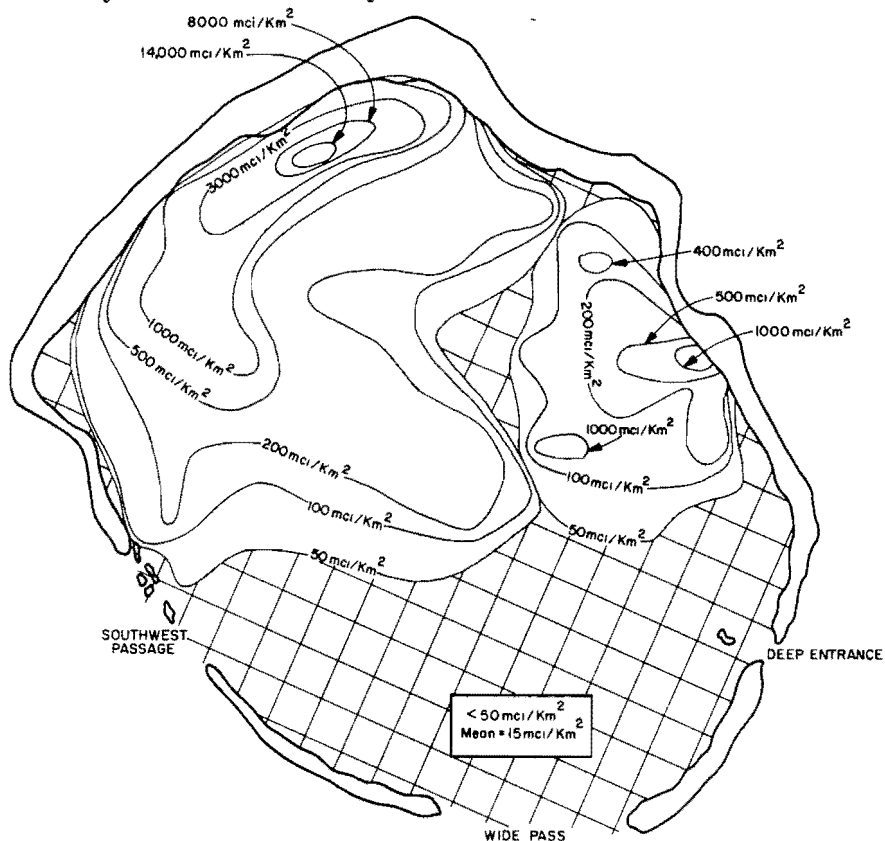


Fig. 55. Activity levels of  $^{239,240}\text{Pu}$  deposited in the sediments of Enewetak Lagoon.

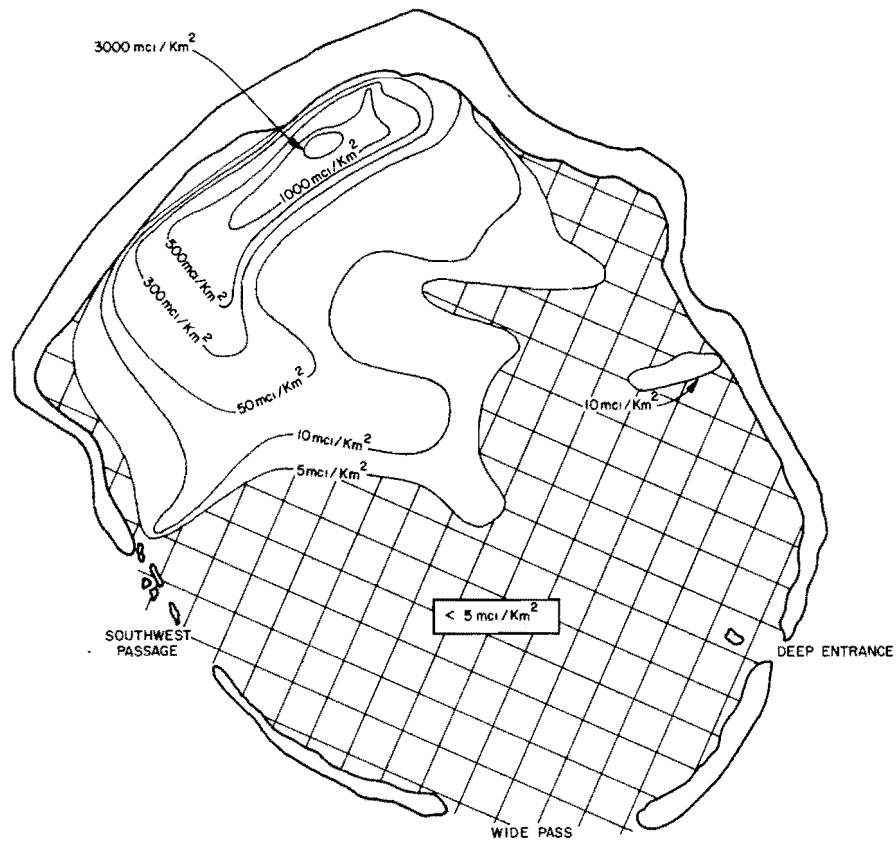


Fig. 56. Activity levels of  $^{137}\text{Cs}$  deposited in the sediments of Enewetak Lagoon.

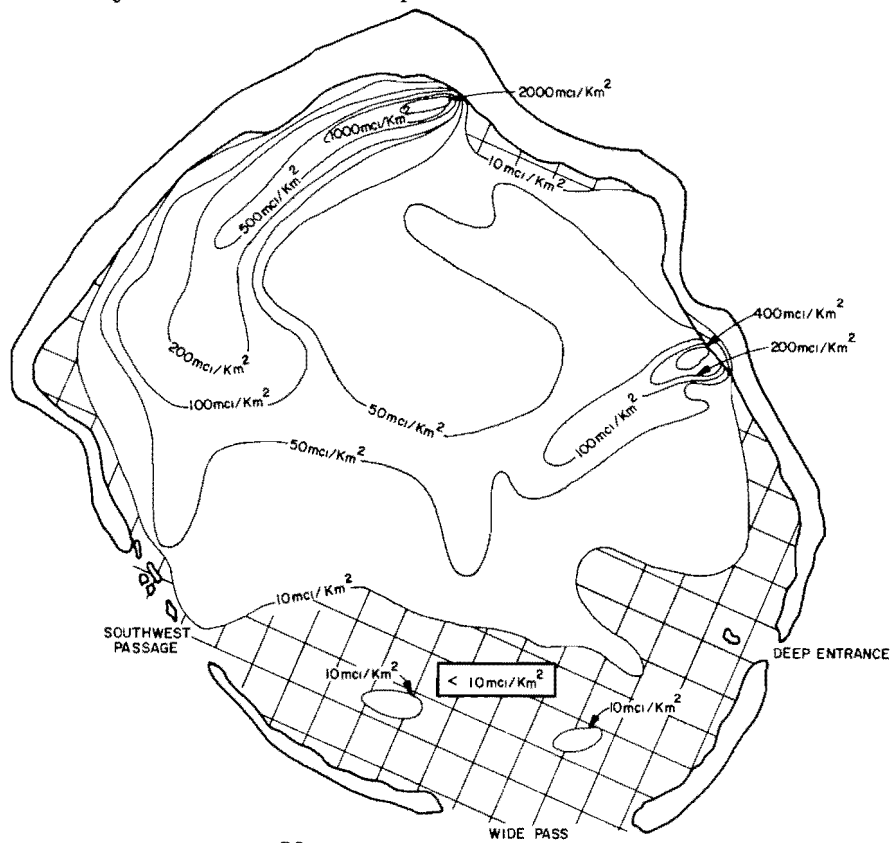


Fig. 57. Activity levels of  $^{60}\text{Co}$  deposited in the sediments of Enewetak Lagoon.

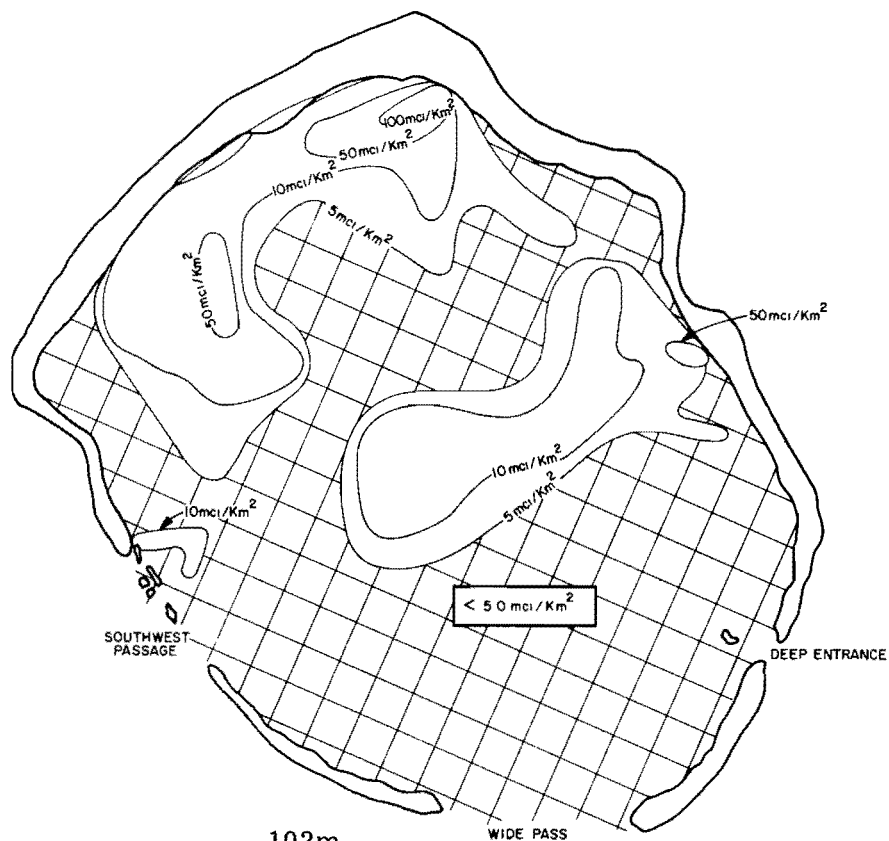


Fig. 58. Activity levels of  $^{102}\text{mRh}$  deposited in the sediments of Enewetak Lagoon.

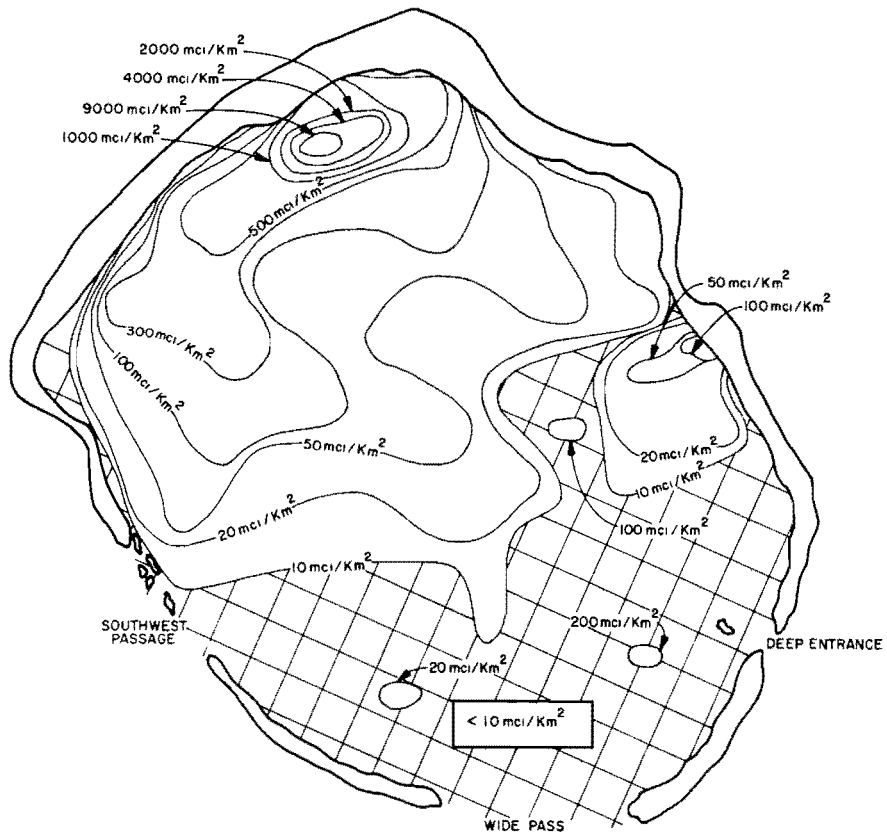


Fig. 59. Activity levels of  $^{241}\text{Am}$  deposited in the sediments of Enewetak Lagoon.

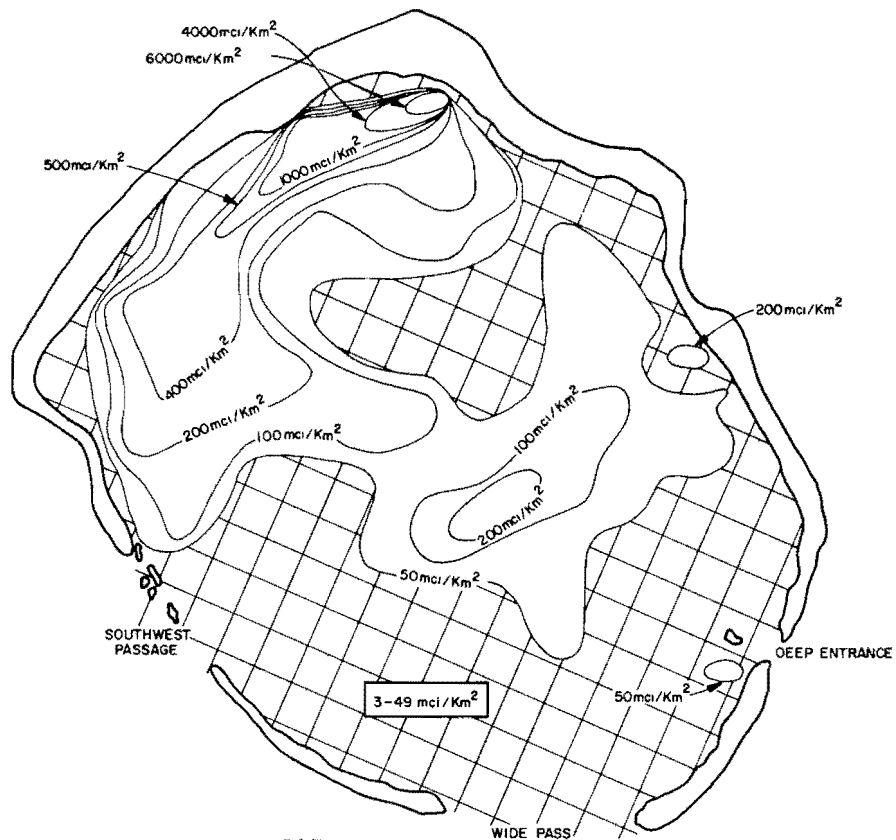


Fig. 60. Activity levels of  $^{207}\text{Bi}$  deposited in the sediments of Enewetak Lagoon.

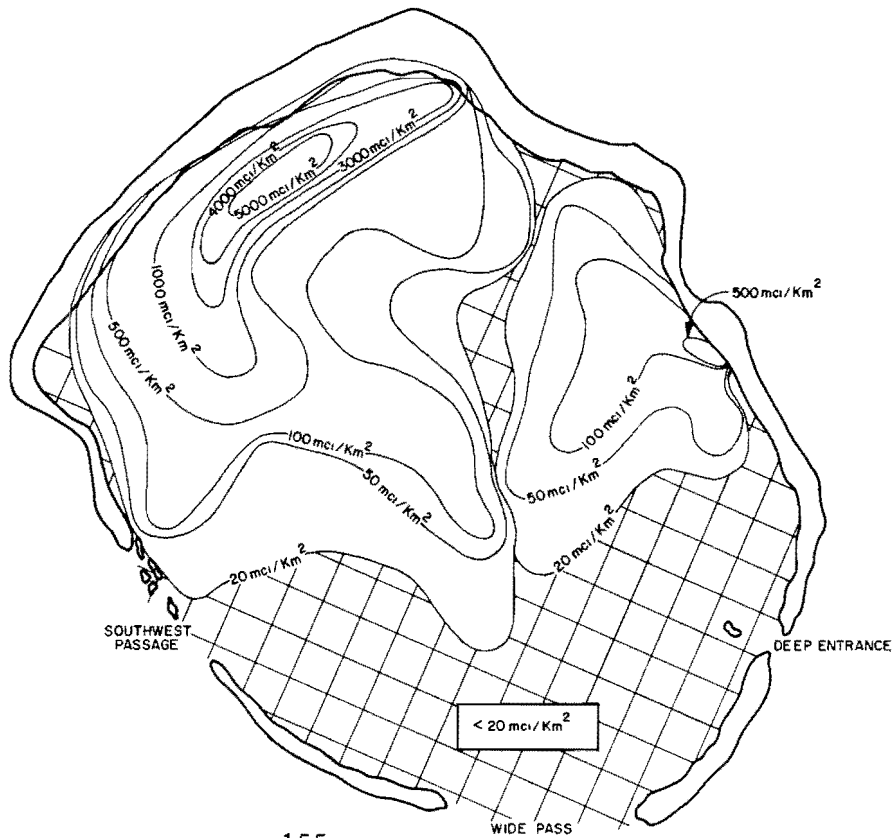


Fig. 61. Activity levels of  $^{155}\text{Eu}$  deposited in the sediments of Enewetak Lagoon.

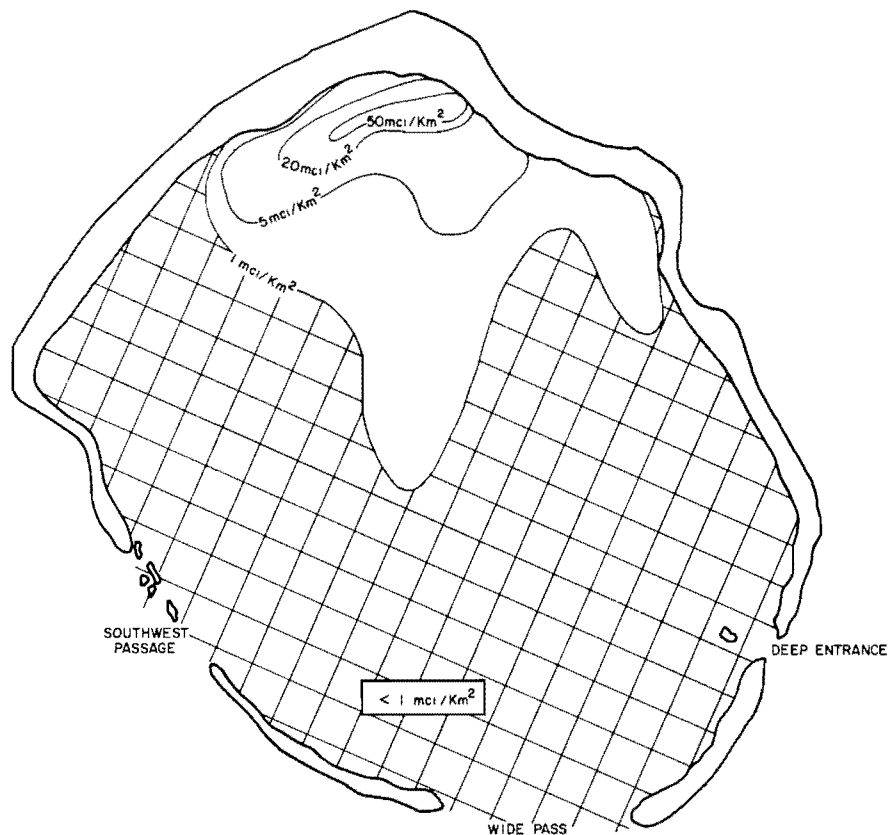


Fig. 62. Activity levels of  $^{152}\text{Eu}$  deposited in the sediments of Enewetak Lagoon.

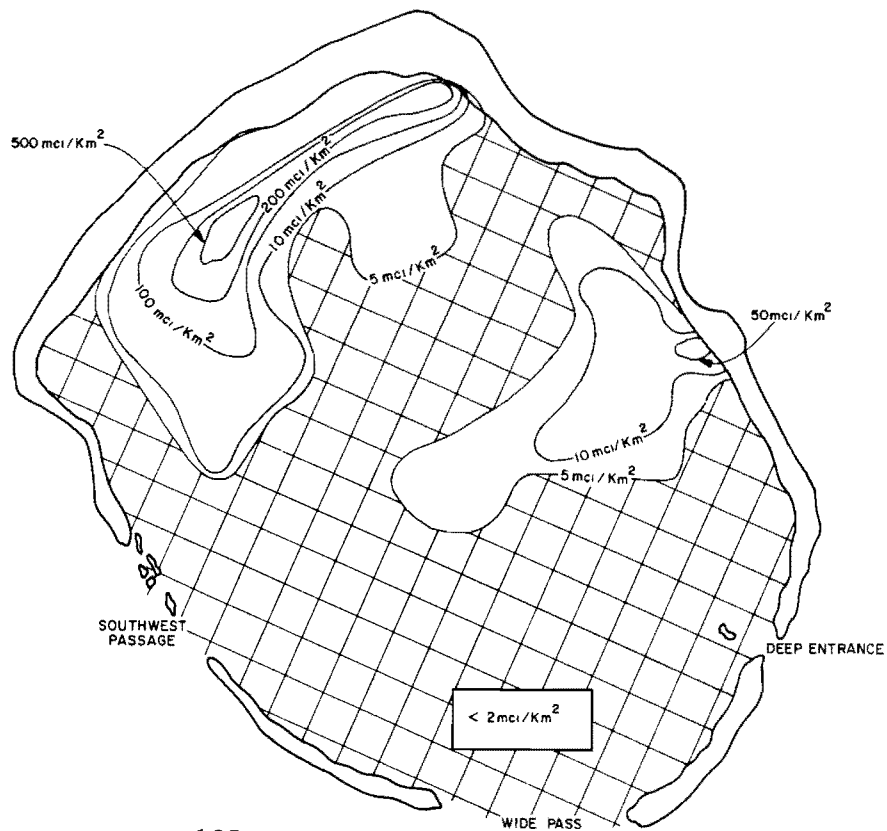


Fig. 63. Activity levels of  $^{125}\text{Sb}$  deposited in the sediments of Enewetak Lagoon.

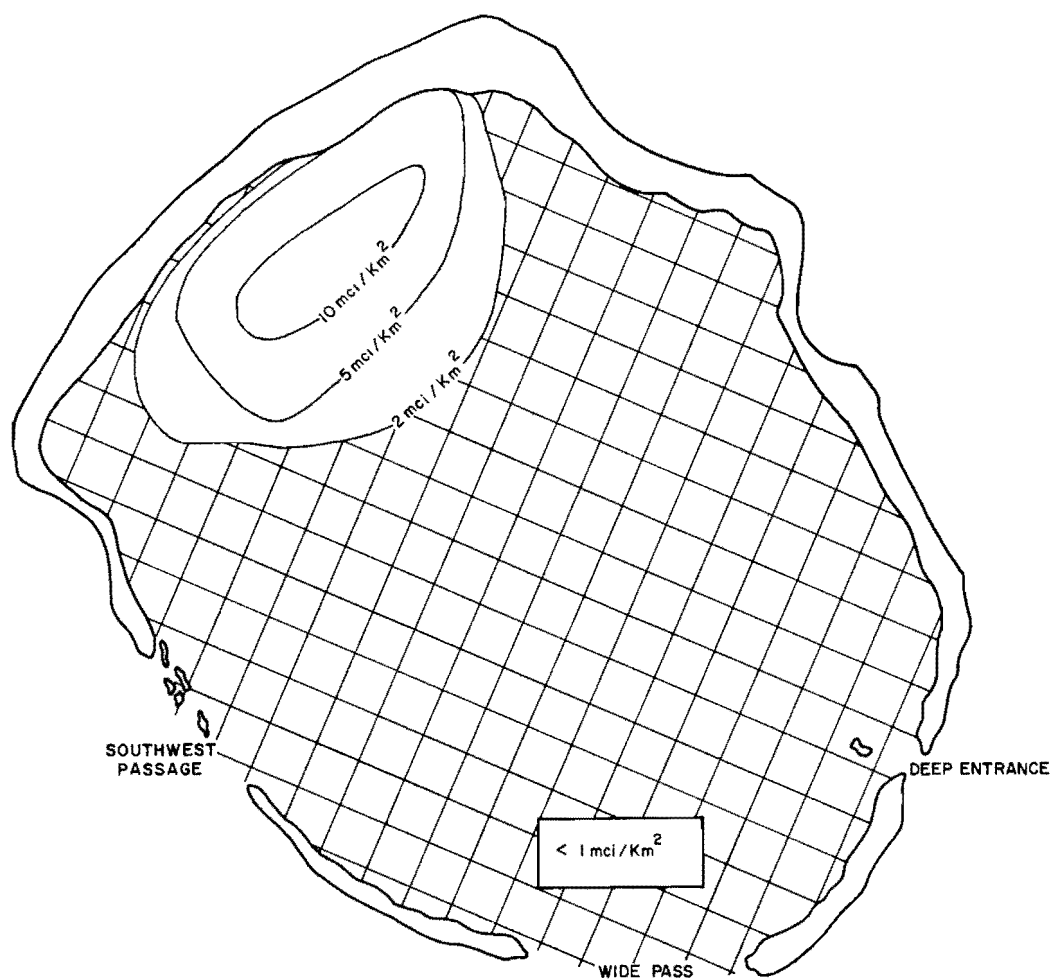


Fig. 64. Activity levels of  $^{101}\text{Rh}$  deposited in the sediments of Enewetak Lagoon.

Table 47. Mean radionuclide concentrations in Enewetak Lagoon sediments.

Radionuclide	Activity/unit area (mCi/km <sup>2</sup> )
$^{90}\text{Sr}$	586
$^{239,240}\text{Pu}$	463
$^{155}\text{Eu}$	369
$^{241}\text{Am}$	172
$^{207}\text{Bi}$	163
$^{137}\text{Cs}$	78
$^{60}\text{Co}$	73
$^{125}\text{Sb}$	22
$^{102m}\text{Rh}$	8.4
$^{152}\text{Eu}$	2.5
$^{101}\text{Rh}$	1.2

with  $^{137}\text{Cs}$  at a level which exceeds the mean value of 78 mCi/km<sup>2</sup> while 20 to 25% of the lagoon floor contains  $^{207}\text{Bi}$ ,  $^{60}\text{Co}$ , and  $^{102m}\text{Rh}$  at levels which exceed their mean level of activity. The activation products appear more widespread in Enewetak sediments than either the transuranics or detected fission products.

For comparative purposes, a few selected radionuclide concentrations found in aquatic sediments elsewhere in the world are shown Table 49. Only values for a few of the radionuclides present in Enewetak are available for comparison but it is immediately apparent from the data in Table 49 that Enewetak sediments



Table 48. Percentage of lagoon bottom area burdened with radionuclides above several levels of activity.

Concentration level (mCi/km <sup>2</sup> )	Percent of lagoon sediment contaminated <sup>a</sup>										
	<sup>90</sup> Sr	<sup>239</sup> Pu	<sup>155</sup> Eu	<sup>241</sup> Am	<sup>207</sup> Bi	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>125</sup> Sb	<sup>102m</sup> Rh	<sup>152</sup> Eu	<sup>101</sup> Rh
14000	0	0.01	0	0	0	0	0	0	0	0	0
10000	0.4	—	0	0	0	0	0	0	0	0	0
9000	— <sup>b</sup>	—	0	0.2	0	0	0	0	0	0	0
8000	—	0.7	0	—	0	0	0	0	0	0	0
7000	2.1	—	0	—	0	0	0	0	0	0	0
6000	—	—	0	—	0.2	0	0	0	0	0	0
5000	—	—	1.0	—	—	0	0	0	0	0	0
4000	—	—	—	—	—	0	0	0	0	0	0
3000	4.9	2.9	—	—	—	0	0	0	0	0	0
2000	—	—	—	1.3	—	0.3	0.3	0	0	0	0
1000	11.6	8.5	7.8	2.5	1.7	1.3	0.6	0	0	0	0
500	16.5	14.1	15.6	5.6	2.5	4.3	1.9	0.7	0	0	0
400	—	14.3	—	—	—	—	—	—	0	0	0
300	—	—	—	—	—	—	—	—	0	0	0
200	—	33.9	—	—	—	—	—	2.5	0	0	0
100	40.3	47.9	32.9	20.5	27.4	—	12.6	6.0	0.5	0	0
50	56.3	59.7	47.7	34.2	49.1	12.1	31.9	6.3	2.7	0.6	0
20	—	—	65.5	51.1	—	—	—	—	—	2.4	0
10	~100	—	—	59.5	—	26.1	70.5	1.85	20.0	—	2.7
5	~100	~100	—	>90	—	38.8	—	32.1	35.5	7.8	10.7
1	~100	~100	~98	—	100	>60	~98	—	—	23.5	17.4

<sup>a</sup>Lagoon area = 932 km<sup>2</sup>.

<sup>b</sup>Value not computed.

contain substantially higher deposits of artificially produced radionuclides than any other geographic area for which we have data.

MIKE and KOA Crater Sediments —

The locations of the sediment samples collected from the area of MIKE and KOA Craters are shown in Fig. 53. Results of analyses for the gamma-emitting radionuclides, <sup>90</sup>Sr, and plutonium radionuclides in the surface grab samples are presented in Table 50. Shown also in Table 50 are the mean values and standard deviations for the radionuclides in both craters; the mean surface concentrations in MIKE and KOA Craters; and the mean concentra-

tions at the three sampling water-depth intervals: (a) greater than 90 ft, (b) from depths greater than 4 ft but less than 90 ft, and (c) from surface sediments around the rim of the craters (samples 25E to 31E). The mean sediment thickness of the crater grab samples was 6.0 cm. Concentrations of the radionuclides in the crater surface sediments are extremely variable. With the exception of <sup>207</sup>Bi, there are higher concentrations of all radionuclides in MIKE Crater surface sediments than are found in KOA Crater deposits.

There appears to be a correlation between sediment radionuclide content and sampling depth. The surface sediments from the deeper depths within the craters

Table 49. Some selected radionuclide data in aquatic sediments.

Radionuclide	Collection date	Location	mCi/km <sup>2</sup>
<sup>239,240</sup> Pu	1968-1970-71	Buzzards Bay, Mass.	2.3 ± 0.2
<sup>239,240</sup> Pu	1971	Lake Ontario	0.6 ± 0.2
<sup>239,240</sup> Pu	1968	Bylot Sound, Greenland	3.9
<sup>239,240</sup> Pu	1968	Bylot Sound, Greenland	135
<sup>90</sup> Sr	1970-71	Buzzards Bay, Mass.	0.6 ± 0.1
	1969	Lake Superior	4.4
	1966	Lake Michigan	3.7
	1966	Ligurian Sea	3.0
<sup>137</sup> Cs	1970-71	Buzzards Bay, Mass.	7.6
	1973	Humboldt Bay, Calif.	21
	1969	Lake Superior	155
	1971	Lake Ontario	14
<sup>60</sup> Co	1963	11 km off mouth of Columbia River, USA	64
	1973	Humboldt Bay, Calif.	3.5
<sup>155</sup> Eu	1966	Ligurian Sea	18

contain higher levels of radionuclides than do sediments from shallower and surface deposits. In the past, any extreme turbulence or large scale mixing of the sediments should have produced a much more uniform distribution of radionuclides than that presently observed. The crater bottom sediments are, therefore, probably not subjected to severe scouring or resuspension, and the principle loss of activity from the deposits may only be from the slow release to the overlying waters and diffusion upward where the activities then mix with the surface waters and are diluted by advective processes. Since 1964, the concentration levels of several radionuclides in the

crater sediments have not diminished at rates substantially faster than predicted by radioactive decay alone. In Table 51 are the mean concentrations of <sup>60</sup>Co, <sup>125</sup>Sb, <sup>137</sup>Cs, and <sup>207</sup>Pb in the crater sediments from both the 1964 and 1972 survey. The value of each 1964 radionuclide detected, when decay corrected, agrees with the value found in the 1972 samples.

Roughly the same ordering of the principal radionuclides is found in the crater deposits as were found in the lagoon sediments. Strontium-90 is the most abundant radionuclide in the surface layers, followed by, in order of decreasing concentration, <sup>239,240</sup>Pu, <sup>155</sup>Eu, <sup>241</sup>Am,

Table 50. Radionuclides in the surface sediments of MIKE and KOA Craters.

Sample No.	Location	Water depth (ft)	Radionuclide concentration (pCi/g) <sup>a</sup>											
			<sup>60</sup> Co	<sup>90</sup> Sr	<sup>101</sup> Rh	<sup>102m</sup> Rh	<sup>125</sup> Sb	<sup>137</sup> Cs	<sup>152</sup> Eu	<sup>155</sup> Eu	<sup>207</sup> Bi	<sup>239</sup> Pu	<sup>238</sup> Pu	<sup>241</sup> Am
35C	MIKE	90	14.5 ± 1.7	82.4 ± 4.7	0.82 ± 7.5	3.09 ± 5.0	1.79 ± 17	18.2 ± 1.9	0.62 ± 21	47.5 ± 3.9	2.45 ± 9.7	67.1 ± 8.4	3.03 ± 17	23.9 ± 15.2
34C	MIKE	65	1.98 ± 2.2	35.4 ± 4.2	N. R. <sup>b</sup>	0.14 ± 19	0.30 ± 24	7.89 ± 1.3	0.13 ± 24	6.8 ± 4	0.36 ± 11	32.1 ± 16	1.08 ± 100	8.61 ± 1.5
38C	MIKE	61	2.86 ± 1.4	43.5 ± 4.2	0.19 ± 7	0.82 ± 4	0.56 ± 11	9.90 ± 1.7	0.21 ± 13	28.4 ± 2	1.3 ± 3	47.3 ± 8	1.67 ± 18	15.4 ± 6
33C	MIKE	92	8.61 ± 1.2	55 ± 5	0.45 ± 5	2.03 ± 4	1.40 ± 12	12.5 ± 1	0.35 ± 25	28.8 ± 3	2.71 ± 2	49.1 ± 6	2.36 ± 10	12.1 ± 11
32C	Junction MIKE and KOA	91	12.0 ± 1.0	52.3 ± 5	0.60 ± 3	2.22 ± 2	2.03 ± 4	10.4 ± 2	0.28 ± 19	30.3 ± 2	2.78 ± 2	37.5 ± 8	2.49 ± 17	10.2 ± 6
36C	KOA	102	1.61 ± 5	27.5 ± 4	0.09 ± 22	0.53 ± 10	0.64 ± 31	2.24 ± 4	<0.09	9.20 ± 4	1.77 ± 6	12.0 ± 8	1.21 ± 12	3.37 ± 18
31C	KOA	112	8.68 ± 3	42.8 ± 4	0.50 ± 8	2.22 ± 3	1.54 ± 10	6.41 ± 2	0.20 ± 48	30.6 ± 6	6.69 ± 2	37.7 ± 7	5.49 ± 9	7.03 ± 25
37C	KOA	60	1.04 ± 7	13.4 ± 5	0.07 ± 12	0.29 ± 7	0.23 ± 20	1.62 ± 2	0.14 ± 19	6.1 ± 3	0.92 ± 3	7.66 ± 8	1.04 ± 12	1.66 ± 12
29C	KOA	110	7.89 ± 2	45.1 ± 3	0.41 ± 6	1.73 ± 3	1.44 ± 7	5.96 ± 2	0.36 ± 18	23.5 ± 3	5.62 ± 1	3.35 ± 7	0.56 ± 7	4.78 ± 14
mean, all samples			6.5 ± 4.6	44 ± 19	0.4 ± 0.3	1.5 ± 1.0	1.1 ± 0.7	8.3 ± 5.1	0.3 ± 0.2	24 ± 14	2.7 ± 2.1	33 ± 21	2.1 ± 1.5	9.7 ± 6.7
mean, MIKE Crater			8.0 ± 5.5	54 ± 18	0.5 ± 0.3	1.7 ± 1.1	1.2 ± 0.8	11.8 ± 3.9	0.3 ± 0.2	28 ± 14	1.9 ± 1.1	47 ± 13	2.1 ± 0.8	14.0 ± 6.1
mean, KOA Crater			6.2 ± 4.8	36 ± 16	0.3 ± 0.2	1.4 ± 0.9	1.2 ± 0.7	5.3 ± 3.6	0.2 ± 0.1	20 ± 12	3.6 ± 2.5	20 ± 17	2.2 ± 2.0	5.4 ± 3.3
mean, all samples >90 ft			8.9 ± 4.4	51 ± 18	0.5 ± 0.2	2.0 ± 0.8	1.5 ± 0.5	9.3 ± 5.6	0.3 ± 0.2	28 ± 12	3.7 ± 2.0	34 ± 24	2.5 ± 1.7	10.2 ± 7.4
mean, all samples <90 ft			2.0 ± 0.9	31 ± 16	0.1 ± 0.1	0.4 ± 0.4	0.4 ± 0.2	6.5 ± 4.3	0.2 ± 0.0	14 ± 13	0.9 ± 0.5	29 ± 20	1.3 ± 0.4	8.6 ± 6.8
mean, all surface sediments around craters (0-6 cm)			1.0 ± 0.9		N. R.	0.1 ± 0.1	0.3 ± 0.3	4.7 ± 6.1	0.2 ± 0.2	4.7 ± 2.9	0.5 ± 0.3			10.4 ± 10.0

<sup>a</sup>Error expressed in % of value given.

<sup>b</sup>N, R.—not reported.

Table 51. Comparison of the concentrations of several radionuclides in MIKE Crater sediment, 1964 to 1972.

Date of sampling	Water depth, ft	Crater location	Mean concentration, pCi/g			
			$^{60}\text{Co}$	$^{125}\text{Sb}$	$^{137}\text{Cs}$	$^{207}\text{Bi}$
7/64	~90	MIKE	29 ± 17	11 ± 7	12 ± 7	5.9 ± 4.5
Decay corrected to Dec. 1972			9.7 ± 5.7	1.3 ± 0.8	9.9 ± 5.8	4.9 ± 3.7
12/72	all	MIKE	7.1 ± 4.9	0.9 ± 0.6	11.6 ± 3.8	1.9 ± 1.1
12/72	>90	MIKE and KOA	7.9 ± 3.9	1.2 ± 0.4	9.1 ± 5.5	3.6 ± 2.0
12/72	>90	MIKE	10.3 ± 3.7	1.3 ± 0.2	15.0 ± 3.9	2.5 ± 0.2

$^{137}\text{Cs}$ ,  $^{60}\text{Co}$ ,  $^{207}\text{Bi}$ ,  $^{238}\text{Pu}$ ,  $^{102\text{m}}\text{Rh}$ ,  $^{125}\text{Sb}$ ,  $^{101}\text{Ru}$ , and  $^{152}\text{Eu}$ . Bismuth-207, more abundant than  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  in the open lagoon, is less abundant in the surface layers of the crater sediments.

The radionuclide concentrations in subsections of 4 cores obtained from the craters are shown in Table 52. With the exception of  $^{207}\text{Bi}$  and  $^{152}\text{Eu}$ , all other radionuclides are found distributed the length of the sediment column sampled. The levels of  $^{60}\text{Co}$ ,  $^{102\text{m}}\text{Rh}$ ,  $^{125}\text{Sb}$ , and  $^{137}\text{Cs}$ , in general, increase down the sediment column.  $^{241}\text{Am}$  and  $^{155}\text{Eu}$  concentrations, although variable near the surface, only slowly decrease in value down the sediment column. The sediment profiles of  $^{207}\text{Bi}$  are shown in Fig. 65. For comparison,  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ ,  $^{241}\text{Am}$ , and  $^{155}\text{Eu}$  concentrations in core 15E are plotted as a function of depth in Fig. 66. The different vertical distribution patterns are obvious, probably indicative of differential movement of one radionuclide relative to another. Unlike the other radionuclides,  $^{207}\text{Bi}$  is not detected below depths of 30 to 40 cm in the sediment column. There also appears to be a discontinuity in the con-

centration profiles of  $^{241}\text{Am}$ ,  $^{137}\text{Cs}$ ,  $^{155}\text{Eu}$ , and  $^{60}\text{Co}$  at the 30- to 35-cm level in the core. These and other observations to be discussed indicate that the sediment surface layers in MIKE and KOA Craters are possibly ejecta from other nuclear events held in the Atoll. Holmes and Narver profiled the postevent depths of MIKE Crater in 1952 and found the maximum crater depth to be near 180 ft below sea level. During 1964, the Holmes and Narver survey indicated the bottom depth of MIKE Crater was then at 90 ft below sea level. Between 1952 and 1964, there was either considerable slippage of the crater slopes to fill in the crater bottom or tests held after 1952, such as KOA or others, contributed fill to the crater area. Clearly natural sedimentation can be ruled out since between the years 1964 to 1972, a period of no testing, there has been no measurable change in the bottom depth of the crater. Presently, at least 30 to 40 cm of sediment, richer in  $^{207}\text{Bi}$ , covers a  $^{207}\text{Bi}$  depleted sediment region in both craters. Rhodium radionuclides,  $^{101}\text{Rh}$  and  $^{102\text{m}}\text{Rh}$ , are also found in the crater sediments. In sample 15E of the mean

Table 52. Radionuclide concentrations in core samples from the crater.

Core No.	Depth increment (cm)	pCi/g <sup>a</sup>										
		<sup>60</sup> Co	<sup>102m</sup> Rh	<sup>101</sup> Rh	<sup>125</sup> Sb	<sup>137</sup> Cs	<sup>152</sup> Eu	<sup>155</sup> Eu	<sup>207</sup> Bi	<sup>241</sup> Am	<sup>239</sup> Pu	<sup>90</sup> Sr
17E(92 ft)												
05789247	0-5	10.8 ± 3	2.4 ± 6	0.59 ± 9	2.4 ± 14	13.1 ± 2	0.3 ± 70	42.9 ± 2	3.17 ± 4	20.1 ± 8	51.4 ± 13	56.3 ± 12
7893	5-10	11.3 ± 2	2.8 ± 5	0.68 ± 10	2.1 ± 16	13.5 ± 2	0.5 ± 30	46.6 ± 2	4.65 ± 3	19.6 ± 8	50.5 ± 10	73.4 ± 8
7894	10-15	27.1 ± 1	4.3 ± 3	0.98 ± 6	8.1 ± 4	16.4 ± 1	0.4 ± 30	63.0 ± 2	11.4 ± 1	22.4 ± 8	60.8 ± 6	91.4 ± 7
7895	15-20	47.3 ± 1	5.7 ± 4	1.45 ± 5	16.9 ± 3	18.6 ± 2	0.5 ± 27	60.4 ± 3	8.2 ± 3	16.4 ± 11	56.3 ± 4	112.2 ± 5
7896	20-25	53.7 ± 1	5.4 ± 4	1.41 ± 4	16.4 ± 3	17.2 ± 2	0.1 ± 100	54.3 ± 2	2.5 ± 7	14.1 ± 5	51.4 ± 3	117.1 ± 6
7897	25-30	59.4 ± 1	5.8 ± 2	1.60 ± 3	22.6 ± 2	17.9 ± 2	0.3 ± 28	54.7 ± 1	1.6 ± 8	12.2 ± 4	47.3 ± 4	159 ± 7
7898	30-35	55.5 ± 2	5.1 ± 4	1.48 ± 5	25.8 ± 3	15.9 ± 3	0.2 ± 100	46.0 ± 1	0.7 ± 20	10.4 ± 5	40.9 ± 6	104 ± 10
7899	35-40	83.8 ± 2	7.0 ± 5	1.95 ± 7	27.9 ± 4	24.0 ± 3	0.4 ± 100	59.6 ± 3	0.3 ± 100	12.2 ± 13	47.8 ± 5	126 ± 8
7900	40-45	83.5 ± 1	7.0 ± 5	1.90 ± 7	29.1 ± 4	23.9 ± 4	0.4 ± 100	61.2 ± 2	0.3 ± 100	13.6 ± 10	45.5 ± 6	132 ± 6
7901	45-50	88.9 ± 2	7.1 ± 5	1.99 ± 8	29.2 ± 4	24.5 ± 1	0.4 ± 100	59.4 ± 2	0.3 ± 100	13.7 ± 11	45.5 ± 6	146 ± 7
7902	50-56	71.3 ± 2	6.3 ± 10	1.77 ± 12	19.5 ± 8	20.0 ± 6	0.6 ± 100	47.8 ± 4	0.5 ± 100	12.6 ± 21	91.4 ± 44	113 ± 9
16E(91 ft)												
05790347	0-5	1.2 ± 100	3.4 ± 11	0.77 ± 14	3.9 ± 18	14.3 ± 5	<0.4	40.4 ± 4	4.45 ± 9	15.3 ± 17	34.6 ± 6	49.6 ± 16
7904	5-10	60.7 ± 3	7.2 ± 11	1.91 ± 17	15.2 ± 11	20.1 ± 6	<0.7	57.6 ± 4	4.93 ± 14	16.1 ± 18	51.4 ± 8	60.4 ± 9
7905	10-15	62.1 ± 2	6.3 ± 9	1.72 ± 14	19.7 ± 8	19.4 ± 5	<0.7	49.5 ± 6	0.5 ± 100	12.7 ± 25	46.4 ± 8	88.7 ± 10
7906	15-20	54.3 ± 2	4.5 ± 10	1.25 ± 16	20.1 ± 8	19.6 ± 5	<0.6	44.9 ± 5	1.6 ± 25	11.3 ± 25	39.8 ± 8	93.7 ± 9
7907	20-25	68.3 ± 2	6.2 ± 9	1.54 ± 13	22.9 ± 7	21.0 ± 5	<0.7	49.4 ± 6	0.5 ± 100	10.7 ± 25	42.0 ± 10	81.9 ± 11
7908	25-30	64.1 ± 3	5.5 ± 9	1.63 ± 14	25.2 ± 6	20.6 ± 5	<0.6	46.3 ± 6	0.5 ± 100	8.9 ± 25	40.2 ± 5	131 ± 6
7909	30-38	64.2 ± 1	5.7 ± 9	1.61 ± 10	22.4 ± 6	20.8 ± 4	<0.6	45.1 ± 6	0.4 ± 100	7.9 ± 26	44.3 ± 5	106 ± 6
14E(110 ft)												
05788347	0-5	7.2 ± 2	1.7 ± 5	0.42 ± 7	1.5 ± 14	5.72 ± 3	0.27 ± 30	28.1 ± 1	5.28 ± 2	5.59 ± 6	25.6 ± 6	31.5 ± 11
7884	5-10	8.2 ± 9	2.1 ± 7	0.52 ± 8	2.0 ± 16	6.46 ± 4	0.48 ± 31	31.9 ± 1	6.92 ± 5	6.13 ± 6	42.3 ± 2	42.1 ± 1
7885	10-15	11.7 ± 3	2.6 ± 7	0.62 ± 10	3.9 ± 10	6.71 ± 4	0.1 ± 100	37.0 ± 1	10.7 ± 4	6.31 ± 6	53.9 ± 2	45.6 ± 1.0
7886	15-25	25.4 ± 2	3.3 ± 7	0.79 ± 14	10.7 ± 7	7.08 ± 5	0.4 ± 100	38.3 ± 6	12.5 ± 5	8.46 ± 27	51.8 ± 3	59.9 ± 4
7887	25-35	44.7 ± 2	4.8 ± 6	1.23 ± 11	15.5 ± 5	9.44 ± 4	0.4 ± 100	35.4 ± 6	3.35 ± 9	6.73 ± 28	36.1 ± 2	49.5 ± 5
7888	35-39	50.4 ± 2	5.7 ± 7	1.49 ± 12	17.6 ± 7	11.6 ± 5	0.5 ± 100	38.8 ± 6	1.14 ± 25	6.11 ± 28	44.2 ± 2	73.9 ± 6
15E(112 ft)												
05791047	0-5	13.5 ± 5	2.5 ± 23	0.47 ± 34	4.21 ± 26	7.14 ± 7	0.5 ± 100	40.5 ± 7	10.5 ± 7	8.7 ± 29	36.4 ± 4	58.6 ± 7
7911	5-10	34.5 ± 1	5.2 ± 5	1.14 ± 7	16.8 ± 3	8.50 ± 5	0.2 ± 100	62.6 ± 5	23.4 ± 2	8.9 ± 12	50.0 ± 4	75.2 ± 6
7912	10-15	42.4 ± 2	4.6 ± 7	1.04 ± 11	15.2 ± 5	10.5 ± 6	0.3 ± 100	45.9 ± 3	6.7 ± 8	8.3 ± 12	37.1 ± 8	27.2 ± 12
7913	15-20	46.7 ± 1	4.5 ± 4	1.14 ± 6	15.4 ± 4	10.9 ± 3	0.37 ± 70	36.8 ± 3	1.7 ± 9	7.2 ± 10	28.6 ± 7	78.4 ± 8
7914	20-25	49.6 ± 2	4.6 ± 4	1.27 ± 6	20.0 ± 3	11.6 ± 3	0.37 ± 70	37.7 ± 3	1.7 ± 9	7.5 ± 10	28.9 ± 2	
7915	25-30	44.9 ± 2	4.5 ± 6	1.06 ± 10	15.6 ± 5	10.9 ± 4	0.3 ± 100	35.2 ± 3	1.3 ± 15	7.5 ± 11	27.5 ± 3	88.7 ± 8
7916	30-35	46.5 ± 4	5.1 ± 12	1.30 ± 18	13.9 ± 10	11.0 ± 9	0.5 ± 100	29.6 ± 5	0.4 ± 100	5.7 ± 22	28.5 ± 3	
7917	35-40	47.8 ± 3	5.2 ± 10	1.29 ± 16	19.5 ± 9	12.7 ± 7	0.6 ± 100	32.7 ± 5	0.5 ± 100	7.6 ± 22		81.5 ± 5
7918	40-45	47.1 ± 1	4.4 ± 4	1.29 ± 5	17.5 ± 3	11.9 ± 3	0.2 ± 100	37.3 ± 3	0.61 ± 18	6.9 ± 12	30.1 ± 3	79.7 ± 7
7919	45-50	48.2 ± 1	4.8 ± 5	1.34 ± 8	20.0 ± 3	12.8 ± 3	0.2 ± 100	39.9 ± 2	2.2 ± 8	7.1 ± 22	29.4 ± 3	154 ± 4
7920	50-55	47.6 ± 1	5.0 ± 6	1.34 ± 5	18.3 ± 3	11.5 ± 3	0.1 ± 100	38.2 ± 1	1.12 ± 14	5.5 ± 16	29.5 ± 4	151 ± 3
7921	55-63	46.9 ± 2	4.5 ± 6	1.32 ± 8	17.6 ± 5	10.5 ± 4	0.2 ± 100	32.2 ± 2	0.2 ± 100	5.3 ± 10	33.6 ± 4	197 ± 2

<sup>a</sup>Error expressed in % of quoted value.

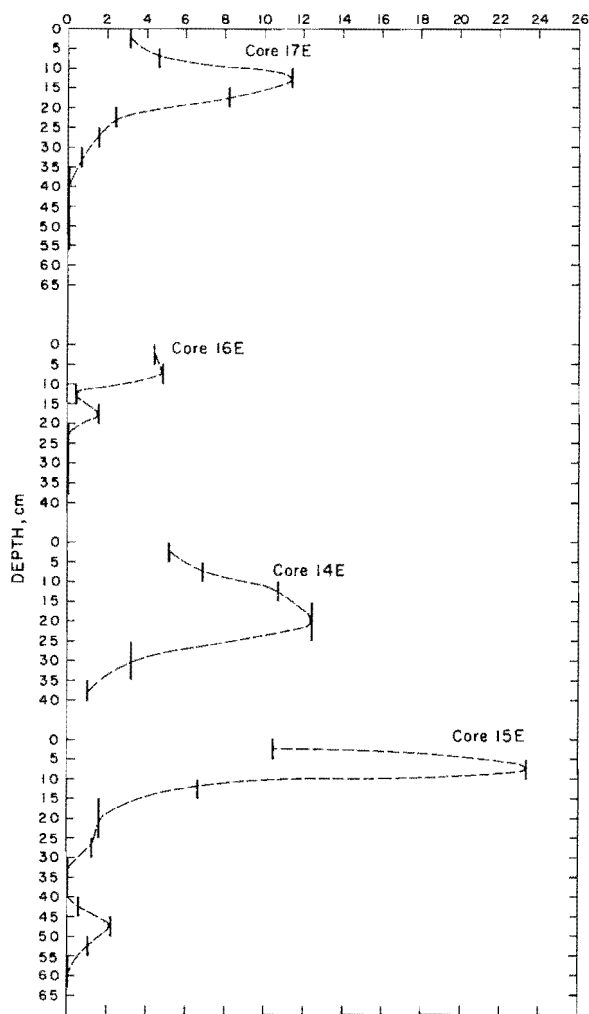


Fig. 65. Profiles of the  $^{207}\text{Bi}$  concentration in crater cores.

ratio of the two rhodium radionuclides, to the maximum depth sampled, is  $0.253 \pm 0.032$ . The ratios in samples 17E, 14E, and 16E are, respectively,  $0.265 \pm 0.019$ ,  $0.249 \pm 0.009$ , and  $0.267 \pm 0.024$ . To within one standard deviation, these values are identical and are distinct from ratios of 0.12 to 0.17 found in some open lagoon sediments. It would be extremely coincidental if  $^{101}\text{Rh}$  and  $^{102\text{m}}\text{Rh}$  were produced in both the MIKE and KOA Events, separated in time by 6 yr, in quantities which today yield identical ratios. Rather, the results suggest a single source for the rhodium isotopes

now found in the sediments of both craters. The origin of the different horizons of the surface crater sediments are unknown, but are probably ejecta from other events held in the northwest sector of the Atoll. Rhodium isotopic ratios identical in value to those found in MIKE and KOA craters are detected in soils from JANET, IRENE, DAISY, and KATE while quite different and distinctive ratios are found in soils from ALICE and BELLE.

Near-Shore Sediments—The average concentrations of the principal gamma-emitting radionuclides in near-shore sediments are tabulated in Table 53. All sediment cores were obtained from the surf-zone in no more than 3 ft of overlying water. Highest levels of activity are found in samples from IRENE, HELEN and the sand bars surrounding MIKE and KOA craters. The areal distribution of activity is similar to that found in the off-shore sediments.

Surprisingly there appears to be little difference in the radionuclide concentration of lagoon and ocean near-shore sediments. This observation again suggests that the bottom lagoon sediments are not subjected to large-scale resuspension and subsequent redistribution within the lagoon. These latter mechanisms would necessarily act as driving forces to produce significantly higher concentrations of radionuclides in the near-shore lagoon deposits relative to the ocean-side sediments.

In Situ Probe Survey—An *in situ*, gamma-spectrometry survey of the lagoon bottom off YVONNE, ELMER, and

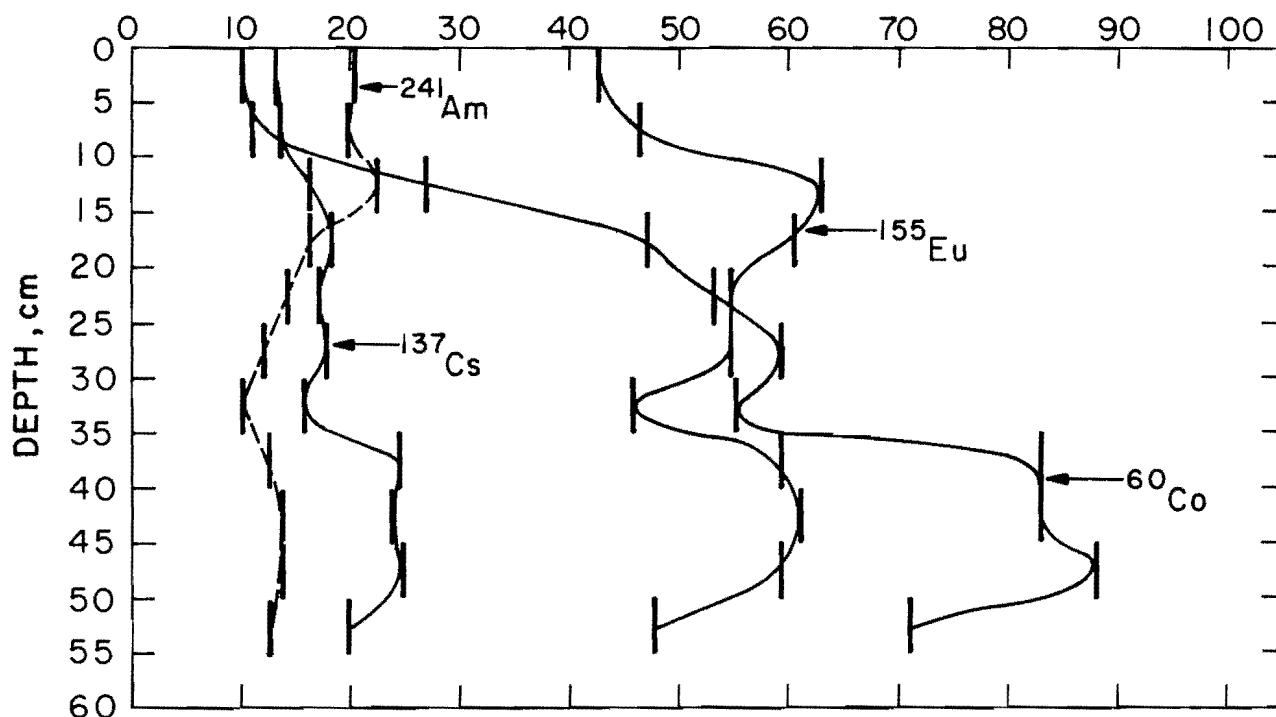


Fig. 66. Selected radionuclide concentration distributions in core 17E-KOA crater.

FRED was made during December, 1972. This survey was conducted to obtain data for the comparison of the results of field measurements with the results of the more sophisticated and time-consuming laboratory analyses of water and sediments. If the field measurements were acceptable, areas of high gamma activity in the lagoon sediments could be identified and the sampling program could be immediately adjusted in accordance with the findings. The gamma probe was built at the Laboratory of Radiation Ecology, University of Washington, and is a modification of an *in situ* probe originally designed by Gordon Riel of the United States Naval Ordnance Laboratory, White Oak, Maryland. The probe is composed of a 3 in.  $\times$  3 in. sodium iodide crystal, a photomultiplier, and a preamplifier, all encased in a brass waterproof housing.

Power was supplied by a pair of 12-V batteries, and the signal cables were connected to a 200-channel analyzer with video display and tape printout subunits, all of which were carried on the AEC 24-ft launch. The probe was capable of operating to depths of 300 ft and of withstanding the shocks associated with its use aboard ships.

Prior to making a probe reading, the boat was anchored and its position determined by taking bearings on known landmarks. The probe was then lowered on a hand-held steel cable to the bottom of the lagoon and a 10- to 20-min count was taken and recorded on paper tape. Using a pipe dredge, a sediment sample was taken from as near to the *in situ* probe location as was possible. After the count was completed, the probe was raised to just below the water's surface and the

Table 53. Concentration levels of principal gamma emitting radionuclides in nearshore sediments.

Island - location	Chart No.	Mean dry density (g/cm <sup>3</sup> )	Length of core (cm)	pCi/g <sup>a</sup> dry			
				<sup>60</sup> Co	<sup>137</sup> Cs	<sup>207</sup> Pb	<sup>155</sup> Eu
FRED - lagoon	(missing), marine pier		15	<0.04	<0.04	0.09 ± 0.03	<0.07
FRED - ocean	38E	1.22 ± 0.04	15	<0.04	<0.03	0.55 ± 0.15	0.18 ± 0.10
FRED - ocean	37E	1.38 ± 0.35	15	<0.04	<0.03	<0.04	0.07 ± 0.04
WALT - lagoon w/end	11E	1.55 ± 0.08	15	<0.02	<0.02	<0.02	<0.05
WALT - lagoon e/end	12E	1.16 ± 0.03	15	<0.03	<0.02	<0.02	0.07 ± 0.04
YVONNE - lagoon	32E	1.49 ± 0.02	14	0.67 ± 0.49	<0.06	0.36 ± 0.07	0.71 ± 0.22
YVONNE - lagoon s/end	33E	1.31 ± 0.11	15	<0.03	<0.01	0.06 ± 0.03	0.09 ± 0.03
YVONNE - lagoon s/end	34E	1.50 ± 0.08	15	<0.03	<0.02	0.11 ± 0.06	0.11 ± 0.06
YVONNE - oceanside s/end	35E	1.40 ± 0.05	15	0.05 ± 0.05	<0.02	0.03 ± 0.03	0.15 ± 0.04
YVONNE - oceanside s/end	36E	1.24 ± 0.22	15	<0.03	<0.01	<0.01	0.15 ± 0.03
URSULA - lagoon s/tip	8E	1.06 ± 0.07	15	<0.06	<0.04	<0.02	0.63 ± 0.29
URSULA - lagoon (center of island)	39E	1.08 ± 0.21	14	<0.04	<0.03	<0.02	0.32 ± 0.16
URSULA - oceanside	42E	0.97 ± 0.11	15	<0.02	0.10 ± 0.04	<0.02	0.20 ± 0.07
TILDA - lagoon e/tip	7E	1.08 ± 0.08	16	0.18 ± 0.15	0.21 ± 0.04	<0.03	0.63 ± 0.05
JANET - lagoon se/end	9E	1.14	15	0.26 ± 0.08	0.64 ± 0.20	0.17 ± 0.10	1.01 ± 0.20
JANET - lagoon nw/end	10E	1.11	16	0.10 ± 0.04	<0.3	0.47 ± 0.20	1.46 ± 0.51
IRENE - Seminole crater area	40E	1.23 ± 0.06	15	4.73 ± 0.74	1.23 ± 0.25	0.25 ± 0.05	2.48 ± 0.43
HELEN - lagoon w/tip	41E	1.13 ± 0.19	12	0.84 ± 0.10	1.19 ± 0.49	1.02 ± 0.23	4.14 ± 1.24
HELEN - lagoon sand bar	25E	1.19 ± 0.05	12	0.46 ± 0.15	0.12 ± 0.03	<0.04	1.15 ± 0.11
HELEN - lagoon s/tip	26E	1.30 ± 0.07	17	0.60 ± 0.23	0.47 ± 0.19	0.23 ± 0.05	3.12 ± 0.73
HELEN - n/end	27E	1.16 ± 0.03	12	0.66 ± 0.12	0.59 ± 0.16	0.74 ± 0.07	2.26 ± 0.48
Sand bars around MIKE and KOA Craters	28E	1.20 ± 0.09	12	0.79 ± 0.22	4.72 ± 2.35	0.62 ± 0.20	4.55 ± 2.03
	29E	1.36 ± 0.02	12	1.02 ± 0.25	5.12 ± 0.34	4.80 ± 1.01	0.54 ± 0.08
	30E	1.21 ± 0.05	17	1.29 ± 0.17	6.21 ± 1.61	0.45 ± 0.09	5.64 ± 0.71
	31E	1.06 ± 0.14	13	2.32 ± 0.70	10.4 ± 10.1	0.89 ± 0.08	6.58 ± 3.57
BELLE - lagoon e/end	6E	1.07 ± 0.09	15	0.24 ± 0.04	0.39 ± 0.21	0.17 ± 0.04	1.42 ± 0.21
BELLE - lagoon w/end	5E	1.18 ± 0.15	14	0.39 ± 0.34	0.54 ± 0.22	0.11 ± 0.06	2.06 ± 1.22
LEROY - n/end	4E	1.15	23	0.03 ± 0.03	<0.02	0.29 ± 0.06	<0.03
HENRY - w/end	3E	1.16	17	<0.05	<0.03	0.13 ± 0.04	<0.08
GLENN - lagoon	2E	1.12	20	<0.04	<0.02	0.26 ± 0.18	<0.07
GLENN - oceanside	1E	1.12	10	<0.03	<0.02	0.18 ± 0.11	<0.04

<sup>a</sup>Calculated mean value and standard deviation obtained by averaging each subsection of core over the length of core.



boat was moved to the next station. The probe remained in the water during a day's operation in order to maintain the detector at a near-constant temperature and thus prevent a shift in the gain component of the analyzer (a change in "gain" affects the identification of the radionuclide).

Sixty-seven probe readings were made in 6 days in the lagoon off YVONNE and six readings were made in the lagoon off ELMER and FRED. Station locations off YVONNE and the depths at each station are shown in Figs. 67 and 68, respectively.

Near YVONNE, gamma peaks of  $^{40}\text{K}$ ,  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ , and  $^{207}\text{Bi}$  could be readily identified from the video display and the tape printout of the probe data. However, only  $^{40}\text{K}$  and  $^{207}\text{Bi}$  were readily detected off FRED and ELMER. Since  $^{207}\text{Bi}$  and  $^{60}\text{Co}$  were detected at most stations off YVONNE, relative concentrations of these radionuclides were determined for the probe readings taken there. The relative concentration of  $^{60}\text{Co}$  was calculated from its 1.33-MeV photon by summing the values from the five channels closest to the 1.33-MeV channel. Relative concentrations of  $^{207}\text{Bi}$  were determined by summing the 1.06-MeV peak channel, one channel below the peak, and the two channels above the peak, and subtracting the value of the sum of the two channels (four total) on each side of the four channels summed for  $^{207}\text{Bi}$ . The results of the relative concentration calculations, standardized to 1-min counts, are shown in Figs. 69 ( $^{60}\text{Co}$ ) and 70 ( $^{207}\text{Bi}$ ).

These results indicated that  $^{60}\text{Co}$  concentrations were greatest when the probe was on the bottom at a depth of 60 to 75 ft

in an area bounded on the south by a line parallel to the personnel pier and on the north by a line perpendicular to HARDTACK Bunker No. 1610. Bismuth-207 concentrations were also high in this area, but the highest  $^{207}\text{Bi}$  levels occurred at a depth of 60 to 70 ft in an area 600 m offshore of craters at the north end of the island. Near-shore  $^{207}\text{Bi}$  levels were high in an area ranging north from just off CACTUS Crater. Cesium-137 concentrations were also high in this area.

Whereas  $^{60}\text{Co}$  showed steadily increasing concentrations out to a depth of 75 ft,  $^{207}\text{Bi}$  concentrations were at low (3.5 to 9.9 relative counts per minute) and moderate (10 to 29 relative counts per minute) levels near the shore, with a band of non-significant readings (relative count < background count) at intermediate depths (20 to 50 ft) followed by moderate and high levels at greater depths. Potassium-40 levels were relatively constant throughout the survey area.

The sediment samples which were taken simultaneously with the in situ probe readings were prepared and analyzed in the same manner as discussed in the section on lagoon sediments. Results of these analyses are shown in Figs. 71 ( $^{60}\text{Co}$ ), 72 ( $^{207}\text{Bi}$ ), 73 ( $^{155}\text{Eu}$ ), 74 ( $^{241}\text{Am}$ ), 75 ( $^{239,240}\text{Pu}$ ), and 76 ( $^{238}\text{Pu}$ ). Americium-241/ $^{239,240}\text{Pu}$  ratios found in the sediment samples are plotted in Fig. 77, while  $^{238}\text{Pu}/^{239,240}\text{Pu}$  ratios are plotted in Fig. 78. Potassium-40,  $^{102\text{m}}\text{Rh}$ ,  $^{125}\text{Sb}$ ,  $^{137}\text{Cs}$ , and  $^{152}\text{Eu}$  were detected in more than 50% of the samples;  $^{154}\text{Eu}$ ,  $^{226}\text{Ra}$ , and  $^{235}\text{U}$  in 15 to 40% of the samples; and  $^{101}\text{Rh}$ ,  $^{106}\text{Ru}$ ,  $^{134}\text{Cs}$ , and  $^{144}\text{Ce}$  were detected in an occasional

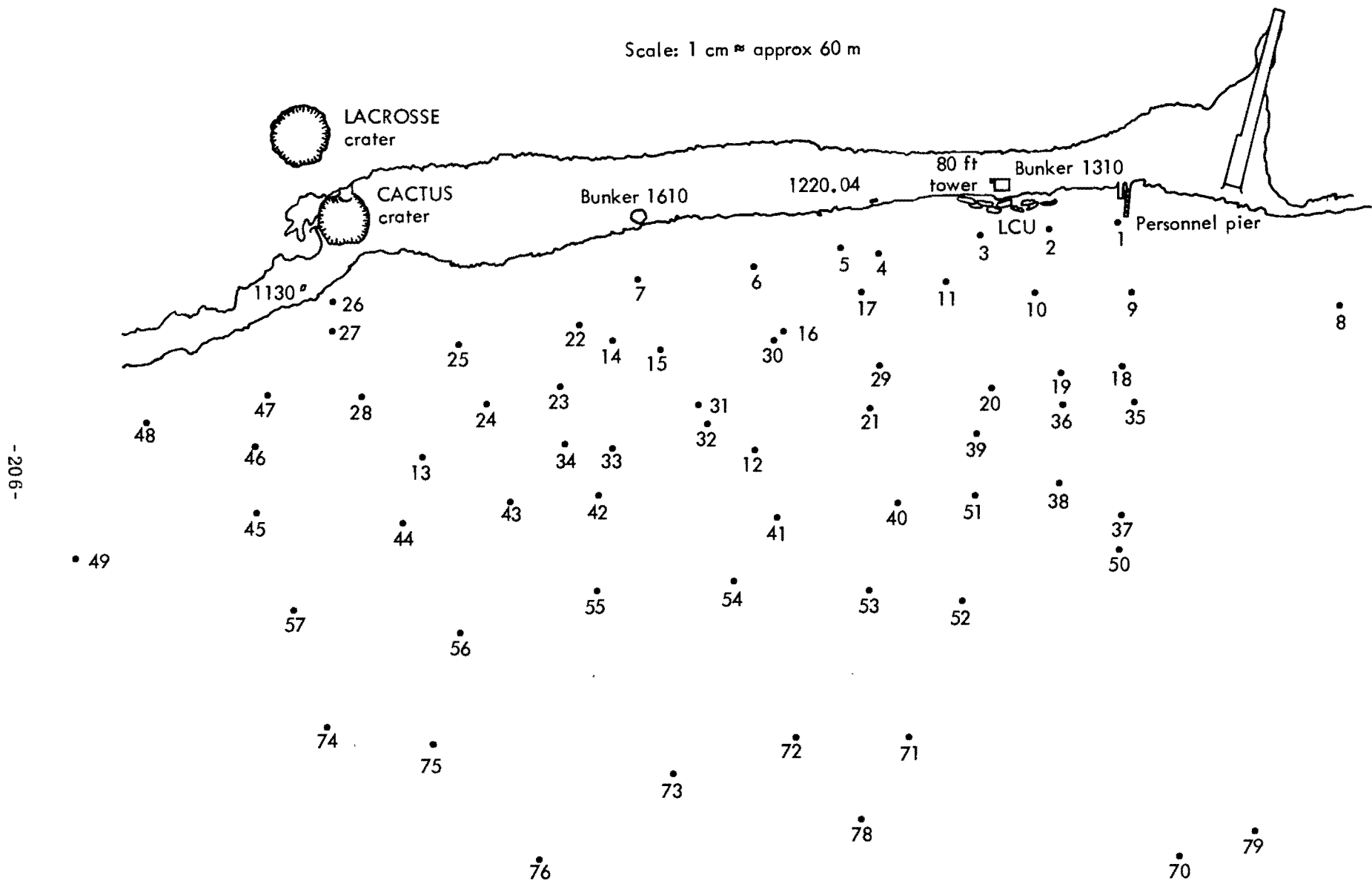


Fig. 67. Station locations for in situ gamma probe reading and sediment samples taken in the lagoon of YVONNE, Enewetak Atoll, December, 1972.

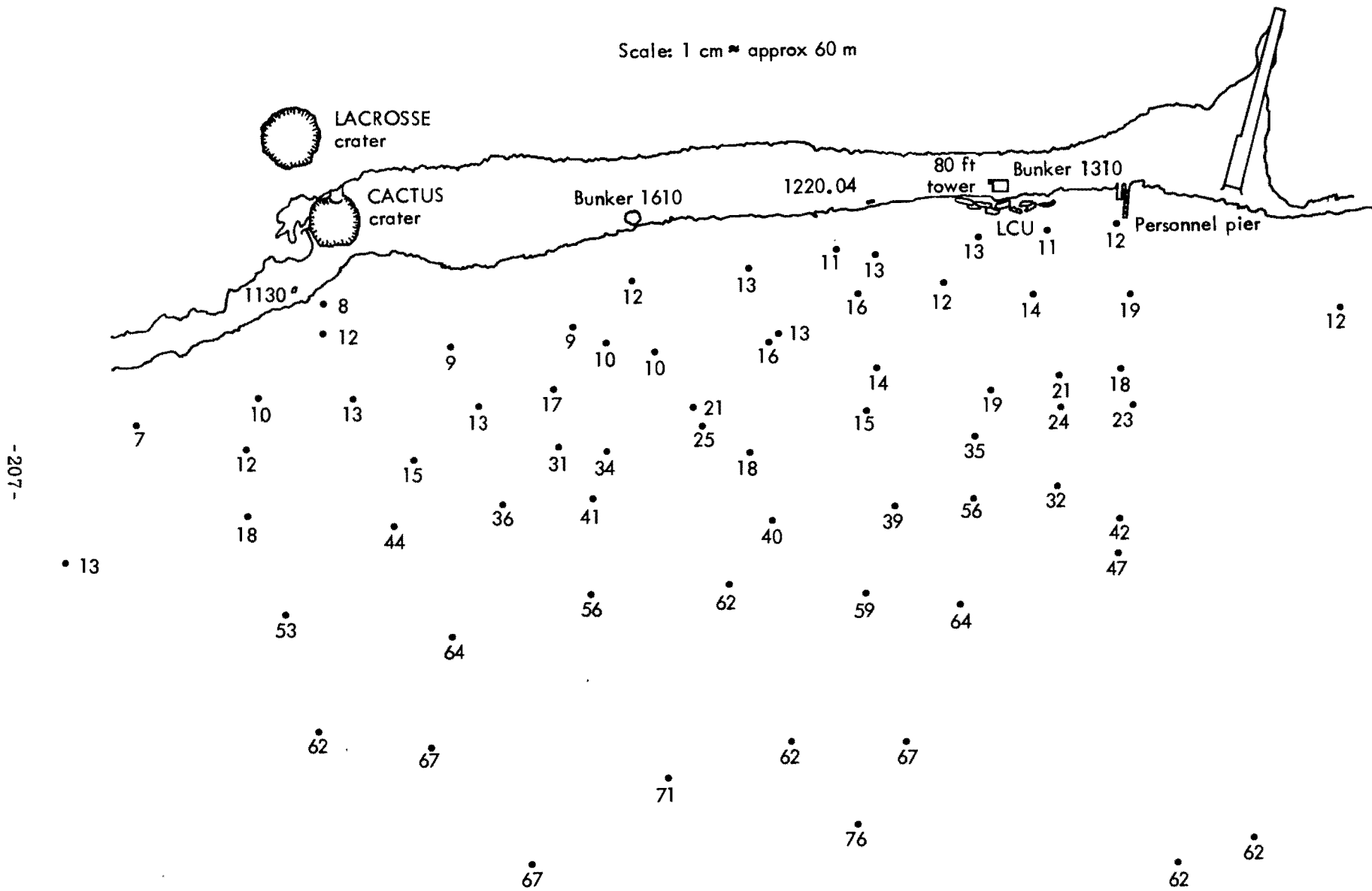


Fig. 68. Depth in feet at in situ probe stations in the lagoon off YVONNE, Enewetak Atoll, December, 1972.

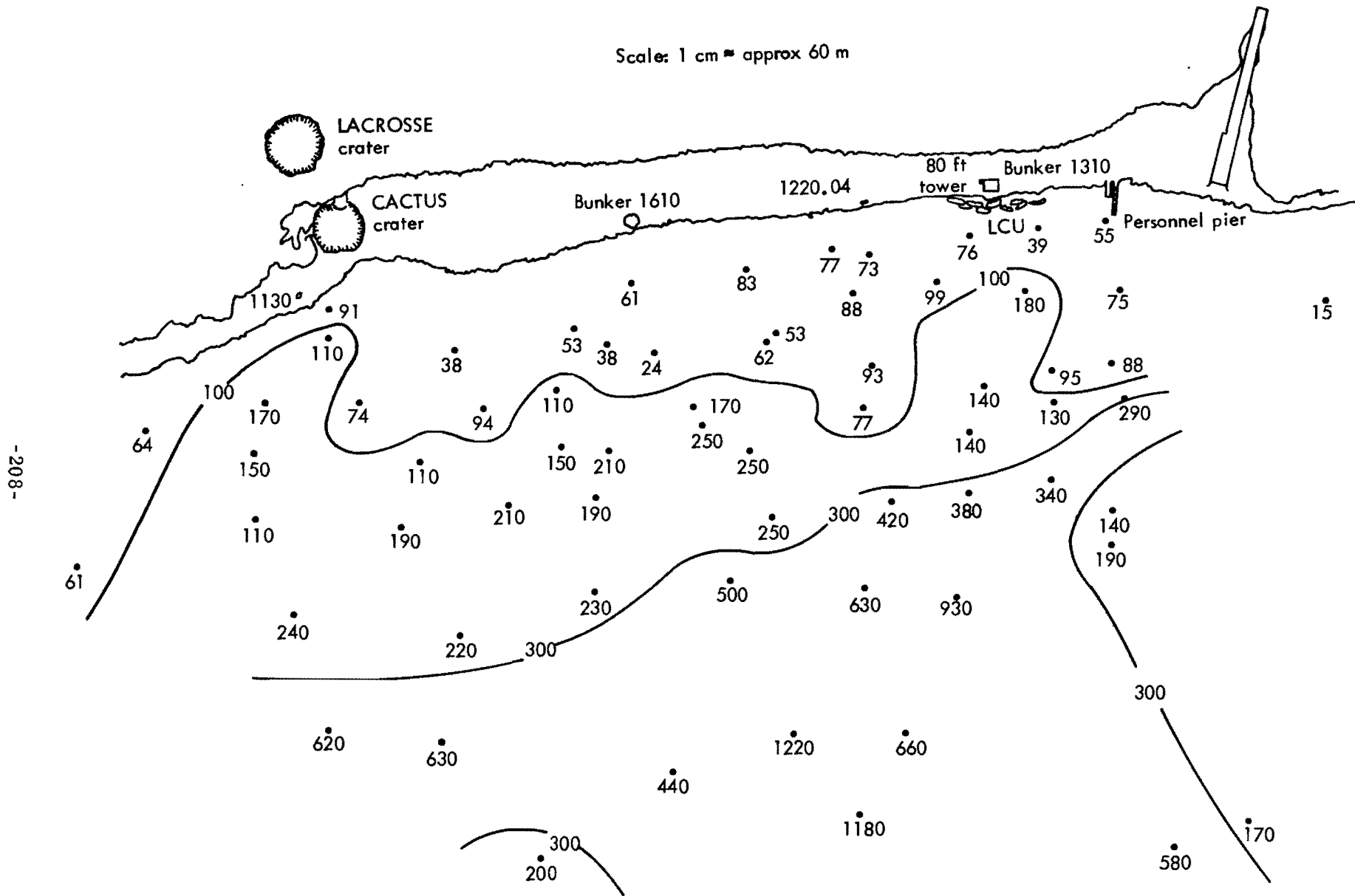
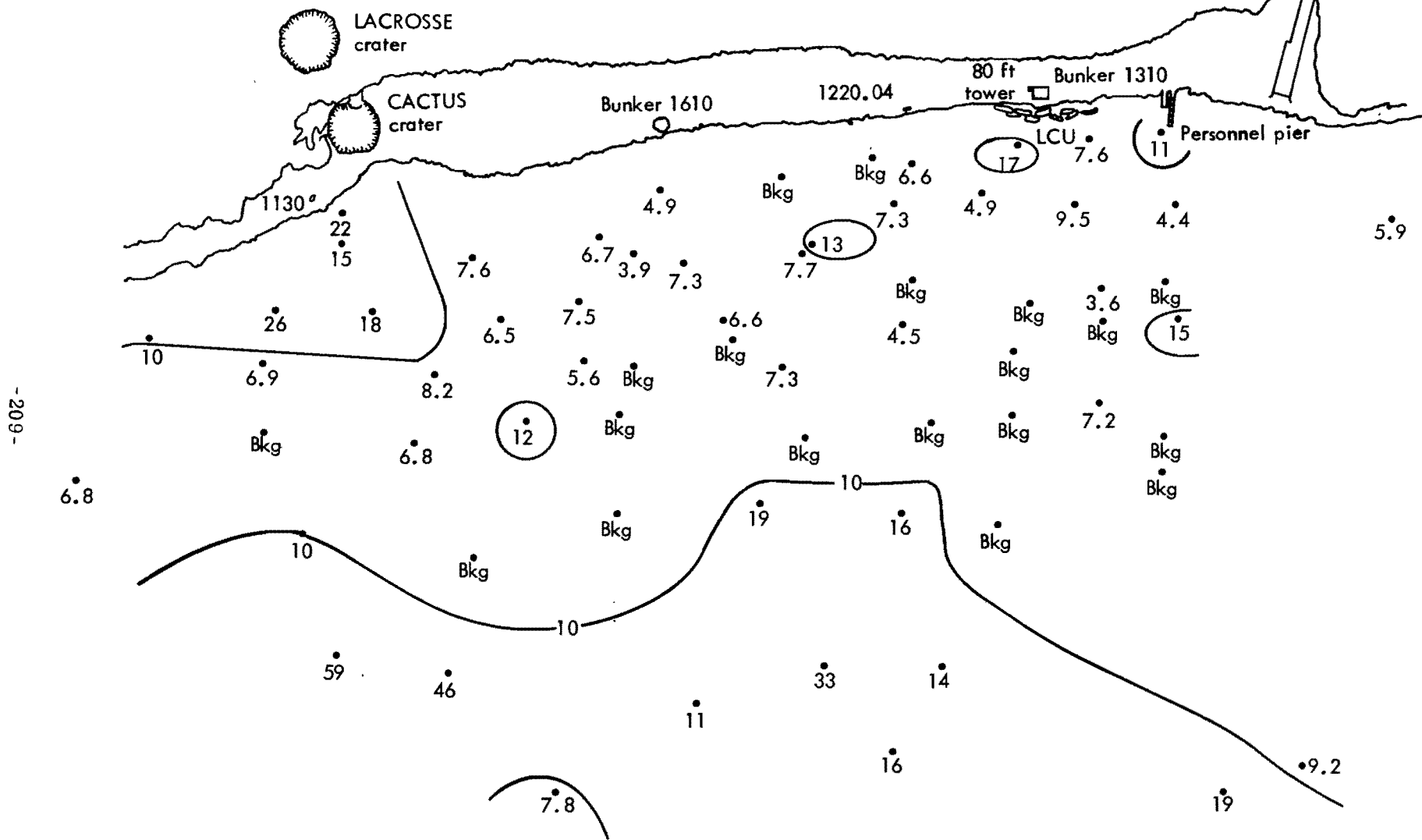


Fig. 69. Relative  $^{60}\text{Co}$  concentration in cpm, measured with an in situ gamma probe on the lagoon bottom off YVONNE, Enewetak Atoll, December, 1972.

Scale: 1 cm = approx 60 m



-209-

Fig. 70. Relative <sup>207</sup>Bi concentrations in cpm, measured with an in situ gamma probe on the lagoon bottom off YVONNE, Enewetak Atoll, December, 1972.

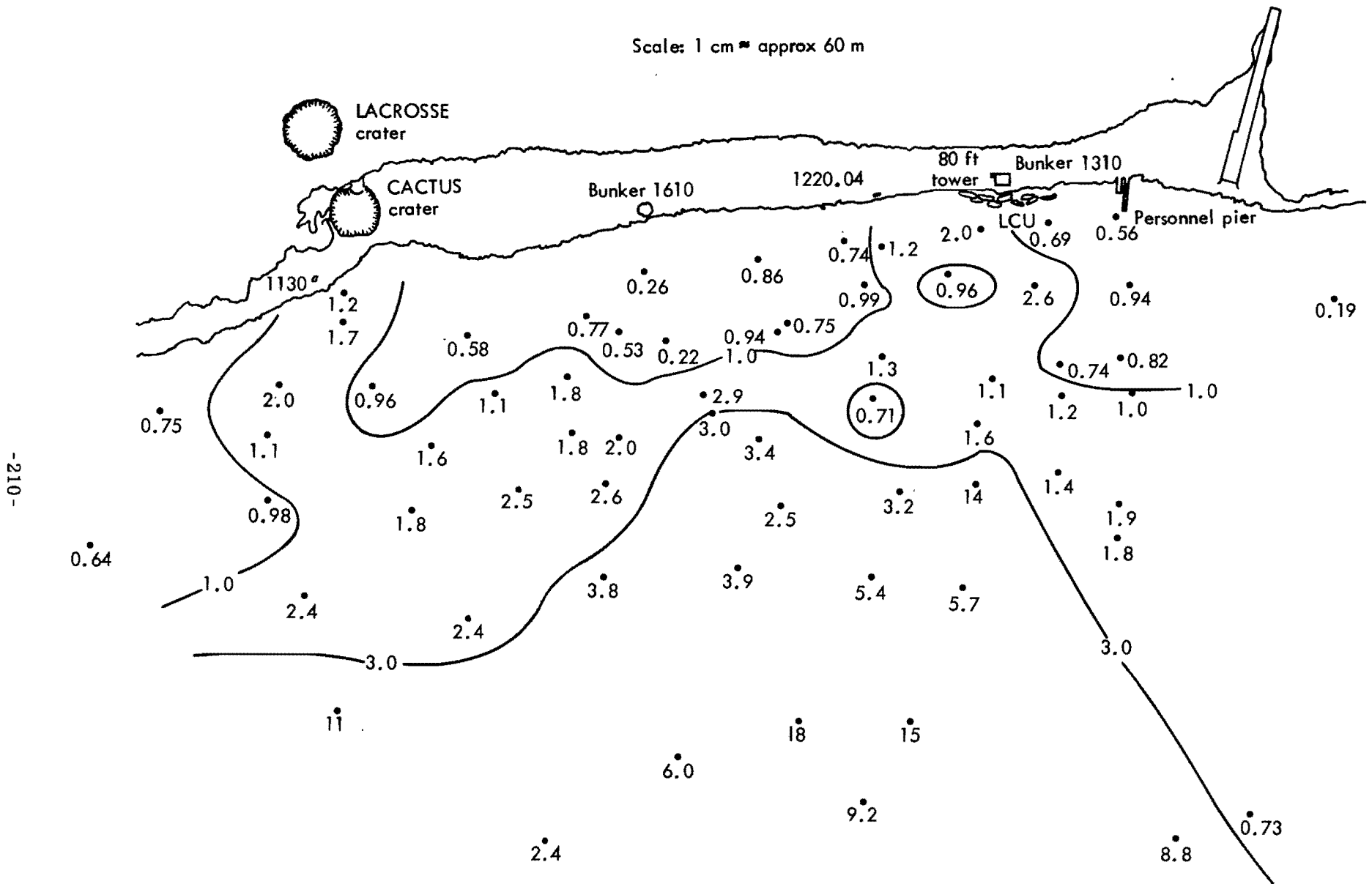


Fig. 71. Cobalt-60 concentration (pCi/g, dry) in sediment samples taken simultaneously with in situ probe readings in the lagoon off YVONNE, Enewetak Atoll, December, 1972.

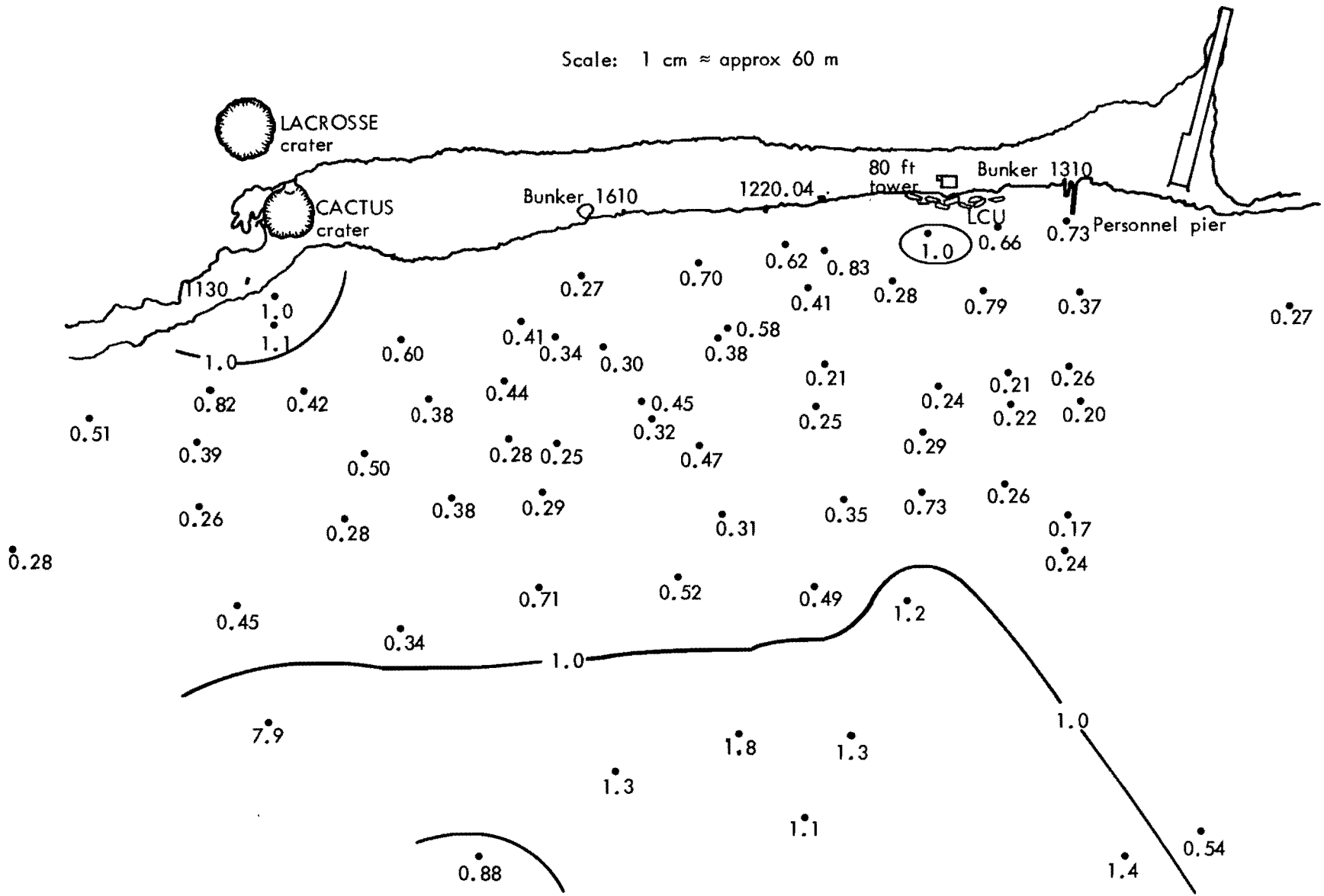
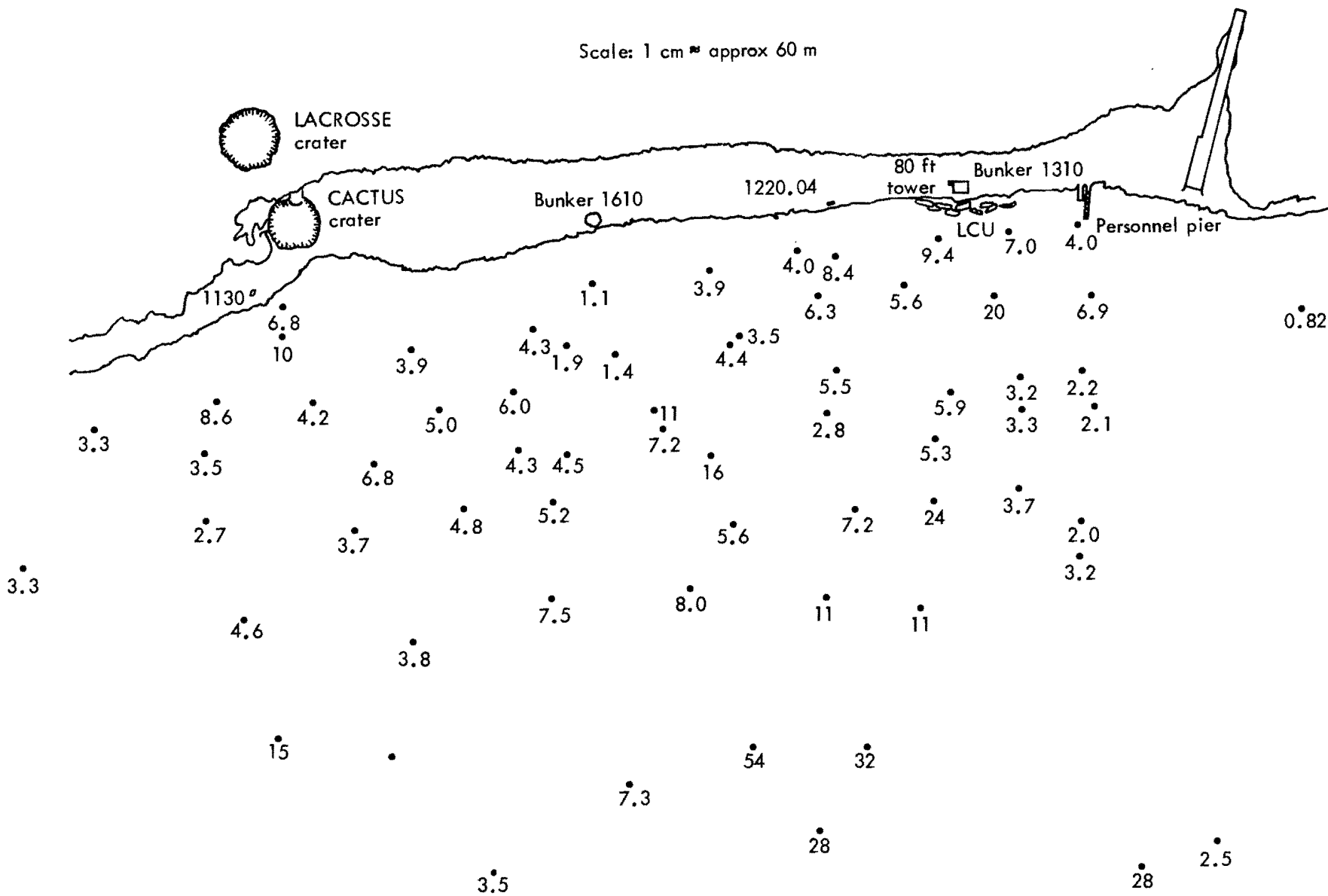


Fig. 72. Bismuth-207 concentration (pCi/g, dry) in sediment samples taken simultaneously with in situ probe readings in the lagoon off YVONNE, Enewetak Atoll, December, 1972.

Scale: 1 cm  $\approx$  approx 60 m



-212-

Fig. 73. Europium-155 concentration (pCi/g, dry) in sediment samples taken simultaneously with in situ probe readings in the lagoon off YVONNE, Enewetak Atoll, December, 1972.



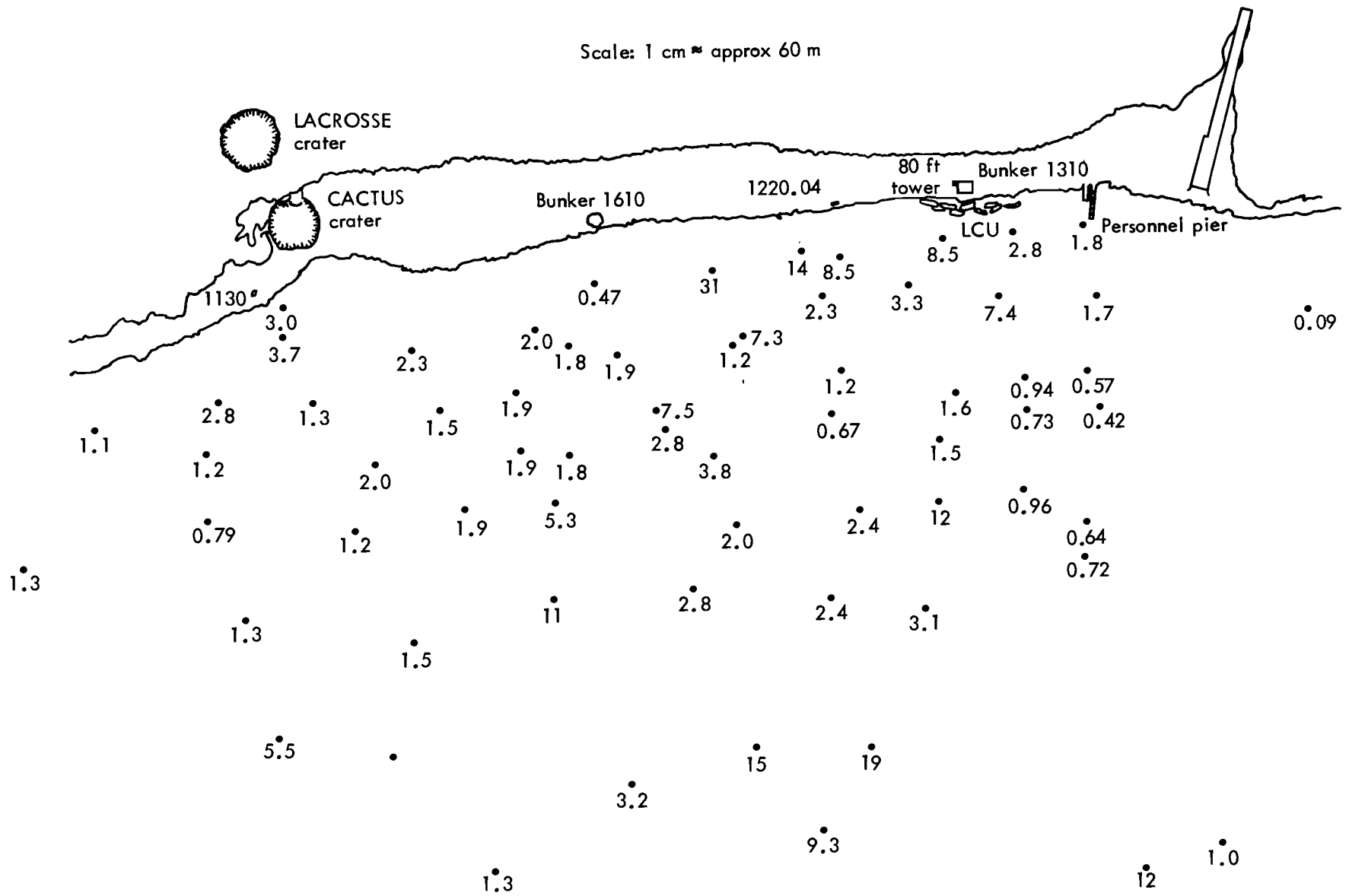


Fig. 74. Americium-241 concentration (pCi/g, dry) in sediment samples taken simultaneously with in situ probe readings in the lagoon off YVONNE, Enewetak Atoll, December, 1972.

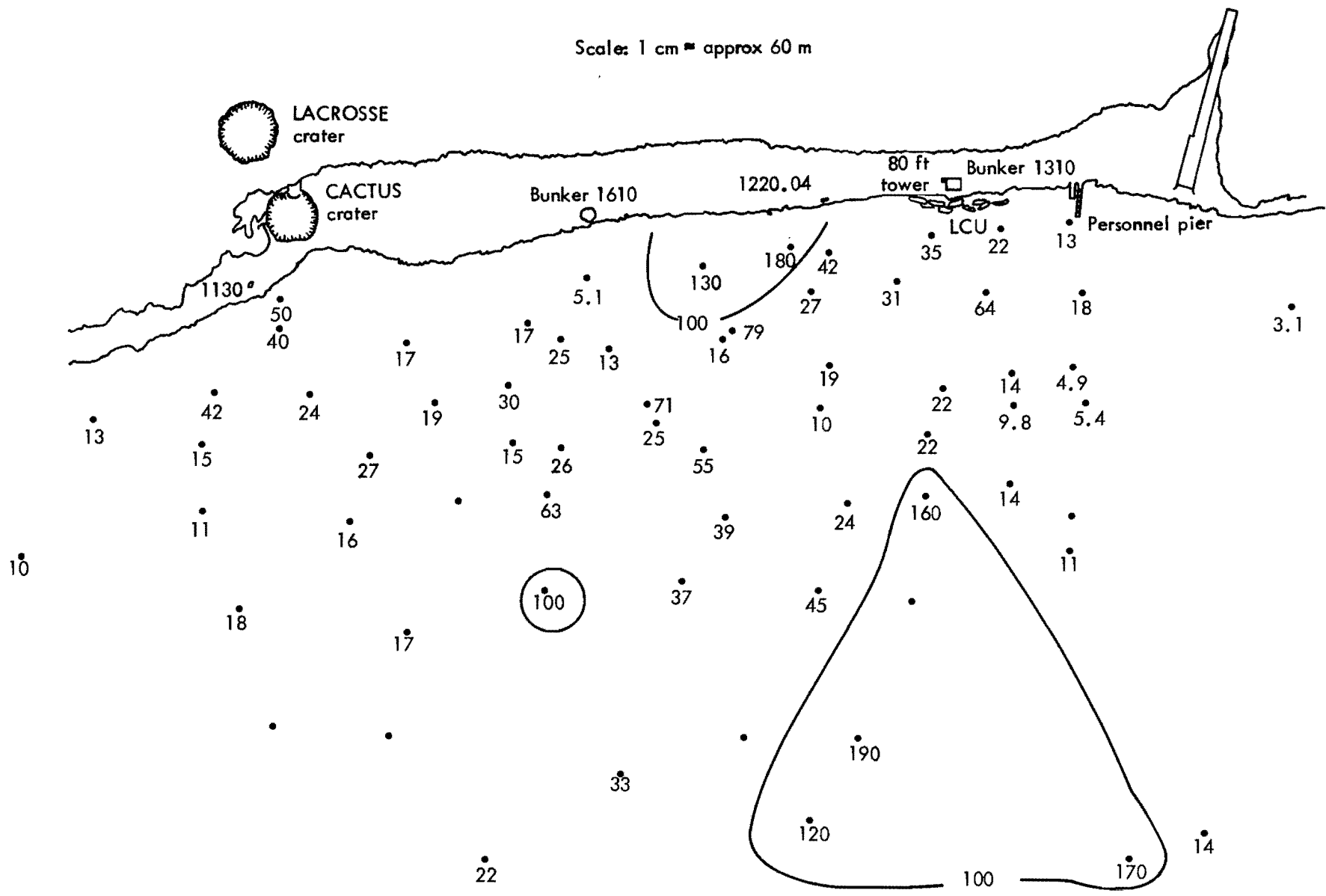


Fig. 75. Plutonium-239,240 concentration (pCi/g, dry) in sediment samples taken simultaneously with in situ probe readings in the lagoon off YVONNE, Enewetak Atoll, December, 1972.

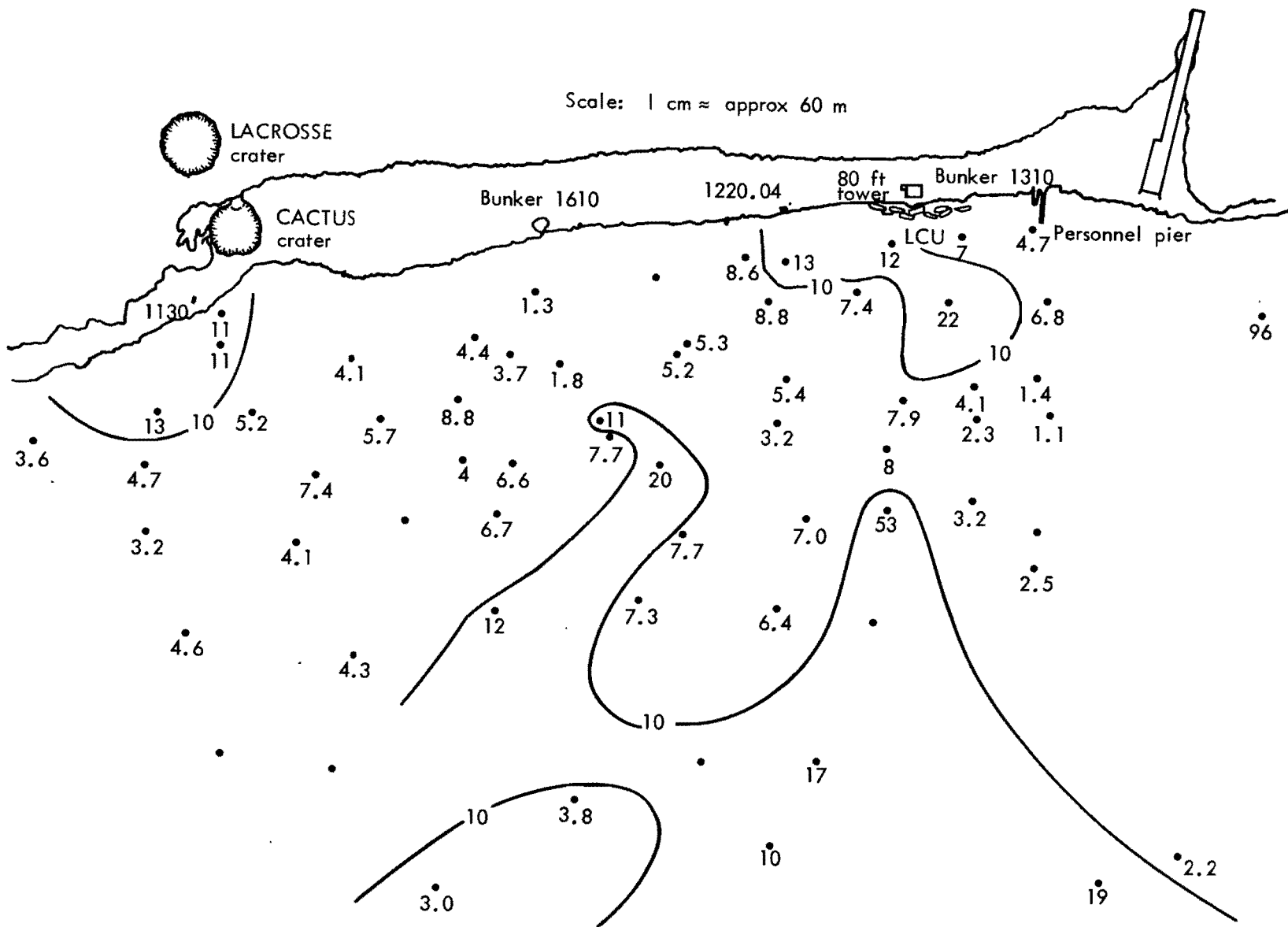
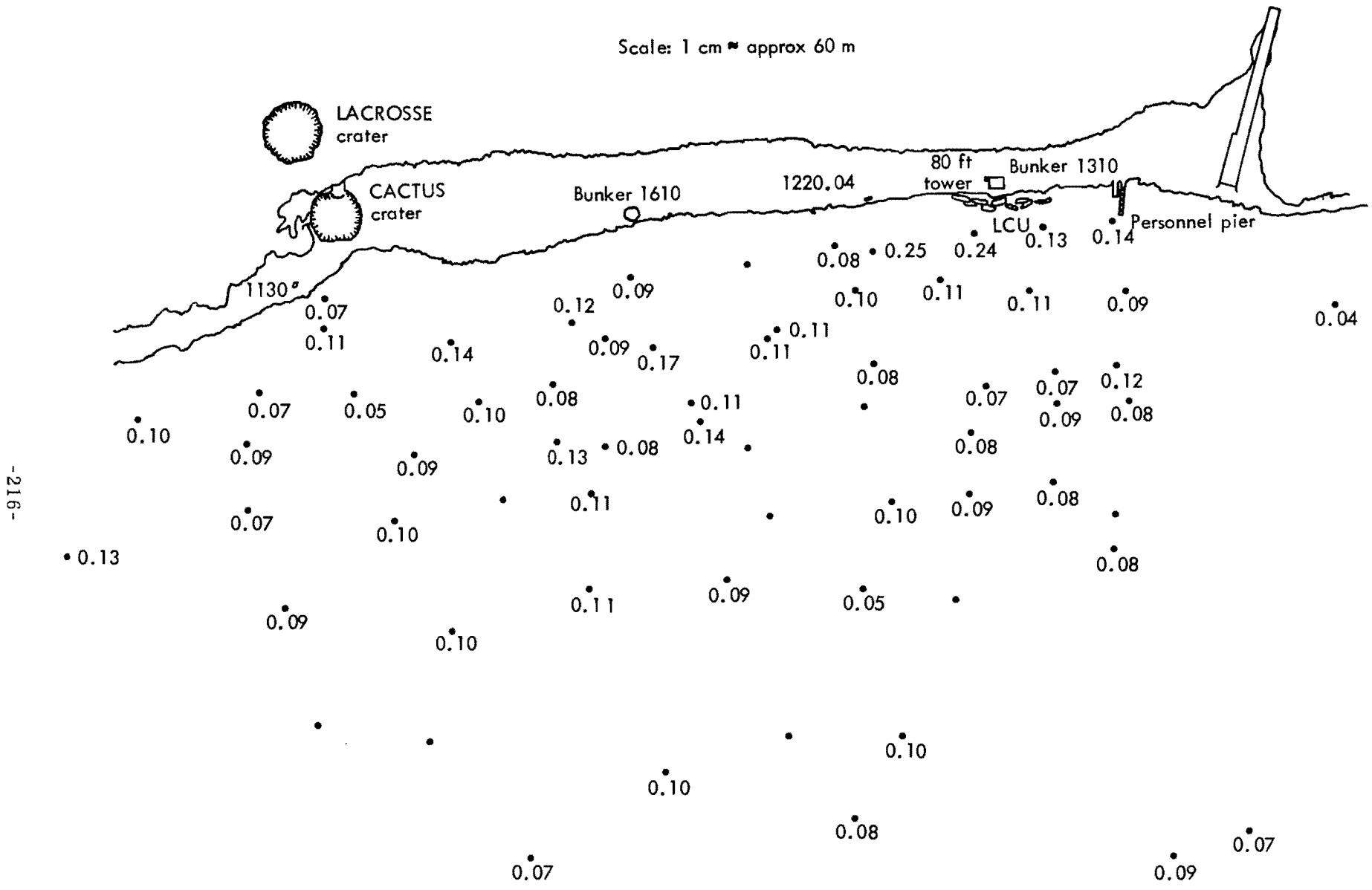


Fig. 76. Plutonium-238 concentration (pCi/g, dry) in sediment samples taken simultaneously with in situ probe readings in the lagoon off YVONNE, Enewetak Atoll, December, 1972.



-216-

Fig. 77. The  $^{241}\text{Am}/^{239,240}\text{Pu}$  ratio in sediment samples taken simultaneously with in situ probe readings in the lagoon off YVONNE, Enewetak Atoll, December, 1972.

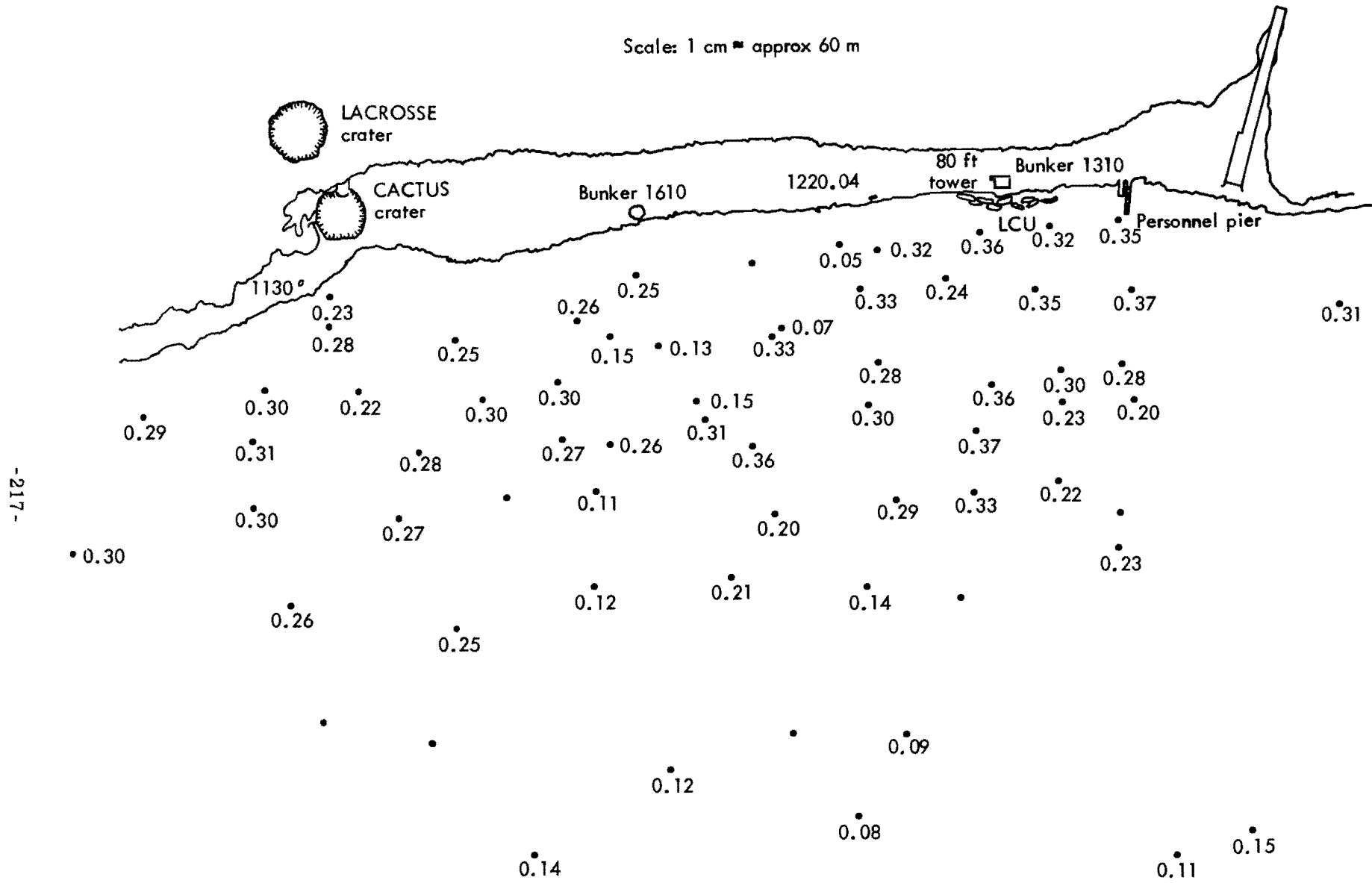


Fig. 78. The ratio  $^{238}\text{Pu}/^{239,240}\text{Pu}$  in sediment samples taken simultaneously with in situ probe readings in the lagoon off YVONNE, Enewetak Atoll, December, 1972.

sample. Radionuclides other than  $^{40}\text{K}$ ,  $^{60}\text{Co}$ , and  $^{207}\text{Bi}$  were generally present at levels less than 1 pCi/g, dry.

It can be seen by comparing Figs. 69 and 71 and Figs. 70 and 72 that a good correlation exists between the degree of  $^{60}\text{Co}$  and  $^{207}\text{Bi}$  contamination indicated by the relative counts and the actual  $^{60}\text{Co}$  and  $^{207}\text{Bi}$  concentration measured in the sediment samples. A rough estimate of the concentration of  $^{60}\text{Co}$  and  $^{207}\text{Bi}$  in sediments, in terms of pCi/g, dry, can be obtained at stations where the gross relative count is greater than background by dividing the net relative count by a factor of 85 for  $^{60}\text{Co}$  and 15 for  $^{207}\text{Bi}$ . Factors ranged from 38 (Station 3) to 290 (Station 38) for  $^{60}\text{Co}$  and from 7 (Station 74) to 72 (Station 35) for  $^{207}\text{Bi}$ . These ranges are not surprising, since the sediments analyzed were surface samples taken within 10 ft of the in situ probe at shallow stations and within 30 ft at deep stations during counting, not at the exact location of the probe.

There are no direct comparisons available between  $^{155}\text{Eu}$ ,  $^{241}\text{Am}$ , and Pu levels in the sediments and in the in situ readings since the NaI crystal and associated components used in the survey were not capable of detecting these isotopes. The distribution (Figs. 73 to 76) of these radionuclides does, however, correlate fairly well with the distribution of  $^{207}\text{Bi}$ , which can be measured with the in situ probe. In general,  $^{155}\text{Eu}$ ,  $^{241}\text{Am}$ , and  $^{239,240}\text{Pu}$  concentrations are high in the sediments from three areas: (1) the shallow near-shore area off CACTUS Crater, (2) the shallow near-shore area from HARDTACK Bunker 1310, northeast

along the shore for 400 m and (3) in an area offshore, from the personnel pier to HARDTACK Bunker 242, at a depth of 60 to 70 ft. The highest concentration of  $^{241}\text{Am}$  was found in a sediment sample taken from shallow water off the center of the northern part of the island, while the highest  $^{155}\text{Eu}$  concentration was found in sediment from a deep-water (62 ft) station, 600 m off the same area of the island.

In summary, the highest levels of the radionuclides detected in the lagoon sediments off YVONNE with the in situ probe and in sediment samples analyzed in the laboratory are found in an area 500 to 700 m offshore at a depth of 60 to 70 ft. Good correlation between the relative counts obtained with the in situ probe and the concentration of  $^{60}\text{Co}$  and  $^{207}\text{Bi}$  found in sediment samples taken simultaneously with the probe readings indicates that the in situ gamma probe can be used effectively to delineate relative levels (i.e., relative to the actual amount of radionuclide present, not relative to other isotopes) of contamination in the lagoon basin.

### Lagoon Water Samples

#### Purpose of Collections

These samples were taken to assess the present concentrations and distribution of specific radionuclides in the lagoon and craters. From the water and biota data, it will be possible to compute the "concentration factors" of specific radionuclides in marine species, an index which will be useful in models designed to predict future levels of activities in pelagic species.

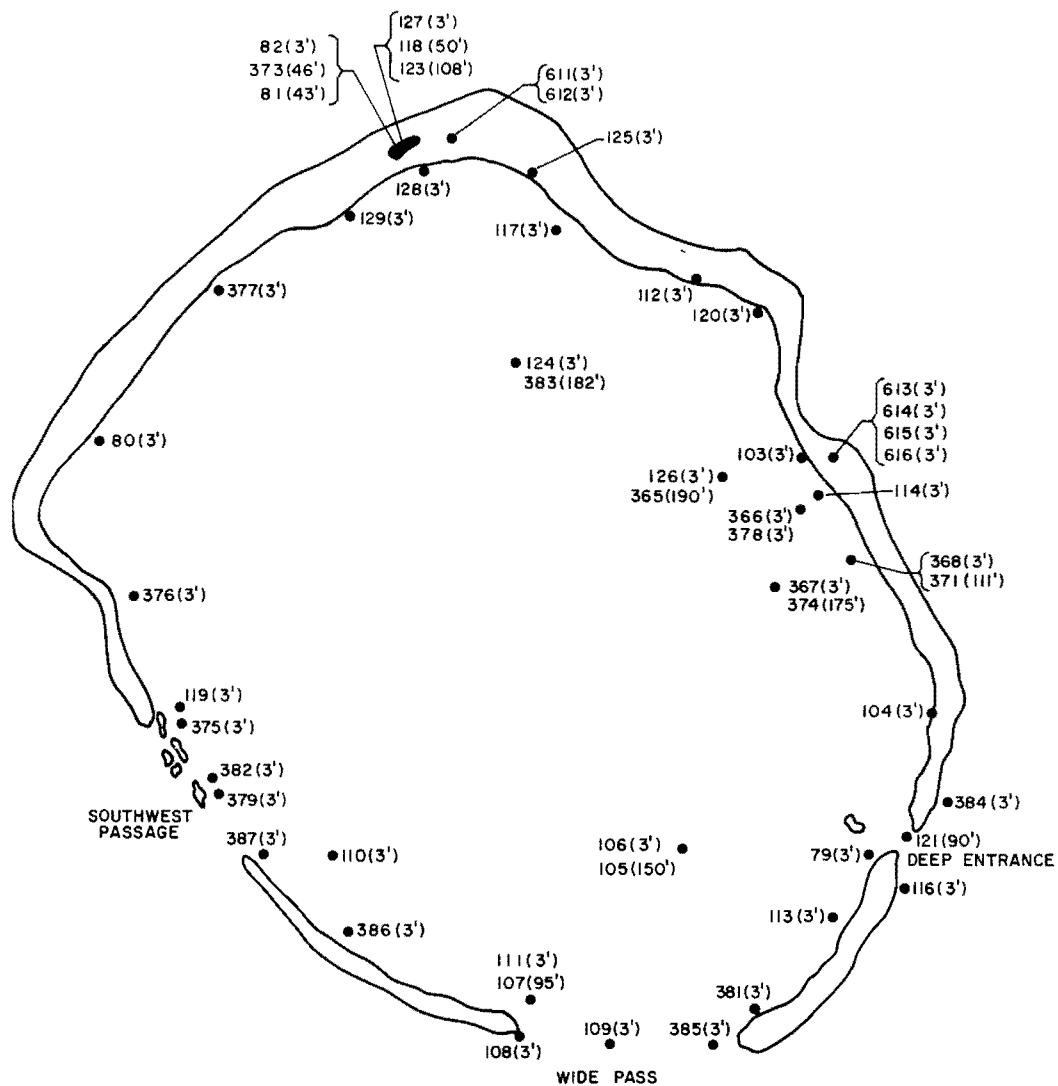


Fig. 79. Location and identification of 55-liter water samples. The depth of the water sampled is shown in parenthesis.

### Sampling Locations and Collection Methods

Figure 79 indicates the location and depth of all water samples collected at Enewetak Atoll during October to December 1972. At those locations where more than one sample was obtained, the deepest was collected within 1 to 2 m of the bottom. All samples were pumped without filtering into 55-liter "Deldrum" containers, acidified to pH 1.5 with HCl, and shipped to LLL for processing.

### Processing and Analysis

A known quantity of carrier or tracer for each radionuclide to be measured was added to the sample. Cesium was first removed by coprecipitation on ammonium molybdophosphate (AMP) and  $^{137}\text{Cs}$  determined on a low-level gamma spectrometer. Strontium, the lanthanides, the transuranics, and transition metals were then precipitated with sodium carbonate. After dissolution of the carbonate, a hydroxide precipitation separated all the

lanthanides, transuranics, and transition metals from strontium (and calcium). Plutonium radionuclides were isolated from the hydroxide fraction and determined by alpha spectrometry, the residual fraction was concentrated and counted on a Ge(Li) diode for gamma emitters, and the  $^{90}\text{Sr}$  fraction was sent to a participating laboratory for further analysis.

Many of the gamma-emitting radionuclides found in the marine sediments were not detected in the water samples by gamma spectrometry. The following radionuclides were below detection limits in all samples:  $^{102\text{m}}\text{Rh} < 80$  fCi/liter;  $^{125}\text{Sb} < 220$  fCi/liter;  $^{106}\text{Ru} < 580$  fCi/liter;  $^{152}\text{Eu} < 104$  fCi/liter;  $^{235}\text{U} < 70$  fCi/liter. Fifteen samples from the northern half of the lagoon did contain

detectable amounts of  $^{60}\text{Co}$ ,  $^{155}\text{Eu}$ ,  $^{207}\text{Bi}$ , and  $^{241}\text{Am}$  (see Table 54). In no other samples were these nuclides above their detection limits.

$^{137}\text{Cs}$  and  $^{239,240}\text{Pu}$ , radiochemically separated and analyzed by more sensitive analytical techniques, were positively identified and determined in all samples. Greater sensitivity for the other radionuclides could have been realized in this way, but it was not economically justifiable. The cesium and plutonium results are listed in Table 55. Table 56 gives the mean surface water concentrations of  $^{137}\text{Cs}$  and  $^{239}\text{Pu}$  in the four quadrants of the lagoon and in the ocean close to the east side of the Atoll. The difference in concentrations between the lagoon and ocean clearly indicates the Atoll to be the

Table 54. Gamma-emitting radionuclides identified in separated hydroxide fraction of water samples.

Sample No.	Concentration, fCi/liter $\pm$ % error			
	$^{60}\text{Co}$	$^{155}\text{Eu}$	$^{207}\text{Bi}$	$^{241}\text{Am}$
103	116 $\pm$ 35		<224	
112	146 $\pm$ 67		<53	
114	518 $\pm$ 29			
123	354 $\pm$ 16	1433 $\pm$ 5	420 $\pm$ 21	346 $\pm$ 15
124	<68		734 $\pm$ 10	
126	<67		261 $\pm$ 16	
129	<40		570 $\pm$ 10	
365	842 $\pm$ 8	940 $\pm$ 7	1266 $\pm$ 9	314 $\pm$ 18
366	121 $\pm$ 33		258 $\pm$ 23	
368	138 $\pm$ 22		204 $\pm$ 22	
373	136 $\pm$ 38		<88	
374	118 $\pm$ 34		<242	
377	<51		413 $\pm$ 42	
383	<50	67 $\pm$ 50	683 $\pm$ 10	36 $\pm$ 50
386	<61		154 $\pm$ 26	
Detection limits (average)	75	100	80	100



Table 55. Radiocesium and plutonium in seawater samples.

Sample No. (see Fig. 79)	Activity, fCi/kg $\pm 1\sigma$			Ratio		Water depth, ft	
	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	$^{238}\text{Pu}$	239/137	238/239	Bottom	Sample
79	296 $\pm$ 19	6.0 $\pm$ 1.1	1.1 $\pm$ 0.3	0.020	0.183	— <sup>a</sup>	3
80	471 $\pm$ 22	32.5 $\pm$ 3.0	2.7 $\pm$ 0.5	0.069	0.083	36	3
81	3200 $\pm$ 21	54.6 $\pm$ 3.8	1.9 $\pm$ 0.4	0.017	0.035	95	93
82	730 $\pm$ 20	23.4 $\pm$ 2.0	2.0 $\pm$ 0.4	0.032	0.085	95	3
103	486 $\pm$ 17	43.6 $\pm$ 1.4	6.8 $\pm$ 0.3	0.090	0.156	60	3
104	241 $\pm$ 18	13.1 $\pm$ 0.7	1.9 $\pm$ 0.2	0.054	0.145	— <sup>a</sup>	3
105	300 $\pm$ 19	17.4 $\pm$ 0.7	2.5 $\pm$ 0.2	0.058	0.144	— <sup>a</sup>	150
106	342 $\pm$ 19	22.4 $\pm$ 0.7	2.2 $\pm$ 0.1	0.065	0.098	— <sup>a</sup>	3
107	190 $\pm$ 14	9.6 $\pm$ 0.5	0.9 $\pm$ 0.1	0.051	0.094	100	95
108	229 $\pm$ 16	10.2 $\pm$ 0.5	1.1 $\pm$ 0.2	0.045	0.108	20	3
109	228 $\pm$ 17	9.6 $\pm$ 0.5	1.0 $\pm$ 0.1	0.042	0.104	70	3
110	377 $\pm$ 18	28.9 $\pm$ 0.9	3.8 $\pm$ 0.2	0.077	0.131	>100	3
111	258 $\pm$ 20	11.6 $\pm$ 0.4	1.4 $\pm$ 0.9	0.045	0.121	— <sup>a</sup>	3
112	163 $\pm$ 19	15.4 $\pm$ 0.7	1.9 $\pm$ 0.2	0.094	0.123	22	3
113	170 $\pm$ 18	4.8 $\pm$ 0.3	0.6 $\pm$ 0.1	0.028	0.125	80	3
114	462 $\pm$ 17	51.9 $\pm$ 1.9	7.1 $\pm$ 0.4	0.112	0.137	100	3
116	32 $\pm$ 19	0.43 $\pm$ 0.25	0.01 $\pm$ 0.01	0.013	0.023	— <sup>a</sup>	3
117	107 $\pm$ 30	11.8 $\pm$ 0.9	1.7 $\pm$ 0.2	0.110	0.144	34	3
118	1100 $\pm$ 17	26.4 $\pm$ 1.4	3.2 $\pm$ 0.3	0.024	0.121	110	50
119	290 $\pm$ 17	18.0 $\pm$ 0.9	2.3 $\pm$ 0.2	0.062	0.128	48	3
120	228 $\pm$ 14	7.4 $\pm$ 0.6	1.1 $\pm$ 0.1	0.032	0.149	— <sup>a</sup>	3
121	251 $\pm$ 22	2.8 $\pm$ 0.7	0.14 $\pm$ 0.05	0.011	0.050	93	90
123	8910 $\pm$ 40	1510 $\pm$ 60	236 $\pm$ 9	0.169	0.156	110	108
124	579 $\pm$ 18	71.2 $\pm$ 2.3	10.0 $\pm$ 0.5	0.123	0.140	190	3
125	59 $\pm$ 9	6.8 $\pm$ 1.0	1.6 $\pm$ 0.2	0.115	0.235	40	3
126	322 $\pm$ 18	30.4 $\pm$ 1.2	3.9 $\pm$ 0.3	0.094	0.128	197	3
127	1170 $\pm$ 19	19.0 $\pm$ 0.8	1.7 $\pm$ 0.2	0.016	0.089	110	3
128	532 $\pm$ 25	33.1 $\pm$ 1.5	3.0 $\pm$ 0.3	0.062	0.091	35	3
129	538 $\pm$ 20	44.4 $\pm$ 1.7	4.4 $\pm$ 0.3	0.083	0.099	175	3
365	427 $\pm$ 21	3780 $\pm$ 210	1280 $\pm$ 70	8.852	0.338	197	195
366	499 $\pm$ 28	77.0 $\pm$ 3.1	13.3 $\pm$ 0.8	0.154	0.173	171	3
367	482 $\pm$ 25	66.2 $\pm$ 3.0	7.9 $\pm$ 0.6	0.137	0.119	175	3
368	410 $\pm$ 23	96.1 $\pm$ 3.7	14.9 $\pm$ 0.8	0.234	0.155	114	3
371	305 $\pm$ 20	75.2 $\pm$ 3.1	11.2 $\pm$ 0.7	0.247	0.149	114	111
373	4220 $\pm$ 40	71.9 $\pm$ 5.8	7.0 $\pm$ 1.0	0.017	0.097	95	46
374	462 $\pm$ 22	63.2 $\pm$ 2.8	9.0 $\pm$ 0.6	0.137	0.142	175	175
375	305 $\pm$ 23	29.0 $\pm$ 1.7	3.7 $\pm$ 0.4	0.095	0.128	90	3

Table 55 (continued).

Sample No. (see Fig. 79)	Activity, fCi/kg $\pm 1\sigma$			Ratio		Water depth, ft	
	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	$^{238}\text{Pu}$	$^{239}/^{137}$	$^{238}/^{239}$	Bottom	Sample
376	250 $\pm$ 20	18.6 $\pm$ 1.2	2.6 $\pm$ 0.3	0.074	0.140	54	3
377	364 $\pm$ 21	62.9 $\pm$ 2.7	9.7 $\pm$ 0.7	0.173	0.154	6	3
378	497 $\pm$ 25	43.1 $\pm$ 1.4	7.1 $\pm$ 0.3	0.087	0.165	171	167
379	246 $\pm$ 19	14.5 $\pm$ 0.7	2.1 $\pm$ 0.2	0.059	0.145	100	3
381	176 $\pm$ 19	6.8 $\pm$ 0.5	0.7 $\pm$ 0.1	0.039	0.103	70	3
382	766 $\pm$ 30	54.3 $\pm$ 2.2	4.0 $\pm$ 0.3	0.071	0.074	30	3
383	295 $\pm$ 25	53.3 $\pm$ 2.0	4.6 $\pm$ 0.3	0.181	0.086	190	182
384	146 $\pm$ 26	0.21 $\pm$ 0.04	0 $\pm$ 0.05	0.001	—	—	3
385	130 $\pm$ 20	1.60 $\pm$ 0.14	0.5 $\pm$ 0.1	0.012	0.312	65	3
386	291 $\pm$ 30	13.9 $\pm$ 0.6	2.0 $\pm$ 0.2	0.048	0.144	40	3
387	109 $\pm$ 32	0.38 $\pm$ 0.10	0.03 $\pm$ 0.01	0.003	0.079	30	3
611	970 $\pm$ 40	1330 $\pm$ 70	411 $\pm$ 22	1.37	0.31		
612	212 $\pm$ 35	302 $\pm$ 4	65 $\pm$ 2	1.42	0.22		
613	118 $\pm$ 62	57 $\pm$ 3	26 $\pm$ 2	0.48	0.46		
614	935 $\pm$ 46	185 $\pm$ 7	98 $\pm$ 3	0.197	0.53		
615	108 $\pm$ 54	46 $\pm$ 2	24 $\pm$ 2	0.426	0.52		
616	302 $\pm$ 57	105 $\pm$ 9	52 $\pm$ 5	0.347	0.50		

<sup>a</sup>Bottom depth not determined.

Table 56. Concentration of  $^{137}\text{Cs}$  and  $^{239}\text{Pu}$  in comparative, surface water samples.

Location	Concentration, fCi/liter	
	$^{137}\text{Cs}$	$^{239}\text{Pu}$
Enewetak Lagoon		
SE quadrant	226	9.1
NE quadrant	334	42.6
NW quadrant	579	33.4
SW quadrant	332	21.6
Ocean, east of Enewetak Atoll	89	0.3
Lake Michigan (1971)	88	1.1
Humboldt Bay, Calif. (1973)	300	
14°N 180°W (1972)	143	0.44
12°N 170°E (1972)	170	0.35
Windscale vicinity (1969)	105,000	
Mean surface, Atlantic 0-31°N (1968)		0.7

Table 57. Comparison of radionuclide concentrations in surface and bottom water samples from Enewetak Lagoon.

Sample No. (Surface sample) (Bottom sample)	Ratio	
	$^{239,240}\text{Pu}$	$^{137}\text{Cs}$
124		
383	1.33	1.96
366		
378	1.78	1.00
367		
374	1.05	1.04
368		
371	1.27	1.34
106		
105	1.29	1.14
111		
107	1.20	1.36
Mean $\pm$ std dev	1.32 $\pm$ 0.24	1.31 $\pm$ 0.35

source of the radionuclides in the lagoon water. For comparison, the concentrations of these nuclides from several other locations in the world are also presented. It is interesting that while the highest plutonium concentrations in water are found in the northeast quadrant, the highest concentrations in the sediments are found in the northwest.

Table 57 gives the surface-to-bottom concentration ratios of  $^{137}\text{Cs}$  and  $^{239,240}\text{Pu}$  at six lagoon stations. (Sample 365 is suspected to be contaminated with bottom sediment and is not included in Table 57.) The surface waters, on the average, contain 30% more  $^{239}\text{Pu}$  and  $^{137}\text{Cs}$  than the bottom waters. The higher surface-to-bottom ratio indicates

that during the sampling period, the water in the lagoon was not well mixed vertically. Furthermore, the finding of the considerably lower concentrations in the bottom waters contradicts the prediction that the sediments are the principal source of radionuclides found in the lagoon water. If they were, leaching or resuspension processes would be expected to concentrate radionuclides in the bottom relative to the surface waters. The higher concentrations at the surface may be caused, in part, by leaching processes or surface runoff from the exposed reef areas.

Table 58 gives the water concentrations of  $^{137}\text{Cs}$  and  $^{239,240}\text{Pu}$  in the five craters on the Atoll. The concentration

Table 58. Concentrations of  $^{137}\text{Cs}$  and  $^{239,240}\text{Pu}$  in crater water samples.

Sample No.	Crater and location	Depth	Collection date	fCi/liter $\pm 1\sigma$	
				$^{239,240}\text{Pu}$	$^{137}\text{Cs}$
82	MIKE (center)	Surface	12/12/72	23.4 $\pm$ 2.0	730 $\pm$ 20
373	MIKE (center)	46 ft	12/12/72	71.9 $\pm$ 5.8	4220 $\pm$ 40
81	MIKE (center)	93 ft	12/12/72	54.6 $\pm$ 3.8	3200 $\pm$ 21
127	KOA (center)	Surface	12/11/72	19.0 $\pm$ 0.8	1170 $\pm$ 19
118		50 ft	12/11/72	26.4 $\pm$ 1.4	1100 $\pm$ 17
123		108 ft	12/11/72	1510 $\pm$ 60	8910 $\pm$ 40
611	SEMINOLE (south edge)	Surface	12/15/72	1330 $\pm$ 70	970 $\pm$ 40
614	CACTUS (windward—east)	Surface	2/8/73	185 $\pm$ 7	935 $\pm$ 46
616	CACTUS (leeward—west)	Surface	2/8/73	105 $\pm$ 9	302 $\pm$ 57
615	LA CROSSE (windward—east)	Surface	2/8/73	46 $\pm$ 2	108 $\pm$ 54
613	LA CROSSE (leeward—west)	Surface	2/8/73	57 $\pm$ 3	118 $\pm$ 62
Background	East of Atoll	Surface	12/9/72	0.32 $\pm$ 0.15	89 $\pm$ 80

levels in the bottom waters of both MIKE and KOA Craters are higher than the surface, and, surprisingly, the mid-depth sample from MIKE Crater contains more  $^{137}\text{Cs}$  and  $^{239,240}\text{Pu}$  than the bottom sample. The latter observation suggests that there may be localized concentrations of fine particulates resuspended in the water above the bottom of the crater.

Water samples from the leeward and windward sides of CACTUS Crater contain more plutonium and cesium than samples from LA CROSSE Crater. The plutonium-238/239 values in the water samples from both CACTUS and LA CROSSE are similar to but larger than the values found in any other lagoon water sample. Note also that the concentrations of  $^{137}\text{Cs}$  and  $^{239}\text{Pu}$  in the water from both sides of LA CROSSE Crater are similar in value, while there is a definite difference between the two sides of CACTUS Crater.

To put in proper perspective the concentrations of the radionuclides measured in the lagoon water, a comparison with the natural concentration of  $^{40}\text{K}$  is useful.  $^{40}\text{K}$  in seawater is, on the average,  $2.95 \times 10^5$  fCi/liter, a concentration several orders of magnitude higher than that for

any fission or activation product measured in any Atoll water sample in this survey.

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## TERRESTRIAL BIOTA SURVEY

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The Terrestrial Biota Survey had as its objective the collection and analysis of all available terrestrial vegetation and animal species which could be used as a basis for estimating population doses through dietary pathways. Not all vegetable and animal components of the anticipated Enewetakese diet are currently available on the Atoll; of those that are, not all are available on every island. Sampling was carried out on an as-available basis and extrapolations were made when required. This chapter describes the sampling and analytical portions of the Terrestrial Biota Survey; dose estimates and extrapolations are discussed in the Dose Assessment chapter.

### Ecological Description of Islands on Enewetak Atoll

A general description of each island on the Atoll is given to provide an ecological background to the biota survey. A more comprehensive description of Enewetak Atoll ecology may be found in other publications (e. g., Woodbury, 1962)\*. Color photographs of each island are presented on the "a" series, vegetation sampling locations are shown on the "g"

\* A. M. Woodbury, A Review of the Ecology of Enewetak Atoll, Pacific Ocean. University of Utah, Institute of Environmental Biological Research, (1962).

series, and animal and bird sampling locations are shown on the "p" series of figures in Appendix II.

### ALICE (Bogallua)

ALICE is covered with a dense to scattered growth of the two common trees on the Atoll: Messerschmidia argentea and Scaevola frutescens.\* These, plus another woody plant, Guettarda speciosa, were collected. The typical beach association of plant species was found in open areas, such as the southwest end of the island, and was composed of Ipomoea pes-caprae, Fimbristylis atollensis, Triumfetta procumbens, and Lepturus repens. An introduced grass, Cynodon dactylon, was also present in sandy disturbed areas, probably the result of man's previous activities on the island. At the southwest and northeast ends of the island, the low scrub growth of Messerschmidia and Scaevola opens up and the vegetation assumes a more scattered appearance, especially at the southwest end, where a sedge-grass meadow prevails. Vegetation is rather dense on the entire seaward side of the island.

Animal species encountered at the time of collections (January 8, 1973) were the long-tailed tropicbird, noddy terns, and fairy terns, which were all nesting. A soil sample was collected from a 12 X 12-in. area to a depth of 2 in.

### BELLE (Bogombogo)

Vegetation of Bogombogo Island consists of a dense scrubby growth of

\* Plant taxonomy according to H. St. John, "Flora of Enewetak Atoll," Pacific Science 14, 313 (1960).

Messerschmidia argentea and Scaevola frutescens. This growth thins at the northeast end of the island where an open scattered growth of these tree species occurs. The ground in this open area is vegetated by the usual complex of disturbed-area beach or strand species described on Bogallua Island. Other woody species which contributed only a small amount to the vegetative cover of Bogombogo Island were Guettarda speciosa and a species of Pandanus. The Pandanus plant was bearing fruit and a collection was made.

Soil on this island was coral sand with a small amount of organic matter in it.

#### CLARA (Ruchi)

Vegetation of Ruchi Island is mainly a scattered growth of Messerschmidia argentea and Scaevola frutescens. The vegetation pattern is more open than on Bogallua or Bogombogo Island to the west, and probably indicates an earlier stage in vegetation development, possibly because of less time for recovery after destruction by testing. Tests conducted just to the east of these islands as late as 1958 produced blast and thermal effects which removed most of the vegetation from these islands.

Samples collected on Ruchi Island were Messerschmidia and Scaevola and a 300-in.<sup>3</sup> soil sample.

#### DAISY (Cochiti)

Vegetation of Cochiti Island is a scattered to open scrubby growth of Messerschmidia argentea and Scaevola frutescens. The density of vegetation is reduced on the northeastern tip of the

island and somewhat so along the entire lagoon side of the island. Coconut palms (Cocos nucifera) with fruit were found on the island. Open ground between the scattered clumps of Messerschmidia and Scaevola was covered with Fimbristylis atollensis, Triumfetta procumbens, and Ipomoea ssp. In addition to the Messerschmidia, Scaevola, and Cocos, a 250 to 300-in.<sup>3</sup> soil sample was collected from the island. Messerschmidia and Scaevola was covered with Fimbristylis atollensis, Triumfetta procumbens, and Ipomoea ssp. In addition to the Messerschmidia, Scaevola, and Cocos, a 250 to 300-in.<sup>3</sup> soil sample was collected from the island.

#### EDNA (Sanildefonso)

EDNA is hardly more than a sandbar occurring on the northern part of the reef. It lies just west of the MIKE Crater and may represent coral ejecta from that shot. The only vegetation on the island, except for algae in the surf, is the tree Messerschmidia argentea which, even with a low salt tolerance, is usually one of the initial invaders of a new land surface. Trees are present on the northern half of the island. A rather large population of hermit crabs is also present, apparently subsisting on the vegetal debris from these plants.

The only sample collected from this island was from Messerschmidia.

#### HELEN (Bogairikk)

HELEN is a small vegetated sandbar contiguous with IRENE (Bogon), extending from the northwest to the southeast, and connected to Bogon by a sandbar. It is covered with an open growth of

Messerschmidia argentea and Scaevola frutescens. Some rank growth of the grass Lepturus repens has occurred in the open areas, encouraged by the manuring effects of the small bird rookery present on the island. A small plant of the tree, Guettarda speciosa, was seen on Bogairikk Island.

The grass, Lepturus repens, and a soil sample were collected on this island.

#### IRENE (Bogon)

The vegetation of IRENE is composed of scattered to open scrubby growth of Messerschmidia argentea and Scaevola frutescens. Other woody species are present on the island but contribute only in a small way to the vegetative biomass. Tree growth is slightly more dense around the eastern rim of SEMINOLE crater than in other areas. Open expanses of ground between tree clumps is covered with the usual ground cover species: Fimbristylis atollensis, Triumfetta procumbens, Ipomoea pes-caprae, and related species. The parasitic Cassytha filiformis was particularly abundant in these areas. Other species observed were Guettarda speciosa, Suriana maritima, and a single group of coconut palms, Cocos nucifera. Collections were made of these species and of two kinds of animals present on the island; noddy terns and eggs were obtained, as well as hermit crabs from the central part of the island. Soil samples were obtained from the three corners of the island. A slightly more radioactive area was present on the northwest corner of the island, and this was sampled by both soil and plant collections.

#### JANET (Engebi)

Vegetation of Engebi is dense to open scrubby growth of Messerschmidia argentea and Scaevola frutescens, with a few other woody species assuming only local importance. Scaevola dominates the vegetation on much of the interior of the island but occurs with Messerschmidia in mixed stands on other parts of the island, such as along the north side of the airstrip. In old cleared areas, shrubs such as Pluchea odorata are abundant and form large clumps 10 to 30 ft in diameter. Fimbristylis atollensis (sedge) forms tussocks 4 to 6 in. in diameter in open areas between shrub and tree clumps, with the ground-cover species, Ipomoea pes-caprae and Triumfetta procumbens. A small clump of coconut palms with young fruit was present to the east of the large concrete building in the center of the island. Other woody species observed were Morinda citrifolia and Sida fallax. Plant samples were collected along two transects of the island. One transect of the island was made along the axis of the lagoon side, and both Messerschmidia and Scaevola were sampled along this transect. Another transect was made from the northwestern tip parallel to the airstrip toward the northeastern corner of the island.

Rats were trapped in three areas on Engebi Island, the first near a slightly more radioactive area on the north side of the airstrip, the second near a bunker at the northwest tip of the island, and a third near the main building at the center of the island. Noddy tern eggs and birds were obtained on the north side of the airstrip.

#### KATE (Muzinbaaikku)

Vegetation of KATE is composed of scattered to dense growth of Messerschmidia argentea and Scaevola frutescens. Stands of the tree Pisonia grandis occur on the southern and northeastern portions of the island, with an open Messerschmidia-Scaevola scrub occupying the central portion. This is the northernmost island on which Pisonia grandis trees occur, and it will very likely act as a dispersal center for this species in the northern half of the Atoll. The significance of Pisonia is that it is an indicator species of the mature climax vegetation of the Atoll. Higher organic matter content of the coral sand soil is observed in Pisonia stands, and the nesting of fairy and noddy terns in Pisonia trees results in higher levels of nutrients in the terrestrial ecosystem.

Other species encountered on Muzinbaaikku Island were Morinda citrifolia and the ubiquitous ground-cover species, Fimbristylis atollensis, Ipomoea pes-caprae, Lepturus repens, and Triumfetta procumbens.

The red-tailed tropicbirds (Phaethon rubricauda) were sampled, and a 12 × 12 × 1-in. deep soil sample was obtained on this island.

#### LUCY (Kirinian)

The vegetation of LUCY is composed of a dense Messerschmidia argentea-Scaevola frutescens growth which assumes an open, scattered aspect on the southern tip of the island. Scaevola typically occupies the island margins, apparently being more salt-tolerant, with Messerschmidia occurring inland and persisting in the vege-

tation type even when a Pisonia stand develops. Salt damage can be seen in both Scaevola and Messerschmidia.

Noddy terns, hermit crabs (Coenobita perlatus), and a soil sample (250 to 300 in.<sup>3</sup>) were obtained on this land.

#### MARY (Bokonaarappu)

The vegetation of Bokonaarappu is an open Messerschmidia argentea-Scaevola frutescens scrub which is densest on the central and northern parts of the island. Several coconut palms (Cocos nucifera) are present and bearing fruit. Other woody species on the island were Morinda citrifolia and Guettarda speciosa. Morinda leaves and fruit were collected, as well as coconuts from six palm trees. A soil sample was collected from a 12 × 12 × 1-in. (depth) area. Noddy terns were also obtained.

#### NANCY (Yeiri)

This small island is covered with a dense growth of Messerschmidia argentea and Scaevola frutescens along the shorelines, with Pisonia grandis occupying the interior. The vegetation apparently has not been modified as much as some adjacent islands, and species indicative of a more advanced successional stage are present. Pisonia grandis, Guettarda speciosa, Cordia subcordata, and Morinda grandis occur on this island with the coconut palm, Cocos nucifera. It appears that the condition of islands in this part of the Atoll must be very similar to conditions prevailing before World War II.

All plant species listed above were sampled, and a soil sample was obtained. Two young coconut crabs (Birgus latro) approximately 6 in. long were found but



were released to populate the island since they were too small to constitute a sample.

#### OLIVE (Aitsu)

The vegetation of OLIVE is composed of scattered to dense scrubby growth of Messerschmidia argentea and Scaevola frutescens. The south end of the island is more open. In addition to Messerschmidia and Scaevola, other species found and collected on the island were Morinda citrifolia and Cordia subcordata.

A soil sample was collected on the island, and noddy terns were obtained along the beaches.

#### PEARL (Rujoru)

The vegetation of PEARL is composed of scattered Messerschmidia argentea and Scaevola frutescens growth, less dense than on Aitsu or Yeiri Islands to the north. This island was subjected to physical effects from a test, and the vegetation is in a relatively immature successional stage. In addition to Messerschmidia and Scaevola, a sample of Morinda citrifolia was collected on PEARL. A 12 × 12 × 1-in. (deep) soil sample, a sample of noddy terns, and eight rats (Rattus exulans) were also collected on the island.

#### RUBY (Eberiru)

This small island is composed primarily of coral sand and coralline limestone. The only woody vegetation found on the island was Messerschmidia argentea, which is usually the primary invader species on bare sandbars. Fimbristylis atollensis sedge is present between the trees.

#### SALLY (Aomon)

SALLY has been modified by recent earthmoving activities connected with the PACE experiments. Between a third and a half of the island has been cleared of vegetation, and bare coral sand and limestone are exposed on most of its southern half.

Remnants of the pre-PACE Program vegetation appear to be the typical Messerschmidia argentea-Scaevola frutescens scrub growth. Scattered clumps or trees of these species occur on the northern half of the island. Pandanus sp. plants were found on SALLY but no fruits were present. Revegetation studies could be conducted on the cleared areas to obtain data on recovery rates of the atoll vegetation because the date of clearing is known.

Noddy and sooty terns and eggs were collected, and a soil sample was obtained from an undisturbed part of the island.

#### TILDA (Bijjiri)

The vegetation of TILDA is composed of scattered to dense stands of Messerschmidia argentea and Scaevola frutescens, with vegetation in the center of the island more dense than that on the north side of the runway. Other species found on the island which make a significant contribution to the plant biomass are Pisonia grandis, Guettarda speciosa, Morinda citrifolia and Pandanus sp. Pisonia trees on the northeast corner of the island showed some damaged foliage, probably due to salt spray. A young coconut palm, Cocos nucifera, was found on the island, but only small, green, immature fruit was available.

A soil sample was collected.

### URSULA (Rojoa)

The vegetation of URSULA is composed of scattered to dense growth of Messerschmidia argentea-Scaevola frutescens. Vegetation on the north and western parts of the island was dense and essentially continuous, while trees on the southeast third of the island were scattered. Guettarda speciosa was the only other woody species observed on the island.

Rats (Rattus exulans) were abundant on URSULA, and a large sample of animals was obtained in a daytime trapping trip. A soil sample was also obtained.

### VERA (Aaraanbiru)

The vegetation of VERA is an example of mature Atoll vegetation, similar to that seen on islands in the southeastern sector of the Atoll. Along the shorelines, Scaevola frutescens and Messerschmidia argentea occur in dense, scrubby growth. The west central part of the island supports a stand of mature coconut palms, Cocos nucifera. In the central part of the island the vegetation is dominated by large trees of Pisonia grandis. Within the stands of Pisonia, old stems of Messerschmidia may persist but do not show much reproduction except by vegetative means such as stem shoots. Morinda citrifolia and Pandanus sp. were also present in the dense forest type on Aaraanbiru Island.

The soil on Aaraanbiru Island had a large amount of organic matter in it. Raw organic matter and organically stained coral sand extended as deep as 20 cm.

### WILMA (Piiraai)

The vegetation of WILMA is scattered to dense growth of Messerschmidia

argentea and Scaevola frutescens. The southern half of the island is more open, which may be related to the test activity on the next island to the south, YVONNE. Guettarda speciosa was the only other woody plant observed in addition to those mentioned above. The usual ground-cover species, such as Fimbristylis atollensis, Triumfetta procumbens, and Ipomoea pes-caprae were present in open or disturbed areas, such as near the helicopter pad and in the central portion of the island.

### YVONNE (Runit)

The vegetation of YVONNE is primarily scattered, scrubby growth of Messerschmidia argentea and Scaevola frutescens, although other woody plants, such as Guettarda speciosa, an early invader of disturbed sites, and the coconut palm, Cocos nucifera, were also found. Open spaces are generally vegetated by typical ground-cover species such as Fimbristylis atollensis, Triumfetta procumbens, Lepturus repens, and Ipomoea pes-caprae.

Several series of vegetation samples were collected on Runit Island. At the north end of the island, south of Cactus and Lacrosse craters, Messerschmidia, Scaevola, and Guettarda were collected. A soil sample was also collected here, and rats were trapped in this area of higher radioactivity. We have called this group of samples Series A.

Farther south, but still north of the metal tower, Series B samples were collected, including Messerschmidia, Scaevola, Cocos, a soil sample, and a rat sample. Noddy terns and their eggs were also obtained.

Slightly south of the landing dock another series of samples, designated Series C was obtained, including samples of Messerschmidia, Scaevola, Cocos (fruits), and soil collected along the old airstrip runway. Noddy tern eggs and a series of rats were also obtained in the "C" area.

The "D" area of Runit was at the southern end in an area of old buildings at the end of a long sand spit.

Messerschmidia, Scaevola, and Cocos (fruits) were collected. In addition, noddy tern eggs were collected, rats were trapped, and two soil samples were obtained for Series "D".

A fourth area, designated the "E" area, was also sampled. This area was located mid-island, but on the seaward side.

Messerschmidia, Scaevola, and a soil sample were obtained.

#### Small Islands Between YVONNE (Runit) and ALVIN (Chinieero)

Four small islands, hardly more than sand spits, occur on the reef between YVONNE (Runit) and ALVIN (Chinieero). These islands apparently had no geographic or native names; perhaps they have formed in recent years. Vegetation of these small islands represents initial stages of plant succession.

#### SAM

This small sandbar or spit is located just south of YVONNE (Runit) and has several small clumps of Messerschmidia argentea and small patches of grasses between them. No samples were collected on SAM.

#### TOM

This is a small triangular island on the reef south of YVONNE with sandbars extending from the north and south ends of the island. Two species of woody plants occur on TOM -- Messerschmidia argentea and Scaevola frutescens. These two plants occurred in separated clumps on the island with little ground vegetation in between, and samples of each were collected.

#### URIAH

This long, narrow island is covered with scattered to dense growth of Messerschmidia argentea and Scaevola frutescens. Ground-cover species are present between the tree clumps in the more open areas, and the south end of the island. Messerschmidia and Scaevola were collected.

#### VAN

VAN is a small, densely vegetated island just north of ALVIN (Chinieero). Sandbars are present at the northern and southern ends of the island, and coral limestone occurs at the water's edge along the lagoon. Messerschmidia argentea and Scaevola frutescens dominate the vegetation, which also includes Pisonia grandis, the large, soft-wooded tree found on islands with mature, undisturbed vegetation. The sea side of the island at the southern end has vegetation which is more scattered than on the northern and lagoon sides. Noddy terns and eggs were collected from the small rookery of birds.

#### ALVIN (Chinieero)

ALVIN is a small island in the center of an elongate sandbar located on the lagoon edge of the reef. Broad sand beaches are present on the lagoon side

and to the north and south of the vegetated area.

The vegetation of Chinieero Island is composed mainly of Messerschmidia argentea with a few clumps of Scaevola frutescens.

#### BRUCE (Aniyaanii)

The main portion of BRUCE is covered with an intermediate-age Pisonia grandis forest. There does not appear to have been large-scale destruction of habitat on this island, although test-period activity is apparent on the north end.

Scattered coconut palms are present in the central and eastern part of the island. The island edges, and old cleared areas support clumps of Messerschmidia argentea and Scaevola frutescens, and a thicket of Cordia subcordata is present along the lagoon beach. Ipomoea spp. and Triumfetta procumbens vines and clumps of Lepturus repens and Fimbristylis atollensis occur in the limited number of open meadow-like areas.

Coconut crabs, Birgus latro, and the roof rat, Rattus rattus, were seen, and coconut crabs were collected for analysis. All the plant species listed above except Ipomoea, Triumfetta, Lepturus, Fimbristylis, and Cordia were sampled.

#### CLYDE (Chinimi)

CLYDE is a small, rectangular islet with large lagoon beaches and a broad coral reef exposed on the sea side, scarcely more than a spit. A large population of sooty terns was nesting there in January.

The vegetation of CLYDE is scattered to open scrub of Messerschmidia argentea

and Scaevola frutescens with grasses, mainly Lepturus repens, occurring in the areas not occupied by shrubs. Several basin-like depressions, possibly solution pits, occur on the island, which receives large amounts of bird guano during the course of one or more nesting periods.

Birds (sooty terns) and eggs, and Messerschmidia and Scaevola were collected.

#### DAVID (Japtan)

DAVID is one of the largest islands on the Atoll, lying just north of the deep passage on the southeastern portion of the reef. On the western half of the island, a coconut palm plantation is present, but much of the area has been recolonized by the two ubiquitous shrub species, Messerschmidia and Scaevola. Vines, grasses, and sedges which typically invade bare ground, were found throughout the island.

Small clumps of arrowroot, Tacca leontopetaloides, were found in openings and among the palms on the western half of the island.

The eastern half of DAVID is covered with a dense growth of Pisonia grandis, Ochrosia oppositifolia, Messerschmidia argentea, and Scaevola frutescens. Occasionally Guettarda speciosa and Morinda citrifolia are found at the edges of this forest. A single large specimen of Pandanus sp. was found in the central part of the island at the eastern edge of the coconut grove.

There is a large number of weedy plant species on DAVID. This island was at least partially covered in the pre-World War II period of colonization by imported soil.

The island supports a modest population of roof rats. The monitor lizard is common. Fairy terns nest in the mature Pisonia forests, and the reef heron was seen along the southern beach.

Samples taken on DAVID included Messerschmidia, Scaevola, Pisonia, Guettarda, Morinda, Tacca, Pandanus, Coenobita, Rattus exulans, Demigretta, Erolia, and Sterna.

### REX

This small, arcuate island and spit lies in the deep passage at the southeast end of the lagoon. A large sand beach is present at its northwest end, while the eastern and southern shores have narrow beaches and broad exposed reefs.

REX is covered with heavy growth of Messerschmidia argentea and Scaevola frutescens, with some large specimens of Pisonia grandis. The west end of the island has several large open areas which support scattered clumps of grasses and sedges. A few birds were nesting on this part of the island (sooty terns), and birds and eggs were collected.

### ELMER (Parry)

Parry Island was the scene of intense test-period activity at the Atoll and is still covered with metal and wooden buildings, concrete pads, and miscellaneous structures. A small airstrip, partially overgrown with Ipomoea and Triumfetta vines, is located on the southern half of the island.

Scattered Messerschmidia argentea and Scaevola frutescens shrubs occur between the buildings, especially on the eastern or

seaward side of the island. Young coconut palms, Cocos nucifera, are present around some buildings. Ipomoea and Triumfetta vines and the parasitic Cassytha filiformis are invading most of the bare sand and gravel areas between buildings.

The roof rat, Rattus rattus, occurs on Parry Island, where it must subsist mainly on the few coconuts produced there and the seeds of flowering plants.

### FRED (Enewetak)

FRED is an elongated island at the southeast end of the Atoll, separated from the islands in the southwestern quadrant of the Atoll by the wide passage through the reef. Most of the recent activity (1960-1973) at Enewetak Atoll has been on this island, which has a long airstrip at its southern end. Bombardment and ground fighting on Enewetak Island during World War II destroyed most of the original vegetation and natural features. Subsequent support and construction activities during the nuclear test period further modified the island with building complexes, concrete pads, and roads.

The present vegetation of FRED consists of the widely distributed species of the Atoll — some of which were replanted by man — and weedy species introduced from North America. The coconut palm has apparently been replanted by man on Enewetak Island during the nuclear test period and thereafter. Other species include the Pandanus and various horticultural, agricultural, and weedy species.

Messerschmidia argentea and Scaevola frutescens are the most common woody plants on Enewetak Island. Large Messerschmidia trees are estimated to be 10-20 yr old, but only a few specimens

of this age are present.

Ground cover includes species of Ipomoea, Triumfetta procumbens, Lepturus repens, Fimbristylis atollensis, and the parasitic Cassytha filiformis. None of the commoner woody species found on islands to the north or west, such as Guettarda speciosa and Morinda citrifolia was seen on FRED.

Mammals were represented on the island by the house mouse, Mus musculus, which was trapped in small numbers around buildings being used for habitation. Several cats and dogs were present on the island, and it is possible that their predation upon the larger roof and Polynesian rats kept their numbers low.

GLENN (Igurin), HENRY (Mui),  
IRWIN (Pokon), JAMES (Ribaion),  
and KEITH (Giriinian)

These five islands in the southwest quadrant of the Atoll can be considered as a group with a similar ecological setting, history, and biota. The description to follow therefore applies to all of the islands, with few minor differences. Except for two nuclear tests conducted in the adjacent lagoon or in the sea just south of the Atoll, these islands have not been disturbed, as have the islands on the northern part of the Atoll. Only a few test-related structures are present on these islands, and these are almost obscured by the heavy growth of vines, shrubs, and trees.

Vegetation of these islands is primarily the Pisonia grandis forest, with such subdominant species as Ochrosia oppositifolia, Morinda citrifolia, and Guettarda speciosa. Suriana maritima and Pemphis acidula are found occasionally at the edges of the

beach. Messerschmidia argentea and Scaevola frutescens are typically found at the edges of the Pisonia forest stands, with old stems of Messerschmidia occasionally persisting under the complete canopy of the Pisonia forest. Tacca leontopetaloides, the arrowroot, was found on several of the islands in small patches. A few small Pandanus trees were seen. On some islands, such as GLENN and KEITH, large coconut palms are present among the Pisonia trees, while on smaller islands younger palms are found, mainly on the lagoon sides of the islands.

The terrestrial biota of this series of islands is the most interesting of those found on the Atoll. Coconut crabs, Birgus latro, are usually found wherever producing coconut palms are present. On Igurin and Giriinian Islands coconut crabs are quite abundant, together with the land form of the hermit crab, Coenobita brevimanus, and the related C. perlatus.

In the Pisonia forest, the fairy tern and the common noddy are found nesting without any serious predation. A considerable amount of bird guano is deposited in these forest stands, and the coral substratum has become darkly stained through the action of organic matter accumulation.

The Polynesian rat, Rattus exulans, was found on GLENN, where it is apparently able to subsist on coconuts and other plant and animal materials. On HENRY, a narrow, spit-like extension of the island (east end) has a small rookery of sooty terns nesting in the grassy ridge just above the beach.

It is quite possible that the vegetation of this series of southwestern islands is affected by storm waves and spray. Storm

waves from the lagoon can deposit significant amounts of salt spray on the islands. Numerous plants with symptoms of salt spray damage were observed along the lagoon side.

### LEROY (Rigili)

LEROY is a small, rectangular land mass located on the southwestern part of the Atoll, separated from ALICE to the north by 21 km, and from KEITH to the east by 12 km of open water and coral reefs. The approach to LEROY from the lagoon is complicated by extensive reefs and tidal flats.

LEROY can be considered unique among islands on the southern half of the Atoll from a radioecological standpoint for two reasons, the second of which is probably more important: (1) Two nuclear tests were conducted relatively close to the island, one in the lagoon and one in the sea to the south; and (2) the island received close-in fallout from tests conducted in the northeast quadrant of the Atoll because fallout clouds frequently left the Atoll in a southwesterly direction.

LEROY has a well-developed sand beach on the lagoon, or northeast, side of the island. A narrow beach with exposed coral limestone occurs on the other three sides of the island. The island is densely vegetated, except for a few openings on the northeast side of the island. Large specimens of Pisonia grandis and coconut palm, Cocos nucifera, form the dense forest which extends almost to the beaches on all sides. The usual transition zone composed of Messerschmidia argentea and Scaevola frutescens occurs at the

edges of the forest, with a few mature trunks of Messerschmidia located in the outer edges of the Pisonia forest.

On the southwest side of the island dense Cordia subcordata thickets occurred at the outer edge of the Pisonia forest. Pemphis acidula, a tall shrub, was seen among the Scaevola and Messerschmidia just above the storm line on the lagoon beach. A large specimen of Pandanus sp. was found on the southeast beach among the Scaevola and Messerschmidia. No fruit was present but foliage samples were collected. Mature coconut-producing palms were scattered through the island in the Pisonia forest.

Fairy terns and the common brown noddy were nesting in the Pisonia trees at the time of sampling in January. Coconut crabs (Birgus latro) were abundant on the island, and several large specimens were obtained for radionuclide analysis. Except for migratory birds and the hermit crab, Coenobita perlatus and C. brevipanum, no other animals were seen on the island.

### Sampling and Sample Preparation

The collection of terrestrial biota on Enewetak Atoll was based on three main criteria: (1) plant or animal species comprising the anticipated diet, (2) plant or animal species not usually considered as food, but included in the Marshallese pharmacopoeia or used as famine food, whose distribution over most of the Atoll permits comparison on an inter-island basis, and (3) plant or animal species not forming part of the Marshallese diet, but considered as "indicator" organisms bearing some relationship to species that might be introduced later. Examples of the first category include Pandanus tectoris, coconuts (Cocos nucifera),

arrowroot (Tacca leontopetaloides), and coconut crabs (Birgus latro). Examples of the second category include Morinda citrifolia, Messerschmidia argentea, and Scaevola frutescens. An example of the third category is the rat, the only mammal inhabiting the islands at present.

Representatives of less widely disseminated plant species were collected wherever adequate samples were available. For example, only two stands of tacca were observed, one on DAVID and the other on LEROY; the first was mature and had numerous tubers, but the second was immature and had inadequate tubers for sampling. Specimens of pandanus leaves were collected on 10 of the islands, but only two of the plants were bearing fruit.

Terrestrial animals on the Atoll were limited to large hermit crabs (Coenobita perlatus), coconut crabs (B. latro), rats (Rattus rattus and R. exulans), and monitor lizards introduced by the Japanese on Japtan (DAVID). The lizards are not eaten by the natives; they are a protected species and were not collected. Rats are not eaten by the natives but are useful as indicator organisms since they are the only mammals on the Atoll. The coconut crab, a terrestrially adapted species, is considered a delicacy. These animals in turn derive their nutrients primarily from land vegetation. The supply of coconut crabs is severely limited.

Birds and their eggs constitute important food items for the natives; both are plentiful and were collected on many of the islands. These birds are primarily ocean or reef feeders (small fish, squid, shrimp, etc.) and are far-ranging in their feeding habits.

## Collection and Preparation for Analysis

Plant Samples — Immediately after collection plant samples were placed in forced-air drying ovens at 125 to 150°C for approximately 24 hr or until dry. Coconuts were drained of milk, and the meats dried. All samples were packaged in plastic bags for shipping. At LLL they were ground in a Wiley mill, redried, packed in aluminum tuna cans with a hydraulic press, and sealed for counting. The cans were submitted for gamma counting with lithium-drifted germanium [Ge(Li)] detectors and wet chemistry. Most of the samples were larger than required for canning; the excess provided a duplicate sample to keep in reserve for other procedures as required.

A number of green drinking coconuts were collected in July 1973 from selected islands for analysis of the milk. The milk was drained from the nuts and freeze-dried. This was packed in small plastic jars for gamma counting and subsequent radiochemical analyses. The meats from these nuts were dried as above and also submitted for analyses.

Mammals — Rats were collected with snap traps. Our own collections on some islands were supplemented from the EMBL\* - Bowling Green collection of rats in return for data on the reproductive organs of the rats collected by our group. Two species were obtained: Rattus exulans (Polynesian rat) and Rattus rattus (roof rat). On all the islands except DAVID, the rat population appeared to be

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\* Enewetak Marine Biological Laboratory.



exclusively either one species or the other. Rats were frozen in deep-freeze chests on Enewetak, returned to LLL packed in dry ice, and stored frozen until dissection and analysis. Thawed specimens were dissected for organ samples (skin, liver, kidney, lung, viscera, and carcass), which were then freeze-dried. Bone and muscle were separated. Bone was ashed at 150°C. All samples were canned for analysis. Species identification of Rattus rattus and Rattus exulans was confirmed by Dr. Jackson at Bowling Green University.

Birds — Birds were shot with a shotgun or captured by hand. The principal species collected were the common noddy (Anous stolidus), the white-capped noddy (Anous tenuirostris), and the sooty tern (Sterna fuscata). A few specimens of the red-tailed tropic bird (Phaeton rubricauda), reef herons, and curlews were taken, but some of these provided inadequate sample sizes for analysis. The birds were frozen with dry ice for shipment. At LLL they were thawed, skinned, and dissected into samples of carcass, liver, and viscera. Individual organ samples were pooled by species and freeze-dried. Muscle and bone were separated; the bone was ashed in muffle furnaces at 150°C, washed with distilled water to remove muscle residue, and redried. Liver, muscle, bone, and viscera were canned or packed in smaller plastic containers and submitted for analysis.

Eggs were collected from nests on the ground, where large numbers were available. They were frozen for shipment. For analysis, the shells were separated, washed, and dried. The edible contents were freeze-dried and canned.

Identification of the birds collected on the islands was confirmed by George Watson at the Smithsonian Institute.

Terrestrial Crustaceans — Coconut crabs (Birgus latro) were freeze-dried whole with the exoskeleton cracked to facilitate drying. At LLL they were dissected into samples of exoskeleton, muscle, tail (hepatopancreas and reproductive organs), and a miscellaneous fraction containing other viscera. These were then canned for analysis. Coenobita perlatus (hermit crabs) were frozen at Enewetak and partially defrosted at LLL so that they could be removed from their shells. They were separated into tails (hepatopancreas) and anterior portions and freeze-dried. Anterior portions were crushed, and muscle and exoskeleton were separated. The fractions were canned for counting.

Soil Samples — Intensive soil-profile sampling of the Atoll was in progress concurrently, but we collected additional samples near areas of intensive sampling of vegetation, in order to determine the soil-plant transfer ratios for specific isotopes. They consisted of 12×12×2 in. samples, which were dried, homogenized, and canned in aluminum tuna cans for counting. They were processed along with the samples from the soil-profile studies.

#### Radionuclide Concentration Levels in Terrestrial Biota Samples.

A total of 1103 specimens were collected in the field as part of the terrestrial biota

survey, distributed as follows:

Soils	42
Plants	208
Birds	116
Eggs	217
Rats	249
Crabs	<u>271</u>
Total	1103

Because many of the individual samples of birds, eggs, rats, and crabs were too small to yield statistically meaningful analytical results, specimens of the same species from a single area were pooled, resulting in the analysis of a total of 273 samples in these four categories.

Radiochemical analytical data for the terrestrial biota samples are shown in Table 59, listed by island, starting with ALICE. Results for all radionuclides

whose analytical errors are less than 30% are tabulated. Nuclides with errors greater than 30% are present at close to the analytical sensitivity limit and are therefore considered to have negligible value for dose-assessment purposes. Those who wish to use data for these nuclides, plus upper limit estimates for each sample where a specific nuclide was not observed, are referred to the microfiche tables in Appendix II.

These basic survey data have been arrayed in two additional ways to facilitate their interpretation and use. In Tables 60 to 75 the survey data are ordered on the species of organism. In Tables 76 to 103 the basic survey data are arranged by island and include the soil, plant, and animal data obtained from the site.

Table 59. Terrestrial biota samples collected at Enewetak Atoll, Oct. 1972 - Jan. 1973.

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>ALICE</u>								
10188501	<u>Messerschmidia argentea</u>	13.38±6.4			138.3±1.0	222.8±0.3	0.025±8.0	
10189101	<u>Guettarda speciosa</u>	11.03±4.3				7.41±1.1		
10188601	<u>Scaevola frutescens</u>	12.82±5.5			32.7±2.1	66.53±0.5		
11919001	<u>Anous stolidus</u> liver	10.20±18.8	127.0±2.0				0.062±13.0	
11921201	<u>Anous stolidus</u> viscera		47.30±4.6					
11922801	<u>Anous stolidus</u> muscle	9.66±8.3	49.55±2.0	0.321±21.7	0.0099±25.0			
11926001	<u>Anous stolidus</u> bone	5.302±12.1	25.68±7.6		20.59±9.9	1.16±4.3		
<u>BELLE</u>								
10226602	<u>Guettarda speciosa</u> leaves	12.48±5.8			152.7±1.0	109.1±0.4		
10226402	<u>Messerschmidia argentea</u> leaves	15.86±5.8			25.2±1.1	5.83±2.1	0.036±9.7	
10226502	<u>Scaevola frutescens</u> leaves	12.45±5.8			2.27±3.6	1.42±4.1	0.072±6.3	$^{238}\text{Pu}$ (0.013±12.0)
10226702	<u>Pandanus tectorius</u> leaves	6.70±15.4	0.438±5.0		391.0±1.0	679.30±0.3		
10226802	<u>Pandanus tectorius</u> fruit	14.38±5.8			206.30±1.0	923.0±0.1		$^3\text{H}$ (0.86±5.2)

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>CLARA</u>								
10225503	<u>Messerschmidia argentea</u> leaves	13.33±5.0			127.5±1.0	149.10±0.3		
10225603	<u>Scaevola frutescens</u> leaves	12.37±5.5	3.37±8.6		51.8±1.0	15.04±0.6	0.048±13.0	
<u>DAISY</u>								
10245504	<u>Cocos nucifera</u> fruit	6.65±10.6			0.20±2.0	7.17±1.4		$^3\text{H}$ (0.41±10.6)
10224304	<u>Messerschmidia argentea</u> leaves	11.10±4.9		1.45±5.1	12.21±1.0	5.90±1.4	0.055±9.8	$^{102\text{m}}\text{Rh}$ (0.313±27.2)
10224404	<u>Scaevola frutescens</u> leaves	20.26±4.4		0.484±3.8	50.90±1.0	38.80±0.7	0.046±8.6	$^{238}\text{Pu}$ (0.0085±16.0)
10930104	<u>Cocos nucifera</u> milk	45.50±24.7			1.40±12.0	1.75±47.0		
<u>EDNA</u>								
10720405	<u>Messerschmidia argentea</u>	11.1±5.3		0.24±22.8		6.73±1.4		
<u>HELEN</u>								
10411308	<u>Lepturus repens</u> grass	4.901±12.0		0.936±5.4	1.44±3.1	2.51±3.0	0.0435±21.0	
<u>IRENE</u>								
10930309	<u>Cocos nucifera</u>							
10930409	<u>Cocos nucifera</u>	99.9±14.8	86.49±6.8		1.608±19.0	5.11±29.1		
10370909	<u>Cocos nucifera</u>	7.05±7.2			0.0667±8.0	1.769±3.2	0.0362±8.0	

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>IRENE</u>								
10411709 (E-18)	<u>Guettarda speciosa</u>	8.14±6.9		9.18±5.0	53.60±1.0	27.33±1.9		
10411909 (C-16)	<u>Lepturus repens</u>	1.95±25.3		0.258±12.6	1.15±3.4	2.57±3.3	0.0112±20.0	
10329209 (B-5)	<u>Messerschmidia argentea</u>	13.04±4.6		23.86±1.1	536.0±1.0	62.6±0.4		
10329509 (C-7)	<u>Messerschmidia argentea</u>	18.16±4.7		0.138±38.8		2.197±3.1	0.0045±12.0	
10329609 (A-1)	<u>Messerschmidia argentea</u>	14.6±5.1		2.77±4.1	21.76±1.0	4.10±2.3	0.0157±2.1	
10411609 (E-15)	<u>Messerschmidia argentea</u>	12.74±4.5		3.39±3.9	159.0±1.0	407.3±1.8	0.00192±8.0	
10466309 (A-20)	<u>Messerschmidia argentea</u> wood	1.94±16.1		1.59±3.2	16.98±1.1	13.02±2.2	0.00617±18.0	
10329309 (B-6)	<u>Scaevola frutescens</u>	17.09±4.7	33.7±2.2	47.4±0.9	110.4±1.0	43.14±0.6	0.0044±19.0	$^{241}\text{Am}$ (0.0044±19.0)
10329409 (C-8)	<u>Scaevola frutescens</u>	14.08±5.2			1.14±5.5	1.67±3.6	0.0031±1.0	
10329709 (A-2)	<u>Scaevola frutescens</u>	12.68±5.9	26.4±2.8	17.07±1.6	8.56±1.0	4.28±2.8	0.0277±7.3	$^{241}\text{Am}$ (0.00883±14.0)
10411809 (E-14)	<u>Scaevola frutescens</u>	10.41±6.7		21.14±1.2	57.21±1.0	205.2±0.8	0.00296±29.0	
10466409 (A-21)	<u>Scaevola frutescens</u> wood	1.817±15.6		0.912±3.5	4.60±2.4	2.219±2.8	0.00295±22.0	
10411409 (A-17)	<u>Fimbristylis atollensis</u> sedge	4.87±11.3		14.7±1.2	4.42±1.7	55.0±1.6	0.878±5.2	$^{238}\text{Pu}$ (0.280±6.0)
10411509 (A-19)	<u>Suriana maritima</u>	5.586±10.7		121.3±0.7	8.514±2.8	26.34±1.5	0.02865±16.	$^{238}\text{Pu}$ (0.00905±29.)

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>IRENE</u>								
11900709	<u>Anous stolidus</u> egg shell		1.18±22.0		7.34±1.6		0.0081±14.0	
11901409	<u>Anous stolidus</u> egg	6.374±7.5	23.0±2.0		0.095±5.0		0.0015±19.0	
11902509	Hermit crab hepatopancreas and gonad	7.045±10.3	12.8±3.0	82.8±0.8	29.7±2.0	124.3±0.5	0.196±3.0	$^3\text{H}$ (0.58±5.1)
11902707	Hermit crab muscle	7.365±8.8	3.32±5.0	62.43±0.9	22.6±1.0	130.7±0.4	0.0694±4.0	$^3\text{H}$ (0.89±3.6)
11902809	Hermit crab exoskeleton	1.94±15.2	0.321±5.0	1.66±5.0	491.0±1.0	27.2±0.7	0.0172±11.0	
11917709	<u>Anous stolidus</u> muscle	9.419±9.9		0.25±39.3				
11919109	<u>Anous stolidus</u> liver	7.883±15.4	49.6±3.0	0.324±21.9	0.509±3.0		0.0091±24.0	
11927409	<u>Anous stolidus</u> bone		57.66±3.0			0.171±40.2		
11921309	<u>Anous stolidus</u> viscera		57.7±3.6					
<u>JANET</u>								
10368310	<u>Scaevola frutescens</u> I-18	17.44±4.8			12.16±1.0	30.50±0.8	0.01635±20.0	
10368410	<u>Scaevola frutescens</u>	18.12±3.9			37.25±1.0	258.60±0.2		
10368510	<u>Scaevola frutescens</u>	14.31±5.0			17.34±1.0	63.29±0.5		
10368610	<u>Scaevola frutescens</u>	13.65±5.1		0.446±13.3	35.72±1.0	223.4±0.3	0.00267±28.0	
10368710	<u>Scaevola frutescens</u>	16.73±4.8			31.53±1.0	294.60±0.2	0.01036±13.0	

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>JANET</u>								
10368810	<u>Scaevola frutescens</u>	12.96±5.4		0.2139±24.0	32.66±1.0	54.95±0.6	0.0067±5.8	$^{238}\text{Pu}$ (0.00676±8.7)
10368910	<u>Scaevola frutescens</u>	20.57±4.1		0.236±23.8	83.33±1.0	405.90±1.0	0.00432±17.0	
10369010	<u>Scaevola frutescens</u>	18.28±4.5			16.71±1.0	134.10±0.4	0.00496±28.0	
10369110	<u>Messerschmidia argentea</u>	12.72±5.8			18.38±1.0	36.42±0.7	0.0152±6.0	
10369210	<u>Messerschmidia argentea</u>	10.50±6.5			46.40±2.0	385.80±0.2	0.00345±21.0	
10369310	<u>Messerschmidia argentea</u>	9.95±7.2			43.51±1.0	124.80±0.4	0.00554±1.9	$^{152}\text{Eu}$ (0.204±33.3)
10369410	<u>Messerschmidia argentea</u>	142.5±5.1			48.20±2.0	299.40±0.2	0.0042±80.0	
10369510	<u>Messerschmidia argentea</u>	12.17±5.4			83.78±1.0	298.70±0.2	0.005±30.0	
10369610	<u>Messerschmidia argentea</u>	15.30±4.4			121.20±1.0	158.30±0.3	0.0029±26.0	
10369710	<u>Messerschmidia argentea</u>	10.43±6.5		0.221±25.2	100.9±1.0	526.1±0.2		
10369810	<u>Messerschmidia argentea</u>	18.32±4.5		0.246±24.1	40.36±1.0	545.9±0.2	0.0103±24.0	
10369910	<u>Messerschmidia argentea</u>	13.29±5.8			45.95±2.0	322.7±0.2		
10370010	<u>Pandanus tectorius</u> leaves	8.12±9.10			4.41±2.0	0.62±8.5		$^{207}\text{Bi}$ (0.11±29.0)
10370110	<u>Pluchea odorata</u>	10.80±6.9		1.25±9.2	46.85±1.0	1553.00±0.1		
10370210	<u>Cocos nucifera</u>	8.04±6.4			0.21±5.0	84.68±0.4		$^3\text{H}$ (0.34±8.3)
11901010	<u>Anous stolidus</u> egg shell		1.28±20.0		16.04±1.4			
11901510	<u>Anous stolidus</u> egg	6.21±9.4	57.21±2.0		0.203±3.0		0.0148±5.0	
11906610	<u>Rattus rattus</u> viscera	12.63±8.0		2.35±6.5	14.14±2.0	880.60±0.2	0.46±6.0	
11906810	<u>Rattus rattus</u> viscera	11.38±16.8		1.97±13.4	6.85±2.0	768.00±0.3	0.36±3.0	

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>JANET</u>								
11907310	<u>Rattus rattus</u> muscle	8.74±8.4	30.9±2.0	0.29±24.5	1.28±4.0	764.00±0.2		$^3\text{H}$ (6.7±1.1)
11909410	<u>Rattus rattus</u> liver	13.42±9.4	77.9±3.0	3.23±4.6	0.004±9.0	632.9±0.8		
11910810	<u>Rattus rattus</u> viscera	16.23±9.9	24.3±5.5	4.95±3.9	55.86±1.1	954.50±0.7	0.729±6.1	
11910910	<u>Rattus rattus</u> muscle		8.69±5.0	0.41±12.3	3.44±3.0	696.80±1.0	0.0076±13.0	
11911010	<u>Rattus rattus</u> muscle		10.5±5.0	0.23±24.3	2.29±2.0	286.5±1.0	0.0097±10.0	
11911110	<u>Rattus rattus</u> viscera			1.72±6.2	17.0±1.0	273.2±1.1	1.40±2.0	
11911210	<u>Rattus rattus</u> muscle	13.87±10.4	16.3±6.0	0.638±15.9	3.14±4.0	765.8±0.8	0.0023±18.0	
11911310	<u>Rattus rattus</u> viscera	18.54±8.7		2.93±5.3	8.74±5.0	999.5±0.7	0.41±3.0	
11912610	<u>Rattus rattus</u> liver	33.00±18.3	105.4±4.0	2.56±14.7	0.015±8.0	741.9±1.0		
11912710	<u>Rattus rattus</u> liver	18.17±11.0	30.9±6.0	3.97±5.9		604.1±0.8		
11912910	<u>Rattus rattus</u> liver		24.4±1.0	2.21±10.8	0.0073±8.0	211.5±1.2		
11913010	<u>Rattus rattus</u> liver		86.9±4.0	6.31±9.4	0.0072±18.0	897.7±0.9	0.018±21.0	$^{151}\text{Sm}$ (34.3±3.0)
11916410	<u>Rattus rattus</u> bone	8.69±7.6		0.304±13.0	115.8±1.0	661.2±1.6	0.26±4.0	
11916510	<u>Rattus rattus</u> bone	5.97±29.5			133.8±1.0	357.9±1.9	0.17±9.0	



Table 59 (continued).

Radionuclide concentration levels, pCi/g cvendry wt (error, %)

Sample No.	Type	<sup>40</sup> K	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	Other
<u>JANET</u>								
11917310	<u>Anous stolidus</u> muscle	9.19±8.1	104.5±2.0	0.51±15.1	0.008±24.0		0.002±26.0	
11917410	<u>Anous stolidus</u> viscera	10.68±19.3	63.96±4.0					
11917510	Terns: common noddy - W.C, S.T. pooled muscle	8.77±6.0	59.5±2.0	0.159±30.6	0.005±21.0		0.005±9.0	
11917610	Terns: pooled - C.N., W.C, S.T. viscera	9.62±12.1	52.2±3.3			0.18±9.9		
11918110	<u>Rattus rattus</u> bone	9.06±11.3		0.218±27.9	68.9±2.0	129.2±1.6	0.030±23.0	
11918210	<u>Rattus rattus</u> bone			0.51±15.2	121.2±3.0	627.5±0.7	3.25±3.0	
11919210	<u>Anous stolidus</u> liver	7.83±22.3	258.1±2.0		0.066±12.0			
11921410	Terns: pooled C.N., W.C, S.T., liver		171.6±2.0				0.0015±23.0	
11924810	<u>Rattus rattus</u> bone	10.32±15.5		0.45±21.2	324.3±1.0	545.5±1.6	0.168±16.0	
11926110	<u>Anous stolidus</u> bone	3.04±39.2	50.0±4.8		0.39±17.0	0.733±13.8		
11926210	Terns: pooled C.N., W.C, S.T., bone	3.32±23.9	39.95±7.5					
10930510	<u>Cocos nucifera</u> fruit	60.05±10.0			1.57±6.0	210.7±1.8		
11907810	<u>Rattus rattus</u> skin					352.9±0.5		
11907910	<u>Rattus rattus</u> skin	6.05±19.6				389.8±0.4		
11908010	<u>Rattus rattus</u> skin	7.8±20.7				180.8±0.6		

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>JANET</u>								
11908110	<u>Rattus rattus</u> <u>skin</u>	10.7±16.4		0.916±23.3		515.3±0.4		
11909510	<u>Rattus rattus</u> <u>kidney</u>	26.1±19.5		2.60±17.3		655.9±1.0		
11909610	<u>Rattus rattus</u> <u>lungs</u>	21.5±21.7			0.45±9.0	587.4±1.0	0.51±10.0	
11911910	<u>Rattus rattus</u> <u>skin</u>	4.94±9.9				405.7±1.8		
11912810	<u>Rattus rattus</u> <u>lungs</u>	76.6±20.1	98.7±11.0		4.11±21.0	1272±1.4		
11914110	<u>Rattus rattus</u> <u>kidney</u>			5.78±21.2		821.6±1.5		
11914210	<u>Rattus rattus</u> <u>lungs</u>				2.93±8.0	1069±1.0		
11914310	<u>Rattus rattus</u> <u>kidney</u>			4.94±15.1		467.1±1.1		
11914410	<u>Rattus rattus</u> <u>kidney</u>			2.63±22.1		274.7±1.3		
11914510	<u>Rattus rattus</u> <u>lungs</u>	48.3±23.7		0.55±13.0		308.1±1.9	1.32±10.0	
11914610	<u>Rattus rattus</u> <u>kidney</u>	62.3±26.6		6.0±18.5		838.3±1.6		
11914710	<u>Rattus rattus</u> <u>lungs</u>	29.7±8.0		2.17±24.2	1.80±5.0	830.2±1.9	0.865±15.0	
11924210	<u>Rattus rattus</u> <u>muscle</u>		26.2±2.0		3.13±3.0	886.9±1.7	0.0128±13.0	

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>KATE</u>								
10189211	<u>Messerschmidia argentea</u> leaves	9.62±6.5			3.75±1.0	4.26±2.1	0.0049±9.0	
10189311	<u>Scaevola frutescens</u> leaves	14.6±5.4				16.36±1.1		
10189411	<u>Pisonia grandis</u> leaves	9.59±6.7		3.85±3.4	23.60±1.0	221.1±0.3	0.0045±21.0	
10189511	<u>Morinda citrifolia</u> leaves	14.50±5.5			23.56±1.0	34.09±0.7		
11917811	<u>Phaethon rubricauda</u> viscera	7.81±13.0						
11921511	<u>Phaethon rubricauda</u> liver							
11923111	<u>Phaethon rubricauda</u> muscle	8.79±6.1						
11926311	<u>Phaethon rubricauda</u> bone					0.10±28.0		$^{65}\text{Zn}$ (0.64±30.1)
<u>LUCY</u>								
10187112	<u>Messerschmidia argentea</u> leaves	10.73±6.2				6.36±1.7		$^{155}\text{Eu}$ (0.05±44.2)
10187212	<u>Scaevola frutescens</u> leaves	13.01±5.5				12.73±1.2		
11919312	<u>Anous stolidus</u> viscera	13.08±10.3	108.6±9.5					
11919412	<u>Anous stolidus</u> liver		199.1±2.0			0.187±11.0		
11923212	<u>Anous stolidus</u> muscle	12.23±10.9	8.78±4.0				0.022±10.0	

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>LUCY</u>								
11925112	Crab hepatopancreas and gonad	10.42±36.2		2.95±9.2		125.7±1.9		
11925212	Crab exoskeleton			0.967±10.9		39.15±1.3		
11926412	<u>Anous stolidus</u> bone		38.5±11.0		0.712±15.0	7.45±4.3		
<u>MARY</u>								
10244114	<u>Morinda citrifolia</u> leaves	16.27±6.9			45.05±1.0		0.034±13.0	
10244214	<u>Messerschmidia argentea</u> leaves	13.24±5.4			7.57±1.9	7.12±1.6		
10244314	<u>Scaevola frutescens</u> leaves	16.14±4.4			16.76±1.1	12.77±1.0		
10244414	<u>Guettarda speciosa</u> leaves	7.70±4.7			36.85±1.0	98.69±1.8		
10244514	<u>Morinda citrifolia</u> fruit	12.45±3.0			4.01±3.0	192.3±0.7	0.012±5.0	
10329814	<u>Cocos nucifera</u> fruit	7.52±6.5	1.18±8.3		0.136±5.4	14.27±1.0		
10466714	<u>Morinda citrifolia</u> fruit	13.45±3.7		0.057±29.2	3.35±2.3	97.43±0.8	0.0022±24.0	
10466814	<u>Lepturus repens</u> leaves				17.39±1.0	105.7±0.9	0.0093±11.0	
11919514	<u>Anous stolidus</u> liver	6.626±27.0	2.51±2.0	0.567±18.5				
11921614	<u>Anous stolidus</u> viscera	11.41±24.6	53.60±1.8					

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>MARY</u>								
11923314	<u>Anous stolidus</u> muscle	6.77±13.6	14.2±3.0	0.316±25.7	0.48±3.0			
11927514	<u>Anous stolidus</u> bone	5.74±13.3	59.9±2.7					
10930714	<u>Cocos nucifera</u> fruit	39.25±8.3			0.635±10.0	67.75±1.4		
10930814	<u>Cocos nucifera</u> fruit	3.80±6.1	76.58±9.5		14.14±9.6	5.59±1.5		
<u>NANCY</u>								
10243615	<u>Guettarda speciosa</u> leaves	8.79±5.4			30.86±1.0	8.73±1.4	0.0097±28.0	
10243715	<u>Pisonia grandis</u> leaves	16.51±4.4		0.237±14.0	36.67±1.0	43.87±1.0	0.0195±14.0	
10243815	<u>Scaevola frutescens</u> leaves	10.74±4.2	0.05±17		11.89±1.0	4.12±1.7	0.0125±16.0	
10243915	<u>Morinda citrifolia</u>	11.16±4.0			43.47±1.0	55.05±0.9	0.0056±26.0	
10329915	<u>Cocos nucifera</u> fruit	6.54±6.9	1.95±6.3		0.167±6.4		18.83±0.8	$^3\text{H}$ (0.333±6.3)
10371215	<u>Messerschmidia argentea</u> leaves	7.81±7.6			27.30±1.0	40.24±0.7	0.023±12.0	
10930915	<u>Cocos nucifera</u> fruit	73.51±17.9	5.95±16.0		1.15±11.0	148.8±4.0		
<u>OLIVE</u>								
10244616	<u>Morinda citrifolia</u> fruit	18.74±4.0			4.48±2.0	30.42±0.7		

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>OLIVE</u>								
10244716	<u>Morinda citrifolia</u> leaves	12.48±5.5	0.063±18	0.33±17.4	37.66±1.0	66.58±0.5	0.011±12	$^{152}\text{Eu}$ (0.13±43.1)
10244816	<u>Morinda citrifolia</u> leaves	18.73±4.4			39.50±1.0	29.57±0.7	0.0036±25.0	
10244916	<u>Messerschmidia argentea</u> leaves	10.73±5.4				9.54±1.2		
10330016	<u>Scaevola frutescens</u> leaves	13.30±5.5				4.35±2.1		
11919616	<u>Anous stolidus</u> liver		332.4±2.0		0.036±16.0		0.010±20.0	
11921716	<u>Anous stolidus</u> viscera	8.81±16.3	57.21±2.4					
11923416	<u>Anous stolidus</u> muscle	7.69±13.5	92.8±2.0				0.092±8.0	
11927616	<u>Anous stolidus</u> bone	4.07±21.9	46.40±3.4	0.31±16.7	0.39±13.0			
<u>PEARL</u>								
10224517	<u>Scaevola frutescens</u> leaves	16.50±4.6			0.348±8.2	0.342±10.3	0.0023±19.0	
10224617	<u>Messerschmidia argentea</u> leaves	14.66±8.0			0.473±5.7	0.295±26.6		
10245417	<u>Scaevola frutescens</u> leaves	12.52±5.2		0.159±28.6	20.99±1.4	30.82±0.7	0.0031±2.7	
11909717	<u>Rattus exulans</u> liver	32.33±12.7	82.0±5.0	5.07±7.7	164.90±6.0	33.30±2.7	0.0119±8.0	
11913117	<u>Rattus exulans</u> viscera			7.45±2.9	1.79±4.0	30.80±1.3	1.77±8.0	

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>PEARL</u>								
11908217	<u>Rattus exulans</u> skin	8.4±16.2		1.58±12.7		15.0±2.3		
11909817	<u>Rattus exulans</u> kidney	51.5±29.5		5.46±17.6		27.9±5.5		
11910517	<u>Rattus exulans</u> lungs				0.84±28.0	51.22±3.7	8.15±6.0	
11919717	Terns liver		317.1±2.0	0.65±26.5				
11921817	Terns, pooled viscera		61.71±2.7	0.435±27.2				
11923517	Terns, pooled muscle	8.67±13.5		0.659±20.0				
11924917	<u>Rattus exulans</u> muscle	11.60±12.4	23.2±8.0	0.888±10.60	0.037±11.0	37.07±1.4	0.117±13.0	
11925017	<u>Rattus exulans</u> bone	9.57±34.1		2.59±10.3	36.1±4.0	53.60±1.4		
11927717	Terns, pooled bone		46.9±5.4			0.793±16.9		
<u>RUBY</u>								
10225118	<u>Messerschmidia argentea</u> leaves	9.19±11.6		0.995±10.3		19.19±2.0		
10225318	<u>Messerschmidia argentea</u> leaves	6.23±5.7		0.905±3.4		39.01±1.7		
<u>SALLY</u>								
10188019	<u>Pandanus tectorius</u> leaves	14.02±10.3	0.703±2.0		1.97±2.0	14.98±2.1	0.015±13.0	

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>SALLY</u>								
10188119	<u>Lepturus repens</u> leaves	3.74±15.9			1.98±1.8	83.20±0.9	0.0227±16.0	
10188219	<u>Messerschmidia argentea</u> leaves	8.28±5.2		0.10±17.4	4.86±1.4	12.63±1.0	0.059±6.7	$^{238}\text{Pu}$ (0.0022±17.0)
10188319	<u>Scaevola frutescens</u> leaves	10.78±6.5			6.67±1.4	13.38±1.3	0.096±14.0	$^{238}\text{Pu}$ (0.0027±26.0)
11900219	<u>Sterna fuscata</u> eggshell				0.265±13.0		0.005±26	
11901619	<u>Sterna fuscata</u> egg	4.57±11.1	37.57±2.0		0.0042±19.0		0.015±4.0	
11906919	<u>Rattus exulans</u> viscera	9.63±9.0		1.48±9.6	14.6±1.0	92.97±0.5	1.30±4.0	
11911419	<u>Rattus exulans</u> liver	10.73±12.3	35.5±4.0	2.54±6.3	0.0021±22.0	63.83±1.2	0.008±15.0	
11915819	<u>Rattus exulans</u> muscle	5.82±17.6				60.86±0.9		$^3\text{H}$ (18.7±1.3)
11917917	<u>Sterna fuscata</u> viscera	4.79±22.40	22.43±5.1					
11919819	<u>Sterna fuscata</u> liver		155.0±3.0					
11919919	<u>Anous tenui</u> liver						0.011±19	
11921919	<u>Anous tenui</u> viscera	5.89±17.30	64.4±1.0					
11923619	<u>Anous tenui</u> muscle	6.31±11.50	36.6±2.0				0.005±11	
11923819	<u>Rattus exulans</u> bone	7.01±15.0		0.81±15.3	25.9±2.0	65.77±0.7	0.039±15.0	



Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>SALLY</u>								
11908319	<u>Rattus exulans</u> skin	4.52±11.9		0.49±16.0		49.1±0.6		
11926519	Sooty tern bone		61.3±4.5	0.34±14.1	1.68±7.6	0.14±27.0		
11927819	Sooty tern bone		35.7±4.7					
11913219	<u>Rattus exulans</u> lungs	13.2±21.4		0.67±23.9	0.22±11.0	73.9±1.8	0.198±6.0	
11914819	<u>Rattus exulans</u> kidney			2.28±14.2		73.3±1.4		
11923719	Noddy tern muscle	7.63±10.8	109.5±2.0		0.014±18.0		0.020±8.0	
<u>TILDA</u>								
10330420	<u>Guettarda speciosa</u> leaves	10.10±5.2			12.57±1.0	5.90±1.4	0.0091±19.0	
10330520	<u>Pandanus tectorius</u> leaves	13.29±7.2	2.94±5.0		15.50±2.0	152.2±0.4	0.0069±18.0	
10330620	<u>Scaevola frutescens</u> leaves	11.39±5.7			9.05±1.7	24.94±0.8	0.0042±26.0	
10330720	<u>Morinda citrifolia</u> leaves	13.94±5.1			12.48±1.1	13.90±1.1		
10330820	<u>Messerschmidia argentea</u> leaves	10.13±5.7			10.27±1.5	58.78±1.9		
<u>URSULA</u>								
10187521	<u>Messerschmidia argentea</u> leaves	10.09±3.7			13.60±1.0	104.9±1.7		

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>URSULA</u>								
10187621	<u>Scaevola frutescens</u> leaves	5.45±10.7			6.13±1.0	91.49±0.8	0.0031±11.0	
10187721	<u>Scaevola frutescens</u> leaves	13.47±9.4				0.293±29.1		
10187821	<u>Guettarda speciosa</u> leaves	14.23±9.0			7.30±1.2	13.27±2.0		
11907021	<u>Rattus exulans</u> viscera	10.87±12.5		1.13±18.5	2.17±1.9	43.14±1.1	0.29±3.0	
11913321	<u>Rattus exulans</u> liver	6.72±31.7	42.2±5.0	3.59±6.2		39.41±3.1	0.041±9.0	$^{207}\text{Bi}$ (0.375±29.9)
11908421	<u>Rattus exulans</u> skin	7.58±11.3		0.41±21.6		18.5±1.4		
11914921	<u>Rattus exulans</u> kidney					38.4±6.6		
11915021	<u>Rattus exulans</u> lungs					45.0±3.0		
11915921	<u>Rattus exulans</u> muscle	9.22±18.6				37.86±1.3		
11916621	<u>Rattus exulans</u> bone	7.26±25.0			19.6±4.0	61.58±1.2	0.146±9.0	
<u>VERA</u>								
10225822	<u>Messerschmidia argentea</u> leaves	7.07±6.5			12.79±1.4	10.77±1.1	0.0024±19.0	
10225922	<u>Scaevola frutescens</u> leaves	8.18±6.4			4.49±1.7	1.686±3.4		
10226022	<u>Morinda citrifolia</u> leaves	10.46±6.8			11.85±2.5	12.12±1.4		

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>URSULA</u>								
10226122	<u>Pisonia grandis</u> leaves	28.58±4.8			23.11±1.1	56.94±1.0		
10226222	<u>Pandanus tectorius</u>	9.171±8.8			4.24±2.8	17.58±1.5	0.0076±15.0	
10245622	<u>Cocos nucifera</u> fruit	5.64±7.6			0.134±6.0	9.297±1.2		
<u>WILMA</u>								
10224823	<u>Messerschmidia argentea</u> leaves	5.00±11.0				6.19±2.9		
10224923	<u>Scaevola frutescens</u> leaves	10.31±6.8				1.245±3.7		
10225023	<u>Guettarda speciosa</u> leaves	10.60±4.3				3.14±1.9		
<u>YVONNE</u>								
10327224	<u>Scaevola frutescens</u> leaves	13.2±5.4		0.511±11.8	1.76±1.6	11.88±1.2	0.0265±20.0	$^{238}\text{Pu}$ (0.0068±32.0)
10327324	<u>Scaevola frutescens</u>	14.16±5.3			0.442±5.4	1.575±3.7	0.0042±3.9	
10327424	<u>Messerschmidia argentea</u> leaves	14.19±5.8			0.6396±5.9	2.28±3.3	0.0036±5.1	
10327524	<u>Scaevola frutescens</u>	15.0±5.1		0.246±22.3	0.662±4.9	8.06±1.5	1.293±5.0	$^{238}\text{Pu}$ (0.061±9.7), $^{241}\text{Am}$ (0.146±5.0)
10327624	<u>Scaevola frutescens</u>	10.68±6.3		20.26±1.4	159.0±1.0	609.9±0.2	0.323±5.0	
10327724	<u>Guettarda speciosa</u>	11.15±5.9		4.52±3.2	64.4±1.0	795.0±0.1	0.0253±1.8	
10327824	<u>Messerschmidia argentea</u>	14.46±5.7			1.428±3.9	3.81±2.4	0.0108±2.9	

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>YVONNE</u>								
10327924	<u>Messerschmidia argentea</u>	10.91±5.6			8.6±2.0	95.3±0.4	0.129±3.0	
10328024	<u>Scaevola frutescens</u>	15.93±4.3			1.94±1.4	28.25±0.7	0.19±5.4	$^{238}\text{Pu}$ (0.076±9.0)
10330124	<u>Scaevola frutescens</u>	18.77±4.1		6.26±2.5	80.63±1.0	658.0±0.1	0.196±2.0	
10330224	<u>Messerschmidia argentea</u>	10.33±7.0			1.94±3.4	17.30±1.1	0.766±1.0	
10330324	<u>Messerschmidia argentea</u>	9.928±6.0		1.16±7.7	257.2±1.0	5644.0±0.0	0.114±6.0	
10371024	<u>Cocos nucifera</u> fruit	6.392±7.2				1.986±2.8		
10371124	<u>Cocos nucifera</u> fruit	8.243±5.8			0.011±5.0	3.96±1.8		$^3\text{H}$ (0.66±8.3)
11900824	<u>Anous stolidus</u> eggshell		1.10±27.0		0.22±18.0			
11900924	<u>Anous stolidus</u> eggshell						0.0086±17.0	
11901724	<u>Anous stolidus</u> egg	4.53±15.5			1.06±6.0			
11901824	<u>Anous stolidus</u> egg	4.129±17.2	56.76±2.0				0.0232±6.0	
11901924	<u>Anous stolidus</u> egg	7.221±9.3	54.5±2.0		0.073±11.0	0.079±46.0		
11906724	<u>Rattus rattus</u> viscera	13.33±8.2		230.0±0.5	4.09±2.0	3531.0±0.1	0.58±3.0	
11907124	<u>Rattus rattus</u> viscera	9.667±12.6		1.99±10.7	0.57±5.0	76.7±0.8	0.393±3.0	
11909924	<u>Rattus rattus</u> liver		126.1±3.0	70.3±3.2		2559.0±0.9	0.0271±12.0	$^{151}\text{Sm}$ (18.7±3.0)
11911524	<u>Rattus rattus</u>	14.15±14.8	135.6±2.0	86.13±1.5	0.0046±7.0	2215.0±0.7	0.0129±13.0	

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>YVONNE</u>								
11911624	<u>Rattus rattus</u> <u>viscera</u>		3.46±18.0	4.186±3.7	0.327±19.0	55.8±1.4	0.211±7.2	$^{238}\text{Pu}$ (0.0964±8.3)
11911724	<u>Rattus rattus</u> <u>viscera</u>	17.77±14.4			0.20±10.0	5.7±5.7	0.0206±11.0	
11911824	<u>Rattus rattus</u> <u>viscera</u>	7.608±15.4		112.6±0.9		2928.0±1.8	1.05±3.0	$^{134}\text{Cs}$ (1.9±19.2)
11913624	<u>Rattus rattus</u>		25.1±2.0	2.9±6.5		56.2±1.7	0.0078±24.0	$^{151}\text{Sm}$ (23.0±3.0)
11913724	<u>Rattus rattus</u> <u>liver</u>		13.8±18.0	5.63±7.9	0.0024±27.0	38.7±2.7	0.011±26.0	
11915424	<u>Rattus rattus</u> <u>liver</u>		17.3±8.0		10.54±2.0	4.62±15.0	0.0398±8.0	
11916024	<u>Rattus rattus</u> <u>muscle</u>	12.35±15.7	32.8±3.0	12.83±4.5	5.09±4.0	4240.0±0.1	0.052±9.0	$^3\text{H}$ (1.8±2.3)
11916124	<u>Rattus rattus</u> <u>muscle</u>	13.07±7.3	78.8±2.0	8.51±2.9	37.8±1.0	3824.0±0.1		
11916224	<u>Rattus rattus</u> <u>muscle</u>	16.82±9.9				86.0±0.9		
11916724	<u>Rattus rattus</u> <u>bone</u>			5.92±2.8	146.4±1.0	1833.0±0.7		$^{134}\text{Cs}$ (1.12±18.8)
11916824	<u>Rattus rattus</u> <u>bone</u>	7.932±12.2		10.57±3.7	135.1±1.0	2200.0±0.7	0.29±5.0	$^{134}\text{Cs}$ (1.36±13.9)
11916924	<u>Rattus rattus</u> <u>bone</u>	9.739±12.2		0.327±28.0	16.7±2.0	48.8±1.2	0.304±11.0	
11918024	<u>Anous stolidus</u> <u>viscera</u>	8.338±24.3	64.4±3.6	0.51±35.3				
11920024	<u>Anous stolidus</u> <u>liver</u>		385.6±2.0	0.37±25.8				

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>YVONNE</u>								
11923924	<u>Anous stolidus</u> muscle	7.387±11.1	22.6±2.0	0.23±36.6	0.0073±28.0		0.020±37.0	
11924324	<u>Rattus rattus</u> muscle	5.77±25.3	4.1±6.0	0.554±24.9	6.76±5.0	49.2±1.7		$^3\text{H}$ (1.1±5.6)
11924424	<u>Rattus rattus</u> muscle	15.87±6.8	1.23±22.0		0.631±3.0	3.74±3.1	0.0077±21.0	
11925324	<u>Rattus rattus</u> bone	23.95±13.7			1.32±8.0	23.8±3.0	0.059±15.0	
11925424	<u>Rattus rattus</u> bone			0.514±9.7	6.40±13.0	38.78±1.1	0.059±11.0	
11926624	<u>Anous stolidus</u> bone		63.5±1.0			5.51±4.8	0.021±26.0	
11908924	<u>Rattus rattus</u> skin	10.7±19.9				3.94±7.0		
11900624	<u>Anous tenuirostris</u> eggs							
11908624	<u>Rattus rattus</u> skin	6.92±18.4		7.43±4.0		1875±0.1		
11908724	<u>Rattus rattus</u> skin	4.74±21.0				42.6±0.9		
11908524	<u>Rattus rattus</u> skin	6.7±10.9		14.0±2.2		2088±0.1		
11908824	<u>Rattus rattus</u> skin			0.69±22.3		28.4±1.2		
11910024	<u>Rattus rattus</u> kidney			257.7±2.9		3427±1.8		
11910124	<u>Rattus rattus</u> lungs	33.1±14.2	252.3±2.4	11.1±5.2	16.2±6.4	2760±0.8		

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>YVONNE</u>								
11910224	<u>Rattus rattus</u> lungs					53.3±3.9	0.57±15.0	
11910324	<u>Rattus rattus</u> kidney	167.2±17				6.19±23.4		
11910424	<u>Rattus rattus</u> lungs					11.6±19.3	0.20±24.0	
11913424	<u>Rattus rattus</u> kidney			261.8±1.1		3286±1.0		
11913524	<u>Rattus rattus</u> lungs	14.3±28.7		10.5±6.1	0.24±11.0	3306±1.7	0.11±9.0	$^{134}\text{Cs}$ (1.5±28.5)
11915124	<u>Rattus rattus</u> kidney			4.96±17.1		59.6±3.7		
11915224	<u>Rattus rattus</u> lungs					39.7±3.4	0.023±34.0	
11915324	<u>Rattus rattus</u> kidney	30.64±24.2		8.03±7.3		29.0±3.5		
<u>ALVIN</u>								
10156130	<u>Messerschmidia argentea</u>	11.57±10.4				0.846±10.1		
11918330	Terns, pooled liver	20.37±10.7						
11922030	Terns, pooled muscle	10.44±12.0						
11925630	Terns, pooled bone	10.32±15.1				5.71±4.8		
<u>TOM</u>								
10187027	<u>Messerschmidia argentea</u>	9.16±4.9				0.26±8.0		

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>TOM</u>								
10155327	<u>Scaevola frutescens</u>	11.5±3.7				0.74±4.0		
<u>URIAH</u>								
10155428	<u>Messerschmidia argentea</u>	11.9±12.5				0.73±10.0		
<u>VAN</u>								
10155529	<u>Messerschmidia argentea</u>	6.81±8.0				0.35±10.7		
10155729	<u>Pisonia grandis</u>	12.9±5.3		0.17±28.2		1.99±3.2		
10155629	<u>Scaevola frutescens</u>	7.11±7.9				0.73±6.3		
11925929	<u>Anous stolidus</u> bone	6.96±20.2	40.3±1.6		0.14±3.0	0.74±2.4		
11900429	<u>Anous stolidus</u> egg shell		1.68±17.0					
11902029	<u>Anous stolidus</u> egg	6.31±10.8	63.5±2.0			0.14±30.7	0.0004±29.0	
11917229	<u>Anous stolidus</u> muscle	10.5±8.2	99.55±2.0	0.29±26.7			0.0014±20.0	
11918929	<u>Anous stolidus</u> liver		278.9±2.0	0.19±33	0.04±8.0			
11921129	<u>Anous stolidus</u> viscera		50.5±1.6					
<u>BRUCE</u>								
10156931	<u>Cocos nucifera</u>	5.93±7.1				0.582±5.6		
10186731	<u>Messerschmidia argentea</u>	8.027±6.3			0.328±5.3	1.158±4.0		
10186831	<u>Scaevola frutescens</u>	9.32±5.5			0.878±2.5	0.751±5.5		



Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
BRUCE								
10186931	<u>Pisonia grandis</u>	17.76±2.8			0.50±4.0	1.456±2.6		
11903931	<u>Birgus latro</u> muscle	11.28±6.4	0.98±37.0	0.20±27.3	0.185±6.0	1.978±3.5		$^3\text{H}$ (0.42±5.2)
11918431	<u>Anous tenuirostris</u> liver	8.369±28.5	326.6±2.0					
11922131	<u>Anous tenuirostris</u> muscle	7.095±12.4	41.3±2.0	0.392±19.9			0.0069±8.0	
11924531	<u>Rattus rattus</u> bone	18.81±12.0			1.69±4.0	13.25±3.1	3.279±4.0	
11925731	<u>Anous tenuirostris</u> bone		44.2±1.3		0.66±12.0			
11904031	<u>Birgus latro</u> exoskeleton	2.59±10.4	0.07±28.0		6.08±3.0	0.287±8.1	0.001±4.0	
11904131	<u>Birgus latro</u> hepatopancreas and gonad	3.018±10.4	5.7±3.0	0.402±10.4	0.133±2.0	0.42±7.1		$^3\text{H}$ (0.16±2.4)
11909031	<u>Rattus rattus</u> liver	30.2±17.0	46.4±7.0	1.617±23.5		1.07±32.6	0.013±11.0	
11912231	<u>Rattus rattus</u> viscera					1.09±132.0	0.035±12.0	
11915531	<u>Rattus rattus</u> muscle	5.207±38.6	2.21±16.0		0.074±9.0	1.472±12.8	0.0086±13.0	
11904231	<u>Birgus latro</u> skin, gills, green gland	7.25±17.7				1.68±8.6		
11904331	<u>Birgus latro</u> shell, gill, dust, gut blood	6.15±14.5				1.34±7.4		
11907531	<u>Rattus rattus</u> hide	8.07±18.7				0.61±23.1		

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>BRUCE</u>								
11909131	<u>Rattus rattus</u> kidney			3.19±20.5				
11913831	<u>Rattus rattus</u> lungs	35.9±34.3						
11920331	<u>Anous tenuirostris</u> viscera		73.9±1.1					
<u>CLYDE</u>								
10155932	<u>Messerschmidia argentea</u>	10.9±5.7				0.426±8.3		
10156032	<u>Scaevola frutescens</u>	11.19±5.7				0.273±12.9		
11900132	<u>Sterna fuscata</u> eggshells	1.365±13.0						
11901132	<u>Sterna fuscata</u> eggs	5.41±9.8						
11920432	<u>Sterna fuscata</u> viscera	7.937±13.0	49.1±4.9					
11920532	<u>Sterna fuscata</u> liver		146.4±2.0		0.015±8.0		0.0017±29.0	
11922432	<u>Sterna fuscata</u> muscle	7.374±8.7	20.4±2.0		0.00635±17.0			
11925832	<u>Sterna fuscata</u> bone	2.36±36.0	36.0±12.0					
<u>DAVID</u>								
10019933	<u>Messerschmidia argentea</u>	13.55±5.1			0.464±4.8	1.086±4.3	0.0061±22.0	
10020533	<u>Tacca leontopetaloides</u>	6.635±9.8			0.096±3.0	8.60±1.5	0.0011±32.0	$^3\text{H}$ (0.52±4.9)
10020633	<u>Cocos nucifera</u>	6.441±8.1			0.01387±6.0	2.593±2.5		$^3\text{H}$ (0.31±13.7)
10020833	<u>Scaevola frutescens</u>	17.59±4.8			0.341±7.4	1.114±4.7	0.0005±5.7	
10021133	<u>Pisonia grandis</u>	19.02±4.7			0.77±3.1	3.118±2.6	0.0013±25.0	
10020033	<u>Pisonia grandis</u>	10.2±6.6			0.56±6.2	1.80±3.4	0.0002±9.8	
10021333	<u>Cocos nucifera</u>	3.761±14.4			0.1784±6.8	1.688±4.0		$^{102}\text{Rh}$ (0.1234±26.2)

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
DAVID								
10022633	<u>Morinda citrifolia</u>	12.59±3.7			0.0251±4.0	3.84±1.5	0.0127±6.00	
10370333	<u>Pandanus tectorius</u>	9.74±7.9	0.13±19.0		3.56±1.0	15.9±1.2		
10370433	<u>Scaevola frutescens</u>	10.69±5.1			0.3716±5.2	4.82±1.6		
10371333	<u>Messerschmidia argentea</u>	11.02±5.1			0.757±8.0	7.243±1.3		
10371433	<u>Pisonia grandis</u>	18.10±3.6			0.608±4.3	1.677±2.9		
10371533	<u>Guettarda speciosa</u>	3.996±11.1			0.322±7.6	3.157±2.5		
10412033	<u>Fimbristylis atollensis</u> sedge	3.383±22.3				7.396±2.1		
10412133	<u>Cocos nucifera</u>	4.694±6.6			0.0263±10.0	0.399±5.9	0.00343±5.0	
10412233	<u>Scaevola frutescens</u>	13.02±9.2			0.314±7.6	5.18±3.2		
10412433	<u>Messerschmidia argentea</u>	13.22±5.3			1.059±5.3	2.581±3.4		
10412333	<u>Scaevola frutescens</u>	16.33±9.4			0.5586±6.6	2.014±7.0		
10412533	<u>Messerschmidia argentea</u>	3.882±16.3			0.748±6.8	15.84±1.3		
11902133	<u>Coenobita perlatus</u> hepatopancreas and gonad	7.613±9.6	0.57±34.0	0.23±28.8	0.191±8.0	1.946±4.3	4.82±33.0	$^3\text{H}$ (0.95±6.1)
11902933	<u>Coenobita perlatus</u> muscle	7.518±8.2		0.284±19.5	0.366±3.0	2.064±3.5	0.0031±8.0	$^3\text{H}$ (0.58±3.5)
11903033	<u>Coenobita perlatus</u> exoskeleton	1.764±12.8	0.039±37.0		4.05±3.0	0.601±4.2	0.010±6.0	
10931133	<u>Cocos nucifera</u> milk	30.93±8.4				23.32±2.0		
11924133	<u>Sterna fuscata</u> muscle	7.459±20.1	59.0±2.0				0.119±30.0	
11924733	<u>Erolia cuminata</u> liver	17.57±32.1						

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>DAVID</u>								
11925533	<u>Demigretta sacra</u> bone	8.761±13.0		0.41±16.0				
11926733	<u>Erolia cuminata</u> bone	28.16±8.5				0.789±19.5		
11926833	<u>Demigretta sacra</u> bone					1.34±6.9		
11926933	<u>Sterna fuscata</u> bone		37.4±9.2			0.745±11.3		$^{134}\text{Cs}$ (0.413±21.5)
11906233	<u>Rattus exulans</u> viscera	12.24±7.1			0.24±6.0	21.97±0.9	0.0087±9.0	
11910633	<u>Rattus exulans</u> liver		3.67±6.0			16.36±2.4	0.00424±18.0	
11918533	<u>Sterna fuscata</u> liver	20.36±16.0	153.2±3.0					
11922233	<u>Rattus exulans</u> muscle	7.802±17.2	0.98±12.0		0.604±6.0	18.78±1.6	0.044±7.0	
11922333	<u>Rattus exulans</u> bone	11.46±13.0			1.37±2.0	28.37±1.3	0.065±10.0	
11924033	<u>Demigretta sacra</u> muscle	4.653±38.0				1.59±10.5		
10020033	<u>Pisonia grandis</u>	10.2±6.6			0.56±6.2	1.8±3.4	0.0002±9.8	
11907633	<u>Rattus exulans</u> hide	6.49±9.1				9.13±1.6		
11912333	<u>Rattus exulans</u> kidney					17.0±3.0		
11913933	<u>Rattus exulans</u> lungs					18.5±5.8	0.031±16.0	
11924633	<u>Erolia cuminata</u> viscera							

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>DAVID</u>								
11920133	<u>Sterna fuscata</u> viscera	8.9±26.7	63.5±5.2					
<u>REX</u>								
10157034	<u>Scaevola frutescens</u>	6.964±8.3				0.495±8.3		
10186534	<u>Messerschmidia argentea</u>	8.896±7.2				2.451±2.9		
10186634	<u>Pisonia grandis</u>	16.0±4.1		0.091±23.1		2.642±2.2		
11900534	<u>Anous stolidus</u> eggshell		0.73±16.0					
11920934	<u>Anous stolidus</u> viscera		50.0±3.7					
11901334	<u>Anous stolidus</u> egg	7.689±8.9	51.4±2.0				0.0077±19.0	
11902434	<u>Coenobita perlatus</u> hepatopancreas and gonad	5.833±10.1	1.82±8.0	0.566±12.5	0.289±4.0	0.783±7.2	0.00346±11.0	
11903134	<u>Coenobita perlatus</u> muscle	6.676±8.8	1.47±12.0	1.436±6.6	0.319±3.0	1.05±5.8	0.0026±12.0	
11903234	<u>Coenobita perlatus</u> exoskeleton	1.838±13.0	0.085±29.0		3.62±2.0	0.249±8.2	0.001±16.0	
11921034	<u>Anous stolidus</u> liver	4.887±35.2	117.6±2.0					
11922734	<u>Anous stolidus</u> muscle	10.81±8.2	43.5±2.0		0.00649±19.0		0.0056±11.0	
11927334	<u>Anous stolidus</u> bone		44.77±3.7					

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>ELMER</u>								
10156235	<u>Messerschmidia argentea</u>				0.982±2.5	2.386±5.0		
10156335	<u>Scaevola frutescens</u>	13.6±9.2			0.272±4.8	2.405±5.1		
10156435	<u>Cocos nucifera</u>	9.734±12.4			0.032±4.0	2.14±5.3		$^3\text{H}$ (0.31±14.4)
10156535	<u>Messerschmidia argentea</u>	9.04±5.4			0.626±2.8	1.657±3.2		
10156635	<u>Scaevola frutescens</u>	11.83±4.0			0.617±2.9	1.475±2.8		
10156735	<u>Cocos nucifera</u>	5.505±8.6				3.451±2.5		
10156835	<u>Pandanus tectorius</u>	8.856±6.6	0.41±13.0		25.14±3.0	3.091±2.4	0.002±22.0	
11906335	<u>Rattus rattus</u> viscera	11.19±6.0		1.39±6.3	0.16±1.0	19.0±1.0	0.0074±14.0	
11907235	<u>Rattus rattus</u> muscle	10.3±6.2	0.10±29.0		0.06±4.0	18.4±1.0	0.016±31.0	$^3\text{H}$ (11.3±1.3)
11907435	<u>Rattus rattus</u> liver	11.1±12.0	0.93±36.0		0.018±15.0	15.6±2.0		
11907735	<u>Rattus rattus</u> hide	6.5±8.7				7.6±1.7		
11909235	<u>Rattus rattus</u> lungs	14.7±20.1			1.0±4.0	16.9±3.8	0.14±10.0	
11909335	<u>Rattus rattus</u> kidney	21.8±9.5		1.74±8.7		15.0±2.3		
11916335	<u>Rattus rattus</u> bone	9.04±7.2			1.42±5.0	9.96±2.4	0.23±6.0	
<u>WALT</u>								
10411036	<u>Guettarda speciosa</u>	9.82±4.0				0.18±10.3		
10411136	<u>Scaevola frutescens</u>	6.986±8.2				1.44±2.4		

Table 59 (continued).

## Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>WALT</u>								
10411236	<u>Messerschmidia argentea</u>	6.658±7.6				0.38±8.3		
<u>FRED</u>								
10000637	<u>Messerschmidia argentea</u>	11.23±6.2			0.43±4.6	0.558±7.5		
10008637	<u>Scaevola frutescens</u>	10.36±6.8			0.234±6.8	0.652±7.2	0.0006±11.0	
10155837	<u>Messerschmidia argentea</u>	8.829±5.1			0.487±3.2	1.78±2.5		
10188837	<u>Cocos nucifera</u>	6.387±6.7			0.0296±7.0	2.386±3.6		$^3\text{H}$ (0.39±11.6)
10188937	<u>Scaevola frutescens</u>	7.14±6.6			0.806±3.3	3.801±2.3		
10189037	<u>Cocos nucifera</u>	5.59±6.9			0.367±18.0	0.53±6.0		
10466937	<u>Pandanus tectorius</u>	3.382±13.1	0.85±6.0		0.422±2.0	4.29±2.3	0.0077±38.0	
<u>GLENN</u>								
10021238	<u>Cocos nucifera</u>	6.13±6.1			0.02±4.0	0.87±3.7		
10370538	<u>Messerschmidia argentea</u>	9.752±6.1			2.51±1.6	1.27±4.1		
10370638	<u>Cocos nucifera</u>	8.279±4.9				1.3±2.9		
10370738	<u>Scaevola frutescens</u>	13.74±5.2			1.342±5.0	0.53±8.0		
10370838	<u>Pisonia grandis</u>	30.28±3.5			1.74±3.0	3.91±2.3		
11902638	<u>Coenobita perlatus</u> <u>hepatopancreas</u> <u>and gonad</u>	8.68±11.4	1.55±7.0	1.124±11.2	0.432±8.0	1.51±6.8	0.006±32	
10008038	<u>Morinda citrifolia</u>	15.7±3.1			0.405±5.3	0.450±5.0		
10008138	<u>Pisonia grandis</u>	25.79±4.3	0.81±19.0		2.88±2.2	1.86±3.8		$^{102}\text{Rh}$ (0.17±21.2)
10008238	<u>Cocos nucifera</u>	7.527±9.1			0.326±6.8	1.655±4.1		
10008338	<u>Morinda citrifolia</u>	22.29±4.3			1.58±3.0	0.638±7.2		

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>GLENN</u>								
10008438	<u>Messerschmidia argentea</u>	21.81±4.7			2.05±1.8	1.245±4.9		
10008538	<u>Scaevola frutescens</u>	12.84±5.7			1.54±2.2	0.637±7.0		
11903338	<u>Coenobita perlatus</u> muscle	7.856±11.3	1.32±18.0	1.97±7.5	0.91±5.0	1.51±6.6	0.11±7.0	
11903438	<u>Coenobita perlatus</u> exoskeleton	1.519±19.2			9.14±2.0	0.252±10.3	0.0011±14.0	
11905338	<u>Birgus latro</u> muscle	10.45±7.1	0.68±13.0			1.88±3.7		$^3\text{H}$ (0.69±4.8)
11905438	<u>Birgus latro</u> exoskeleton	1.06±29.0			10.4±1.0	0.313±9.3	0.0035±10.0	
11905538	<u>Birgus latro</u> hepatopancreas and gonad	2.338±15.0		0.276±15.7	0.269±3.0	0.545±6.1		$^3\text{H}$ (0.27±10.7)
11906538	<u>Rattus exulans</u> viscera	11.75±6.4		2.06±5.3	0.28±6.0	1.88±4.0	0.036±13.0	
11910738	<u>Rattus exulans</u> liver	12.79±10.2	19.28±4.0	1.81±6.9		1.455±8.5	0.035±6.0	
11915638	<u>Rattus exulans</u> bone	10.61±9.0		0.711±15.8	2.67±2.0	6.02±2.2	0.87±4.0	
11915738	<u>Rattus exulans</u> muscle	8.18±8.3	4.49±4.0	0.48±15.4	1.03±3.0	1.76±3.7	0.017±7.0	
10021538	<u>Pisonia grandis</u> wood	7.26±7.8				0.37±10.2		
11905638	<u>Birgus latro</u> skin, gills, green gland	7.35±18.6		0.83±22.8		1.74±7.8		
11906438	<u>Rattus exulans</u> hide	2.3±11.9				0.33±8.0		
11912438	<u>Rattus exulans</u> kidney			2.4±14.0		1.46±19.1		



Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>GLENN</u>								
11912538	<u>Rattus exulans</u> lungs	20.7±11.9				1.74±11.0	0.30±7.0	
<u>HENRY</u>								
10020739	<u>Messerschmidia argentea</u>	12.77±5.8			1.98±2.9	0.52±8.0		
10021039	<u>Lepturus repens</u>	11.29±7.1			0.059±13.0	0.099±37.4	0.0021±20.0	
10021439	<u>Scaevola frutescens</u>	12.64±5.8				0.195±17.1		
10021639	<u>Morinda citrifolia</u>	17.3±3.3			0.325±5.1	1.28±3.2		
10022739	<u>Cocos nucifera</u>	3.39±5.5				0.59±2.5		
11902239	<u>Coenobita perlatus</u> hepatopancreas and gonad	5.725±9.9		0.98±8.4	0.496±3.0	1.17±5.3		
11903539	<u>Coenobita perlatus</u> muscle	7.694±7.8	0.98±12.0	1.996±5.2	0.64±1.0	1.08±5.5	0.0066±7.0	
11903639	<u>Coenobita perlatus</u> exoskeleton	2.344±13.5	0.08±17.0		9.64±1.0	0.24±10.5	0.0009±20.0	
11912139	<u>Anous stolidus</u> egg	3.385±9.9	54.1±2.0					$^{65}\text{Zn}$ (0.79±23.1)
11912039	<u>Anous stolidus</u> eggshell		8.6±1.9					
<u>IRWIN</u>								
10245040	<u>Messerschmidia argentea</u>	13.54±5.9			1.73±2.6	0.533±8.6		
10245140	<u>Pisonia grandis</u>	21.77±4.1			0.595±5.4	1.88±3.3	0.0015±15.0	
10245240	<u>Cocos nucifera</u>	6.995±7.0				0.329±9.5		
10245340	<u>Terminalia samoensis</u>	11.36±5.8			0.923±4.6	0.772±5.7	0.0013±7.9	
11901240	<u>Anous stolidus</u> egg	7.49±10.2	5.14±6.0				0.0009±21.0	

Table 59 (continued).

## Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>IRWIN</u>								
11902340	<u>Coenobita perlatus</u> hepatopancreas and gonad	7.752±9.3	1.78±5.0	0.893±10.0	0.446±4.0	0.579±10.0	0.0053±13.0	
11903740	<u>Coenobita perlatus</u> muscle	6.743±9.3	0.75±17.0	1.77±6.2	0.309±4.0	0.553±10.0	0.01248±13.0	
11903840	<u>Coenobita perlatus</u> exoskeleton	2.73±13.9	0.11±11.0		4.78±1.0	0.098±24.6	0.00078±19.0	
11918640	<u>Anous stolidus</u> liver	15.84±14.5	423±2.0	0.63±22.4	0.23±15.0		0.0242±26.0	
11922540	<u>Anous stolidus</u>	9.279±15.9	169±2.0	0.61±27.9			0.0434±8.0	
11927040	<u>Anous stolidus</u> bone		49.1±5.3					
11900340	<u>Anous stolidus</u> eggshell							
11920640	<u>Anous stolidus</u> viscera		46.0±9.9					
<u>JAMES</u>								
10242541	<u>Messerschmidia argentea</u>	17.7±3.5		0.25±23.3		1.76±2.7		
10242641	<u>Pisonia grandis</u>	12.66±5.8				1.55±3.9		
10242741	<u>Guettarda speciosa</u>	13.74±5.7				0.683±6.9		
10242841	<u>Morinda citrifolia</u>	16.99±5.2			1.85±3.5	2.23±3.4		
10242941	<u>Scaevola frutescens</u>	9.419±7.6				0.517±8.8		
11905741	<u>Birgus latro</u> muscle	9.617±6.2	1.84±6.0	1.05±8.7	0.079±5.0	1.25±4.1		
11905841	<u>Birgus latro</u> exoskeleton	1.445±18.2	0.30±8.0	0.11±4.5	5.9±2.0	0.223±10.4	0.00195±12.0	
11905941	<u>Birgus latro</u> hepatopancreas and gonad	4.005±12.8	12.8±2.0	1.56±6.6		0.317±14.2		

Table 59 (continued).

## Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>JAMES</u>								
11906041	<u>Birgus latro</u> skin, gills, green gland	7.13±20.1		2.3±9.6		1.15±11.2		
11906141	<u>Birgus latro</u> miscellany	5.35±16.2		0.98±15.5		0.79±10.4		
<u>KEITH</u>								
10226942	<u>Pandanus tectorius</u>	12.7±5.9	12.2±3.0		13.11±4.0	0.86±6.1		$^3\text{H}(2.0±4.0)$
10243042	<u>Messerschmidia argentea</u>	12.45±5.8		0.20±24.6	0.318±9.2	0.255±14.0	0.00445±27.0	
10243142	<u>Pisonia grandis</u>	30.81±3.6			3.0±2.6	3.65±2.4		
10243242	<u>Cocos nucifera</u>	7.689±6.6				0.95±4.5		
10243342	<u>Guettarda speciosa</u>	12.87±5.7			1.74±4.6	0.471±8.7		
10243442	<u>Pandanus tectorius</u>	8.18±5.2	0.36±29.0			0.569±5.4		
10243542	<u>Scaevola frutescens</u>	15.52±8.2			0.64±4.6	0.427±17.4		
11904442	<u>Birgus latro</u> muscle	10.11±6.0	1.46±6.0	0.42±13.2	1.19±4.0	1.92±3.2		
11904542	<u>Birgus latro</u> exoskeleton	3.349±12.4	0.18±10.0		9.96±1.0	0.512±8.1	0.00067±26.0	
11904642	<u>Birgus latro</u> hepatopancreas and gonad	3.205±13.3	6.17±3.0	1.03±8.1	0.401±6.0	0.496±8.6	0.0098±6.0	
11920742	<u>Anous stolidus</u> viscera	8.968±16.3	80.2±3.0					
11922642	<u>Anous stolidus</u> muscle	12.96±7.9		0.452±20.9			0.001±18.0	
11927142	<u>Anous stolidus</u> bone	3.797±31.6	68.5±3.4	0.312±23.5				
11918742	<u>Anous stolidus</u> liver			0.69±17.5				

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>KEITH</u>								
11904742	<u>Birgus latro</u> skin, gills, green gland	7.37±13.2		2.54±7.0		3.87±3.2		
11904842	<u>Birgus latro</u> shell, gills, dust, gut blood	11.4±18.4				1.60±11.6		
<u>LEROY</u>								
10020443	<u>Pandanus tectorius</u>	7.995±7.9	0.21±16.0		1.69±3.0	9.14±1.5	0.0022±11.0	
10020343	<u>Pandanus tectorius</u> fruit	30.2±4.9			16.26±1.0	26.2±1.1		
10020143	<u>Scaevola frutescens</u>	13.29±5.6			3.74±1.3	1.80±3.6		
10020243	<u>Pisonia grandis</u>	34.27±3.4			14.86±1.0	10.17±14.0		
10020943	<u>Messerschmidia argentea</u>	15.09±5.3		0.21±25.5	14.37±1.0	4.71±2.1		
10022543	<u>Cocos nucifera</u>	4.07±5.1			0.189±5.0	3.83±1.9		$^{102}\text{Rh}$ (0.13±24.9)
11904943	<u>Birgus latro</u> muscle	8.797±5.9	1.59±5.0	1.234±6.5	1.577±2.0	12.6±1.0	0.0031±19.0	$^3\text{H}$ (0.88±3.4)
11905043	<u>Birgus latro</u> exoskeleton	1.579±19.9	0.17±10.0	0.171±21.3	89.6±1.0	2.52±2.2	0.025±17.0	
11905143	<u>Birgus latro</u> hepatopancreas and gonad	2.47±11.8	5.05±3.0	0.45±8.2	2.58±2.0	3.67±1.4	0.0038±21.0	$^3\text{H}$ (0.21±14.8)
11917143	<u>Anous tenuirostris</u> muscle	10.95±10.4	64.4±2.0	2.065±8.4			0.0033±22.0	
11918843	<u>Anous tenuirostris</u> liver		810.8±2.0	2.83±13.7	0.402±9.0		0.0072±31.0	
11920843	<u>Anous tenuirostris</u> viscera	7.824±19.0	71.6±1.3	1.01±15.6				

Table 59 (continued).

Radionuclide concentration levels, pCi/g oven-dry wt (error, %)

Sample No.	Type	$^{40}\text{K}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	Other
<u>LEROY</u>								
11927243	<u>Anous tenuirostris</u> bone		109.5±4.4	0.94±22.3				
11905243	<u>Birgus latro</u> miscellany	5.16±12.1		1.78±5.6		11.14±1.2		

Table 60. Radionuclide concentrations in *Messerschmidia argentea* collected at Enewetak Atoll, 1972-1973.

Island	Activity, pCi/g, dry wt				
	$^{40}\text{K}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$
ALICE	13.38	----	138.3	222.8	0.025
BELLE	15.86	----	25.2	5.83	0.036
CLARA	13.33	----	127.5	149.10	----
DAISY	11.10	1.45	12.21	5.90	0.055
EDNA	11.1	0.24	----	6.73	----
IRENE	13.04	23.86	536.0	62.60	----
IRENE	18.16	----	----	2.20	0.004
IRENE	14.61	2.77	21.76	4.10	0.0157
IRENE	12.74	3.39	159.0	407.30	0.002
IRENE (wood)	1.94	1.59	16.98	13.02	0.006
JANET	12.72	----	18.4	36.42	0.015
JANET	10.50	----	46.4	385.80	0.003
JANET	9.95	----	43.51	124.80	0.005
JANET	14.25	----	48.20	299.40	0.004
JANET	12.17	----	83.78	298.70	0.005
JANET	15.30	----	121.2	158.30	0.003
JANET	10.43	0.22	106.0	526.10	----
JANET	18.32	0.25	40.36	545.90	0.010
JANET	13.29	----	45.75	322.70	----
KATE	9.62	----	3.75	4.26	0.005
LUCY	10.73	----	----	6.36	----
MARY	13.24	----	7.57	7.12	----
MARY/NANCY	12.62	0.67	----	55.05	----
NANCY	7.81	----	27.30	40.24	0.023
OLIVE	10.73	----	----	9.54	----
PEARL	14.66	----	0.47	0.29	----
RUBY	9.19	0.99	----	19.19	----
RUBY	6.23	0.90	----	39.01	----
SALLY	8.28	0.10	4.86	12.63	0.059
TILDA	10.13	----	10.27	58.78	----
URSULA	10.09	----	13.60	104.90	----
VERA	7.07	----	12.79	10.77	0.002
WILMA	5.00	----	----	6.19	----

Table 60 (continued).

Island	Activity, pCi/g, dry wt				
	$^{40}\text{K}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$
YVONNE	14.19	----	0.64	2.28	0.004
YVONNE	14.26	----	1.43	3.81	0.011
YVONNE	10.91	----	8.60	95.30	0.129
YVONNE	10.33	----	1.94	17.30	0.766
YVONNE	9.33	1.16	257.20	5644.00	0.114
TOM	9.16	----	----	0.26	----
VAN	6.81	----	----	0.34	----
URIAH	11.90	----	----	0.73	----
ALVIN	11.57	----	----	0.85	----
BRUCE	8.03	----	0.33	1.16	----
CLYDE	10.90	----	----	0.43	----
DAVID	13.55	----	0.46	1.09	0.0061
DAVID	11.02	----	0.76	7.24	----
DAVID	13.22	----	1.06	2.58	----
DAVID	3.88	----	0.75	15.84	----
REX	8.89	----	----	2.45	----
ELMER	----	----	0.98	2.39	----
ELMER	9.04	----	0.63	1.66	----
WALT	6.66	----	----	0.38	----
FRED	11.23	----	0.43	0.56	----
FRED	8.83	----	0.49	1.78	----
GLENN	21.81	----	2.05	1.24	----
GLENN	9.75	----	2.51	1.27	----
HENRY	12.77	----	1.98	0.52	----
IRWIN	13.54	0.25	1.73	0.53	----
JAMES	17.95	----	----	1.76	----
KEITH	12.45	0.20	0.32	0.25	----
LEROY	15.09	----	14.37	4.71	----

Table 61. Radionuclide concentrations in *Scaevola frutescens* collected at Enewetak Atoll, 1972-1973.

Island	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	<sup>55</sup> Fe
ALICE	12.82	----	32.7	66.53	----	----
BELLE	12.45	----	2.27	1.42	0.072	----
CLARA	12.37	----	51.80	51.04	0.048	3.37
DAISY	20.26	0.48	50.9	38.80	0.046	----
IRENE	17.09	47.40	110.40	43.14	0.0044	33.7
IRENE	14.08	----	1.14	1.67	0.031	----
IRENE	12.68	17.07	8.56	4.28	0.028	26.4
IRENE	10.41	21.14	57.21	205.20	0.003	----
IRENE (wood)	1.82	0.91	4.60	2.22	0.003	----
JANET	17.44	----	12.16	30.50	0.016	----
JANET	18.12	----	36.93	258.60	----	----
JANET	14.31	----	17.34	63.29	----	----
JANET	13.65	0.45	35.72	223.40	0.003	----
JANET	16.73	----	31.53	294.60	0.010	----
JANET	12.96	0.21	32.66	54.95	0.007	----
JANET	20.57	0.24	83.33	405.90	0.004	----
JANET	18.28	----	16.61	134.10	0.005	----
KATE	14.60	----	----	16.36	----	----
LUCY	13.01	----	----	12.73	----	----
MARY	16.14	----	16.76	12.77	----	----
NANCY	10.74	----	11.89	4.12	0.012	0.05
OLIVE	13.30	----	----	4.35	----	----
PEARL	16.50	----	0.35	0.34	----	----
PEARL	12.52	0.16	20.99	30.82	----	----
SALLY	10.78	----	6.67	13.38	0.096	----
TILDA	11.39	----	9.05	24.94	0.0042	----
URSULA	5.45	----	6.13	91.49	----	----
URSULA	13.47	----	----	0.29	----	----
VERA	8.18	----	4.49	1.69	----	----
WILMA	10.31	----	----	1.24	----	----



Table 61 (continued).

Island	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	<sup>55</sup> Fe
YVONNE	13.20	0.511	1.76	11.88	0.026	----
YVONNE	14.16	----	0.44	1.57	0.004	----
YVONNE	15.00	0.25	0.66	8.06	1.293	----
YVONNE	10.68	20.26	159.00	609.90	0.323	----
YVONNE	15.93	----	1.94	28.25	0.190	----
YVONNE	18.77	6.26	80.63	658.00	0.196	----
TOM	11.49	----	----	0.73	----	----
VAN	7.11	----	----	0.73	----	----
BRUCE	9.32	----	0.88	9.75	----	----
CLYDE	11.19	----	----	0.27	----	----
DAVID	17.59	----	0.34	1.11	0.0005	----
DAVID	10.69	----	0.37	4.82	----	----
DAVID	13.02	----	0.31	5.80	----	----
DAVID	16.33	----	0.56	2.01	----	----
REX	6.94	----	----	0.49	----	----
ELMER	13.60	----	0.27	2.40	----	----
ELMER	11.83	----	0.62	1.47	----	----
WALT	6.99	----	----	1.44	----	----
FRED	10.36	----	0.23	0.65	0.0006	----
FRED	7.14	----	0.81	3.80	----	----
GLENN	12.84	----	1.54	0.64	----	----
GLENN	13.74	----	1.34	0.53	----	----
HENRY	12.64	----	----	0.19	----	----
HENRY	9.42	----	----	0.52	----	----
KEITH	15.52	----	0.64	0.43	----	----
LEROY	13.29	----	3.74	1.80	----	----

Table 62. Mean concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in Messerschmidia and Scaevola on IRENE, JANET, and YVONNE.

Island	Mean $^{137}\text{Cs}$ concentration, pCi/g, dry wt	
	<u>Messerschmidia</u>	<u>Scaevola</u>
IRENE	93.84	51.29
JANET	299.79	183.16
YVONNE	1152.53 <sup>a</sup>	219.61
	Mean $^{90}\text{Sr}$ concentration, pCi/g, dry wt	
	<u>Messerschmidia</u>	<u>Scaevola</u>
IRENE	82.20	57.21 <sup>b</sup>
JANET	61.51	33.29
YVONNE	53.96	40.72

<sup>a</sup>One high value of 5644 pCi/g influences this value (N = 5, see Table 60).

<sup>b</sup>N = 1.

Table 63. Radionuclide concentrations in Cocos nucifera collected at Enewetak Atoll, 1972-1973.

Island	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>55</sup> Fe	239,240Pu	<sup>3</sup> H
DAISY	5.65	7.17	0.195	----	----	----
DAISY <sup>a</sup>	45.50	----	1.405	----	----	----
IRENE <sup>a</sup>	99.90	5.11	1.610	86.49	----	----
IRENE	7.05	1.77	0.067	----	0.036	----
JANET	8.04	84.68	0.210	----	----	0.34
JANET <sup>a</sup>	60.05	210.70	1.570	----	----	----
MARY	7.52	14.27	0.136	1.18	----	----
MARY <sup>a</sup>	39.25	67.75	0.635	----	----	----
MARY	3.75	5.59	14.140	76.58	----	----
NANCY	6.54	18.83	0.167	1.95	----	----
NANCY <sup>a</sup>	73.51	148.80	1.150	5.95	----	----
VERA	5.64	9.30	0.134	----	----	----
YVONNE	6.39	1.99	----	----	----	----
YVONNE	8.24	3.96	0.011	----	----	0.66
BRUCE	5.93	0.58	----	----	----	----
DAVID	6.44	2.59	0.014	----	----	0.31
DAVID	3.76	1.67	0.178	----	----	----
DAVID	4.69	0.40	0.026	----	----	----
DAVID <sup>a</sup>	30.93	23.32	----	----	----	----
ELMER	9.73	2.14	0.032	----	----	0.31
ELMER	5.50	3.45	----	----	----	----
FRED	6.39	2.39	0.029	----	----	0.39
FRED	5.59	0.53	0.367	----	----	----
GLENN	7.53	1.65	0.326	----	----	----
GLENN	6.12	0.86	0.020	----	----	----
GLENN	8.28	1.30	----	----	----	----
HENRY	3.95	0.70	----	----	----	----
KEITH	7.69	0.95	----	----	----	----
LEROY	4.12	3.54	0.189	----	----	----

<sup>a</sup>Milk.

Table 64. Radionuclide concentrations in Morinda citrifolia collected at Enewetak Atoll, 1972-1973.

Island	Activity, pCi/g. dry wt					
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$
KATE	14.50	34.09	----	23.56	0.0010	----
MARY	16.27	----	----	45.05	0.0340	----
MARY <sup>a</sup>	12.45	192.30	----	4.01	0.0120	----
MARY <sup>a</sup>	13.45	97.43	0.057	3.35	0.0022	----
NANCY	11.16	55.05	----	43.47	0.0056	----
OLIVE <sup>a</sup>	18.74	30.42	----	4.48	----	----
OLIVE	12.48	66.58	0.33	37.66	0.011	0.063
OLIVE	18.73	29.57	----	39.50	----	----
TILDA	13.94	13.90	----	12.48	----	----
VERA	10.46	12.12	----	11.85	----	----
DAVID	12.82	4.10	----	0.02	0.013	----
GLENN	22.29	0.64	----	1.58	----	----
GLENN	19.16	.58	----	0.40	----	----
HENRY	17.50	1.26	----	0.32	----	----
IRWIN	6.99	0.33	----	----	----	----
JAMES	16.99	2.23	----	1.85	----	----

<sup>a</sup>Fruit.

Table 65. Radionuclide concentrations in Guettarda speciosa collected at Enewetak Atoll, 1972-1973.

Island	Activity, pCi/g. dry wt				
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{239,240}\text{Pu}$	$^{60}\text{Co}$
ALICE	11.03	7.41	----	----	----
BELLE	12.48	109.10	152.7	----	----
IRENE	8.14	27.33	53.6	----	9.18
MARY	7.70	98.69	36.85	----	----
NANCY	8.79	8.73	30.86	0.0097	----
TILDA	10.10	5.90	12.57	0.0091	----
URSULA	14.23	13.27	7.30	----	----
WILMA	10.60	3.14	----	----	----
YVONNE	11.15	795.00	64.40	0.0253	4.52
DAVID	3.99	3.16	0.32	----	----
WALT	9.82	0.18	----	----	----
JAMES	13.74	0.68	----	----	----
KEITH	12.87	0.47	1.74	----	----

Table 66. Radionuclide concentrations in Pisonia grandis collected at Enewetak Atoll, 1972-1973.

Island	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>239,240</sup> Pu	<sup>55</sup> Fe
KATE	9.59	221.10	3.85	23.60	0.0045	----
NANCY	16.51	43.87	0.24	36.67	0.0195	----
VERA	28.58	56.94	----	23.11	----	----
BRUCE	17.76	1.46	----	0.50	----	----
VAN	12.92	1.99	0.17	----	----	----
DAVID	19.02	3.12	----	0.77	0.0013	----
DAVID	18.10	1.67	----	0.61	----	----
DAVID	10.2	1.80	----	0.56	0.0002	----
REX	16.00	2.64	0.091	----	----	----
GLENN	25.79	1.86	----	2.88	----	0.81
GLENN	30.28	3.91	----	1.74	----	----
GLENN (wood)	7.26	0.37	----	----	----	----
IRWIN	21.77	1.88	----	0.59	0.0015	----
JAMES	12.66	1.55	----	----	----	----
KEITH	30.81	3.65	----	3.00	----	----
LEROY	34.27	10.17	----	14.86	----	----

Table 67. Radionuclide concentrations in Pandanus tectorius collected at Enewetak Atoll, 1972-1973.

Island	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>239,240</sup> Pu	<sup>55</sup> Fe	<sup>3</sup> H
BELLE (fruit)	14.38	923.00	206.30	----	----	0.86
BELLE (leaves)	6.70	679.30	----	----	0.438	----
JANET (leaves)	8.12	0.62	4.41	----	----	----
SALLY (leaves)	14.02	14.98	1.97	0.015	0.703	----
TILDA (leaves)	13.29	152.20	15.50	0.0069	2.94	----
VERA (leaves)	9.17	17.58	4.24	0.0076	----	----
DAVID (leaves)	9.74	15.0	3.56	----	0.13	----
ELMER (leaves)	8.86	3.09	25.14	0.0020	0.41	----
FRED (leaves)	3.38	4.29	0.42	0.0077	0.85	----
KEITH (leaves)	12.70	0.86	13.11	----	12.2	2.0
KEITH (leaves)	8.18	0.57	----	----	0.36	----
LEROY (leaves)	7.99	9.14	1.69	0.0022	0.21	----
LEROY (fruit)	30.2	26.2	16.26	----	----	----

Table 68. Radionuclide concentrations in miscellaneous plant species collected at Enewetak Atoll, 1972-1973.

Island		Activity, pCi/g, dry wt					
		$^{40}\text{K}$	$^{137}\text{Cs}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{239,240}\text{Pu}$	$^3\text{H}$
HELEN <sup>a</sup>	<u>Lepturus repens</u>	4.90	2.51	0.94	1.44	0.0435	----
IRENE <sup>a</sup>	<u>Lepturus repens</u>	1.95	2.57	0.26	1.15	0.0112	----
IRENE <sup>b</sup>	<u>Fimbristylis atollensis</u>	4.87	55.00	14.70	4.42	0.8780	----
IRENE <sup>c</sup>	<u>Suriana maritima</u>	5.59	26.34	121.30	8.51	0.0286	----
JANET <sup>c</sup>	<u>Pluchea odorata</u>	10.80	1553.00	1.25	46.85	-----	----
MARY <sup>a</sup>	<u>Lepturus repens</u>	-----	105.70	-----	17.39	0.0093	----
SALLY <sup>a</sup>	<u>Lepturus repens</u>	3.74	83.20	-----	1.98	0.0227	----
DAVID <sup>d</sup>	<u>Tacca leontopetaloides</u>	6.63	1.09	-----	0.46	0.0011	0.52
DAVID <sup>b</sup>	<u>Fimbristylis atollensis</u>	3.38	7.40	-----	-----	-----	----
HENRY <sup>a</sup>	<u>Lepturus repens</u>	11.29	0.10	-----	0.059	0.0021	----
IRWIN <sup>c</sup>	<u>Terminalia samoensis</u>	11.36	0.77	-----	0.932	0.0013	----

<sup>a</sup>Grass.  
<sup>c</sup>Shrub.  
<sup>b</sup>Sedge.  
<sup>d</sup>Herb.

Table 69. Radionuclide concentrations in Coenobita (hermit crab)<sup>a</sup> at Enewetak Atoll, 1972-1973.

Island/organ	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	<sup>55</sup> Fe	<sup>3</sup> H
LUCY							
Hepatop. <sup>b</sup>	10.42	2.95	----	125.70	----	----	----
Exoskel. <sup>c</sup>	----	0.97	----	39.15	----	----	----
IRENE							
Hepatop.	7.04	82.80	29.60	124.30	0.196	12.8	0.58
Muscle	7.36	62.40	22.6	130.70	0.069	3.32	----
Exoskel.	1.94	1.66	----	27.20	0.017	0.32	----
DAVID							
Hepatop.	7.61	0.23	0.19	1.95	4.82	0.57	0.95
Muscle	7.52	0.28	0.33	2.06	0.0031	----	0.58
Exoskel.	1.76	----	4.05	0.60	0.010	0.039	----
REX							
Hepatop.	5.83	0.57	0.30	2.06	0.0031	1.82	----
Muscle	6.68	1.44	0.32	1.05	0.0026	1.47	----
Exoskel.	1.84	----	3.62	0.25	0.001	0.085	----
GLENN							
Hepatop.	8.68	1.12	0.43	1.51	0.006	1.55	----
Muscle	7.86	1.97	0.91	1.51	0.011	1.32	----
Exoskel.	1.52	----	9.14	0.25	0.001	----	----
HENRY							
Hepatop.	5.72	0.98	0.50	1.17	----	----	----
Muscle	7.69	2.00	0.64	1.08	0.0066	0.98	----
Exoskel.	2.34	----	9.64	0.24	----	0.08	----
IRWIN							
Hepatop.	7.75	0.89	0.45	0.58	0.0053	1.78	----
Muscle	6.74	1.77	0.31	0.55	0.0125	0.75	----
Exoskel.	2.73	----	4.78	0.01	0.0008	0.11	----

<sup>a</sup> Collection contained both C. perlatus and C. brevimanus.

<sup>b</sup> Hepatopancreas/gonad.

<sup>c</sup> Exoskeleton.

Table 70. Radionuclide concentrations in Birgus latro (coconut crab) collected at Enewetak Atoll, 1972-1973.

Island/organ	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	<sup>55</sup> Fe	<sup>3</sup> H
BRUCE							
Muscle	11.28	0.20	0.18	1.98	----	0.98	0.42
Exoskeleton	2.59	----	6.08	0.29	0.001	0.07	----
Hepatopancreas	3.02	0.40	0.13	0.42	----	5.70	0.16
GLENN							
Muscle	10.45	----	----	1.88	----	0.68	0.69
Exoskeleton	1.06	----	10.4	0.31	0.0035	----	----
Hepatopancreas	2.34	0.27	----	0.54	----	----	0.27
JAMES							
Muscle	9.62	1.05	0.079	1.25	----	1.84	----
Exoskeleton	1.44	0.11	5.9	0.22	0.002	0.30	----
Hepatopancreas	4.00	1.56	----	0.32	----	12.8	----
KEITH							
Muscle	10.11	0.42	1.19	1.92	----	1.46	----
Exoskeleton	3.35	----	9.96	0.51	0.007	0.18	----
Hepatopancreas	3.20	1.03	0.40	0.50	0.0098	6.17	----
LEROY							
Muscle	8.80	1.23	1.58	12.60	0.0031	1.59	0.88
Exoskeleton	1.58	0.17	89.6	2.52	0.025	0.17	----
Hepatopancreas	2.55	0.84	2.58	3.85	0.0038	5.05	----



Table 71. Distribution of radionuclides in Rattus exulans (rice rat) collected at Enewetak Atoll, 1972-1973.

Island/organ	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>55</sup> Fe	<sup>239,240</sup> Pu
PEARL						
Liver	32.33	33.30	5.07	164.90	82.0	0.012
Viscera	----	30.80	7.45	1.79	----	1.77
Muscle	11.60	37.07	0.89	0.37	23.2	0.117
Bone	9.57	53.60	2.59	36.1	----	----
SALLY						
Liver	10.73	63.83	2.54	0.002	35.5	0.008
Viscera	9.63	92.97	1.48	14.6	----	1.30
Muscle	5.82	60.86	----	----	----	----
Bone	7.01	65.77	0.81	25.9	----	0.039
URSULA						
Liver	6.72	39.41	3.59	----	42.2	0.041
Viscera	10.87	43.14	1.13	2.17	----	----
Muscle	9.22	37.86	----	----	----	----
Bone	7.26	61.58	----	19.6	----	0.146
DAVID						
Viscera	12.24	21.97	----	0.24	----	0.0087
Liver	----	16.36	----	----	3.67	0.004
Muscle	7.80	18.78	----	0.60	0.98	0.044
Bone	11.46	28.37	----	1.37	----	0.065
Skin	6.49	9.13	----	----	----	----
Kidney	----	17.0	----	----	----	----
Lung	----	18.5	----	----	----	0.031
GLENN						
Liver	12.79	1.45	1.81	----	19.28	0.035
Muscle	8.18	1.76	0.48	1.03	4.49	0.017
Viscera	11.75	1.88	2.06	0.28	----	0.036
Bone	10.61	6.02	0.71	2.67	----	0.87
Skin	2.3	0.33	----	----	----	----
Kidney	----	1.46	2.40	----	----	----
Lung	20.7	1.74	----	----	----	0.30

Table 72. Distribution of radionuclides in Rattus rattus (roof rat) collected on Enewetak Atoll, 1972-1973.

Island/organ	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>55</sup> Fe	<sup>239,240</sup> Pu	<sup>3</sup> H
JANET							
Viscera <sup>a</sup>	12.63	880.60	2.35	14.14	----	0.46	----
Muscle <sup>a</sup>	8.74	764.00	0.29	1.28	30.9	----	----
Liver <sup>a</sup>	13.42	632.90	3.23	0.004	77.9	----	----
Bone <sup>a</sup>	8.69	661.20	0.30	115.8	----	0.26	----
Viscera	11.38	768.00	1.97	6.85	----	0.36	----
Muscle	----	696.80	0.41	3.44	8.69	0.0073	----
Liver	18.17	604.10	3.97	----	30.9	----	----
Bone	5.97	357.20	----	133.8	----	0.17	----
Viscera	16.23	954.50	4.95	55.86	24.32	0.729	----
Liver	33.00	741.90	2.56	0.01	105.4	----	----
Bone	10.32	545.50	0.45	324.3	----	0.168	----
Viscera	----	273.20	1.72	----	----	----	----
Muscle	----	286.50	0.23	2.29	10.5	0.0097	----
Liver	----	211.5	2.21	0.07	24.4	----	----
Bone	9.06	129.20	0.22	68.92	----	0.0302	----
Viscera	18.54	999.50	2.93	8.74	----	0.410	----
Muscle	13.87	765.80	0.64	3.14	16.3	0.0023	----
Liver	----	897.70	6.31	0.007	86.9	0.018	----
Bone	----	627.50	0.51	121.2	----	3.250	----
BRUCE							
Skin	8.07	0.61	----	----	----	----	----
Kidney	----	----	3.19	----	----	----	----
Lung	35.9	----	----	----	----	----	----
Viscera	----	1.09	----	----	----	0.035	----
Muscle	5.21	1.47	----	0.07	2.21	0.009	----
Liver	30.20	1.07	1.62	----	46.40	0.013	----
Bone	18.81	13.25	----	1.69	----	3.278	----

<sup>a</sup>Collected by Enewetak Marine Biological Laboratory personnel, February, 1973.

Table 72 (continued).

Island/organ	Activity, pCi/g, dry wt							
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>55</sup> Fe	<sup>239,240</sup> Pu	<sup>3</sup> H	Other
ELMER								
Viscera	11.19	18.98	1.39	0.16	----	0.0074	----	
Muscle	10.30	18.40	----	0.05	0.10	0.016	11.3	
Liver	11.12	15.60	----	0.02	0.93	----	----	
Bone	9.04	9.96	----	1.42	----	0.23	----	
Skin	6.50	7.60	----	----	----	----	----	
Lung	14.7	16.90	----	1.0	----	0.14	----	
Kidney	21.8	15.0	1.74	----	----	----	----	
YVONNE, Sector A								
Muscle	12.35	4240.00	12.35	5.09	32.80	0.052	1.8	
Bone	----	1833.00	5.92	146.40	----	0.057	----	<sup>134</sup> Cs 1.12
Viscera	7.61	2928.00	112.60	----	----	1.05	----	<sup>134</sup> Cs 1.90
Skin	6.69	2088.00	14.00	----	----	----	----	
Liver	----	2559.00	7.03	----	126.10	0.027	----	<sup>151</sup> Sm 18.70
Kidney	----	3427.00	257.70	----	----	----	----	
Lung	14.26	3306.00	10.53	0.24	----	0.107	----	
Muscle	13.07	3824.00	8.51	37.79	78.83	0.003	----	
Bone	7.93	2199.00	10.57	135.10	----	0.29	----	
Viscera	13.33	3531.00	230.00	4.09	----	0.581	----	
Skin	6.92	1875.00	7.43	----	----	----	----	
Liver	14.15	2215.00	86.13	0.005	135.60	0.013	----	
Kidney	----	3286.00	261.80	----	----	----	----	
Lung	33.12	2760.00	11.08	16.17	----	----	----	
YVONNE, Sector B								
Muscle	16.82	86.04	----	----	----	----	----	
Bone	9.74	48.78	0.33	16.67	----	0.304	----	
Viscera	9.67	76.71	1.99	0.57	----	0.393	----	
Skin	4.74	42.64	----	----	----	----	----	
Liver	----	56.22	2.90	----	25.01	0.008	----	<sup>151</sup> Sm 23.00
Kidney	----	59.64	4.95	----	----	----	----	
Lung	----	39.72	----	----	----	----	----	

Table 72 (continued).

Island/organ	Activity, pCi/g, dry wt							
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>55</sup> Fe	<sup>239,240</sup> Pu	<sup>3</sup> H	Other
YVONNE, Sector C								
Skin	----	29.39	0.69	----	----	----	----	
Lung	----	53.33	----	----	----	0.568	----	
Viscera	----	55.81	----	----	3.46	0.211	----	<sup>238</sup> Pu 0.096
Liver	----	38.68	5.63	0.002	13.83	0.011	----	
Kidney	30.64	29.00	8.03	----	----	----	----	
Muscle	5.77	49.19	0.55	6.76	4.12	----	----	
Bone	----	38.78	0.51	6.40	----	0.058	----	
YVONNE, Sector D								
Muscle	15.87	3.74	----	0.63	1.23	0.008	----	
Bone	23.95	23.80	1.32	----	----	0.058	----	
Lung	----	11.55	----	----	----	0.201	----	
Viscera	17.77	5.69	0.20	----	----	0.020	----	
Liver	----	4.62	----	10.54	17.30	0.398	----	

Table 73. Distribution of  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  in birds collected at Enewetak Atoll, 1972-1973.

	Activity, pCi/g, dry wt									
	$^{90}\text{Sr}$					$^{239,240}\text{Pu}$				
	Liver	Muscle	Bone	Eggshell	Egg	Liver	Muscle	Egg	Eggshell	Bone
Common noddy ( <u>Anous stolidus</u> )										
ALICE		0.01	20.6			0.06				
IRENE	0.51			7.34	0.095	0.009		0.0015	0.0081	
JANET	0.066	0.008	0.39	16.04	0.203		0.0018	0.0148		
LUCY	0.187		0.71				0.022			
MARY		0.48								
YVONNE		0.0073		0.49	1.06		0.02	0.0232	0.0086	0.021
				0.22	0.073					
VAN	0.04	0.04	0.143		0.002		0.0014	0.00047		
REX		0.0065					0.0056	0.00077		
IRWIN	0.23					0.0242	0.0434	0.00088		
KEITH							0.001			
White-capped noddy ( <u>Anous tenuirostris</u> )										
SALLY						0.011	0.005			
BRUCE			0.66				0.0069			
LEROY	0.402					0.0072	0.0033			
Sooty tern ( <u>Sterna fuscata</u> )										
SALLY			1.68	0.265	0.0042					0.005
CLYDE	0.015	0.0063				0.0017				
DAVID							0.119			
Pooled terns										
JANET		0.005				0.0015				

Table 74. Distribution of  $^{60}\text{Co}$  and  $^{55}\text{Fe}$  in birds collected at Enewetak Atoll, 1972-1973.

	Activity, pCi/g, dry wt									
	$^{60}\text{Co}$				$^{55}\text{Fe}$					
	Viscera	Liver	Muscle	Bone	Viscera	Liver	Muscle	Bone	Egg	Eggshell
<u>Common noddy</u> ( <u>Anous stolidus</u> )										
ALICE			0.32		47.3	127.0	49.55	25.7		
IRENE		0.324	0.25		57.66	49.6		57.66	23.0	1.18
JANET			0.51		64.0	258.	104.5	50.0	57.2	1.28
LUCY					108.6	199.	8.78	38.5		
MARY		0.567			53.6	2.51	14.2	59.9		
OLIVE				0.31	57.2	332.4	92.8	46.4		
YVONNE	0.51	0.37	0.23		64.4	385.6	22.6	63.5	56.8 54.5	1.10
<u>Common noddy</u> ( <u>Anous stolidus</u> )										
VAN		0.195	0.29		50.5	279.	99.55	40.3	63.5	1.68
REX					50.0	117.6	43.5	44.8	51.4	0.73
HENRY									54.1	8.56
IRWIN		0.63			45.95	423.	169.	49.1	5.14	
KEITH		0.69	0.452	0.312	80.18			68.5		
<u>White-capped noddy</u> ( <u>Anous tenuirostris</u> )										
SALLY				0.34	64.4		36.6	61.3		
BRUCE			0.392		73.9	327.	41.3	44.2		
LEROY	1.01	2.38	2.07	0.94	71.6	810.8	64.4	109.5		
<u>Sooty tern</u> ( <u>Sterna fuscata</u> )										
SALLY					22.4	155.0		35.7	37.6	
CLYDE					49.1	146.4	20.4	36.0		
DAVID					63.5	153.	59.0	37.4		
<u>Pooled sample</u> ( <u>Terns, noddys, etc.</u> )										
JANET			0.16		52.2	171.6	59.5	40.0		
PEARL	0.435	0.647	0.659		61.7			46.9		
Other species:										
<u>Red-tailed tropic bird</u> ( <u>Phaethon rubricauda</u> )										
KATE										
<u>Reef heron</u> ( <u>Demigretta sacra</u> )										
DAVID										
				0.41						

Table 75. Distribution of  $^{137}\text{Cs}$  and  $^{40}\text{K}$  in birds collected at Enewetak Atoll, 1972-1973.

	Activity, pCi/g, dry wt							
	$^{40}\text{K}$					$^{137}\text{Cs}$		
	Viscera	Liver	Muscle	Bone	Egg	Bone	Egg	Viscera
<u>Common noddy</u> ( <u>Anous stolidus</u> )								
ALICE		10.2	9.66	5.3		1.16		
IRENE		7.88	9.42		6.37	0.17		
JANET	10.68	7.83	9.19	3.04	6.21	0.73		
LUCY	13.08		12.23			7.45		
MARY	11.41	6.63		5.74				
OLIVE	8.81			4.07				
YVONNE	8.34		7.39		4.53	5.51	0.079	
					4.13			
					7.22			
VAN			10.48	6.96	6.31	0.74	0.136	
REX		4.89	10.81		7.69			
HENRY					3.39			
IRWIN		15.84	9.28		7.49			
KEITH	8.97		12.96	3.80				
<u>White-capped noddy</u> ( <u>Anous tenuirostris</u> )								
SALLY	5.89		6.31			0.137		
BRUCE		8.37	7.09					
LEROY	7.82		10.95					
<u>Sooty tern</u> ( <u>Sterna fuscata</u> )								
SALLY	4.79				4.57			
CLYDE	7.94		7.37	2.36	5.41	1.4		
DAVID	8.90	20.36	7.46			0.745		
<u>Pooled sample</u> (terns, noddys, etc.)								
JANET	9.62		8.77	3.32				0.18
PEARL			8.67			0.793		
ALVIN		20.37	10.44	10.32		5.71		
Other species:								
<u>Red-tailed tropic bird</u> ( <u>Phaethon rubricauda</u> )								
KATE	7.81		8.79			0.10		
<u>Reef heron</u> ( <u>Demigretta sacra</u> )								
DAVID			4.65	8.76		1.34	1.59	
<u>Sandpiper</u> ( <u>Erolia acuminata</u> )								
DAVID		17.57		28.16		0.789		

Table 76. Distribution of radionuclides in terrestrial biota and soils on ALICE, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe
Soil Island range	-----	5.6-141	14-430	1.4-33	3.9-68	-----
Mean	-----	36	80	5.9	12	-----
Soil survey						
Sample 15	-----	13.00	32.00	2.7	5.80	-----
Biota soil sample	-----	69.05	580.20	100.90	83.78	-----
<u>Plants</u>						
<u>Scaevola</u>						
<u>frutescens</u>	12.82	66.53	32.7	-----	-----	-----
<u>Messerschmidia</u>						
<u>argentea</u>	13.38	222.80	138.30	-----	0.025	-----
<u>Guettarda</u>						
<u>speciosa</u>	11.03	7.40	-----	-----	-----	-----
<u>Animals</u>						
<u>Anous stolidus</u>						
Common noddy						
Liver	10.20	-----	-----	-----	0.062	127.0
Viscera	-----	-----	-----	-----	-----	47.20
Muscle	9.66	-----	0.01	0.32	-----	49.55
Bone	5.30	1.16	20.59	-----	-----	25.68



Table 77. Distribution of radionuclides in terrestrial biota and soil on BELLE, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe	<sup>3</sup> H
<u>Soil - Dense</u>							
Island range	----	14-170	14-670	3.1-30	7.2-130	----	----
Mean	----	48	123	10	26	----	----
<u>Sparse</u>							
Island range	----	3.3-44	35-130	2.4-9.6	5.8-26	----	----
Mean	----	8.6	44	4.6	11	----	----
<u>Soil survey</u>							
Sample 32	----	0.67	16.0	0.38	6.50	----	----
Sample 33	----	0.84	15.0	0.57	6.00	----	----
Mean	----	0.76	15.5	0.48	6.25	----	----
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	15.86	5.83	25.2	----	0.036	----	----
<u>Scaevola</u>							
<u>frutescens</u>	12.45	1.42	2.27	----	0.072	----	----
<u>Guettarda</u>							
<u>speciosa</u>	12.48	109.10	152.7	----	----	----	----
<u>Pandanus</u>							
<u>tectorius</u> (fruit)	14.38	923.00	206.30	----	----	----	0.86
<u>tectorius</u> (leaves)	6.70	679.30	391.0	----	----	0.44	----

Table 78. Distribution of radionuclides in terrestrial biota and soil on CLARA, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt					
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$
Soil - Island range	-----	5.6-110	13-310	0.91-20	3.5-88	-----
Mean	-----	26	65	6.4	22	-----
Soil survey						
Sample 7	-----	48.0	95.0	11.0	33.0	-----
Sample 9	-----	110.0	173.0	20.0	55.0	-----
Biota soil sample	-----	5.7	61.7	6.8	-----	-----
<u>Plants</u>						
<u>Messerschmidia</u>						
<u>argentea</u>	13.33	149.10	127.50	-----	-----	-----
<u>Scaevola</u>						
<u>frutescens</u>	12.37	51.00	51.8	-----	0.048	3.37

Table 79. Distribution of radionuclides in terrestrial biota and soil on DAISY, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>3</sup> H	<sup>238</sup> Pu
<u>Soil - Dense</u>							
Island range	----	3.4-33	100-380	6.4-26	22-98	----	----
Mean	----	11	190	11	41		
<u>Sparse</u>							
Island range	----	0.86-9.0	16-120	0.37-7.4	3.8-33	----	----
Mean	----	3.8	32	0.85	15		
<u>Soil survey</u>							
Sample 13	----	4.50	28.0	1.20	20.0	----	----
Sample 14	----	7.70	45.0	0.99	26.0	----	----
Sample 19	----	7.50	120.0	1.30	33.0	----	----
Mean	----	6.60	62.00	1.20	26.0	----	----
Biota soil sample	----	65.86	554.1	21.34	148.00	----	----
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	11.10	5.90	12.21	1.45	0.055	----	----
<u>Scaevola</u>							
<u>frutescens</u>	20.26	38.80	50.90	0.48	0.046	----	0.0085
<u>Cocos nucifera</u>							
Meat	6.65	7.17	0.20	----	----	0.41	----
Milk	45.50	----	1.40	----	----	----	----

Table 80. Areas sampled on IRENE (Bogon), Enewetak Atoll, 1972-1973.

<u>Sector</u>	<u>Description</u>
A	Southern extension of western end of island, south side of Seminole crater; <u>Scaevola</u> and <u>Messerschmidia</u> vegetation.
B	North side of Seminole crater, most radioactive site on island, <u>Messerschmidia</u> and <u>Scaevola</u> vegetation.
C	Eastern end of island, open scrub forest or savanna, grasses and sedges, "cold" part of island.
D	Center of island, halfway between crater and east end, scattered <u>Messerschmidia</u> and <u>Scaevola</u> .
E	Sandy and rocky beach area, throwout from Seminole crater, scattered shrubs, sedges, and grasses, area of integrated sample collection.

Table 81. Radionuclides in terrestrial biota and soil on IRENE (Bogon), Enewetak Atoll, 1972-1973.

Sector A	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>55</sup> Fe	<sup>239,240</sup> Pu	Other
<u>Soil</u>							
No. 21	----	0.92	5.20	13.00	----	5.800	
Biota-A	----	1.45	5.41	21.62	----	10.450	
Mean soil data	----	1.18	5.30	17.31	----	8.12	
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	14.60	4.10	2.77	21.76	----	0.0157	
<u>Scaevola frutescens</u>	12.68	4.28	17.07	8.56	26.40	0.0277	<sup>241</sup> Am 0.0088
<u>Fimbristylis atollensis</u>	4.87	55.00	14.70	4.42	----	0.878	<sup>238</sup> Pu 0.280
<u>Suriana maritima</u>	5.59	26.34	121.30	8.51	----	0.0286	<sup>238</sup> Pu 0.009
<u>Animals</u>							
<u>Anous stolidus</u> Common noddy							
Eggshell	----	----	----	7.34	1.18	0.0081	
Egg	6.37	----	----	0.09	23.00	0.0015	
Muscle	9.42	----	0.25	----	----	----	
Liver	7.88	----	0.32	0.51	49.60	0.0091	
Bone	----	0.17	----	----	----	----	
<u>Sector B</u>							
<u>Soil</u>							
No. 1	----	1.00	37.00	14.00	----	5.800	
No. 2	----	4.60	0.47	25.00	----	8.700	
No. 3	----	3.00	10.00	82.00	----	24.000	
Mean soil data	----	2.90	15.80	40.00	----	12.00	
Biota-A soil	----	6.59	3.65	89.64	----	5.00	
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	13.04	62.60	23.86	536.00	----	----	
<u>Scaevola frutescens</u>	17.09	43.14	47.40	110.40	3.70	0.0044	<sup>241</sup> Am 0.0044

Table 81 (Continued).

Sector C	Activity, pCi/g, dry wt						
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{55}\text{Fe}$	$^{239,240}\text{Pu}$	Other
<u>Ecosystem level</u>							
<u>Soil</u>							
No. 12	----	0.43	0.43	9.10	----	3.700	
No. 13	----	0.55	0.12	9.50	----	2.800	
No. 32	----	3.60	0.81	29.00	----	3.500	
Mean soil data	----	1.50	0.45	16.00	----	3.300	
Biota-C soil	----	0.47	----	10.27	----	3.020	
<u>Plants</u>							
<u>Messerschmidia argentea</u>							
	18.16	2.20	0.14	----	----	0.0045	
<u>Scaevola frutescens</u>							
	14.08	1.67	----	1.14	----	0.031	
<u>Lepturus repens</u>							
	1.95	2.57	0.26	1.15	----	0.0112	
<u>Cocos nucifera</u>							
Milk	99.90	5.11	----	1.61	86.49	----	
<hr/>							
Sector D							
<u>Soil</u>							
No. 48	----	8.20	21.00	50.00	----	29.000	
<u>Plants</u>							
<u>Cocos nucifera</u>							
Meat	7.05	1.77	----	0.07	----	0.036	
<u>Animals</u>							
<u>Coenobita perlatus (hermit crabs)</u>							
Hepatopancreas	7.04	124.30	82.80	29.60	12.80	0.196	$^3\text{H}$ 0.58
Muscle	7.36	130.70	62.40	22.6	3.32	0.069	$^3\text{H}$ 0.89
Exoskeleton	1.94	27.20	1.66	491.00	0.32	0.017	
<hr/>							
Sector E							
<u>Soil</u>							
No. 25	----	3.50	7.40	100.00	----	7.700	
No. 51	----	19.00	11.00	59.00	----	12.000	
No. 62	----	41.00	14.00	25.00	----	11.000	
No. 63	----	3.00	8.90	25.00	----	9.200	
Average soil data	----	16.6	10.30	52.00	----	10.000	

Table 81 (Continued).

Sector E Ecosystem level	Activity, pCi/g, dry wt						
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{55}\text{Fe}$	$^{239,240}\text{Pu}$	Other
<u>Plants</u>							
<u>Messerschmidia</u> <u>argentea</u> <sup>a</sup>	12.74	407.30	3.39	159.00	----	0.0019	
<u>Messerschmidia</u> <u>argentea</u> (wood)	1.94	13.02	1.59	16.98	----	0.0062	
<u>Scaevola</u> <u>frutescens</u> <sup>a</sup>	10.41	205.20	21.14	57.21	----	0.0029	
<u>Scaevola</u> <u>frutescens</u> (wood)	1.82	2.22	0.91	4.60	----	0.0029	
<u>Guettarda</u> <u>speciosa</u>	8.14	27.33	9.18	53.60	----	----	

<sup>a</sup>Integrated samples, 20-25 trees sampled.

Table 82. Location of biota samples collected on JANET (Engebi), Enewetak Atoll, 1972-1973.

Sector	Site description
A	South end of island in <u>Scaevola-Messerschmidia</u> regrowth.
B	On south side of the east end of the airstrip, in scattered <u>Messerschmidia</u> -ground cover species.
C	Mid-island on seaward side, near small clump of young coconut palms, dense <u>Scaevola-Messerschmidia</u> scrub.
D	On south side of the west end of the airstrip, open scrub growth.
E	In middle of airstrip, on south side, open meadow-like area with scattered <u>Messerschmidia</u> .
F	Near hot spot on island, north of airstrip, 300 yd from shoreline in open <u>Messerschmidia</u> scrub.
G	In center of island, near large blockhouse complex, dense regrowth of <u>Messerschmidia-Scaevola</u> .
H	Western tip of island, at west end of airstrip near small blockhouse, scattered regrowth of <u>Messerschmidia-Scaevola</u> .
I	Near docking area, mid-island on the lagoon side, dense regrowth of <u>Scaevola-Messerschmidia</u> .



Table 83. Distribution of radionuclides in terrestrial biota and soil on JANET (Engebi), Enewetak Atoll, 1972-1973.

Sector A	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>239,240</sup> Pu	<sup>55</sup> Fe	Other
<u>Soil</u>							
No. 121	----	0.60	0.10	6.30	0.99	----	
No. 127	----	26.00	1.00	16.00	4.10	----	
Average	----	13.30	0.55	11.20	2.50	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>	9.95	124.80	----	43.51	0.0055	----	
<u>Scaevola frutescens</u>	12.96	54.95	0.02	32.66	0.0068	----	<sup>238</sup> Pu 0.0068
							<sup>152</sup> Eu 0.20
<u>Sector B</u>							
<u>Soil</u>							
No. 21	----	29.00	2.50	52.00	7.100	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>	18.32	555.90	0.25	40.36	0.0103	----	
<u>Scaevola frutescens</u>	16.73	294.60	----	31.53	0.0103	----	
<u>Pandanus tectorius</u> (leaves)	8.12	0.62	----	4.41	----	----	<sup>207</sup> Bi 0.11
<u>Sector C</u>							
<u>Soil</u>							
Soil survey							
No. 63	----	10.00	1.40	27.0	3.70	----	
No. 65	----	11.00	0.93	20.0	2.20	----	
No. 71	----	36.00	2.90	71.0	14.00	----	
Mean	----	19.00	1.74	39.3	6.63	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>	10.50	385.80	----	44.60	0.0034	----	
<u>Scaevola frutescens</u>	18.28	134.10	----	16.71	0.0049	----	
<u>Cocos nucifera</u>							
Meat	8.04	84.68	----	0.21	----	----	<sup>3</sup> H 0.34
Milk	60.05	210.70	----	1.57	----	----	

Table 83 (Continued).

Sector D	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>239,240</sup> Pu	<sup>55</sup> Fe	Other
<u>Soil</u>							
Soil survey No. 131	----	42.00	4.52	95.00	2.50	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>							
	15.30	158.30	----	121.20	0.0029	----	
<u>Pluchea odorata</u>							
	10.80	1553.00	1.26	46.85	----	----	
<u>Sector E</u>							
<u>Soil</u>							
Soil survey							
No. 58	----	78.00	1.50	140.00	23.00	----	
No. 61	----	47.00	2.30	45.00	8.90	----	
No. 62	----	56.00	1.20	120.00	28.00	----	
Mean	----	60.00	1.60	101.60	19.90	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>							
	12.17	298.70	----	83.80	0.005	----	
<u>Scaevola frutescens</u>							
	13.65	223.40	0.45	35.70	0.003	----	
<u>Sector F</u>							
<u>Soil</u>							
Soil survey No. 12	----	25.00	9.30	120.00	23.00	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>							
	10.43	526.10	----	100.90	----	----	
<u>Scaevola frutescens</u>							
	20.57	405.90	0.24	83.30	0.0043	----	
<u>Animals</u>							
<u>Rattus rattus (roof rat)</u>							
Viscera	16.23	955.00	4.96	55.90	0.730	24.30	
Kidney	----	822.00	5.78	----	----	----	
Liver	33.00	742.00	2.56	0.01	----	105.40	
Lung	----	1069.00	----	2.93	----	----	

Table 83 (Continued).

Sector F Ecosystem level	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>239,240</sup> Pu	<sup>55</sup> Fe	Other
<u>Animals</u>							
<u>Rattus rattus</u> (roof rat)							
Muscle	----	887.00	----	3.13	0.013	26.20	
Bone	10.32	546.00	0.45	324.30	0.168	----	
Skin	----	353.00	----	----	----	----	
<hr/>							
Sector G							
<u>Soil</u>							
<u>Soil survey</u>							
No. 55	----	52.00	6.70	180.00	52.00	----	
No. 59	----	36.00	1.30	42.00	7.10	----	
No. 69	----	34.00	3.50	88.00	20.00	----	
No. 86	----	53.00	2.00	58.00	6.10	----	
Average	----	43.80	3.37	92.00	21.30	----	
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	14.25	299.40	----	48.20	----	----	
<u>Scaevola frutescens</u>	18.12	258.60	----	37.25	----	----	
<u>Animals</u>							
<u>Rattus rattus</u> (roof rat)							
Viscera <sup>a</sup>	12.63	881.00	2.35	14.14	0.460	----	
Viscera <sup>b</sup>	11.38	768.00	1.97	6.85	0.362	----	
Kidney <sup>a</sup>	26.14	656.00	2.60	----	----	----	
Kidney <sup>b</sup>	----	467.00	4.94	----	----	----	
Liver <sup>a</sup>	13.42	633.00	3.23	.004	----	77.93	
Liver <sup>b</sup>	18.17	604.00	3.97	----	----	30.86	
Muscle <sup>a</sup>	8.74	764.00	0.29	1.28	----	30.86	<sup>3</sup> H 6.70
Muscle <sup>b</sup>	----	697.00	0.41	3.44	0.007	8.69	
Lung <sup>a</sup>	21.54	587.00	0.45	----	0.509	----	
Lung <sup>b</sup>	76.60	1272.00	4.11	----	----	98.7	

<sup>a</sup> Collections made by Enewetak Marine Biological Laboratory personnel in February 1973.

<sup>b</sup> Collections made by AEC Enewetak Terrestrial Biota Survey in January 1973.

Table 83 (Continued).

Sector G Ecosystem level	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>239,240</sup> Pu	<sup>55</sup> Fe	Other
<u>Animals</u>							
<u>Rattus rattus</u> (roof rat)							
Bone <sup>a</sup>	8.69	661.00	0.30	115.80	0.26	----	
Bone <sup>b</sup>	5.97	358.00	----	133.80	0.167	----	
Skin <sup>a</sup>	4.94	406.00	----	----	----	----	
Skin <sup>b</sup>	6.05	390.00	----	----	----	----	
<hr/>							
Sector H							
<u>Soil</u>							
Soil survey							
No. 113	----	1.10	0.56	9.70	6.30	----	
No. 122	----	1.40	0.63	13.00	6.50	----	
No. 123	----	2.30	1.10	13.00	4.00	----	
No. 143	----	5.90	1.80	31.00	11.00	----	
Mean	----	2.69	1.27	16.67	6.95	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>							
	13.29	322.70	----	45.95	----	----	
<u>Scaevola frutescens</u>							
	14.31	63.30	----	17.34	----	----	
<u>Animals</u>							
<u>Rattus rattus</u> (roof rat)							
Viscera	----	273.20	1.72	17.30	1.40	----	
Kidney	----	275.00	2.63	----	----	----	
Liver	----	211.50	2.21	0.01	0.0016	24.40	
Lung	48.30	308.00	----	0.55	1.320	----	
Muscle	----	286.50	0.23	2.29	0.0097	10.54	
Bone	9.06	129.00	0.22	68.90	0.0302	----	
Skin	7.81	181.00	----	----	----	----	

<sup>a</sup> Collections made by Enewetak Marine Biological Laboratory personnel in February 1973.

<sup>b</sup> Collections made by AEC Enewetak Terrestrial Biota Survey in January 1973.

Table 83 (Continued).

Sector H Ecosystem level	Activity, pCi/g. dry wt						
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$	Other
<u>Birds</u>							
<u>Anous stolidus</u> (Common noddy)							
Viscera	9.62	----	----	----	----	52.25	
Liver	----	171.60	----	0.005	0.0015	----	
Muscle	9.19	----	0.51	0.008	0.002	104.50	
Eggshell	----	----	----	16.04	----	1.28	
Egg	6.21	----	----	0.20	0.0148	57.21	
Bone	3.04	0.73	----	0.39	----	50.0	
<hr/>							
Sector I							
<u>Soil</u>							
Soil survey							
No. 118	----	6.50	0.43	18.00	3.50	----	
No. 125	----	9.70	0.19	25.00	2.10	----	
Mean	----	8.10	0.31	22.00	2.80	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>							
	12.72	36.43	----	18.38	0.0152	----	
<u>Scaevola frutescens</u>							
	17.44	30.50	----	12.16	0.0163	----	
<u>Animals</u>							
<u>Rattus rattus (roof rat)</u>							
Viscera	18.54	999.50	2.93	8.74	0.416	----	
Kidney	62.34	838.30	5.99	----	----	----	
Liver	----	897.70	6.32	0.01	0.018	86.94	$^{151}\text{Sm}$ 34.30
Muscle	13.87	765.80	0.64	3.14	0.023	16.31	
Bone	----	627.50	0.51	121.20	3.248	----	
Skin	10.70	515.30	0.92	----	----	----	
Lung	29.70	830.00	2.17	1.80	0.865	----	

Table 84. Distribution of radionuclides in terrestrial biota and soil on KATE, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt					
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	Other
<u>Soil - Dense</u>						
Island range	----	0.08-37	1.6-200	0.03-5.8	0.17-50	
Mean	----	13.1	43.5	1.90	11.02	
<u>Soil - Sparse</u>						
Island range		1.8-16	1.6-49	0.03-3.5	0.17-14	
Mean		4.8	11	0.46	2.3	
Soil survey No. 17	----	3.90	45.0	2.3	14.0	
Biota soil sample	----	4.30	47.0	1.1	11.0	
Mean	----	4.10	46.0	1.7	12.5	
<u>Plants</u>						
<u>Messerschmidia</u>						
<u>argentea</u>	9.62	4.26	3.75	----	0.005	
<u>Scaevola</u>						
<u>frutescens</u>	14.60	16.36	----	----	----	
<u>Pisonia</u>						
<u>grandis</u>	9.59	221.10	23.60	3.85	0.0045	
<u>Morinda</u>						
<u>citrifolia</u>	14.50	34.09	23.56	----	0.001	
<u>Animals</u>						
<u>Phaethon rubricaudus</u>						
(red-tailed tropic bird)						
Viscera	7.81	----	----	----	----	
Muscle	8.79	----	----	----	----	
Bone	----	0.10	----	----	----	$^{65}\text{Zn}$ 0.64

Table 85. Distribution of radionuclides in terrestrial biota and soil on LUCY, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						Other
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$	
<u>Soil</u>							
Island range	----	2.2-25	10-83	0.26-3.8	2.4-22	----	
Mean	----	11	32	1.5	7.7	----	
<u>Soil survey</u>							
No. 16	----	0.10	4.40	0.05	2.10	----	
No. 18	----	0.12	4.40	0.05	1.50	----	
Biota soil sample	----	2.24	22.40	0.90	4.90	----	
<u>Plants</u>							
<u>Messerschmidia</u> <u>argentea</u>	10.73	6.36	----	----	----	----	$^{155}\text{Eu}$ 0.05
<u>Scaevola</u> <u>frutescens</u>	13.01	12.73	----	----	----	----	
<u>Animals</u>							
<u>Coenobita perlatus</u> (hermit crab)							
Hepatopancreas/ gonad	10.42	125.70	----	2.95	----	----	
Exoskeleton	----	39.15	----	0.97	----	----	
<u>Anous stolidus</u> (common noddy)							
Viscera	13.08	----	----	----	----	108.60	
Liver	----	----	0.19	----	----	----	
Muscle	12.23	----	----	----	0.022	8.78	
Bone	----	7.45	0.71	----	----	38.50	

Table 86. Distribution of radionuclides in terrestrial biota and soil on PEARL, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt					
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$
<u>Soil</u>						
Hot spot						
Range	----	7.4-55	35-140	3.6-70	15-530	----
Mean	----	19	62	12	51	----
Remainder						
Range	----	1.2-34	3.2-61	0.49-49	0.85-100	----
Mean	----	7.6	17	4.1	11	----
Soil survey						
No. 41	----	12.0	33.0	2.2	12.0	----
No. 42	----	9.1	19.0	1.1	7.6	----
No. 43	----	0.24	32.0	0.05	1.1	----
No. 44	----	1.80	5.90	1.90	2.4	----
Mean	----	5.78	15.30	1.30	5.8	----
Biota soil sample	----	7.90	17.04	1.90	6.68	----
<u>Plants</u>						
<u>Messerschmidia</u>						
<u>argentea</u>	14.66	0.29	0.47	----	----	----
<u>Scaevola</u>						
<u>frutescens</u>	16.50	0.34	0.35	----	0.0023	----
<u>Scaevola</u>						
<u>frutescens</u> <sup>a</sup>	12.52	30.82	20.99	0.16	0.0031	----
<u>Animals</u>						
<u>Sterna fuscata</u>						
(sooty tern)						
Liver	----	----	----	0.65	----	317.00
<u>Rattus exulans</u>						
(rice rat)						
Liver	32.33	33.30	164.90	5.07	0.0119	82.00
Viscera	61.49	30.80	1.79	7.45	1.77	----
Muscle	11.60	37.07	0.04	0.89	0.117	23.20
Bone	9.57	53.60	36.10	2.59	----	----
Skin	8.40	15.00	----	1.58	----	----
Kidney	51.50	27.90	----	5.40	----	----
Lungs	----	51.22	0.84	----	8.15	----

<sup>a</sup>From an area of higher environmental radioactivity in center of island.



Table 87. Distribution of radionuclides in terrestrial biota and soil on URSULA, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						Other
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239, 240</sup> Pu	<sup>55</sup> Fe	
<u>Soil</u>							
Island range	----	0.13-7.8	2.0-19	0.05-1.7	0.26-7.3	----	
Mean	----	1.7	6.8	0.31	1.3	----	
<u>Soil survey</u>							
No. 14	----	2.90	10.00	0.74	3.00	----	
No. 17	----	5.30	13.00	1.20	4.20	----	
Biota soil sample	----	1.40	9.70	0.69	0.54	----	
Mean	----	3.20	11.50	0.87	3.60	----	
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	10.09	104.90	13.60	----	----	----	
<u>Scaevola</u>							
<u>frutescens</u>	5.45	91.49	6.13	----	----	----	
<u>Guettarda</u>							
<u>speciosa</u>	14.23	13.27	7.30	----	----	----	
<u>Animals</u>							
<u>Rattus exulans</u>							
(rice rat)							
Viscera	10.87	43.14	2.17	1.13	----	----	
Liver	6.72	39.41	----	3.59	0.041	42.20	<sup>207</sup> Bi 0.375
Muscle	9.22	37.86	----	----	----	----	
Bone	7.26	61.58	19.60	----	0.146	----	
Skin	7.58	18.50	----	0.41	----	----	
Kidney	----	38.40	----	----	----	----	
Lungs	----	45.00	----	----	----	----	

Table 88. Distribution of radionuclides in terrestrial biota and soil on SALLY, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						Other
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe	
<u>Soil</u>							
Island range	----	0.03-30	0.87-140	0.05-69	0.21-130	----	
Mean	----	3.0	8.4	0.54	4.3	----	
<u>Soil survey</u>							
No. 4	----	3.20	15.0	0.81	1.90	----	
No. 7	----	1.50	8.3	0.70	0.39	----	
Biota soil sample	----	10.30	24.55	1.26	1.89	----	
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	8.28	12.63	4.86	0.10	0.059	----	
<u>Scaevola frutescens</u>	10.78	13.38	6.67	----	0.096	----	<sup>238</sup> Pu 0.0027
<u>Pandanus tectorius</u>	14.02	14.98	1.97	----	0.015	0.703	
<u>Lepturus repens</u> (grass)	3.74	83.20	1.98	----	0.0227	----	
<u>Animals</u>							
<u>Rattus exulans (rice rat)</u>							
Viscera	9.63	92.97	14.60	1.48	1.300	----	
Liver	10.73	63.83	0.002	2.54	0.008	35.50	
Lung	13.20	73.90	0.22	0.67	0.198	----	
Muscle	5.82	60.86	----	----	----	----	<sup>3</sup> H 18.7
Bone	7.01	65.77	25.90	0.81	0.039	----	
Skin	4.52	49.10	----	0.49	----	----	
Kidney	----	73.30	----	2.28	----	----	
<u>Sterna fuscata (sooty tern)</u>							
Viscera	4.79	----	----	----	----	22.43	
Liver	----	----	----	----	----	155.00	
Muscle	7.63	----	0.014	----	0.020	109.50	
Egg	4.57	----	0.004	----	0.015	37.57	
Eggshell	----	----	0.265	----	0.005	----	
Bone	----	----	----	----	----	35.70	
<u>Anous tenuirostris (white-capped tern)</u>							
Viscera	5.89	----	----	----	----	64.40	
Liver	----	----	----	----	0.011	----	
Muscle	6.31	----	----	----	0.005	36.60	
Bone	----	0.14	1.68	0.34	----	61.3	

Table 89. Distribution of radionuclides in terrestrial biota and soil on TILDA, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe
<u>Soil</u>						
<u>Dense</u>						
Range	----	3.5-20	17.54	0.61-1.9	1.4-17	----
Mean	----	8.4	27	1.2	7.6	----
<u>Sparse</u>						
Range	----	0.04-5.3	2.2-47	0.21-1.7	1.1-34	----
Mean	----	1.0	8.7	0.37	2.5	----
Soil survey No. 4	----	3.20	10.14	2.58	1.11	----
Biota soil sample	----	4.90	98.65	3.75	29.32	----
<u>Plants</u>						
<u>Messerschmidia</u>						
<u>argentea</u>	10.13	58.78	10.27	----	----	----
<u>Scaevola frutescens</u>	11.39	24.94	9.05	----	0.0042	----
<u>Morinda citrifolia</u>	13.94	13.90	12.48	----	----	----
<u>Pandanus tectorius</u>	13.29	152.20	15.50	----	0.0069	----
<u>Guettarda speciosa</u>	10.10	5.90	12.57	----	0.0091	----

Table 90. Distribution of radionuclides in terrestrial biota and soil on VERA, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe
<u>Soil</u>						
Range	----	0.03-12	1.1-68	.04-2.2	0.60-25	----
Mean	----	2.0	6.3	0.56	2.5	----
Soil survey No. 10	----	2.10	1.40	0.2	0.75	----
Biota soil sample	----	2.80	8.90	0.3	2.98	----
<u>Plants</u>						
<u>Messerschmidia</u>						
<u>argentea</u>	7.07	10.77	12.79	----	0.0024	----
<u>Scaevola frutescens</u>	8.18	1.69	4.49	----	----	----
<u>Morinda citrifolia</u>	10.46	12.12	11.85	----	----	----
<u>Pandanus tectorius</u>	9.17	17.58	4.24	----	0.0076	----
<u>Cocos nucifera</u>	5.64	9.30	0.13	----	----	----
<u>Pisonia grandis</u>	28.58	56.94	23.11	----	----	----

Table 91. Distribution of radionuclides in terrestrial biota and soil on WILMA, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt				
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$
<u>Soil</u>					
Range	----	0.31-7.2	0.26-13	0.01-0.70	0.1-5.3
Mean	----	1.3	3.3	0.12	1.1
<u>Soil survey</u>					
No. 21	----	1.10	4.2	0.18	1.30
No. 22	----	1.80	2.5	0.14	0.70
Mean	----	1.45	3.4	0.16	1.00
<u>Plants</u>					
<u>Messerschmidia argentea</u>	5.00	6.19	----	----	----
<u>Scaevola frutescens</u>	10.31	1.24	----	----	----
<u>Guettarda speciosa</u>	10.60	3.14	----	----	----

Table 92. Locations of biota samples collected on YVONNE (Runit), Enewetak Atoll, 1972-1973.

Sector	Description
A	At north end of island, near Cactus crater in scattered <u>Messerschmidia-Scaevola</u> regrowth.
B	At north end of island, on lagoon side of road, 150 yd south of Cactus crater.
C	Mid-island, on peninsula which extends into seaward reef, along old airstrip.
D	Old camp area at south end of island.

Table 93. Distribution of radionuclides in terrestrial biota and soil on YVONNE, Enewetak Atoll, 1972-1973.

Sector A Ecosystem level	Activity, pCi/g, dry wt						Other
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe	
<u>Soil</u>							
Soil survey							
No. 139	----	7.30	----	16.00	23.00	----	
No. 140	----	6.50	10.00	4.10	5.60	----	
No. 141	----	47.00	190.00	54.00	55.00	----	
Mean	----	20.26	100.00	24.70	27.87	----	
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	9.93	5644.00	257.20	1.16	0.253	----	
<u>Scaevola frutescens</u>	18.77	658.00	80.63	6.26	0.195	----	
<u>Scaevola frutescens</u>	10.68	609.00	159.00	20.26	0.322	----	
<u>Guettarda speciosa</u>	11.15	794.00	64.41	4.52	0.002	----	
<u>Animals</u>							
<u>Rattus rattus (roof rat)</u>							
Muscle	12.35	4240.00	5.09	12.35	0.052	32.80	<sup>3</sup> H 1.8
Bone	----	1833.00	146.40	5.92	0.057	----	
Viscera	7.61	2928.00	----	112.60	1.05	----	
Skin	6.69	2088.00	----	14.00	----	----	
Liver	----	2559.00	----	7.03	0.027	126.10	<sup>151</sup> Sm 18.70
Kidney	----	3427.00	----	257.70	----	----	
Lung	14.26	3306.00	0.24	10.53	0.107	----	<sup>134</sup> Cs 1.5
Muscle	13.07	3824.00	37.79	8.51	0.003	78.83	
Bone	7.93	2199.00	135.10	10.57	0.029	----	<sup>134</sup> Cs 1.36
Viscera	13.33	3531.00	4.09	230.00	0.581	----	
Skin	6.92	1875.00	----	7.43	----	----	
Liver	14.15	2215.00	0.005	86.13	0.013	135.60	
Kidney	33.10	3286.00	----	261.80	----	252.30	
Lung	33.12	2760.00	16.17	11.08	----	----	

Table 93 (Continued).

Sector B Ecosystem level	Activity, pCi/g. dry wt						
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$	Other
<u>Soil</u>							
Soil survey							
No. 135	0.31	0.52	2.50	0.29	3.400	----	
No. 136	----	1.70	3.50	0.84	7.000	----	
No. 137	1.60	1.60	2.50	0.28	9.400	----	
Biota soil sample	1.26	4.33	6.13	0.69	----	----	
Mean	----	2.04	3.65	0.52	6.60	----	
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	10.91	95.32	8.60	----	0.013	----	
<u>Scaevola frutescens</u>	15.93	28.25	1.94	----	0.190	----	
<u>Cocos nucifera</u>							
Meat	8.24	3.96	0.01	----	----	----	$^3\text{H}$ 0.66
<u>Animals</u>							
<u>Rattus rattus</u> (roof rat)							
Muscle	16.82	86.04	----	----	----	----	
Bone	9.74	48.78	16.67	----	0.304	----	
Viscera	9.67	76.71	0.57	1.99	0.393	----	
Skin	4.74	42.64	----	----	----	----	
Liver	----	56.22	----	2.90	0.008	25.01	$^{151}\text{Sm}$ 23.00
Kidney	----	59.64	----	4.96	----	----	
Lung	----	39.72	----	----	0.023	----	
<u>Anous stolidus</u> (common noddy)							
Egg	7.22	----	0.07	----	----	54.50	
Eggshell	----	----	----	----	0.009	----	
Viscera	8.34	----	----	----	----	64.41	
Liver	----	----	----	0.37	----	385.60	
Muscle	7.39	----	0.007	0.23	0.02	22.61	
Bone	----	5.51	----	----	0.021	63.50	

Table 93 (Continued)

Sector C Ecosystem level	Activity, pCi/g, dry wt						
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$	Other
<u>Soil</u>							
Soil survey							
No. 26	----	3.40	3.40	2.80	6.300	----	
No. 28	----	2.30	9.40	9.50	21.000	----	
No. 29	----	0.55	1.50	4.60	3.300	----	
No. 55	----	2.30	4.30	2.20	5.300	----	
Mean	----	2.13	4.65	4.70	8.970	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>							
	14.19	2.28	0.064	----	0.008	----	
<u>Messerschmidia argentea</u>							
	14.46	3.81	1.43	----	0.011	----	
<u>Messerschmidia argentea</u>							
	10.91	95.32	8.60	----	0.129	----	
<u>Scaevola frutescens</u>	13.21	11.88	1.76	0.51	0.026	----	$^{238}\text{Pu}$ 0.0068
<u>Scaevola frutescens</u>	14.16	1.57	0.44	----	0.004	----	
<u>Scaevola frutescens</u>	15.00	8.06	0.66	0.25	1.293	----	$^{238}\text{Pu}$ 0.061 $^{241}\text{Am}$ 0.146
<u>Scaevola frutescens</u>	10.68	609.90	159.00	20.26	0.322	----	
<u>Scaevola frutescens</u>	15.93	28.25	1.94	----	0.190	----	$^{238}\text{Pu}$ 0.076
<u>Animals</u>							
<u>Rattus rattus (roof rat)</u>							
Skin	----	28.40	----	0.69	----	----	
Lung	----	53.33	----	----	0.568	----	
Viscera	----	55.81	----	----	0.211	3.46	$^{238}\text{Pu}$ 0.096
Liver	----	38.68	0.002	5.63	0.011	13.83	
Kidney	30.64	29.00	----	8.03	----	----	
Muscle	5.77	49.19	6.76	0.55	----	4.12	$^3\text{H}$ 1.10
Bone	----	38.78	6.40	0.51	0.059	----	

Table 93 (Continued).

Sector D Ecosystem level	Activity, pCi/g, dry wt					
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$ Other
<u>Soil</u>						
Soil survey						
No. 43	----	0.25	43.00	0.05	210.00	----
No. 2	----	0.21	1.20	0.12	0.37	----
Biota soil sample	----	0.82	----	8.00	----	----
<u>Plants</u>						
<u>Messerschmidia</u>						
<u>argentea</u>	14.19	2.28	0.64	----	0.004	----
<u>Scaevola frutescens</u>	14.16	1.57	0.44	----	0.004	----
<u>Cocos nucifera</u>						
Meat	6.39	1.99	----	----	----	----
<u>Animals</u>						
<u>Rattus rattus</u> (roof rat)						
Muscle	15.87	3.74	0.63	----	0.008	1.23
Bone	23.95	23.80	1.32	1.31	0.058	----
Lung	----	11.55	----	----	0.201	----
Viscera	17.77	5.69	----	0.20	0.020	----
Liver	----	4.62	10.54	----	0.398	17.30
Skin	10.70	3.94	----	----	----	----
Kidney <sup>a</sup>	16.72	6.19	----	----	----	----
<u>Anous stolidus</u> (common noddy)						
Eggshell	----	----	0.22	----	----	1.10
Egg	4.13	----	----	----	0.023	56.76

<sup>a</sup>Analysis showed 167.20 pCi/g  $^{40}\text{K}$ .



Table 94. Distribution of radionuclides in terrestrial biota and soil on BRUCE, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						Other
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$	
<u>Soil</u>							
Range	----	0.02-111	0.03-1.8	0.03-0.74	0.02-0.22	----	
Mean	----	0.40	0.59	0.12	0.08	----	
<u>Soil survey</u>							
No. 4	----	0.59	0.30	0.08	0.02	----	
No. 5	----	0.37	0.32	0.04	0.03	----	
No. 6	----	0.20	0.03	0.04	0.04	----	
Mean	----	0.327	0.22	0.05	0.03	----	
Biota soil sample	0.64	2.60	1.53	1.25	0.26	----	
<u>Plants</u>							
<u>Cocos nucifera</u>	5.93	0.58	----	----	----	----	
<u>Pisonia grandis</u>	17.76	1.46	0.50	----	----	----	
<u>Messerschmidia</u>							
<u>argentea</u>	8.03	1.16	0.33	----	----	----	
<u>Scaevola frutescens</u>	9.32	0.75	0.88	----	----	----	
<u>Animals</u>							
<u>Rattus rattus (roof rat)</u>							
Liver	30.20	1.07	----	1.62	0.013	46.4	
Viscera	----	1.09	----	----	0.035	----	
Muscle	5.21	1.47	0.07	----	0.009	2.21	
Kidney	----	1.20	----	3.19	----	----	
Lungs	35.88	1.55	----	----	----	----	
Skin	8.07	0.61	----	----	----	----	
Bone	18.81	13.25	1.69	----	3.28	----	
<u>Anous tenuirostris (white-capped noddy)</u>							
Liver	8.37	----	0.03	----	0.022	326.6	
Viscera	----	----	----	----	----	73.9	
Muscle	7.10	----	----	0.39	0.006	41.3	
Bone	----	----	0.66	----	----	44.2	
<u>Birgus latro (coconut crab)</u>							
Muscle	11.28	1.98	0.18	0.20	----	0.98	$^3\text{H}$ 0.42
Hepatopancreas	3.02	0.42	0.13	0.20	----	5.70	$^3\text{H}$ 0.16
Exoskeleton	2.59	0.29	6.08	----	0.001	0.07	

Table 95. Distribution of radionuclides in terrestrial biota and soil on DAVID, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						Other
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe	
<u>Soil</u>							
Range	----	0.03-1.0	0.08-2.6	0.01-0.14	0.01-0.23	----	
Mean	----	0.39	0.55	0.034	0.054	----	
<u>Soil survey</u>							
No. 2	0.38	0.56	2.60	0.02	0.05	----	
No. 3	----	0.45	0.32	0.03	0.01	----	
Biota soil sample	----	0.36	0.41	0.03	0.02	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>	13.55	1.09	0.46	----	0.0061	----	
<u>Messerschmidia argentea</u>	11.02	7.24	0.76	----	----	----	
<u>Messerschmidia argentea</u>	13.22	2.58	1.06	----	----	----	
<u>Messerschmidia argentea</u>	3.88	15.84	0.75	----	----	----	
<u>Scaevola frutescens</u>	17.59	1.11	0.34	----	0.0005	----	
<u>Scaevola frutescens</u>	10.69	4.82	0.37	----	----	----	
<u>Scaevola frutescens</u>	13.02	5.18	0.31	----	----	----	
<u>Scaevola frutescens</u>	16.33	2.01	0.56	----	----	----	
<u>Morinda citrifolia</u>	12.26	3.51	0.02	----	0.013	----	
<u>Pandanus tectorius</u>	9.74	15.90	3.56	----	----	0.13	
<u>Tacca leontopetaloides</u>	6.63	1.09	0.46	----	0.0061	----	<sup>3</sup> H 0.52
<u>Fimbristylis atollensis</u>	3.83	7.39	----	----	----	----	
<u>Pisonia grandis</u>	19.02	3.12	0.77	----	0.0013	----	
<u>Pisonia grandis</u>	10.2	1.8	0.56	----	0.0002	----	
<u>Guettarda speciosa</u>	4.00	3.16	0.32	----	----	----	
<u>Cocos nucifera</u>	6.44	2.59	0.01	----	----	----	<sup>3</sup> H 0.31
<u>Cocos nucifera</u>	3.76	1.67	0.18	----	----	----	<sup>102</sup> Rh 0.123
<u>Cocos nucifera</u>	4.69	0.40	0.03	----	0.0034	----	
<u>Cocos nucifera</u>							
Milk	30.93	23.32	----	----	----	----	

Table 95 (Continued).

Ecosystem level	Activity, pCi/g, dry wt						
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$	Other
<u>Animals</u>							
<u>Coenobita perlatus</u> (hermit crab)							
Hepatopancreas	7.61	1.95	0.19	0.23	4.82	0.57	$^3\text{H}$ 0.95
Muscle	7.52	2.06	0.31	0.28	0.0031	----	$^3\text{H}$ 0.58
Exoskeleton	1.76	0.60	4.05	----	0.010	0.04	
<u>Sterna fuscata</u> (sooty tern)							
Muscle	7.46	----	----	----	0.119	59.0	
Bone	----	0.74	----	----	----	37.4	$^{134}\text{Cs}$ 0.413
Liver	20.36	----	----	----	----	153.20	
Viscera	8.9	----	----	----	----	63.5	
<u>Erolia acuminata</u> (sandpiper)							
Liver	17.57	----	----	----	----	----	
Bone	28.16	0.79	----	----	----	----	
<u>Demigretta sacra</u> (reef heron)							
Bone	8.76	1.34	----	0.41	----	----	
Muscle	4.65	1.59	----	----	----	----	
<u>Rattus exulans</u> (rice rat)							
Viscera	12.24	21.97	0.24	----	0.0087	----	
Liver	----	16.36	----	----	0.0042	3.67	
Muscle	7.80	18.78	0.60	----	0.044	0.98	
Bone	11.46	28.37	1.37	----	0.065	----	
Skin	6.49	9.13	----	----	----	----	
Kidney	----	17.0	----	----	----	----	
Lung	----	18.5	----	----	0.031	----	

Table 96. Distribution of radionuclides in terrestrial biota and soil on REX, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe
<u>Soil</u>						
Soil survey						
No. 3	----	0.92	0.70	0.04	0.050	----
No. 4	----	1.10	1.60	0.05	0.060	----
No. 6	----	0.23	0.37	0.08	0.020	----
Mean	----	0.75	0.89	0.06	0.040	----
<u>Plants</u>						
<u>Scaevola frutescens</u>	6.96	0.49	----	----	----	----
<u>Messerschmidia argentea</u>	8.90	2.45	----	----	----	----
<u>Pisonia grandis</u>	16.00	2.64	----	0.091	----	----
<u>Animals</u>						
<u>Anous stolidus (common noddy)</u>						
Eggshell	----	----	----	----	----	0.73
Egg	7.69	----	----	----	0.0077	51.4
Liver	4.89	----	----	----	----	117.6
Muscle	10.81	----	0.006	----	0.0056	43.5
Bone	----	----	----	----	----	44.77
Viscera	----	----	----	----	----	50.0
<u>Coenobita perlatus (hermit crab)</u>						
Hepatopancreas	5.83	0.78	0.30	0.57	0.0035	1.82
Muscle	6.68	1.05	0.32	1.44	0.0026	1.47
Exoskeleton	1.84	0.25	3.62	----	0.001	0.085

Table 97. Distribution of radionuclides in terrestrial biota and soil on ELMER, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						Other
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$	
<u>Soil</u>							
Soil survey							
No. 19	----	0.50	0.44	----	0.100	----	
No. 67	----	0.22	0.31	----	0.060	----	
No. 68	----	0.51	0.24	----	0.020	----	
Biota soil sample	----	2.44	2.26	----	0.19	----	
Biota soil sample	0.40	0.40	0.71	----	0.03	----	
<u>Plants</u>							
<u>Messerschmidia argentea</u>							
<u>Messerschmidia argentea</u>	----	2.39	0.98	----	----	----	
<u>Scaevola frutescens</u>	13.60	2.40	0.27	----	----	----	
<u>Cocos nucifera</u>	9.73	2.14	0.03	----	----	----	$^3\text{H}$ 0.31
<u>Messerschmidia argentea</u>							
<u>Messerschmidia argentea</u>	9.04	1.66	0.63	----	----	----	
<u>Scaevola frutescens</u>	11.83	1.47	0.62	----	----	----	
<u>Cocos nucifera</u>	5.50	3.45	----	----	----	----	
<u>Pandanus tectorius</u>	8.86	3.09	25.14	----	0.002	0.41	
<u>Animals</u>							
<u>Rattus rattus (roof rat)</u>							
Viscera	11.19	19.00	0.16	1.39	0.0074	----	
Liver	11.12	15.60	0.018	----	----	0.93	
Bone	9.04	9.96	1.42	----	0.23	----	
Muscle	10.3	18.4	0.06	----	0.016	0.10	$^3\text{H}$ 11.3
Skin	6.5	7.6	----	----	----	----	
Lung	14.7	16.9	1.0	----	0.14	----	
Kidney	21.8	15.0	----	1.74	----	----	

Table 98. Distribution of radionuclides in terrestrial biota and soil on FRED, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt					
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	Other
<u>Soil</u>						
Soil survey						
No. 18	----	0.16	0.85	----	----	
No. 52	----	0.48	1.50	0.15	0.17	
<u>Plants</u>						
<u>Messerschmidia argentea</u>						
	11.23	0.56	0.43	----	----	
<u>Messerschmidia argentea</u>						
	8.83	1.78	0.49	----	----	
<u>Scaevola frutescens</u>						
	10.36	0.65	0.23	----	0.0006	
<u>Scaevola frutescens</u>						
	7.14	3.80	0.81	----	----	
<u>Cocos nucifera</u>						
	6.39	2.39	0.03	----	----	$^3\text{H}$ 0.39
<u>Cocos nucifera</u>						
	5.59	0.53	0.37	----	----	
<u>Pandanus tectorius</u>						
	3.38	4.29	0.42	----	0.0077	$^{55}\text{Fe}$ 0.85

Table 99. Distribution of radionuclides in terrestrial biota and soil on GLENN, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						Other
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe	
<u>Soil</u>							
Range	----	0.01-0.25	0.09-3.9	0.01-0.25	0.005-0.26	----	
Mean	----	0.60	1.37	0.069	0.105	----	
<u>Soil survey</u>							
No. 15	----	1.20	0.24	0.12	0.13	----	
No. 16	----	0.53	0.95	0.03	0.04	----	
No. 17	----	0.58	0.71	0.02	0.04	----	
Mean	----	0.77	0.63	0.06	0.07	----	
Biota soil sample	----	1.67	----	0.13	0.30	----	
<u>Plants</u>							
<u>Scaevola frutescens</u>	12.84	0.64	1.54	----	----	----	
<u>Scaevola frutescens</u>	13.74	0.53	1.34	----	----	----	
<u>Messerschmidia argentea</u>	21.81	1.24	2.05	----	----	----	
<u>Messerschmidia argentea</u>	9.75	1.27	2.51	----	----	----	
<u>Pisonia grandis</u>	25.79	1.86	2.88	----	----	0.81	<sup>102</sup> Rh 0.17
<u>Pisonia grandis</u>	30.28	3.91	1.74	----	----	----	
<u>Morinda citrifolia</u>	22.29	0.64	1.58	----	----	----	
<u>Morinda citrifolia</u>	14.16	0.76	0.40	----	----	----	
<u>Cocos nucifera (meat)</u>	9.10	1.65	0.33	----	----	----	
<u>Cocos nucifera (meat)</u>	8.28	1.30	----	----	----	----	
<u>Animals</u>							
<u>Birgus latro (coconut crab)</u>							
Hepatopancreas	15.0	0.54	0.27	0.28	----	----	<sup>3</sup> H 0.27
Muscle	10.45	1.88	----	----	----	0.68	<sup>3</sup> H 0.69
Exoskeleton	1.06	0.31	10.40	----	0.0035	----	
<u>Coenobita perlatus (hermit crab)</u>							
Hepatopancreas	8.68	1.51	0.43	1.12	0.006	1.55	
Exoskeleton	1.52	0.25	9.14	----	0.0011	----	
Muscle	7.86	1.51	0.91	1.97	0.011	1.32	

Table 99 (Continued).

Ecosystem level	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe	Other
<u>Animals</u>							
<u>Rattus rattus</u> (roof rat)							
Viscera	11.75	1.88	0.28	2.06	0.036	----	
Liver	12.79	1.45	----	1.18	0.035	----	
Bone	10.61	6.02	2.67	0.71	0.87	----	
Muscle	8.18	1.76	1.03	0.48	0.017	4.49	
Skin	2.3	0.33	----	----	----	----	
Kidney	----	1.46	----	2.40	----	----	
Lung	20.7	1.74	----	----	0.30	----	

Table 100. Distribution of radionuclides in terrestrial biota and soil on HENRY, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe	Other
<u>Soil</u>							
Soil survey							
No. 7	----	0.01	0.24	0.01	0.21	----	
No. 8	----	0.19	0.28	0.05	0.11	----	
Biota soil sample	1.40	0.98	----	----	----	----	
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	12.77	0.52	1.98	----	----	----	
<u>Scaevola frutescens</u>	12.64	0.19	----	----	----	----	
<u>Morinda citrifolia</u>	17.01	1.19	0.32	----	----	----	
<u>Cocos nucifera</u>	3.66	0.70	----	----	----	----	
<u>Animals</u>							
<u>Coenobita perlatus</u> (hermit crab)							
Hepatopancreas	5.72	1.17	0.50	0.98	----	----	
Muscle	7.69	1.08	0.64	2.00	0.0066	0.98	
Exoskeleton	2.34	0.24	9.64	----	0.0009	0.08	
<u>Anous stolidus</u> (common noddy)							
Egg	3.38	----	----	----	----	54.1	<sup>65</sup> Zn 0.79
Eggshell	----	----	----	----	----	8.6	



Table 101. Distribution of radionuclides in terrestrial biota and soil on JAMES, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt					
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239, 240</sup> Pu	<sup>55</sup> Fe
<u>Soil</u>						
Soil survey						
No. 6	----	0.08	0.57	0.06	0.03	----
No. 8	----	0.02	0.39	0.12	0.11	----
Mean	----	0.05	0.48	0.09	0.07	----
Biota soil sample	----	----	1.81	9.04	0.16	----
<u>Plants</u>						
<u>Messerschmidia</u>						
<u>argentea</u>	17.71	1.76	----	0.25	----	----
<u>Scaevola frutescens</u>		9.42	0.52	----	----	----
<u>Pisonia grandis</u>	12.66	1.55	----	----	----	----
<u>Guettarda speciosa</u>	13.74	0.68	----	----	----	----
<u>Morinda citrifolia</u>	16.99	2.23	1.85	----	----	----
<u>Animals</u>						
<u>Birgus latro</u> (coconut crab)						
Muscle	9.62	1.25	0.079	1.05	----	1.84
Hepatopancreas	4.00	0.32	----	1.56	----	12.80
Exoskeleton	1.44	0.22	5.90	0.11	0.002	0.30

Table 102. Distribution of radionuclides in terrestrial biota and soil on KEITH, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						Other
	$^{40}\text{K}$	$^{137}\text{Cs}$	$^{90}\text{Sr}$	$^{60}\text{Co}$	$^{239,240}\text{Pu}$	$^{55}\text{Fe}$	
<u>Soil</u>							
Soil survey							
No. 7	----	1.40	3.40	0.28	0.430	----	
No. 9	----	0.81	1.60	0.11	0.100	----	
No. 11	----	0.05	0.06	0.07	0.130	----	
Biota soil sample (coconut)	----	0.18	1.38	0.14	0.080	----	
Biota soil sample ( <u>Pisonia</u> )	----	0.19	1.57	5.21	0.070	----	
<u>Plants</u>							
<u>Messerschmidia</u>							
<u>argentea</u>	12.45	0.25	0.32	0.20	0.0044	----	
<u>Scaevola frutescens</u>	15.52	0.43	0.64	----	----	----	
<u>Pisonia grandis</u>	30.81	3.65	3.00	----	----	----	
<u>Cocos nucifera</u>	7.69	0.95	----	----	----	----	
<u>Guettarda speciosa</u>	12.87	0.47	1.74	----	----	----	
<u>Pandanus tectorius</u> (leaves)	12.70	0.86	13.11	----	----	12.20	$^3\text{H}$ 2.0
<u>Pandanus tectorius</u> (flower)	8.18	0.57	----	----	----	0.36	
<u>Animals</u>							
<u>Birgus latro</u> (coconut crab)							
Muscle	10.11	1.92	1.19	0.42	----	1.46	
Exoskeleton	3.35	0.51	9.96	----	0.0007	0.18	
Hepatopancreas	3.20	0.50	0.40	1.03	0.0098	6.17	
<u>Anous stolidus</u> (common noddy)							
Viscera	8.97	----	----	----	----	8.02	
Muscle	12.96	----	----	0.45	0.001	----	
Bone	3.80	----	----	0.31	----	68.5	
Liver	----	----	----	0.69	----	----	

Table 103. Distribution of radionuclides in terrestrial biota and soil on LEROY, Enewetak Atoll, 1972-1973.

Ecosystem level	Activity, pCi/g, dry wt						Other
	<sup>40</sup> K	<sup>137</sup> Cs	<sup>90</sup> Sr	<sup>60</sup> Co	<sup>239,240</sup> Pu	<sup>55</sup> Fe	
<u>Soil</u>							
Range	----	0.5-10	1.6-34	0.04-5.0	0.02-2.0	----	
Mean	----	3.2	11	0.58	0.63	----	
<u>Soil survey</u>							
No. 2	----	2.4	15.0	1.60	0.88	----	
No. 4	----	2.6	9.2	2.2	0.89	----	
Mean	----	2.5	12.0	1.9	0.88		
Biota soil sample	----	7.3	11.8	3.6	2.23	----	
<u>Plants</u>							
<u>Cocos nucifera</u>	4.10	3.54	0.19	----	----	----	<sup>102</sup> Rh 0.13
<u>Scaevola frutescens</u>	13.29	1.80	3.74	----	-----	----	
<u>Messerschmidia argentea</u>							
	15.09	4.71	14.37	0.21	----	----	
<u>Pisonia grandis</u>							
	34.27	10.17	14.86	----	----	----	
<u>Pandanus tectorius</u>							
	7.99	9.14	1.69	----	0.0022	0.21	
<u>Pandanus tectorius</u>	30.2	26.2	16.26	----	----	----	
<u>Animals</u>							
<u>Birgus latro (coconut crab)</u>							
Muscle	8.80	12.60	1.58	1.23	0.003	1.59	<sup>3</sup> H 0.88
Exoskeleton	1.58	2.52	8.96	0.71	0.025	0.17	
Hepatopancreas	2.54	3.83	2.58	0.84	0.004	5.05	<sup>3</sup> H 0.21
<u>Anous tenuirostris (white-capped noddy)</u>							
Muscle	10.95	----	----	2.06	0.003	64.4	
Liver	----	----	0.40	2.83	0.007	810.8	
Viscera	7.82	----	----	1.01	----	71.6	
Bone	----	----	----	0.94	----	109.5	

## Discussion of Survey Data

The data on terrestrial biota samples collected in the Enewetak Atoll survey are shown in Table 59. It should be emphasized that an attempt was made to obtain samples of the range of edible species important to the evaluation of potential dosages. If an organism was not collected on an island, it is most likely that it did not occur there in significant numbers or in sufficient density to be encountered by the survey crews in several hours of collecting effort. We sampled judiciously so as not to alter the ecological state by our presence or removal of specimens. Because of the construction and test activities on the northern islands, the biota on many islands were in early stages of recovery or ecological succession, and therefore characterized by a limited number of species from a rather small flora (St. John, 1960). On some islands, only two ubiquitous woody species, Messerschmidia argentea and Scaevola frutescens, were found with a few widespread indigenous or introduced herb, grass, and vine species.

A wide range of plant species was sampled in order to obtain information on the transfer of radionuclides from soil to plants; while not eaten by man, several species were collected to provide a broad background on soil-plant relationships. It is apparent in the survey data that considerable variation occurs in the uptake of radionuclides from the stratum by plants, and the inclusion of non food plant species in the collections provides greater perspective on this subject.

Because most of the animals collected in the Enewetak survey were physically small, pooling of samples and organs from a single large sample of animals from a given island or area was necessary to obtain an adequate sample size for analysis. Therefore, the radionuclide data on mammals, birds, and land crustacea represent integrated or population values rather than single animal analyses.

In Table 59, the basic survey data are listed according to the island from which the samples were obtained. This information is essentially the biological data bank for evaluation of dose to man through the terrestrial food chain.

In Tables 60 to 75, the survey data are ordered on the species of organism and permit the range of radionuclide concentration in a single species throughout the Atoll to be observed in a single table. In Tables 76 to 103, the basic survey data are arranged by island and include the soil, plant, and animal data obtained from the site.

Data presented in Tables 60 to 75 will be discussed here to provide a detailed ecological description of the Enewetak terrestrial biota survey. In Table 60, the radionuclide concentrations in Messerschmidia argentea, a broad-leaved evergreen tree which was collected throughout the Atoll, are listed.  $^{137}\text{Cs}$  was found in M. argentea on every island. Highest concentrations were observed at the northern end of YVONNE (Runit), on JANET (Engebi), and on IRENE (Bogon). Elevated concentrations of  $^{137}\text{Cs}$  were found in Messerschmidia in islands from ALICE, across the northern arc of islands and

south along the eastern rim of the Atoll to YVONNE. One value on DAVID (Japtan) of 15.84 pCi/g  $^{137}\text{Cs}$  is approximately 2-3 times the other values from that island. This sample had an unusually low potassium content.

Correlation between  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  radioactivity in Messerschmidia and other plant species was not generally high. The differential uptake of these two radionuclides is undoubtedly influenced by the character of the Atoll substratum or soil. Most soils develop in place from the chemical and physical erosional products derived from the geological parent materials, which on Enewetak Atoll is composed entirely of coralline or algal limestone, or calcium and magnesium carbonate. The low potassium content of the Atoll substratum, the lack of clay-size particles (usually responsible for potassium and cesium complexing in soils), and the calcareous nature of the Atoll substratum suggest differential movement of cesium and strontium.

Highest  $^{137}\text{Cs}$  concentration occurred in the Messerschmidia collected at the northern end of YVONNE (Runit), and the highest  $^{90}\text{Sr}$  in Messerschmidia was on IRENE. The southern chain of islands from GLENN (Igurin) to KEITH (Giriinian) have Messerschmidia trees (leaves) with concentrations of  $^{137}\text{Cs}$  from 0.25 to 1.76 pCi/g. Scaevola frutescens leaf concentrations also fall in this range. Vegetation growing in the San Francisco Bay area (approximately 38° N latitude) in 1972 had a mean con-

centration of 0.25 pCi/g dry wt  $^{137}\text{Cs}^*$ , which is at the lower limit of concentrations observed in the southern arc of islands at Enewetak Atoll. Soil in the San Francisco area ranged from 0.01 to 0.10 pCi  $^{137}\text{Cs}$ /g dry wt in 1972.

The levels of  $^{137}\text{Cs}$  observed on the southern and eastern islands south of BRUCE are higher than expected from world background for the southwest Pacific area. In 1964, a radiobiological survey of Enewetak and Bikini Atolls was conducted by the University of Washington Laboratory of Radiation Biology, and levels of  $^{137}\text{Cs}$  in Messerschmidia and Scaevola on GLENN (Igurin) ranged from 2.4 to 5.0 pCi/g dry wt.† These southern islands received fallout from the peripheries of clouds which typically exited the Atoll toward the southwest. This is suggested by the elevated concentrations of  $^{137}\text{Cs}$  in Messerschmidia, Scaevola, Pisonia, and Pandanus on LEROY (Rigili).

The radionuclide concentrations in Scaevola frutescens (Table 61) show patterns similar to those seen in Messerschmidia, but generally lower in value. Highest concentrations were again found on the northern end of YVONNE (Runit), where the maximum

\* P. H. Gudiksen, C. L. Lindeken, J. W. Meadows, and K. O. Hamby, Environmental Levels of Radioactivity in the Vicinity of the Lawrence Livermore Laboratory, 1972 Annual Report, Lawrence Livermore Laboratory, Rept. UCRL-51333 (1973).

† A. D. Welander, K. Bonham, L. R. Donaldson, R. F. Palumbo, S. P. Gessel, F. G. Lowman, and W. B. Jackson, Bikini-Enewetak Studies 1964 Part I, Ecological Observations, University of Washington Laboratory of Radiation Biology, Seattle, Rept. UWFL-93, Part I (1966).

$^{137}\text{Cs}$  concentrations in both species occurred. Maximum concentrations of  $^{60}\text{Co}$  in both Messerschmidia and Scaevola were found on IRENE (Bogon) adjacent to Seminole crater. Highest  $^{239,240}\text{Pu}$  concentrations were observed on the north end of YVONNE (Runit) in both Messerschmidia (0.766 pCi/g) and Scaevola (1.293 pCi/g). The highest  $^{90}\text{Sr}$  value in Scaevola also occurred on YVONNE (Runit). There are 12 islands on which Messerschmidia or Scaevola had over 25 pCi/g of either  $^{137}\text{Cs}$  or  $^{90}\text{Sr}$ . These are:

ALICE	NANCY
CLARA	PEARL
IRENE	RUBY
JANET	TILDA
MARY	URSULA
MARY/NANCY*	YVONNE

The arc of islands bounded by ALICE (Bogallua) on the west and YVONNE (Runit) on the east embraces the portion of the Atoll with the highest levels of environmental radioactivity. This is reflected by the radionuclide concentrations in the dominant vegetation of those sites. Within this sector of the Atoll, the highest levels of environmental radioactivity in the biota were found on IRENE (Bogon), JANET (Engebi), and YVONNE (Runit). In Table 62, the  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in Messerschmidia and Scaevola on the three most radioactive islands are compared. From this table it is apparent that both  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  are higher in Messerschmidia than in Scaevola. No explanation for this species difference can be made from these data. Scaevola is thought to be slightly more halophytic or salt-tolerant

\*Small islet or bar between MARY and NANCY.

than Messerschmidia. The  $^{40}\text{K}$  concentrations, and hence the stable potassium levels, were found to be somewhat higher in Scaevola.

The concentrations of radionuclides on Cocos nucifera, the coconut palm, on the islands of Enewetak Atoll are shown in Table 63. On the northern and eastern arc of islands, from DAISY to YVONNE, the coconut palms were young and most of the trees were just beginning to bear nuts at the time of the survey. On JANET (Engebi) fruit-bearing coconut palms were found along the eastern, or seaward, side of the island. These collections on JANET, and two others on MARY and NANCY, had the highest concentrations of  $^{137}\text{Cs}$ . Almost every high concentration of  $^{137}\text{Cs}$  in coconut milk was correlated with high  $^{40}\text{K}$ . Two high concentrations of  $^{55}\text{Fe}$  were found in coconuts from IRENE and MARY. The only  $^{239,240}\text{Pu}$  detected in coconuts was found on IRENE (Bogon), in a radioactive area on the eastern side of the island.

The small tree, Morinda citrifolia, bears a soft, edible fruit. The leaves of this tree, and the fruit when available, were collected on 11 islands. Radionuclide concentrations in Morinda are given in Table 64. High  $^{137}\text{Cs}$  concentrations were found in Morinda on the northeastern arc of the islands from KATE to VERA. The highest  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  values are observed on MARY.

A second small tree species, Guettarda speciosa, was collected on 13 islands (Table 65). It is apparently an early invader of bare or denuded habitats, or perhaps regenerates readily

from root stocks left in the ground. \* Elevated  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations were seen in Guettarda on BELLE, MARY, IRENE, and YVONNE.

The large tree, Pisonia grandis, which was not found on the Atoll north of KATE, was collected on 12 islands (Table 68). North of DAVID, Pisonia was found on five islands, two of which had been disturbed (KATE and NANCY) during the test period. On the southern islands from GLENN to LEROY, and on DAVID and BRUCE on the eastern side of the Atoll, Pisonia grandis forms almost mono-specific stands with essentially closed canopies. On the northern two islands (KATE and NANCY), scattered trees of Pisonia are reinvading the disturbed habitats which are typically dominated by Messerschmidia and Scaevola at this time. Pisonia collected on KATE, NANCY, and VERA had the highest  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in the species on the Atoll. The plant species Pisonia appears to have a high potassium content from its  $^{40}\text{K}$  concentration; some plants have more than 3% potassium in their leaves. The mean  $^{40}\text{K}$  concentration in Pisonia is 21.0 pCi/g, which is higher than any plant sampled except coconut milk. The Pisonia forest soon creates an organic layer or mull in the soil of the island, and the potassium cycle of the site becomes enriched. The elevated levels of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in Pisonia on LEROY again suggest that this island received fallout from tests conducted to the northeast across the lagoon.

\*R. F. Palumbo, "Recovery of the Land Plants at Enewetak Atoll Following a Nuclear Detonation," Radiation Botany 1, 182 (1962).

The Pandanus tree, Pandanus tectorius, was found on 11 islands at Enewetak Atoll (Table 67). Two trees bore fruit at the time of the survey, one on BELLE in the northern part of the Atoll and the other on KEITH in the southern islands. The fruit of this plant had 1.35 times the  $^{137}\text{Cs}$  concentration that leaves from the same plant had. Pandanus on LEROY had elevated  $^{137}\text{Cs}$  levels which were seen in other trees on that island. A high uptake of  $^{90}\text{Sr}$  is indicated by elevated levels of that radionuclide in Pandanus leaves on ELMER and KEITH, where soil concentrations are low.

In Table 68, radionuclide concentrations in miscellaneous plant species are given. Lepturus repens is an indigenous grass which invades disturbed sites on the islands, and may be locally abundant around bird rookeries. A sedge counterpart, Fimbristylis atollensis, is also found in meadow-like areas in open stands or savannahs of Messerschmidia, such as on the north end of JANET. Suriana maritima is a halophytic shrub species which was collected on the southern margin of Seminole crater on IRENE. Pluchea odorata is a low succulent shrub typically found on the edges of natural openings in the trees and was collected at the western end of the airstrip on JANET. Tacca leontopetaloides, or arrowroot, is a coarse herb which has a large edible corm or storage organ that is eaten after rigorous processing. It was found in abundance in deep organic soil on DAVID, and in small patches on some of the southern islands. Terminalia samoensis is a low shrub which was

observed and collected on one of the southern islands (IRWIN).

Lepturus had elevated concentrations of  $^{137}\text{Cs}$  on MARY and SALLY, but concentrations were low on HELEN and IRENE, probably because collections were made on the beach where radioactivity levels are low. Fimbristylis, the sedge, collected from the margin of Seminole crater on IRENE had high  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ ,  $^{60}\text{Co}$ , and  $^{239,240}\text{Pu}$  concentrations. Suriana growing in the same area also showed an accumulation of the same radionuclides, especially  $^{60}\text{Co}$ , which is prominent in most of the collections from IRENE.

Pluchea odorata, another shrubby species, was collected on JANET and had high concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ . This plant had the highest concentration of  $^{137}\text{Cs}$  of any plant on JANET.

Tacca leontopetaloides, or arrowroot, had low concentrations of radionuclides on DAVID, but no specimens were found on islands with higher levels of radioactivity. Hence, any tendency for accumulation of radionuclides in the underground storage organs cannot be evaluated. This is a commonly used food plant which can be cultivated on islands with deep organic soils.

The radionuclide concentrations in land crustacea (Tables 69 and 70), in both species of rats (Tables 71 and 72), and in birds (Tables 73, 74, and 75) will be discussed in the next section, where these organisms will be placed in the context of the location in which they were collected. They are compiled here to facilitate reference to a specific organism and its occurrence on the

islands of the Atoll, and to summarize radionuclide data for the animal species. These animals are significant in the Atoll ecology because they are food organisms, or they play a role similar to that of man in the island ecosystem.

The data on radionuclide concentrations in terrestrial biota have been combined with soil-survey data to produce an analysis of the island ecosystem at the time of the survey. Because of the highly variable distributions of soil radionuclide concentrations, it is probably not appropriate to use mean values of a radionuclide concentration in the soil, since they may be high because of a few high values. To make this comparison as realistic as possible, data from the soil-survey location closest to the vegetation and animal collection site have been used. In most cases, a terrestrial biota soil sample was taken in the area in which the plant species were collected, and these data are also used in the ecosystem analysis. The terrestrial biota soil sample usually was taken to a depth of 5.0 cm and from an area of 30 cm<sup>2</sup>. These soil samples often contained higher concentrations of radioactivity than the soil-survey samples, which were taken to 15-cm depths, because of the surficial nature of radioactivity in many areas. The mean value and range of soil radionuclide concentrations will also be given in this analysis.

In Table 76, the analysis of ALICE is presented. Three plant species constituted the bulk of the vegetative biomass and no mammals were known to be present. The common noddy, Anous stolidus, was nesting on the island at the time of the survey.



Messerschmidia argentea had  $^{137}\text{Cs}$  concentrations that were about 1.6 times the maximum values for that radionuclide in soil on the island. The soil  $^{137}\text{Cs}$  concentrations in the closest survey point for the 15-cm depth were 13 pCi/g, while the sample taken in the biota survey contained 69.05 pCi/g. Radioactivity depth profiles on the island showed both isotropic depth distribution of  $^{137}\text{Cs}$  and logarithmic depth decreases in radioactivity. The biota soil sample is probably biased toward high concentrations because of the possibility of sampling a highly active surface layer of soil which would have had as much as 100 pCi/g  $^{137}\text{Cs}$ . Calculated concentration factors for  $^{137}\text{Cs}$  in Messerschmidia therefore range from 3.2 to 17, depending upon which soil sample is considered appropriate.

Samples of the common noddy, Anous stolidus, were obtained on ALICE and, although the animals were collected on the land, their food base is derived from the lagoon or the sea. Radioactivity in birds exhibited a qualitative correlation with radioactivity levels found in the lagoon adjacent to their nesting site. Some species may be pelagic feeders, and their body burdens reflect radionuclide concentrations in the open sea.

Data obtained on BELLE are summarized in Table 77. Vegetation recovery on this island was studied by Palumbo (1962), and Welander\* presented data on BELLE obtained in a 1964 survey

\* A. D. Welander, "Distribution of Radionuclides in the Environment and Bikini Atolls," in Proc. of Second National Symposium on Radioecology, Ann Arbor, Mich. 1967 (1969), p. 346.

of Enewetak Atoll. Three plant species were collected on BELLE, including a Pandanus which was bearing fruit at the time. Both Pandanus leaves and fruit showed a strong tendency to accumulate  $^{137}\text{Cs}$  from the soil. Three soil samples collected in the vicinity of the Pandanus plant had a mean  $^{137}\text{Cs}$  concentration of 44.3 pCi/g (Nos. 39, 42, and 52), which is close to the dense vegetative cover mean soil value of 48 pCi/g, indicating a concentration factor of about 20 for fruit and 15 for leaves. Soil samples (Nos. 32 and 33) collected by the soil-survey crews were adjacent to the Messerschmidia and Scaevola trees sampled, and their low radioactivity is reflected in the low concentrations of  $^{137}\text{Cs}$  in those two species. Guettarda occurred closer to the center of the island, where higher soil radioactivity occurred. These results agree with those presented by Welander, except that higher concentration factors are evident in the 1973 data. Concentration effects for  $^{90}\text{Sr}$  are seen in plants in BELLE but, in general, they are small. However, Pandanus leaves have slightly more than three times the soil concentration.

CLARA radioecological relationships are analyzed in Table 78. Two plant species were collected on the island. Two soil samples (Nos. 7 and 9) were collected in the vicinity of the plant samples, both of which were higher in radionuclides than the biota sample collected with the plants. Soil sample No. 7 appeared to be closest to the area sampled, and the radionuclide concentrations in it were used for comparison with the vegetation data. Messerschmidia showed a small concentration factor of

about three, while no large factors were observed for  $^{90}\text{Sr}$  or for Scaevola.

Table 79 contains summary data of terrestrial biota and soil radioactivity on DAISY. Young, nut-bearing coconut palms were found on the island, but only a low level of  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  was detected in the meat of the nut. Low levels of  $^{239,240}\text{Pu}$  were detected in both Messerschmidia and Scaevola in the presence of rather high levels in the soil. The biota soil sample collected at the plant collection site was higher than three soil-survey samples collected in the same general area.

Radionuclide concentrations in biota on IRENE are summarized in Tables 80 and 81. Five areas were sampled on this island, which has a crater at its western end. The area around the crater is generally more radioactive than the eastern part of the island. The five sample areas are listed and described in Table 80. In area E, along the eastern edge of the crater, integrated vegetation samples of Messerschmidia and Scaevola were collected. These samples were obtained by collecting 10 to 20 leaves from each of 25 trees in a transect along the eastern end of the crater; a small stand of young coconut palms was found in the dense growth on the eastern end of the island.

Three biota-survey soil samples were collected on IRENE, and the ecosystem analysis uses soil-survey data obtained in areas being sampled. An attempt was made to obtain a sample of rats on the island, but large numbers of hermit crabs and birds prevented this by tripping the traps and taking the bait.

Plant samples from IRENE are characterized by higher levels of  $^{60}\text{Co}$  than are found in plants on other islands.

Relatively low concentrations of all radionuclides except  $^{55}\text{Fe}$  are found in coconuts on IRENE. High concentrations of  $^{40}\text{K}$  in coconuts, especially in coconut milk, have been found several times in the analyses made on Enewetak samples. Plant samples collected in the B area generally have higher  $^{137}\text{Cs}$  concentrations than the A or C areas. Both Messerschmidia and Scaevola had high levels of  $^{90}\text{Sr}$ , with a concentration factor of 13 occurring in Messerschmidia. Biota soil sample B had a slightly higher  $^{137}\text{Cs}$  concentration, while  $^{60}\text{Co}$  was higher in the A-area soil sample. Suriana maritima, a large shrub growing on the eastern edge of the crater throw-out, had the highest  $^{60}\text{Co}$  concentration found on the island, with a concentration factor for  $^{60}\text{Co}$  of about 22. This  $^{60}\text{Co}$  concentration was the highest found in plants on Enewetak Atoll.

Hermit crabs living on vegetal debris on IRENE had correspondingly high  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  concentrations in hepatopancreas and muscle tissues. The hepatopancreas of these land crustacea typically contains elevated levels of  $^{60}\text{Co}$  and  $^{239,240}\text{Pu}$ , as well as  $^{137}\text{Cs}$ . The exoskeleton of hermit crabs had high concentrations of  $^{90}\text{Sr}$ , an observation also made by Welander at Enewetak and Bikini.

Common noddys nesting on a grassy spit at the southern edge, or lagoon side, of the island had low levels of  $^{90}\text{Sr}$ ,  $^{60}\text{Co}$ ,  $^{55}\text{Fe}$ , and  $^{239,240}\text{Pu}$  in their tissues. The highest concentrations of radionuclides in the IRENE

noddys was  $^{55}\text{Fe}$  in the liver.

The large island of JANET (Engebi) was sampled in nine areas. These sample areas or sectors are listed in Table 82 with a brief description of their location on the island. The ecosystem analysis of JANET is shown in Table 83.

High concentration factors for  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  are apparent for Messerschmidia and Scaevola in Sector A. In Sector B a strong concentration mechanism is seen in both Messerschmidia and Scaevola (10 to 20 times). A high  $^{239,240}\text{Pu}$  level in the soil resulted in an increase of this radionuclide in plant leaves.

In Sector C,  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  were the prominent radionuclides in the soil samples collected adjacent to the biota collection site, and both radionuclides were detected in the three plant species in the area. A high  $^{40}\text{K}$  and  $^{137}\text{Cs}$  level was found in coconut milk, but the level in coconut meat was lower. The concentration of  $^{137}\text{Cs}$  in Messerschmidia was 20 times the mean soil concentration.

In Sector D, the shrub Pluchea odorata had a concentration factor for  $^{137}\text{Cs}$  of approximately 31, while Messerschmidia had a concentration factor of only three. In Sector E, Messerschmidia and Scaevola had concentration factors for  $^{137}\text{Cs}$  of about 3 to 5 times the soil levels of  $^{137}\text{Cs}$ , but exhibited no concentration effect for  $^{90}\text{Sr}$ .

Near the most radioactive area on the island, Sector F supported a population of roof rats, Rattus rattus, which were trapped during the night. Concentration factors in plants for  $^{137}\text{Cs}$  at this site ranged from 16 to 21, and in animals another factor of two is apparent over the

plant concentrations. In a 1964 survey, Welander\* observed lower concentration factors on the same island. The variation that is seen from sector to sector in our data may account for these relatively small differences. Viscera and lung  $^{137}\text{Cs}$  concentrations and  $^{239,240}\text{Pu}$  in the bones of the rats was also observed. Rat body burdens of radioactivity may be related directly to radionuclide concentrations in Scaevola and Messerschmidia, according to Jackson and Carpenter†, because these plants constitute more than 70% of the diet of the rats.

A similar relationship was seen in Sector G area, near a large blockhouse complex in the center of the island. A large population of roof rats was evident in this area, feeding even in the daylight. Soil radioactivity was composed of  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ , and  $^{239,240}\text{Pu}$ , with approximately twice as much  $^{90}\text{Sr}$  as  $^{137}\text{Cs}$ . Both  $^{60}\text{Co}$  and  $^{239,240}\text{Pu}$  appeared in the animal samples but not in the plant samples. Concentration factors for  $^{137}\text{Cs}$  are about six for Messerschmidia and seven for Scaevola, while  $^{90}\text{Sr}$  has factors of less than one for both types. Lung and viscera again have the highest values in rat organs. Localization of  $^{60}\text{Co}$  and  $^{55}\text{Fe}$  in the liver, and  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  in the bone is evident in this series of animal samples.

In Sector H,  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ , and  $^{239,240}\text{Pu}$  are apparent in four soil

\*Welander, op. cit.

†W. B. Jackson and M. L. Carpenter, "Radioisotope Cycling in Terrestrial Communities at Enewetak Atoll," in Proc. of Second National Symposium on Radioecology, Ann Arbor, Mich. (1969), p. 644,

samples collected in the area. The soil again contains higher  $^{90}\text{Sr}$  than  $^{137}\text{Cs}$  concentrations. Concentration factors for both  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  are seen in Messerschmidia (3 and 120), and lower factors are found in Scaevola (1 and 24). Roof rats trapped in Sector H show the high concentration factors observed in Sectors F and G for  $^{137}\text{Cs}$ . High concentrations of  $^{239,240}\text{Pu}$  were detected in viscera and lungs, suggesting ingestion and inhalation of plutonium particles from the surface soil stratum. Rodents preen their pelage frequently, and undoubtedly ingestion occurs in this manner.\* The highest concentration of  $^{90}\text{Sr}$  in rats occurred in the bones.

Common noddys nesting in the area had an unusually high concentration of  $^{137}\text{Cs}$  in their livers. It is possible that they were eating some terrestrial materials which are high in  $^{137}\text{Cs}$ . Fish in the vicinity of JANET are not highly contaminated with  $^{137}\text{Cs}$ . Fish samples collected in the lagoon near JANET had maximum concentrations of 6.7 pCi  $^{137}\text{Cs}/\text{g}$ , but most were lower.

In Sector I, a sample of roof rats was obtained, and a three-level analysis of the area is possible. Soil-survey samples indicate a low level of  $^{137}\text{Cs}$ ,  $^{239,240}\text{Pu}$ , and  $^{60}\text{Co}$ , with higher concentrations of  $^{90}\text{Sr}$  in the surface 15 cm of soil.

Vegetation in this area showed small concentration factors of 3 to 4 over soil  $^{137}\text{Cs}$  concentrations. Rat  $^{137}\text{Cs}$  body burdens were about 30 times the plant concentrations, and therefore over 100

times for soil-to-animal transfer.

Concentration factors of 10 to 20 for  $^{60}\text{Co}$  were apparent for visceral organs over that which occurred in the soil of the area. Bone contained high concentrations of  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$ . Liver and muscle contained  $^{55}\text{Fe}$ , and viscera (mainly gastrointestinal tract) contained  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$ , as well as a high level of  $^{137}\text{Cs}$ . The soil-to-bone concentration factor for  $^{90}\text{Sr}$  was approximately five. Concentration factors for  $^{90}\text{Sr}$  in plants at Enewetak Atoll, however, are usually low.

Table 84 contains the radionuclide concentrations in biota collected on KATE. The biota-survey soil sample and the nearest soil-survey samples agree quite well in this analysis. The red-tailed tropicbird, Phaethon rubricaudus, was found nesting on this island and was collected for analysis. This is a valuable measurement because this bird is mainly a pelagic sea feeder and provides a south-west Pacific oceanic background value for biota radionuclide concentrations.

Pisonia grandis was collected on KATE and was not found north of this site. It contained a level of  $^{137}\text{Cs}$  approximately 55 times the soil  $^{137}\text{Cs}$  concentration in the area. It is interesting that the  $^{40}\text{K}$  value in Pisonia on KATE is in the same range as other tree species (~10 pCi/g), while on southern islands, in mature Pisonia forests,  $^{40}\text{K}$  values are in the range of 16 to 30 pCi/g. The KATE Pisonia  $^{40}\text{K}$  value is the lowest concentration found in the species on the Atoll. A small concentration factor of about two for  $^{60}\text{Co}$  was found in Pisonia.

The red-tailed tropic bird had almost no radioactivity in its body, except for a

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\* N. R. French, P. Hayden, and T. Tagami, "The Source of Ingested Radioactivity in Desert Rodents," Health Physics 11, 637 (1965).

small amount of  $^{137}\text{Cs}$  in the bone.

A summary of radionuclide concentrations in biota collected on LUCY is made in Table 85. The biota-survey sample is higher than the two soil-survey samples obtained in the same locality, which agreed quite closely with each other. A low level of  $^{137}\text{Cs}$  occurred in the two plant species, Messerschmidia and Scaevola. In the hermit crabs, which feed primarily on vegetal debris, there were higher levels of  $^{137}\text{Cs}$  and a relatively high concentration of  $^{60}\text{Co}$  in the hepatopancreas. If the soil-survey data are used, concentration factors from soil to crab are more than 100 for  $^{137}\text{Cs}$  and for  $^{60}\text{Co}$ . In this ecosystem, the hermit crab may be considered a "grazing" arthropod, and the soil-plant-animal economy is closely coupled.

The ecosystem analysis of PEARL is given in Table 86. The soil-survey data for the PEARL collection sites agreed well with the biota-survey soil sample, and the average of the two values may be used. No concentration effect for  $^{137}\text{Cs}$  was seen in Messerschmidia and Scaevola at the collection site. Scaevola collected in an area indicated as radioactive by the aerial survey had higher concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ .

Rice rats collected on PEARL in the sampled area exhibit concentration factors of approximately 100 from plant to animal, but only five from soil to animal.

The ecosystem analysis of URSULA is given in Table 87. Good agreement is seen in the soil-survey data and the biota-survey soil data. Low levels of the four prominent radionuclides occurred in the soils on URSULA. Concentration

factors are seen for  $^{137}\text{Cs}$  in Messerschmidia and Scaevola in the range of 30 to 35. The rice rat population had lower levels of radionuclides in their organs than most of the vegetation sampled. The usual pattern of  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$  in the bone and  $^{60}\text{Co}$  in the liver is again manifested in this sample series.  $^{55}\text{Fe}$  typically is concentrated in the livers of both mammals and birds.

Data on radionuclide concentrations in biota collected on SALLY is made in Table 88. This small island has experienced a considerable amount of recent disturbance, and the remnants of a partially recovered vegetation were sampled. Two soil-survey samples were obtained in the biota collection site. A biota soil sample was also collected, and it contained higher concentrations of all radionuclides found in the soil. The two soil-survey samples agreed relatively well, and the mean concentrations of these two samples will be used in this analysis. Held\* has described radionuclide accumulation at the interface between the organic soil or surface litter and the mineral horizon or stratum below. Most of the northern and northeastern islands do not have deep accumulations of organic litter on the surface, and this phenomenon may only be present on relatively undisturbed islands.

Low levels of  $^{60}\text{Co}$  and  $^{239,240}\text{Pu}$  are present in the soils on SALLY, with slightly more than two times as much  $^{90}\text{Sr}$  in the soil as  $^{137}\text{Cs}$ . The grass

\* E. F. Held, S. P. Gessel, and R. B. Walker, Atoll Soil Types in Relation to the Distribution of Fallout Radionuclides, University of Washington Laboratory of Radiation Biology, Seattle, Rept. UWFL-92 (1965).

Lepturus repens shows a concentration factor of about 35 for  $^{137}\text{Cs}$  and less than one for  $^{90}\text{Sr}$ . Messerschmidia, Scaevola, and Pandanus exhibited only modest accumulation levels of  $^{137}\text{Cs}$  (5 to 6). This Pandanus plant did not show the high concentration factor for  $^{137}\text{Cs}$  in leaves that the specimen collected on BELLE did.

Table 89 contains a summary of radionuclide data obtained on TILDA. A soil-survey sample was collected in the area where biota were sampled, and a biota soil sample was also collected. The biota soil sample again has higher concentrations of radionuclides than the soil-survey sample.  $^{90}\text{Sr}$  concentrations in the biota soil sample are almost 10 times those in the soil-survey sample. Both the  $^{60}\text{Co}$  and the  $^{90}\text{Sr}$  concentrations in the biota soil sample are higher than the maximum concentrations for these radionuclides found by the soil survey.

The  $^{137}\text{Cs}$  activity in plants shows some concentration effects, especially in Pandanus, which had a concentration factor of about 18, using the dense vegetative cover mean soil value. Scaevola had three times and Messerschmidia had seven times the concentration of  $^{137}\text{Cs}$  in soil.

Radionuclide concentrations in biota collected on VERA are shown in Table 90. This heavily vegetated island has one of the northernmost examples of mature Atoll forest vegetation characterized by Pisonia stands. A soil-survey sample was collected close to the biota sample area, and a biota soil sample was collected in the same area. The  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  concentrations in the biota soil sample were 6.3 and 3.9 times the

levels in the soil-survey sample.  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  concentrations in the two soil samples agreed quite well.

Six plant species were collected on VERA. The presence of Pisonia and Pandanus as large plants is a good indicator of successional maturity of Atoll vegetation. The highest  $^{137}\text{Cs}$  concentration in plants was in Pisonia, which had a concentration factor of about 24. Pandanus leaves showed a concentration factor for  $^{137}\text{Cs}$  of seven. Pandanus exhibited a concentration factor of nine for  $^{90}\text{Sr}$ , which is a comparatively high value in plants. On BELLE a Pandanus plant had a  $^{90}\text{Sr}$  concentration factor of three. The higher concentrations of radionuclides in the shallower biota soil sample on an island such as VERA, with a well-developed organic matter horizon on the soil surface, was observed on Rongelap.\* Most of the mineral cycling must take place in this organic layer, and it is a logical site for soluble radionuclides to be complexed to organic colloids.

Table 91 shows radionuclide concentrations in biota collected on WILMA. Two soil-survey samples were collected close to the biota sample site. These two samples were comparable in radionuclide concentrations, and the mean value will be used. Low levels of four radionuclides were present in the soil of WILMA, with slightly more than two times as much  $^{90}\text{Sr}$  as  $^{137}\text{Cs}$ .

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\*D. W. Cole, S. P. Gessel, and E. E. Held, "Tension Lysimeter Studies of Ion and Moisture Movement in Glacial Till and Coral Atoll Soils," Soil Sci. Soc. Amer. Proc. 25, 321 (1961).

Three plant species were collected on WILMA, and they all had low levels of  $^{137}\text{Cs}$ , with more  $^{40}\text{K}$  than fission products in the plants.

Tables 92 and 93 contain radionuclide concentrations in biota collected on YVONNE. This long, narrow island was sampled at four sites to obtain a representative series of biota samples where the physiography was somewhat diverse, and where there was considerable variation in the radioactivity levels of the island. The locations of the five sample sites are described in Table 92.

The data obtained in Sector A of YVONNE are shown in Table 93. This area was at the north end of the island — the most radioactive site of those sampled. Three soil-survey samples which were collected near the biota sample site exhibit some variation; one sample is considerably more radioactive than the other two. Mean soil radionuclide concentrations may be elevated because of this high value.  $^{90}\text{Sr}$  was approximately five times higher in the soil of this area than  $^{137}\text{Cs}$ . Concentration factors for  $^{137}\text{Cs}$  in Messerschmidia and Scaevola are quite high when the mean soil concentration is used to calculate the factor. With such a high concentration of  $^{137}\text{Cs}$  in Messerschmidia and Scaevola, it is probable that the plants were growing on soil with high  $^{137}\text{Cs}$  concentration, and the use of the highest soil value is justified. Concentration factors when using the value for soil survey No. 141 (47 pCi  $^{137}\text{Cs}$ /g of soil) become 120 for Messerschmidia and 14 for Scaevola. Only a small concentration mechanism is seen for  $^{90}\text{Sr}$  in Messerschmidia (1.4).

Two large samples of roof rats were obtained in the area and, when pooled, provided two population samples of the mammals living in Sector A. Typical patterns of radionuclide localization in the mammalian body are apparent in these data.  $^{137}\text{Cs}$  concentrations are highest in the muscle, bone, and viscera. Bone  $^{137}\text{Cs}$  concentrations have been quite high in many of these animal samples, and similar bone levels were reported by Yamagata and Yamagata\* in humans. High concentrations of  $^{239,240}\text{Pu}$  in viscera and lung are produced by ingestion of particles, either in preening by the rats or in the process of eating plant materials.  $^{55}\text{Fe}$  is detected in the highly vascularized tissues of liver and muscle. Concentrations of  $^{60}\text{Co}$  in the kidneys were five times the high soil concentration. The highest concentrations of  $^{90}\text{Sr}$  were found in the bone.

The second site sampled on YVONNE, Sector B, was on the north end of the island, 150 yd south of Cactus crater. The vegetation and general topography were similar to those in the Sector A site.

Three soil-survey samples were obtained in the area, and one biota soil sample was collected. The larger surface area of the biota sample resulted in higher concentration of most radionuclides detected at the site. An average was taken of all four samples for comparison with the biota.

The concentration factor for  $^{137}\text{Cs}$  apparent in Messerschmidia is about 47 and in Scaevola about 14. A concentra-

\*N. Yamagata and T. Yamagata, "The Concentration of  $^{137}\text{Cs}$  in Human Tissues and Organs," Bull. Inst. Public Health (Tokyo) 9(2), 72 (1960).

tion factor of about two was found in the meat of the coconut for  $^{137}\text{Cs}$ . A small concentration factor of 2.4 for  $^{90}\text{Sr}$  was seen in Messerschmidia. Of the two common tree species, Messerschmidia showed the highest concentration factor for both  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ .

A small collection of roof rats, Rattus rattus, was obtained in the area, but the radionuclide concentrations were elevated much above the level observed in plants. Concentration factors from soil to animal were in the range 19 to 43 for  $^{137}\text{Cs}$ , and in the bone  $^{90}\text{Sr}$  was 4.75 times the concentration in the soil. High  $^{239,240}\text{Pu}$  concentrations were seen in the bone and viscera.

The common noddy, Anous stolidus, was nesting on the island in Sector B, and a sample was obtained with a shotgun. Eggs showed little radioactivity, except for  $^{55}\text{Fe}$  and a small amount of  $^{90}\text{Sr}$ . The viscera of the bird, mainly the gastrointestinal tract, which would contain the food eaten recently, showed detectable levels of only  $^{55}\text{Fe}$ . The livers of the noddys contained  $^{60}\text{Co}$  and  $^{55}\text{Fe}$  in rather high concentration.

Table 93 contains a summary of radionuclide concentrations in biota collected in Sector C on YVONNE. This area was mid-island along the short airstrip that extends east to west. Four soil-survey samples were obtained in the area, three of which showed general agreement; the fourth was somewhat higher. The mean concentrations of radionuclides in the soil from these samples will be used in this analysis. Soil radionuclide concentrations are in general low, except for  $^{239,240}\text{Pu}$ .  $^{90}\text{Sr}$  is present in 2.2 times the concen-

tration of  $^{137}\text{Cs}$ .

Plants in Sector C were sampled several times, and the data show some rather wide variations, both between and within species. Of the three Messerschmidia samples, one contained 25 to 42 times the  $^{137}\text{Cs}$  concentration of the other two. The same variation was seen in the concentrations of  $^{137}\text{Cs}$  in Scaevola. Comparatively high concentrations of  $^{239,240}\text{Pu}$  were seen in the plants collected in this area, with one value as high as 1.29 pCi/g. One Scaevola collection had rather high concentration factors for the species, 286 for  $^{137}\text{Cs}$  and 34 for  $^{90}\text{Sr}$ . With the soil radionuclide concentrations exhibiting the variations shown in these data, it is possible that the high activity seen in a single collection in a series is due to a small, localized "hot" spot.

A sample of roof rats was easily obtained in this area, since they are quite numerous at the north end of YVONNE. The highest concentrations of radionuclides in these animals was due to  $^{137}\text{Cs}$  and occurred in the lungs and viscera. High concentrations of  $^{239,240}\text{Pu}$  were also present in the lungs and viscera of these animals. Concentration factors are difficult to assess in this area because of the variation in plant radionuclide concentrations. Concentrations of  $^{137}\text{Cs}$  in the muscle of rats were about 23 times the concentration in the soil. The mean  $^{137}\text{Cs}$  concentration of the plants in the area, exclusive of the high Messerschmidia (95.32 pCi/g) and Scaevola (609.90 pCi/g), is 7.33 pCi/g. Rat muscle exhibits a 6.7 concentration factor over  $^{137}\text{Cs}$  concentrations in plants.



A summary of radionuclide concentrations in biota collected in Sector D on YVONNE is made in Table 93. Two soil-survey samples were obtained in the area, and a biota soil sample was also obtained. The biota soil sample again is higher than the soil-survey samples in  $^{137}\text{Cs}$  and  $^{60}\text{Co}$ . One soil-survey sample is very high in  $^{239,240}\text{Pu}$  and also has a high  $^{90}\text{Sr}$  concentration.  $^{137}\text{Cs}$  concentrations on this part of the island are not much higher than the southern arc of islands from GLENN to KEITH. Radionuclides in general are low in plants in this area.

Sector D area is at the south end of YVONNE. A small sample of roof rats was trapped in the area, and a collection of common noddy eggs was made. The rat organs and tissue had low levels of  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ ,  $^{55}\text{Fe}$ , and  $^{137}\text{Cs}$ . Lung and bone had the highest  $^{137}\text{Cs}$  burdens, with lower values occurring in the muscle, viscera, and liver. The livers had the highest  $^{55}\text{Fe}$ ,  $^{90}\text{Sr}$ , and  $^{239,240}\text{Pu}$  concentrations. It appears that there were plutonium-contaminated areas at the southern end of the island, with only modest fission-product levels occurring in the area.

The eggs of the common noddy contained  $^{55}\text{Fe}$  and a small amount of  $^{239,240}\text{Pu}$ .

Data on radionuclide concentrations in biota collected on BRUCE are given in Table 94. This completely vegetated island has a mature Pisonia forest on it which was apparently modified only slightly by test activities. The island is far enough from test areas to not have been affected by physical effects of weapons tests. Three soil-survey

samples were collected in the area where biological samples were obtained. A biota soil sample was also collected in the area, and had radionuclide concentrations that were higher than any of the soil-survey samples used in this analysis. Slightly more  $^{137}\text{Cs}$  than  $^{90}\text{Sr}$  was present in the soil on BRUCE.

Scaevola frutescens had the highest  $^{137}\text{Cs}$  concentrations in plants, and the coconut palm nut meat had the lowest – less than 1 pCi/g. A low level of  $^{90}\text{Sr}$  was present in Pisonia, Messerschmidia, and Scaevola.

Coconut crabs, Birgus latro, were abundant on the island, and a sample of five was collected.  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{90}\text{Sr}$  were present in coconut crabs in low levels.  $^{137}\text{Cs}$  was present in the highest concentration in the muscle of the crabs. Less than 1 pCi/g of  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{90}\text{Sr}$  occurred in the hepatopancreas. As observed in other land crustacea,  $^{90}\text{Sr}$  was relatively high in the exoskeleton.

A sample of roof rats, Rattus rattus, was trapped on BRUCE. Low concentrations of  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ , and  $^{239,240}\text{Pu}$  were detected in the rat organs. The highest radionuclide concentration in rat livers was  $^{55}\text{Fe}$ , with a low level of  $^{60}\text{Co}$ .  $^{137}\text{Cs}$  concentrations were higher in bone than in any other tissue.

White-capped noddys, Anous tenuirostris, were collected on BRUCE; the analysis of liver, muscle, and viscera showed low levels of all radionuclides.

In Table 95, radionuclide concentrations in biota collected on DAVID are shown. This large island is covered by dense Pisonia and Ochrosia on the

eastern portions, with a scrub vegetation of Messerschmidia and Scaevola occupying areas disturbed by test activities on the island. Mature coconut palms occur on the western, or lagoon, side of the island and in the central portion. Five soil-survey samples and two biota soil samples were obtained in the areas where biological samples were collected. Low concentrations, less than 1 pCi/g, of  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ ,  $^{60}\text{Co}$ , and  $^{239,240}\text{Pu}$  were present in the soil on DAVID, and biota- and soil-survey samples exhibited good agreement.

Replicate samples of the major plant species were collected on DAVID to evaluate the island variations in vegetation radionuclide content. Four Messerschmidia and Scaevola samples were collected on the island and, except for one sample of Messerschmidia, exhibit general agreement within the species for the most prominent fission product,  $^{137}\text{Cs}$ . A single sample of Messerschmidia had 15.84 pCi/g  $^{137}\text{Cs}$ , while the other three samples were in the range of 1 to 8 pCi/g. This Messerschmidia sample had an unusually low  $^{40}\text{K}$  concentration, approximately 25% of the value observed in the other three samples. The mean Messerschmidia  $^{137}\text{Cs}$  concentration, including the high value, was 6.69 pCi/g, which would be a concentration factor of about 17, using a mean biota- and soil-survey value of 0.40 pCi/g. The mean Scaevola  $^{137}\text{Cs}$  concentration of 3.3 pCi/g indicated a concentration factor of about eight for the species.

A large Pandanus located in the central part of the island had the highest  $^{137}\text{Cs}$  concentration in plants, except for

coconut milk. The Pandanus concentration factor for  $^{137}\text{Cs}$  on DAVID was about 40.

The herb, Tacca leontopetaloides, was collected on DAVID. A large sample of the corms of this plant was collected in a meadow-like area on the western half of the island. The radionuclide concentrations are low, with  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  occurring in levels at or less than 1 pCi/g. The sedge, Fimbristylis atollensis, was very abundant on bare ground on DAVID and contained a low level of  $^{137}\text{Cs}$ .

Pisonia grandis, which forms continuous stands of tall trees on the eastern half of DAVID, had low levels of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ . High  $^{40}\text{K}$  concentrations are seen on DAVID in this species and on most of the southern islands.

Cocos nucifera, the coconut, was collected from three sites on DAVID and had a mean concentration of  $^{137}\text{Cs}$  of 2.66 pCi/g in the meat. The analysis of coconut milk, however, indicated that in the milk solids 23.32 pCi/g of  $^{137}\text{Cs}$  was present, and the high value of  $^{40}\text{K}$  indicated a potassium content in excess of 3.5%. This high concentration of  $^{137}\text{Cs}$  in coconut milk may be partially an analytical artifact. The whole coconut milk from DAVID coconuts contained 4.7% solids, and the coconut milk therefore would have a wet concentration of 1.09 pCi/g  $^{137}\text{Cs}$ . This value is in the same range as the coconut meat, which is 34.1% solids and has a  $^{137}\text{Cs}$  concentration of 1.30 pCi/g wet weight.

The hermit crab, Coenobita perlatus, was collected on DAVID, and three tissues were analyzed for radioactivity.

The hepatopancreas and muscle of these small land crabs contained small amounts of  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ , and  $^{239,240}\text{Pu}$ .

The sooty tern was collected on DAVID but was not particularly abundant there, probably nesting farther northward on the Atoll, where sandy spits and beaches such as those on CLYDE provided sites. Very low concentrations of radionuclides were found in the terns, although  $^{55}\text{Fe}$  was present in the livers at a concentration of 153.2 pCi/g. A small amount of  $^{137}\text{Cs}$  was present in the bone, and  $^{239,240}\text{Pu}$  was detected in the muscle.

Two other birds were collected on DAVID – the sandpiper, which is probably a migratory species at Enewetak Atoll, and the reef heron, which is indigenous. The sandpiper contained only a small amount of  $^{137}\text{Cs}$ . The reef heron had slightly higher concentrations of  $^{137}\text{Cs}$  in the bone and muscle, and a small amount of  $^{60}\text{Co}$  in the bone.

A sample of rice rats, Rattus exulans, was obtained on the western side of DAVID in the vicinity of the site where Tacca and Morinda were collected.  $^{137}\text{Cs}$  was the radionuclide in the highest concentration in the rice rats; the highest value was found in the bone. This localization of  $^{137}\text{Cs}$  in the bone was also noted by Takizawa and Sugai\* in a study of human tissues in Japan. Highest values in the period 1962-1966 were found in the bones of people living in northern Japan. High bone concentrations of  $^{137}\text{Cs}$  have been consistently noted in these analyses for mammals

\* Y. Takizawa and R. Sugai, "Plutonium-239, Strontium-90, and Cesium-137 Concentrations in Human Organs of the Japanese," Arch. Environ. Health 23, 446 (1971).

living in areas of high environmental radioactivity. A low concentration of  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  was found in the rice rats on DAVID.

Table 96 contains a summary of radionuclide concentrations in biota of the small island, REX. This island, although small in area, has mature Atoll vegetation on it. Three soil-survey samples were collected in the area in which biota samples were obtained. Low concentrations of the four radionuclides typically found on the islands occurred on REX, where slightly more  $^{90}\text{Sr}$  than  $^{137}\text{Cs}$  was present in the soil.

Three plant species were collected on REX, and the most prominent radionuclides were  $^{40}\text{K}$  and  $^{137}\text{Cs}$ . Pisonia and Messerschmidia had concentrations of  $^{137}\text{Cs}$  of about 2.5 pCi/g and Scaevola contained less than 1 pCi/g. Concentration factors were about three.

Hermit crabs, Coenobita perlatus, were abundant on the island, and a large collection was made.  $^{137}\text{Cs}$  concentrations in hermit crabs did not exceed those observed in the soil or the vegetation.  $^{90}\text{Sr}$  and  $^{60}\text{Co}$  were detected in the muscle and hepatopancreas of hermit crabs in low concentrations. Low levels of  $^{239,240}\text{Pu}$  were also found in these tissues.

Common noddys were nesting on the island, and their tissues contained low concentrations of  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$ . The concentration of  $^{55}\text{Fe}$  in the liver of the common nody was the highest radionuclide concentration found on this island.

An ecosystem analysis of ELMER is given in Table 97. Three soil-survey samples were obtained in the area of biota sampling, and two biota group soil

samples were also obtained. Three radionuclides were detected in the soil on ELMER, and a low level of  $^{40}\text{K}$  was found in one of the biota soil samples. One biota soil sample contained higher concentrations of  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ , and  $^{239,240}\text{Pu}$  than the other three samples by factors of 2 to 11.

Four plant species were sampled on ELMER. Pandanus had the highest concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ , which was concentrated 79 times over the soil concentration (mean soil-survey sample = 0.33 pCi/g  $^{90}\text{Sr}$ ). Concentration factors for  $^{137}\text{Cs}$  are much lower, about 3 to 6.

A sample of roof rats, Rattus rattus, was obtained on ELMER by trapping at night.  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  were the only man-made radionuclides detected in rat tissues and organs.  $^{137}\text{Cs}$  in viscera, liver, and bone showed concentrations 25 to 46 times mean soil concentrations, and 5 to 7 times the plant concentrations.

Table 98 contains an analysis of the soil radioactivity and vegetation on FRED. A large number of soil samples were collected on FRED by the soil-survey group. Two soil-survey samples were collected in the general area in which vegetation samples were obtained. Low concentrations of four radionuclides were detected in FRED soil materials. Two samples did not agree very closely in the concentrations, differing by factors of 1.5 to 3 for  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$ .  $^{60}\text{Co}$  and  $^{239,240}\text{Pu}$  were detected in only one sample of the pair.

Four species of plants were sampled on FRED. Pandanus was again the highest in  $^{137}\text{Cs}$  concentration but did not have the high concentration of  $^{90}\text{Sr}$  that was observed in the same species on ELMER.

Low levels of  $^{239,240}\text{Pu}$  were detected in Scaevola and Pandanus.

A summary of radionuclide concentrations in biota collected on GLENN is given in Table 99. Three soil-survey samples were collected in the biota sample area, and one large-surface-area biota soil sample was obtained. The concentrations of  $^{137}\text{Cs}$  in the biota soil sample were slightly higher than in the soil-survey sample, but in general, radionuclide concentrations in the two types of samples were comparable. All four samples will be averaged in this analysis.  $^{137}\text{Cs}$  is the most abundant radionuclide in the soil.

Plants growing on GLENN have two fission-product radionuclides and one naturally occurring radioisotope in all of the species sampled.  $^{137}\text{Cs}$  was present in Pisonia and Messerschmidia in concentrations of 1.2 to 3.9 pCi/g, with fractional picocurie/gram concentrations occurring in Morinda, Scaevola, and Cocos.  $^{90}\text{Sr}$  concentrations were slightly higher than  $^{137}\text{Cs}$  concentrations in all species except Cocos. The high levels of  $^{40}\text{K}$  and stable potassium in Pisonia seem to indicate a positive correlation between  $^{137}\text{Cs}$  concentration and stable potassium content. The Pisonia leaves contained 3.0 and 3.5% potassium on the basis of their  $^{40}\text{K}$  concentrations. Only slight concentration effects are seen in the vegetation on GLENN for the typical radionuclide that is concentrated in the biota,  $^{137}\text{Cs}$ .

A sample of rice rats (Rattus exulans) was collected in the central portion of the island where they subsist on coconuts and other plant materials.  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  were the most prominent radionu-

clides in the rat tissues, with the highest concentration occurring in the bone. The highest concentrations of  $^{60}\text{Co}$  occurred in the kidney, viscera, and liver.

Two land crustaceans were collected on GLENN. The hermit crab, Coenobita perlatus, and the coconut crab, Birgus latro, were quite abundant in the Pisonia and coconut forest of the island. Small amounts of  $^{137}\text{Cs}$  were present in the hepatopancreas of the hermit crab, which also contained  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  also occurred in hermit crab hepatopancreas in sub-picocurie/gram levels.

The coconut crabs on GLENN had small amounts of  $^{137}\text{Cs}$  in the muscle and hepatopancreas. Traces of  $^{60}\text{Co}$  and  $^{90}\text{Sr}$  were also detected in the hepatopancreas.

There was essentially no concentration effect for  $^{137}\text{Cs}$  from plant to animal in the crustacea on GLENN. A factor of approximately six times the soil  $^{137}\text{Cs}$  concentration was seen in the bones of rice rats. A mean  $^{137}\text{Cs}$  concentration for all plants on GLENN is 1.32 pCi/g dry wt, and most of the animal tissues are within a factor of two of this value, except for rat bone.

Data on radionuclide concentrations in biota collected on HENRY are summarized in Table 100. This island is in the southeastern arc of islands characterized by mature atoll forest vegetation with small, local disturbances on them. Comparatively deep, organic soils are found in the Pisonia forests, and the effects of bird guano deposits may be quite evident as cemented strata beneath the organic horizons. Two soil-survey samples and a biota soil sample were obtained in the area sampled on

HENRY. The biota sample contained a measurable concentration of  $^{40}\text{K}$ , probably due to the high organic content. The highest soil concentration of  $^{137}\text{Cs}$  was found in the biota soil sample.  $^{90}\text{Sr}$  was approximately twice the  $^{137}\text{Cs}$  concentration in the soil-survey samples.

Four species of plants were sampled on HENRY, and only two man-made radionuclides were detected. Low concentrations are seen for  $^{137}\text{Cs}$  in plants; however, Messerschmidia exhibited almost an eightfold concentration factor for  $^{90}\text{Sr}$ .

Hermit crabs, Coenobita perlatus, showed a small concentration effect for  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ , but a concentration factor of 66 for  $^{60}\text{Co}$  in the muscle.  $^{60}\text{Co}$  was not detected in the plants sampled.

Table 101 contains a summary of radionuclide concentrations in biota collected on JAMES. Two soil-survey samples and a biota soil sample were collected in the area studied. Low levels of  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  were found on JAMES with higher concentrations of  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$ . The biota soil sample contained higher concentrations of radionuclides than either of the two soil-survey samples. The mean soil-survey data will be used in analyzing the JAMES terrestrial ecosystem.

Five plant species were collected on the island, and the prominent radionuclide in their leaves was  $^{137}\text{Cs}$ . Morinda had  $^{137}\text{Cs}$  concentrations 44 times those in soils, while Scaevola contained approximately 10 times as much.  $^{90}\text{Sr}$  appeared only in Morinda, at a level 3.8 times the soil concentration.

Coconut crabs, Birgus latro, occurred in modest numbers in the areas around

coconut palms in the Pisonia forest, where a sample of these crustacea was collected. Only small concentration factors were seen for  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in the coconut crab. Again a concentration effect for  $^{60}\text{Co}$  is apparent in the muscle and hepatopancreas of the crab where concentration factors of 12 and 17 occur. No  $^{60}\text{Co}$  was detected in plants.

Data on radionuclide concentrations in biota collected on KEITH are summarized in Table 102. This island is the westernmost island in the southern arc of islands, and from its higher levels of environmental radioactivity it apparently received more fallout than islands to the east, such as GLENN and HENRY.

Three soil-survey samples and two biota soil samples were collected on KEITH. One biota soil sample was collected under Pisonia trees and another under coconut palms. Biota soil samples had less radioactivity than the 15-cm-deep soil-survey samples. Mean soil radionuclide concentrations on KEITH are several times the concentrations found on JAMES, but not quite as high as those found on LEROY to the west.

Six plant species were collected on KEITH. Two samples of large Pandanus plant were obtained, one of leaves and the other a mature fruit. Pandanus again showed a concentration effect (a factor of eight) for  $^{90}\text{Sr}$ . A comparatively high  $^{137}\text{Cs}$  concentration was measured in Pisonia, which had a concentration factor of about five.

Coconut crabs, Birgus latro, on KEITH contained four man-made radionuclides and  $^{40}\text{K}$  in their tissues. No concentration effects were seen for  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in the coconut crabs.  $^{60}\text{Co}$  was

found in the hepatopancreas and muscle but was not detected in plants on the island.

Common noddys nesting on KEITH had two radionuclides in their tissues,  $^{60}\text{Co}$  and  $^{239,240}\text{Pu}$  in low concentration.

Table 103 contains a summary of radionuclide data in biota collected on LEROY. This island is in the southwestern quadrant of the Atoll and received fallout from tests conducted in the northeastern portion of the Atoll. Two soil-survey samples were obtained in the areas sampled by the terrestrial biota group, and a biota soil sample was also collected in this area. The biota soil sample contained higher concentrations of all four radionuclides present on the island, except  $^{90}\text{Sr}$ .

Five plant species were collected on LEROY, all of which contained  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ . Only the Pandanus contained a trace of  $^{239,240}\text{Pu}$ .  $^{137}\text{Cs}$  was present in highest concentration in the flowering stalk of Pandanus. Pisonia grandis had the highest  $^{40}\text{K}$  concentration of the plants collected.  $^{90}\text{Sr}$  was also the highest in Pandanus. If the mean soil-survey concentration is used, concentration factors for  $^{137}\text{Cs}$  are 3.6 for Pandanus, 4 for Pisonia, 1.8 for Messerschmidia, and 1.4 for the coconut palm, Cocos nucifera.

Coconut crabs, Birgus latro, were collected on LEROY, and their tissues contained low concentrations of the four radionuclides detected in the soil. Muscle of the coconut crab exhibited a 3.5 concentration factor for  $^{137}\text{Cs}$  in coconuts. No concentration effects were observed for  $^{90}\text{Sr}$ ,  $^{60}\text{Co}$ , or  $^{239,240}\text{Pu}$  in the coconut crab.

White-capped noddys were nesting on

the island, and a sample was obtained for radionuclide analysis. The birds appeared to be feeding in the lagoon adjacent to the island. The most abundant radionuclide in the birds was  $^{55}\text{Fe}$ , which was highest in the liver and muscle.

### Conclusions

The distribution of radionuclides in the terrestrial biota throughout the islands of Enewetak Atoll generally conforms to the results of the environmental radiation survey. On islands with elevated levels of radiation, the biota contained elevated concentrations of radionuclides. The most prominent radionuclides are  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ ,  $^{55}\text{Fe}$ ,  $^{60}\text{Co}$ , and  $^{239,240}\text{Pu}$ .

Concentration factors are observed in many species, especially for  $^{137}\text{Cs}$ . Low concentration factors are observed for  $^{90}\text{Sr}$  in plants, with the exception of Pandanus. Uptake coefficients are generally very low (about  $10^{-3}$ ) for  $^{239,240}\text{Pu}$  in plants, and only occasional concentration effects are seen for  $^{60}\text{Co}$ , typically in the livers of animals.

The most effectively transferred radionuclide within the terrestrial ecosystems of Enewetak Atoll appears to be  $^{137}\text{Cs}$ . This occurs for at least two reasons.  $^{137}\text{Cs}$  remains soluble in the Atoll soil or substratum, where it is taken up by plants and incorporated into organic matter. It then apparently enters the potassium pool of the ecosystem, and follows the kinetics of that element, at least in a superficial sense.

The chemical form of a radionuclide in the unusual substratum of the islands of Enewetak Atoll will affect its transfer within the ecosystem and the biota,

especially on to man.  $^{90}\text{Sr}$ , for example, which is present in higher concentrations in the substratum on many islands, is not as prominent in the biota because it is probably tied up as insoluble carbonates in the Atoll soil.

Radionuclides are apparently transferred from plants, where initial concentration effects take place, to terrestrial animals, either warm- or cold-blooded, where additional concentration effects occur. The efficiency of this transfer is somewhat difficult to describe from survey data whose main purpose was not functional research, but strong indications of the trophic relationships in atoll ecology are inherent in the data.

Radionuclides such as  $^{60}\text{Co}$  and  $^{55}\text{Fe}$  enter the elemental pools for those elements and are typically found wherever those elements accumulate or sequester in animal tissues. Livers, kidneys, and hepatopancreases are such sites in mammals, birds, and crustacea.

Most radionuclide distributions in elements of the terrestrial biota sampled in this survey conform to the classical patterns that have evolved in the development of radiobiological science; e.g.,  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{239,240}\text{Pu}$  have an affinity for bone,  $^{137}\text{Cs}$  is also found in physiologically active tissues such as muscle, and  $^{55}\text{Fe}$  and  $^{60}\text{Co}$  typically are retained in the liver and kidney.

One difficult aspect in the analysis of these data has been the variation in the basic ecological conditions present on the islands surveyed throughout the Atoll. One might attempt to compare radionuclide concentrations within a single species, such as Messerschmidia

argentea, or more appropriately Cocos  
nucifera, throughout the Atoll, but islands  
in the northern part of the Atoll are re-  
covering from severe physical disturbance.  
The physiology of plants under such condi-  
tions is undoubtedly different from those  
growing and reproducing under stable or  
quasi-stable successional conditions in  
undisturbed habitats in the southern part  
of the Atoll. Therefore, attempts to de-

velop generalizations from the spectrum  
of ecological conditions which were en-  
countered in the Enewetak survey must be  
made cautiously. Thus, a concentration  
factor determined for a species which is  
colonizing a catastrophically disturbed  
habitat may be quite different for the  
same species growing in a stable environ-  
ment in climatic and edaphic equilibrium.



## AIR-SAMPLING PROGRAM

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### Introduction

An air-sampling program was carried out on Enewetak to evaluate potential population dosages from inhalation of resuspended soil radioactivity, and to develop information on this pathway for guidance in cleanup and rehabilitation activities. The air-sampling program sought first to ascertain the level of any inter-island atmospheric transport of radioactivity which was reflected in elevated air levels in the Atoll in general, and second, to evaluate air levels in the vicinity of known elevated soil burdens of radioactivity.

To meet these objectives, sampling was carried out on FRED and DAVID, representing low soil radioactivity areas, and on JANET, SALLY, and YVONNE, representing areas with more significant soil contamination.

### Air-Sampling Equipment

#### Ultra High-Volume Air Samplers (UHVS)

Two portable UHVS's (see Figs. 80 and 81, and Wells et al.\*\*) were obtained from Lawrence Livermore Laboratory (LLL) resuspension studies in progress on the Nevada Test Site and adapted to

\*\*W. Wells, B. R. Clegg, and J. C. Taylor, An Ultra-High Volume Air Sampler for the Collection of Airborne Particulates in Low Concentrations, Lawrence Livermore Laboratory report in preparation (1973).



Fig. 80. Truck-mounted portable ultra high-volume air sampler.

the special field conditions of the survey. These samplers were designed and built at LLL to provide the very high-volume flow rate needed to sample large volumes of air in short time intervals. The flow rate through the sampler was approximately  $2000 \text{ m}^3/\text{hr}$ , or about 20-50 times the flow rate of more conventional high-volume samplers. A special low-ash polystyrene filter, Delbag Microsorban, is used with this sampler. The filter medium is over 99% efficient for particles of  $0.3 \mu\text{m}$  diameter, and has a filter collecting area of  $1.25 \text{ m}^2$ . Samplers were powered on Enewetak by 15-hp gasoline engines and fueled for 40 hr of operation by 55-gal gasoline drums. The UHVS's were calibrated at Livermore for flow rate and total integrated volume by standard flowmeter measurements. Field air volumes were measured by an



Fig. 81. Portable ultra high-volume air sampler.

integrating flowmeter which was verified by a pitot-tube, instantaneous-flow-rate indicator. One UHVS unit was mounted on a 1/2-ton truck for off-island use on an LCM (Landing Craft Mechanized) and was limited in deployment to islands accessible by this craft. The second UHVS unit remained on FRED for continuous measurements.

#### Low-Volume Air Samplers (VCS)

Specially instrumented hand-held vacuum cleaners were used to collect week-long air samples on FRED and YVONNE. These samplers filtered at a rate between 8 and 20 m<sup>3</sup>/hr. Approximate flow-rate-over-time-of-sampling was obtained by averaging the initial and final flow rates determined by direct measurement. The VCS units were powered by base electricity on FRED

and by small gasoline generators on YVONNE. These generators were connected redundantly so as to improve power reliability of these inherently poor sources.

#### Andersen Cascade Impactors (ACI)

Two five-stage particle spectrometers (Fig. 82) were used to obtain data on the particle-size distribution of airborne radioactivity. These Andersen Cascade Impactors sampled at 34 m<sup>3</sup>/hr and separated five particle fractions on Fiberglas filter paper in the following increments: 0.1-1.1 μm, 1.1-2.0 μm, 2.0-3.3 μm, 3.3-7.0 μm, and >7 μm.

#### Sampling Operations

Daily observations were made of rainfall, wind velocity, and relative humidity. Weather information was



Fig. 82. Five-stage particle spectrometer.

available every 6 hr from the Enewetak Coast Guard Station. On YVONNE, a battery-powered station was used to measure wind velocity over the duration of the air-sampling operation.

Table 104 provides a summary of all samples collected, time of sampling, volume of air filtered, wind velocities, and the precipitation record. Figures 83 through 88 show the locations of sampling stations. Soil data appropriate to each air-sampling location may be found in the figures of Appendix II.

#### FRED

UHVS, VCS, and ACI samples (Table 104) were obtained from October 21 to 23, 1972, and from November 28 until December 19. The sampler location (Fig. 83) was such as to measure regional ocean background or air which crosses YVONNE, depending on the wind direction. East winds prevailed 80% of the time; however, for two periods, October 22-23 and December 11-14, moderately high winds from the NNE prevailed which would be expected to reflect any pickup and transport of

radioactivity from YVONNE to the southern part of the Atoll.

#### DAVID

Sampling was carried out on DAVID with the portable UHVS from October 19 to 22, resulting in two separate day-long samples. The sampling station was in the central part of the island (Fig. 84), with the winds from the east and northeast.

The FRED sampling location served to measure regional ocean background levels and, at other times, depending on wind direction, to measure inter-island transport. Ocean background was measured 80% of the sampling time during the typical east tradewinds. Samples UH5 and UH10 ( $128,000 \text{ m}^3$ ) were taken during a  $010\text{-}050^\circ$  northeast wind which sampled air along populated areas of FRED, as well as inter-island air from YVONNE. Neither sample exhibited radionuclide levels above ocean values.

Blank samples of  $1.25 \text{ m}^2$  of the Delbag Micrasorban filter paper used in the UHVS samplers, when analyzed in the same way as the samples for which data are shown in Table 105, show  $^{239,240}\text{Pu}$  levels as high as  $0.6 \text{ pCi/total paper}$ , or about  $0.01 \text{ fCi/m}^3$  if a sample volume of  $40,000 \text{ m}^3$  is assumed. These "background" levels have not been subtracted from the data in Table 105 since they appear to be quite variable; therefore, tabulated values for  $^{239,240}\text{Pu}$  in the range of  $0.01 \text{ fCi/m}^3$  or less should be used with the understanding that they may represent upper limits.

The JANET and SALLY sampling positions were downwind from the highest gamma levels observed in the aerial

Table 104. Air samples collected on Enewetak Atoll.

	Sample No.	Sampling period (1972)	Particle-size range, $\mu\text{m}$	Volume $\text{m}^3$	Wind direction	Wind speed, knots	Precipitation, in.
FRED	UH3	Oct 21-22		60,000	E, ENE	9-10	< 0.01
	UH5	Oct 22-23		30,900	NE, NNE	10-15	0.0-0.01
	UH6	Nov 28-30		58,700	E	18-20	0.01
	UH7	Nov 30-Dec 1		61,000	E, ENE	15-21	0.01
	UH8	Dec 1-2		16,400	E	15-18	0.0-0.01
	UH9	Dec 7-11		101,000	NE	15-20	0.40
	UH10	Dec 11-14		97,400	NNE	11-17	0.25
	UH11	Dec 14-17		97,500	NE	15-22	0.04
	UH12	Dec 17-19		74,000	NE	23-24	0.01
	UH13	Blank		(40,000 $\text{m}^3$ assumed)			
	VC11	Nov 28-Dec 7		1,640			
	VC21	Nov 28-Dec 7		1,640			
	VC12	Dec 7-18		2,300			
	VC22	Dec 7-18		2,300			
	A11A	Nov 28-Dec 7	(0.01-1.1)	7,300			
	A11B	Nov 28-Dec 7	(1.1-2.0)	7,300			
	A11C	Nov 28-Dec 7	(2.0-3.3)	7,300			
	A11D	Nov 28-Dec 7	(3.3-7.0)	7,300			
	A11E	Nov 28-Dec 7	(>7.0)	7,300			
A12A	Dec 7-18	(0.01-1.1)	9,900				
A12B	Dec 7-18	(1.1-2.0)	9,900				
A12C	Dec 7-18	(2.0-3.3)	9,900				
A12D	Dec 7-18	(3.3-7.0)	9,900				
A12E	Dec 7-18	(>7.0)	9,900				
DAVID	UH1	Oct 19-20		56,000	E, ENE, NE	6-10	0.01
	UH4	Oct 21-22		36,400	NE, NNE	10-15	0.0-0.01
JANET	UH21	Dec 4-5		36,000	NE, E	13-18	0.37
	UH22	Dec 5-6		22,800	E	15-20	0.40
	UH23	Dec 8-9		19,800	NE, ESE	9-15	0.14
SALLY	UH24	Dec 13-14		34,400	NE, ENE	8-18	0.0-0.01
	UH25	Dec 14-15		39,000	NNE, NE	15-22	0.01
YVONNE	UH26 (Pu area)	Dec 15-16		27,000	NE	15-25	0.03
	UH27 (Pu area)	Dec 16-17		34,000	NNE, NE	20-25	0.03
	UH28 (Cactus)	Dec 17-19		21,400	NE	22-24	0.01
	VC31 (Pu area)	Dec 2-9		1,800			
	VC41 (Pu area)	Dec 2-9		1,800			
	A21A (Pu area)	Dec 2-9	(0.01-1.1)	5,700			
	A21B (Pu area)	Dec 2-9	(1.1-2.0)	5,700			

Table 104 (continued).

	Sample No.	Sampling period (1972)	Particle-size range, $\mu\text{m}$	Volume $\text{m}^3$	Wind direction	Wind speed, knots	Precipitation, in.
YVONNE	A21C (Pu area)	Dec 2-9	(2.0-3.3)	5,700			
	A21D (Pu area)	Dec 2-9	(3.3-7.0)	5,700			
	A21E (Pu area)	Dec 2-9	(>7.0)	5,700			
	VC32 (Pu area)	Dec 9-19		2,100			
	VC42 (Pu area)	Dec 9-19		2,100			
	VC43 (Pu area) (blind sample)						
	A22A	Dec 9-19	(0.01-1.1)	7,750			
	A22B	Dec 9-19	(1.1-1.1)	7,750			
	A22C	Dec 9-19	(2.0-3.3)	7,750			
	A22D	Dec 9-19	(3.3-7.0)	7,750			
	A22E	Dec 9-19	(>7.0)	7,750			

survey. All of these samples, however, exhibited the type of results observed on the FRED samples.

As an extreme test of resuspension, the UHVS was located in an area of highest plutonium surface contamination on YVONNE (Fig. 88). Both UHVS samples at that location exhibited measurable plutonium levels (1.8 and 2.6 fCi/m<sup>3</sup>). The UH27 sample returned a detectable <sup>241</sup>Am value of 0.30 fCi/m<sup>3</sup>  $\pm$  32%. Only one ACI sample measured a high <sup>239,240</sup>Pu value (0.18-fCi/m<sup>3</sup>), but that was in the respirable range of particle sizes (<1.1  $\mu\text{m}$ ). In addition, one VCS sample taken during the same period (Dec. 2-9, 1972) exhibited a high value of <sup>239,240</sup>Pu (0.41 fCi/m<sup>3</sup>). Other low-volume and cascade-impactor samples yielded plutonium air concentrations similar to those observed on FRED.

A resuspension factor can be inferred at the high plutonium site on YVONNE if one assumes that an average 200 pCi/g plutonium soil concentration in the top centimeter is available for suspension on the surface layer. The 2.6 fCi/m<sup>3</sup> air concentration (UH27), for example, indicates an approximate resuspension factor of 10<sup>-9</sup>/m.

Two days of sampling near the CACTUS crater measured a <sup>239-240</sup>Pu air concentration equal to 1.1 fCi/m<sup>3</sup> and a <sup>238</sup>Pu concentration equal to 0.13 fCi/m<sup>3</sup>. No detectable <sup>241</sup>Am was found. Such a high air concentration is somewhat anomalous because the surface plutonium concentrations in this area are not known to be nearly so high as at the central YVONNE site. Ocean spray is a possible source, because the CACTUS crater water contains a surface concentration of 200



100 METERS



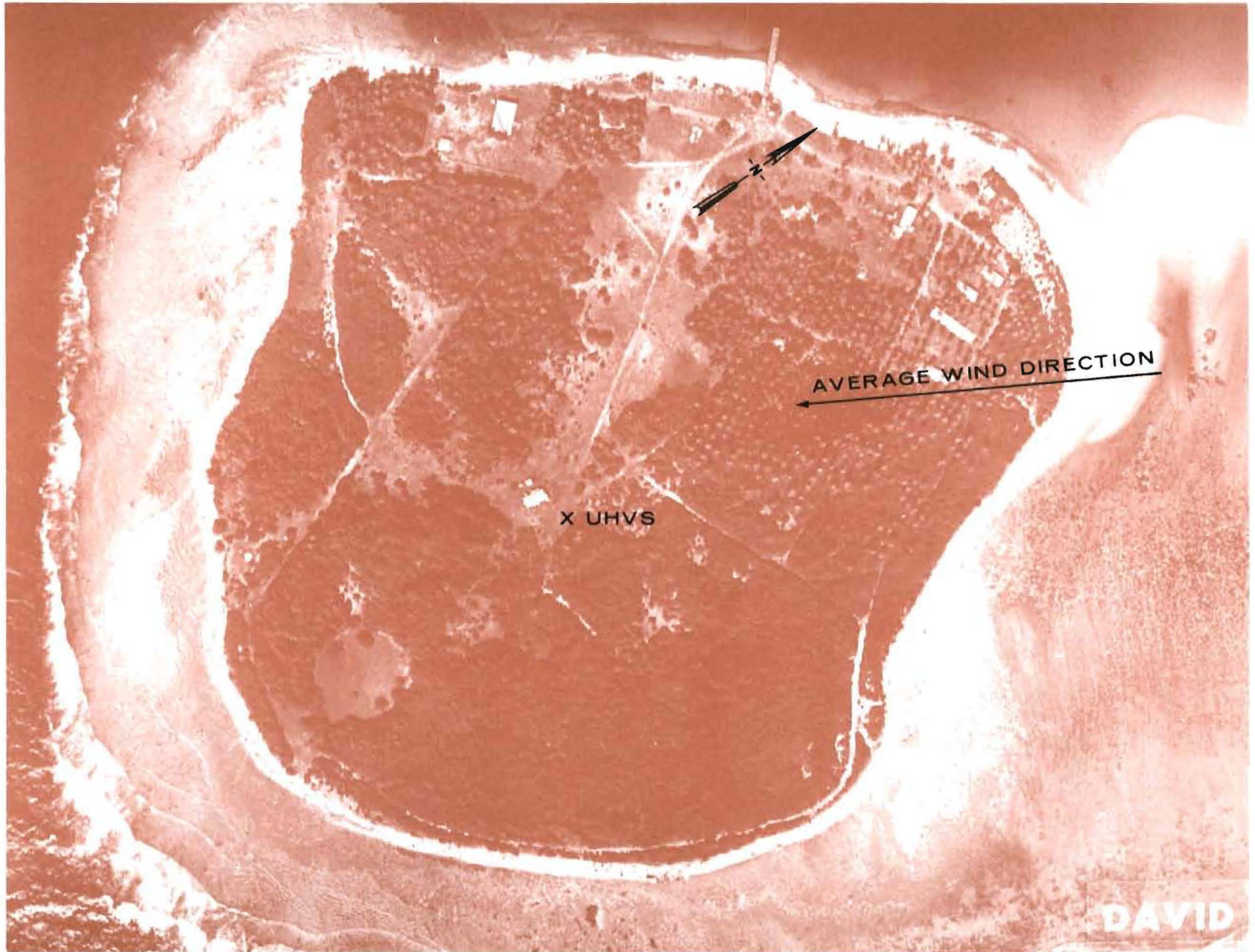
-355-

Fig. 83. Air-sample station location, Fred B.





100 METERS

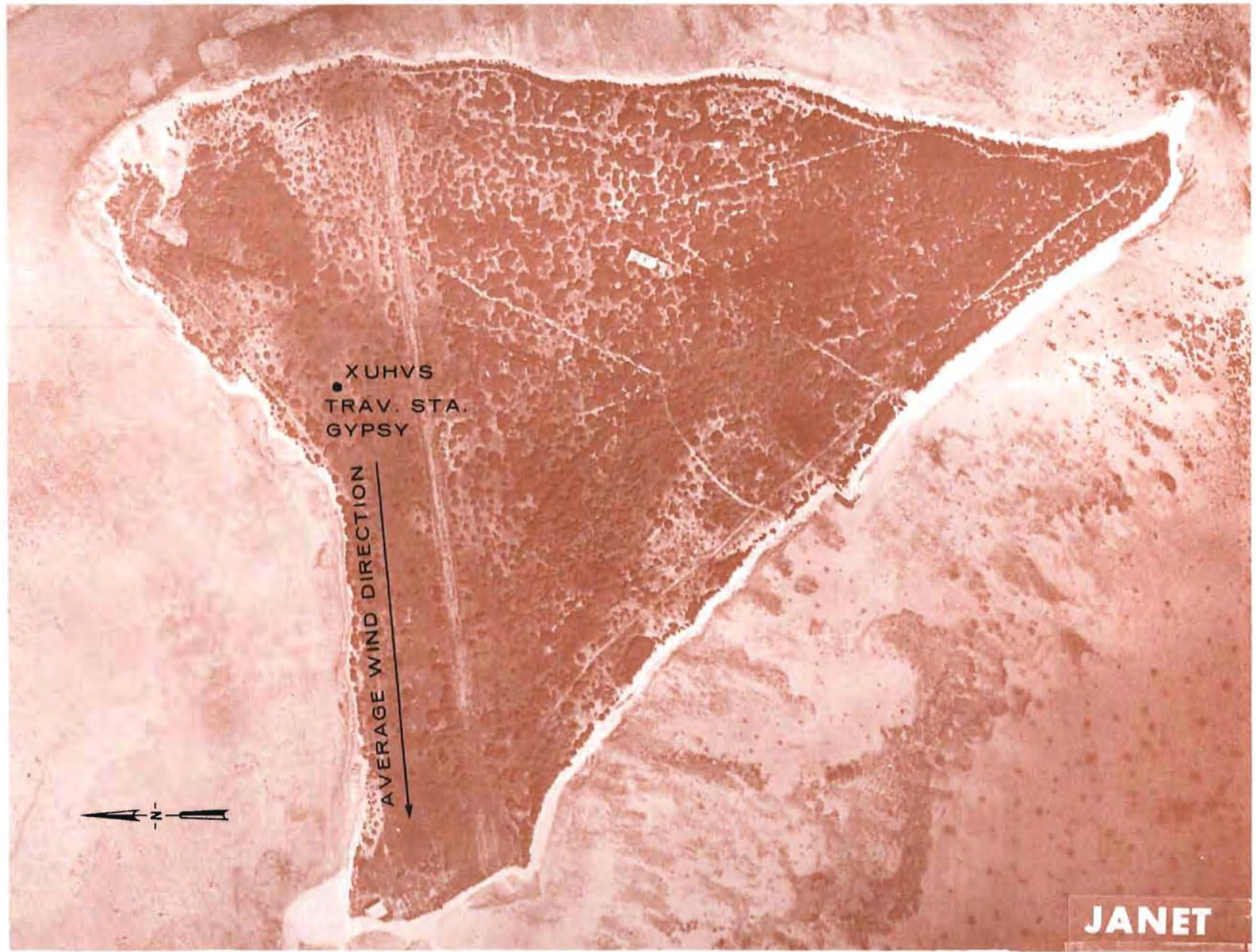


-357-

Fig. 84. Air-sample station location, David.



100 METERS

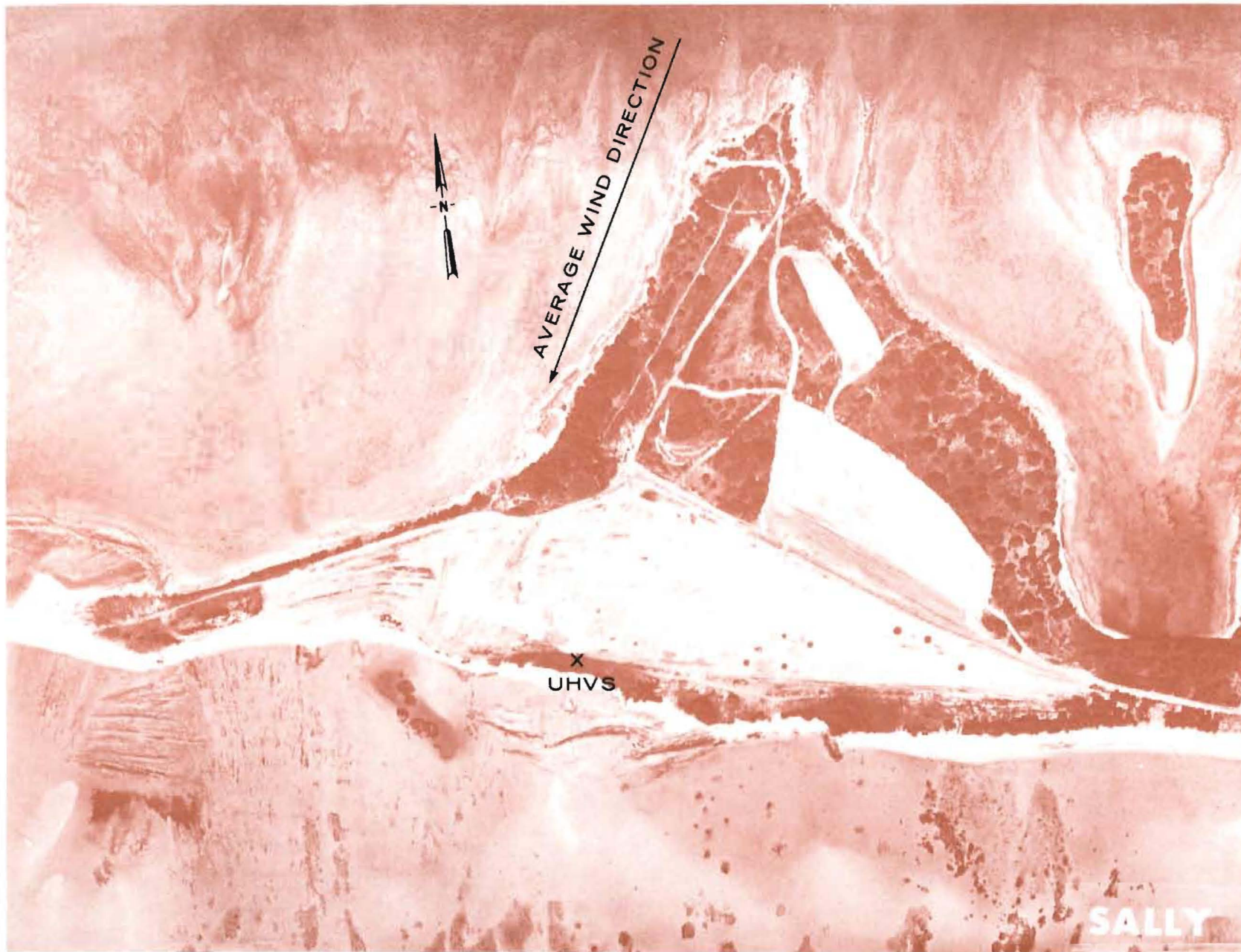


- 359 -

Fig. 85. Air-sample station location, Janet.



100 METERS

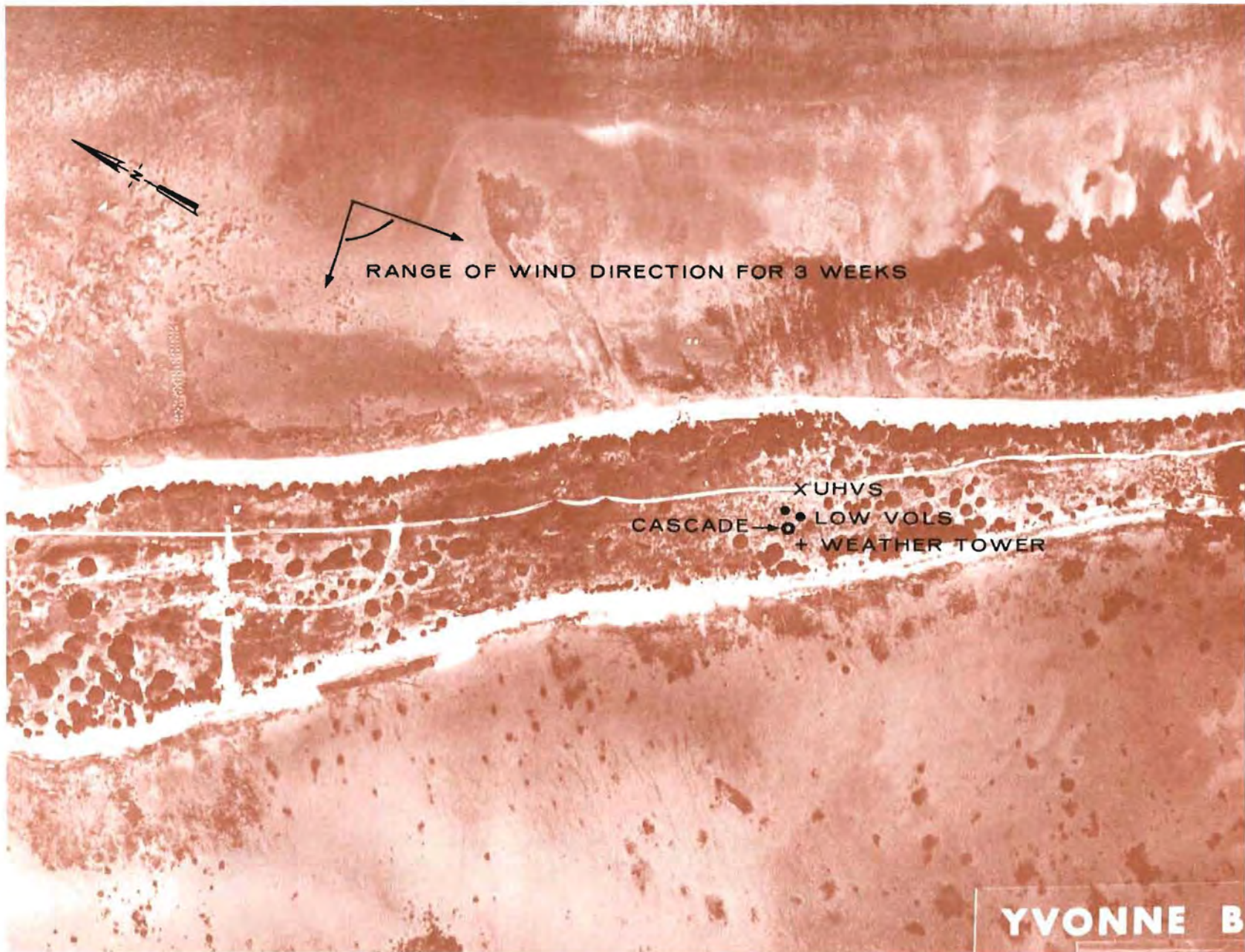


-361-

Fig. 86. Air-sample station location, Sally.



100 METERS



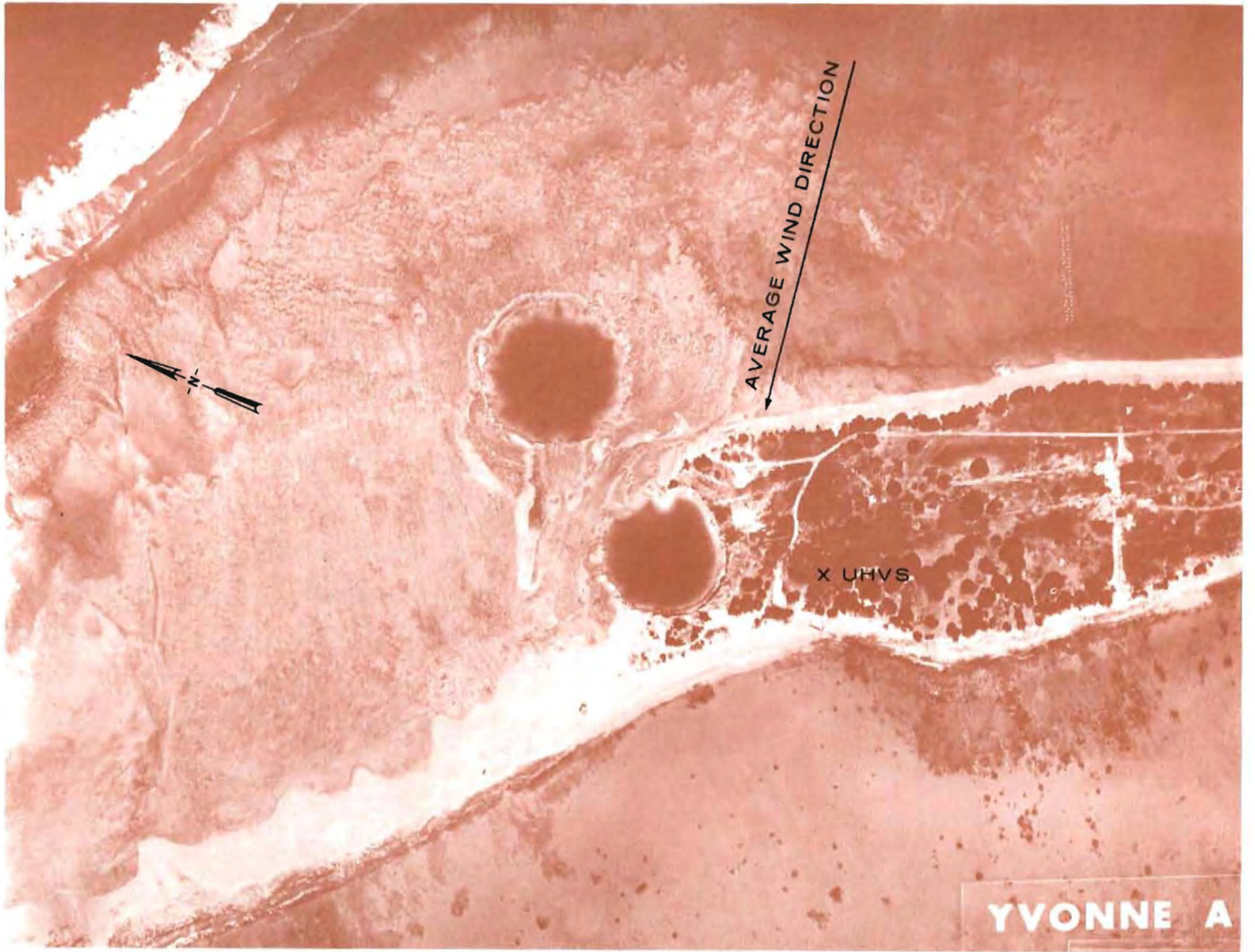
-363-

Fig. 87. Air-sample station location, Yvonne B.





100 METERS



-365-

Fig. 88. Air-sample station location, Yvonne A.



Table 105. Radionuclide concentrations in Enewetak air samples.

		Concentration, fCi/m <sup>3</sup> (standard error, %) <sup>a</sup>								
		<sup>7</sup> Be	<sup>40</sup> K	<sup>54</sup> Mn	<sup>95</sup> Zr	<sup>106</sup> Ru	<sup>137</sup> Cs	<sup>144</sup> Ce	<sup>239,240</sup> Pu	<sup>238</sup> Pu Other <sup>b</sup>
FRED	UH3	-NDET	-NDET	0.38±10	0.11±20	<0.25 NDET	0.21±19	0.5±17	<0.003 NDET	-NDET
	UH5	94±4	-NDET	0.6±12	0.3±20	1.3±32	0.39±17	1.1±18	0.0067±12	-NDET
	UH6	81±10	4.5±16	0.23±20	0.3±26	1.0±35	0.41±18	1.9±19	0.0086±6	-NDET
	UH7	58±3	-NDET	0.22±14	0.12±18	-NDET	1.1±5	0.36±17	-NDET	-NDET
	UH8	40±25	10±32	0.8±20	-NDET	<1.5 NDET	<0.17 NDET	-NDET	0.0032±26	0.0028±22
	UH9	32±10	-NDET	0.14±25	-NDET	<0.29 NDET	<0.036 NDET	0.23±36	0.0012±13	-NDET
	UH10	95±3	-NDET	-NDET	0.08±14	0.42±20	0.43±5	0.22±11	0.003±21	-NDET
	UH11	110±50	5.4±24	-NDET	-NDET	1.6±32	0.34±30	0.83±26	0.012±20	-NDET
	UH12	6±10	-NDET	-NDET	0.03±22	<0.2 NDET	0.13±18	0.28±16	<0.03 NDET	-NDET
	VC11	-NDET	-NDET	-NDET	-NDET	-NDET	-NDET	-NDET	-NDET	-NDET
	VC21	116±50	↓	1.9±42	↓	↓	1.2±41	↓	↓	↓
	VC12	81±34	↓	4.0±30	↓	↓	-NDET	↓	↓	↓
VC22	70±50	↓	1.3±36	↓	↓	2.5±19	↓	↓	↓	
A11A	52±50	↓	-NDET	↓	↓	-NDET	↓	0.017±22	↓	
A11B	-NDET	↓	↓	↓	↓	↓	↓	0.005±25	↓	
A11C	↓	1.6±18	↓	↓	↓	↓	↓	-NDET	↓	
A11D	↓	-NDET	↓	↓	↓	↓	↓	↓	↓	
A11E	↓	27±10	↓	↓	↓	↓	↓	↓	↓	
A12A	43±50	-NDET	0.4±28	↓	↓	↓	↓	↓	↓	
A12B	-NDET	7.7±32	0.4±28	↓	↓	↓	↓	↓	↓	
A12C	↓	15±14	0.5±23	↓	↓	↓	↓	↓	↓	
A12D	↓	6.0±40	0.5±25	↓	↓	↓	↓	↓	↓	
A12E	↓	-NDET	-NDET	↓	↓	↓	↓	↓	↓	
DAVID	UH1	38±5	-NDET	0.3±14	-NDET	<0.29 NDET	0.15±23	-NDET	0.025±6	-NDET
	UH4	-NDET	-NDET	0.4±12	0.2±30	<0.46 NDET	0.17±32	0.4±27	0.024±7	0.008±9

Table 105 (continued).

		Concentration, fCi/m <sup>3</sup> (standard error, %) <sup>a</sup>								
		<sup>7</sup> Be	<sup>40</sup> K	<sup>54</sup> Mn	<sup>95</sup> Zr	<sup>106</sup> Ru	<sup>137</sup> Cs	<sup>144</sup> Ce	<sup>239,240</sup> Pu	<sup>238</sup> Pu Other <sup>b</sup>
JANET	UH21	41±15	-NDET	-NDET	-NDET	< 0.45 NDET	2.1±7	-NDET	0.006±16	0.007±11
	UH22	-NDET	-NDET	-NDET	-NDET	< 1.0 NDET	0.44±33	-NDET	<0.006 NDET	-NDET
	UH23	22±10	9.2±24	1.3±10	-NDET	< 0.9 NDET	0.71±17	-NDET	<0.008 NDET	-NDET
SALLY	UH24	53±18	-NDET	-NDET	-NDET	< 0.65 NDET	0.66±19	-NDET	0.005±21	-NDET
	UH25	60±2	-NDET	-NDET	0.2±18	< 0.34 NDET	0.34±13	1.5±12	0.0011±19	-NDET
YVONNE	UH26	167±9	-NDET	-NDET	-NDET	< 0.86 NDET	0.49±24	2.5±23	1.8±5	0.04±9
	UH27	193±2	-NDET	-NDET	0.4±6	1.6±22	0.82±5	3.7±7	2.6±13	<0.14 NDET b
	UH28	143±22	22±25	-NDET	-NDET	< 3.3 NDET	<0.58 NDET	-NDET	1.1±12	0.13±13 b
	VC31	-NDET	25±37	1.1±43	↓	-NDET	-NDET	-NDET	0.49±9	-NDET
	VC41	↓	-NDET	1.5±34	↓	↓	↓	↓	-NDET	↓
	VC32	↓	4.2±23	-NDET	↓	↓	↓	↓	0.033±14	↓
	VC42	190±50	-NDET	2.1±23	↓	↓	↓	↓	-NDET	↓
	A21A	152±50	↓	0.6±34	↓	2.6±66	↓	↓	0.18±25	↓
	A21B	-NDET	32±11	-NDET	↓	-NDET	↓	↓	-NDET	↓
	A21C	↓	16±24	↓	↓	↓	↓	↓	↓	↓
A21D	↓	-NDET	↓	↓	↓	↓	↓	↓	↓	
A21E	↓	17±19	↓	↓	↓	↓	↓	↓	↓	
A22A	41±15	21±12	0.5±30	↓	↓	↓	↓	0.011±22	↓	
A22B	7.5±60	15±17	0.5±35	↓	↓	↓	↓	0.01±18	↓	
A22C	-NDET	15±25	0.5±43	↓	↓	↓	↓	-NDET	↓	
A22D	↓	-NDET	-NDET	↓	↓	↓	↓	0.074±9	↓	
A22E	↓	-NDET	-NDET	↓	↓	↓	↓	0.022±12	↓	

<sup>a</sup>NDET = Not detected (when preceded by a dash, the limit of sensitivity was not established.)

<sup>b</sup><sup>241</sup>Am (0.30±32); <sup>125</sup>Sb (0.27±24); <sup>103</sup>Ru (5.5±17).

Table 106. Comparison of radionuclides in surface air (fCi/m<sup>3</sup>) on Enewetak, Livermore, California, and Balboa, Panama.

Nuclide	YVONNE	Remainder of Enewetak Atoll	Livermore, Calif., 1972	Balboa, Panama, 9°N 79°W, 1972-1973
<sup>7</sup> Be	< 49-193	< 6-116	90-250	43-143 <sup>c</sup>
<sup>54</sup> Mn	< 0.6-2.1	< 0.14-4.0	-	-
<sup>95</sup> Zr	< 0.4-0.4 <sup>a</sup>	0.03-0.3	0.005-0.4	< 0.9-8.5
<sup>103</sup> Ru	< 5.5-5.5 <sup>a</sup>	NDET <sup>b</sup>	0.29-3.4	-
<sup>125</sup> Sb	< 0.27-0.27 <sup>a</sup>	NDET	0.04-0.23	-
<sup>106</sup> Ru	< 0.9-2.6	< 0.2-1.6	0.14-2.9	-
<sup>137</sup> Cs	< 0.49-0.82	< 0.04-2.5	0.63-3.2	0.09-1.7
<sup>144</sup> Ce	< 2.5-3.7	< 0.22-1.9	0.24-3.1	0.7-11.2
<sup>239, 240</sup> Pu	< 0.03-2.6	< 0.001-0.025	0.01-0.05	< 0.001-0.030
<sup>238</sup> Pu	< 0.04-0.13	< 0.0028-0.008	0.001-0.005	< 0.001-0.003
<sup>241</sup> Am	< 0.3-0.30 <sup>a</sup>	NDET	NDET	NDET

<sup>a</sup>Detected only one sample.

<sup>b</sup>Not detected.

<sup>c</sup>Oct. -Dec. 1972 range.

fCi/1 (see the marine survey data). If we assume the total <sup>40</sup>K (excepting the filter material <sup>40</sup>K) is a normal isotopic constituent of ocean water, then we can calculate an average air mass loading equal to 2 mg/m<sup>3</sup>. This unusually high mass loading partially clogged the filter media during the sampling. If this total airborne salt is from CACTUS crater, then only 0.012 fCi/m<sup>3</sup> of <sup>239</sup>Pu can be contributed to the 1.1 fCi/m<sup>3</sup> found in sample UH28. We must conclude that another surface source exists because the oceanborne contribution cannot be any higher than 0.1% of the total.

Some observations regarding the climatic conditions which existed during the survey may be appropriate at this point. As is shown in Table 104, most of the air samples were taken during the period from November 28 to December 19 (only two samples were taken on FRED and two on DAVID before typhoon OLGA struck). Wind speeds were almost always greater than 10 knots and often greater than 20 knots at all sampling locations. In addition, frequent light rain showers served to keep the ground surface damp. Table 107 presents climatological data which have been published for Enewetak

and Kwajalein. It is apparent that December represents a fairly average month so far as total rainfall and rainfall frequency are concerned, while average wind speeds are higher than those observed most of the year.

#### JANET

Three UHVS 24-hr samples were obtained on JANET from December 4 to 9. Wind speeds ranged from 10 to 20 knots, and rainfall during this sampling period was higher than for most days in the Atoll during the survey. Using information from the aerial survey, a sampling location was chosen in the area of highest activity (Fig. 85). This area contained surface contamination in soil, in pCi/g, as follows:  $^{137}\text{Cs}$  (av 15, range 0.6-180),  $^{239}\text{Pu}$  (av 8.5, range 1-170), and  $^{60}\text{Co}$  (av 2.0, range 0.1-6).

#### SALLY

Two UHVS 24-hr samples were obtained on SALLY from December 13 to 15. Rainfall was very low in this interval, and winds were stronger than usual. The sampling location was chosen on the basis of the aerial survey (Fig. 86). Subsequent to the sampling, it was learned that the sampling location was an old Radiation Exclusion (Radex) area which contained surface contamination in soil, in pCi/g, as follows:  $^{137}\text{Cs}$  (av 3.7, range 0.4-30),  $^{239}\text{Pu}$  (av 7, range 0.2-130), and  $^{60}\text{Co}$  (av 0.7, range 0.1-69).

#### YVONNE

Air sampling using UHVS's, VCS's, and ACI's was carried out from December 3 to 19, 1972. The portable UHVS was

fielded for three days in the area of highest plutonium surface activity recorded for YVONNE (Figs. 87 and 88). The surface soil has been described previously in connection with the soil-sampling program.

Winds were generally high and gusty during the sampling of YVONNE, and light daily rainfall was frequent. Air was sampled downwind from CACTUS crater on December 17-19, using the UHVS.

#### Results and Conclusions

A number of radionuclides were detected in the surface air of Enewetak Atoll, including  $^7\text{Be}$  (53 d),  $^{40}\text{K}$  (1.26  $10^9$  y),  $^{54}\text{Mn}$  (303 d),  $^{95}\text{Zr}$  (65 d),  $^{103}\text{Ru}$  (39.6 d),  $^{106}\text{Ru}$  (1 y),  $^{125}\text{Sb}$  (2.7 y),  $^{137}\text{Cs}$  (30 y), and  $^{239}\text{Pu}$  (2.4  $10^4$  y),  $^{238}\text{Pu}$  (86 y), and  $^{241}\text{Am}$  (458 y). Data for all samples collected are shown in Table 105.  $^7\text{Be}$  and  $^{40}\text{K}$  are naturally occurring activities.  $^{54}\text{Mn}$ ,  $^{95}\text{Zr}$ ,  $^{103}\text{Ru}$ ,  $^{106}\text{Ru}$ ,  $^{125}\text{Sb}$ , and  $^{144}\text{Ce}$  are intermediate-lived activation and fission products found in current worldwide fallout, but present in Enewetak soils in only very reduced quantities due to radioactive decay over the long period since testing ended. Longer-lived  $^{137}\text{Cs}$ ,  $^{238}\text{Pu}$ ,  $^{239}\text{Pu}$  and  $^{241}\text{Am}$  in air could result from either local resuspension or from worldwide fallout.

The natural  $^7\text{Be}$  provided convenient order-of-magnitude verification of the accuracy of air volume measurement.  $^7\text{Be}$  is formed by cosmic-ray interactions with  $^{14}\text{N}$  in the troposphere\* and is found

\*P. F. Gustafson, M. A. Kerrigan, and S. S. Bar, "Comparison of  $\text{Be}^7$  and  $\text{Cs}^{137}$  Radioactivity in Ground Level Air," Nature 191, 454 (July 29, 1961).

Table 107. Climatological data for Kwajalein and Enewetak<sup>a</sup>.

Wind speed, knots <sup>b</sup>	Percentage of total time at each wind-speed interval												Av	
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		
0-3	1	1	1	0	1	1	6	10	16	9	3	1	4.2	
4-10	15	12	22	20	27	27	49	60	59	63	42	20	34.7	
11-21	68	80	70	75	69	70	44	29	24	28	53	70	56.7	
22-33	15	7	7	5	3	2	1	1	1	0	2	9	4.4	
>33	1	0	0	0	0	0	0	0	0	0	0	0	0	
Prevailing wind direction and frequency <sup>b</sup>	NE	NE	NE	NE	NE	NE	E/NE	E	NE	NE	NE	NE	--	
	86%	87%	81%	77%	67%	64%	36%	31%	27%	33%	55%	74%	--	
							each							
Precipitation <sup>c</sup>													Yr	Yr. of record
Av. amount, in.	1.02	1.84	1.86	1.28	4.57	3.37	6.45	6.81	6.24	9.09	6.30	2.63	51.46	30
Greatest amount, in.	1.95	10.21	7.33	3.86	8.38	7.03	15.35	14.41	13.17	18.07	17.38	9.18	69.86	13
Least amount, in.	0.12	0.40	0.37	0.49	0.37	1.33	1.36	4.22	1.53	2.60	1.94	0.86	24.42	13
Mean number of days, 0.01 in. or more.	11	10	13	13	16	16	21	21	20	21	21	16	198	10

<sup>a</sup>U. S. Hydrographic Office, Sailing Directions for the Pacific Islands, H. O. Pub. No. 82, Vol. 1, Second Edition (1964), updated to Dec. 5, 1970.

<sup>b</sup>Wind data for Kwajalein.

<sup>c</sup>Precipitation data for Enewetak.

in surface air in concentrations of approximately 100 fCi/m<sup>3</sup>.<sup>†</sup> We compared our Enewetak data with Livermore, Calif. data<sup>\*\*</sup> (typically higher due to slower rainout of the condensation nuclei), and with data taken at Balboa, Panama, which is at nearly the Enewetak latitude.<sup>††</sup> The range of <sup>7</sup>Be values for Enewetak Atoll, Balboa, Panama, and Livermore, Calif. are in reasonable agreement (Table 106).

<sup>†</sup>One femtocurie (fCi) equals 10<sup>-15</sup> curie, or 0.0022 disintegration per minute.

<sup>\*\*</sup>P. H., Gudiksen, C. L. Lindeken, J. W. Meadows, and K. O. Hamby, Environmental Levels of Radioactivity in the Vicinity of the Lawrence Livermore Laboratory, Lawrence Livermore Laboratory, Rept. UCRL-51333 (1973).

<sup>††</sup>Health and Safety Lab., HASL-276, Appendix, Fallout Program, New York, Oct. 1, 1973.

ENGINEERING SURVEY —  
RADIOLOGICAL ASPECTS  
O. D. T. Lynch, Jr.  
Nevada Operations Office  
U. S. Atomic Energy Commission  
Las Vegas, Nevada

### Purpose and Scope

As part of the Enewetak precleanup survey, the Defense Nuclear Agency (DNA) contracted with Holmes and Narver, Inc. (H and N) to conduct an engineering survey of Enewetak Atoll in December 1972. The purpose of this survey was to identify and examine all existing structures now on the Atoll, provide their descriptions, and develop cost estimates for removal of such structures as part of the cleanup effort. An additional purpose was to develop plans for such a cleanup and the necessary support, including the setup of a large camp facility required to implement cleanup activities.

Each island was visited by the engineering team, and each structure was located, examined, categorized, and indicated in the notes and on the drawings. The results of this engineering effort were reported to DNA.\*

Radiological support was provided to the engineering survey by a team of AEC and EPA personnel. The purpose of the radiological effort was twofold:

- To provide radiological safety support to the engineering team on those islands which had known or suspected radiological hazards.
- To survey, evaluate, and report the radiological conditions of the structures and scrap on these islands.

\*Engineering Study for a Cleanup Plan, Enewetak Atoll - Marshall Islands, Holmes and Narver, Inc., Repts. HN-1348.1 and HN-1348.2 (1973).

### Islands Requiring Radiological Support

The islands for which radiological support was required and for which measurements were reported were: ALICE, BELLE, CLARA, DAISY, EDNA, IRENE, JANET, PEARL, SALLY, and YVONNE. Of these ten islands, five had surface ground zeros (SGZ) and one, EDNA, was little more than a sandbar. The islands of IRENE, JANET, PEARL, SALLY, and YVONNE had SGZ's and thus had possible radiological hazards. The remaining five islands had received heavy, close-in fallout.

### Instrumentation

Since the purpose of the radiological support was to survey structures and scrap, not areas, and to provide radiological safety services, instrumentation specific for that purpose was used. A detailed description of each instrument is provided in the Terrestrial Soil and Radiation Survey chapter of this report and will not be discussed here. However, it is appropriate to identify at this point the instrumentation used and the reason for the selection.

During the engineering survey effort the only alpha survey meter available for field use was the PAC-IS. This instrument was used only on those islands where surface ground zeros were located. Since this survey was performed at the end of the rainy season, alpha emissions were effectively masked by the moisture on structures and scrap surfaces. For this reason, the alpha survey meter was really only useful for personnel monitoring prior to leaving a contaminated island, particularly YVONNE.

Beta-gamma radiation detection was



provided by the E-500B and Ludlum Model 3 survey meter with pancake probe. The E-500B was used for high-range radiation levels (greater than 3mR/hr) and the Ludlum for lower levels of beta and low-energy gamma-radiation emitters on scrap metal and structures.

Low-level gamma exposure rates (less than 3mR/hr) were measured with the Baird-Atomic scintillator.

#### Execution of the Radiological Support Effort

The engineering survey effort was carried out by Holmes and Narver, Inc., under the direction of Earl Gilmore, Project Manager, H and N, Las Vegas, Nevada. The radiological support effort was directed by O. D. T. Lynch, Jr., NVOO, USAEC who was assisted by William E. Moore, James R. Martin, Rex Price, and Jack Thrall of EPA, Las Vegas.

Radiological survey measurements of structures and scrap metal were recorded directly on as-built drawings provided by H and N. These drawings were also used by the engineering team to locate the structures they were examining.

As a part of the radiological support provided to the engineering survey, single profile soil samples were collected on each of the following islands: IRENE, JANET, PEARL, SALLY, ALICE, BELLE, CLARA, and DAISY. These soil samples were taken to a depth of 40 to 60 cm from contaminated areas noted during the November aerial radiological survey. The results of analyses of these profile samples are included in the Terrestrial Soil and Radiation Survey data. The locations of these special soil sample profiles are indicated on the "f" series of figures in Appendix II.

#### Radiological Results

As a result of the radiological monitoring and safety support, none of the team members received any significant external exposure to radiation. Subsequent urine samples and whole-body counts from selected members of the monitoring team indicated that no detectable exposure was received due to internal deposition of radionuclides.

#### Scrap and Structure Survey

Contaminated structures and activated/contaminated scrap were found on a number of islands. The locations of this scrap and the contact exposure rates measured are indicated on the as-built drawings that follow (Figs. 89 through 113, inclusive). Area exposure rates and approximate isopleths are also shown, so that a simple comparison can be made between scrap radiation levels and the surrounding "background."

In many cases, the contact exposure rate was not significantly different from the surrounding area exposure rate. In this situation, the determination of whether or not the scrap was contaminated was inconclusive. This determination could be made only if the scrap were to be removed from the high background area and resurveyed. Such a procedure was not considered warranted at this time. Rather, it is suggested that the scrap be assumed contaminated if it rests in an area where exposure rates are, say, greater than 100  $\mu$ R/hr.

Radioactive scrap conditions are summarized in Table 108, on an island-by-island basis. In general, the scrap found on ALICE, BELLE, CLARA, DAISY, and EDNA is apparently not con-

Table 108. Radioactive scrap conditions by island.

Island	Relative scrap quantities	Scrap radioactivity	Remarks
ALICE	Significant	Apparently not contaminated above background.	Background is up to 170 $\mu$ R/hr. An M-boat wreck on beach reads 8 mR/hr.
BELLE	Insignificant	Apparently not contaminated above background.	Background up to 250 $\mu$ R/hr.
CLARA	Insignificant	Apparently not contaminated above background.	Background up to 100 $\mu$ R/hr.
DAISY	Insignificant	Apparently not contaminated above background.	Background up to 140 $\mu$ R/hr.
EDNA	None	Not applicable.	Sandbar
JANET	Large	Up to 8 mR/hr.	Activated scrap metal in all sizes can be found in piles or individual pieces scattered over the island.
PEARL	Small	Up to 5 mR/hr.	Confined to SGZ area.
SALLY	Large	Scrap metal up to 120 $\mu$ R/hr; concrete surfaces, alpha to $10^3$ dpm/50 cm <sup>2</sup> .	Most scrap metal is apparently not contaminated. Several structures contain plutonium-contaminated debris.
YVONNE	Large	Activated/contaminated to 60 mR/hr.	Most scrap metal is activated or contaminated. Also much plutonium contamination.

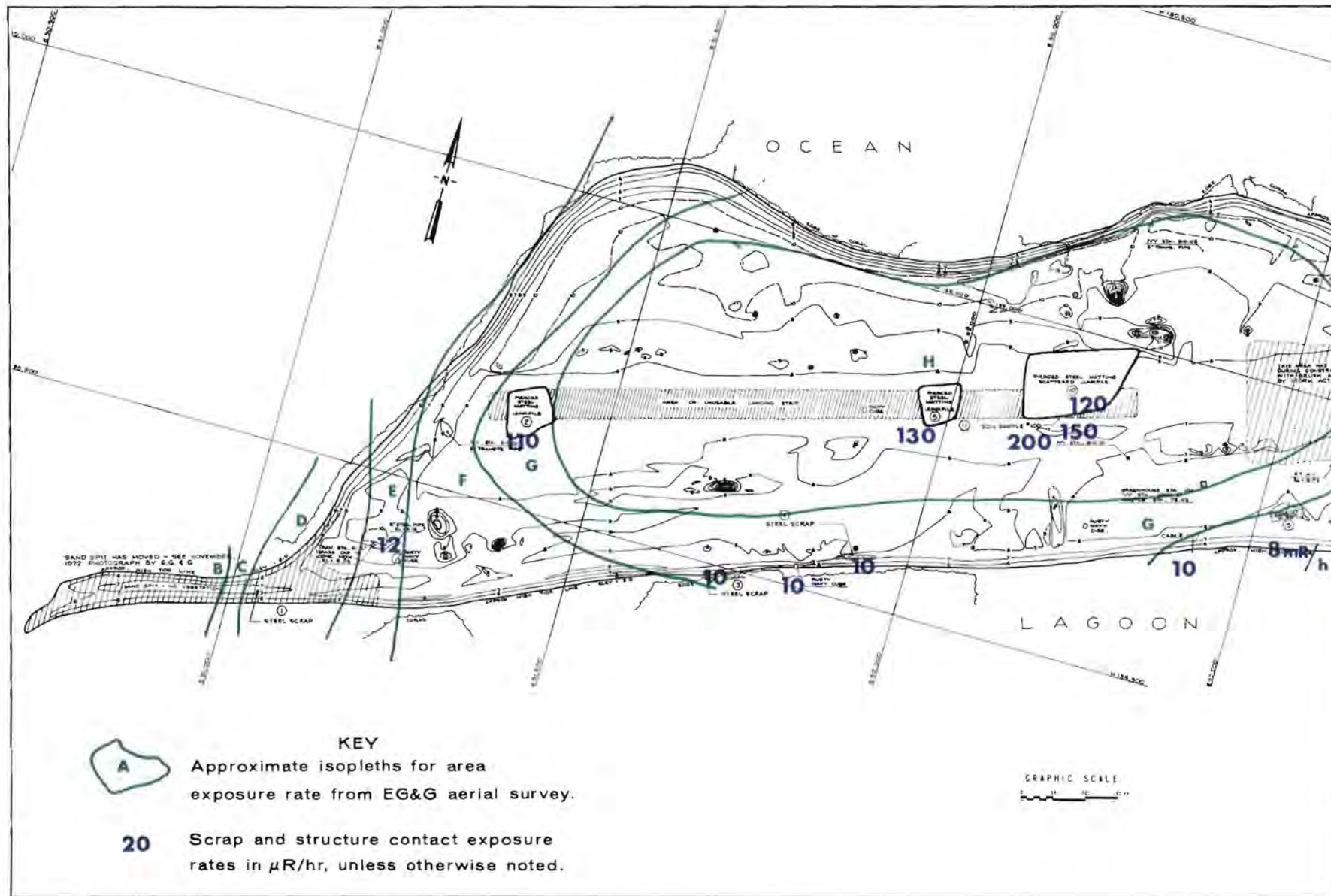


Fig. 89. Scrap and structure radiation measurements, ALICE, WEST.



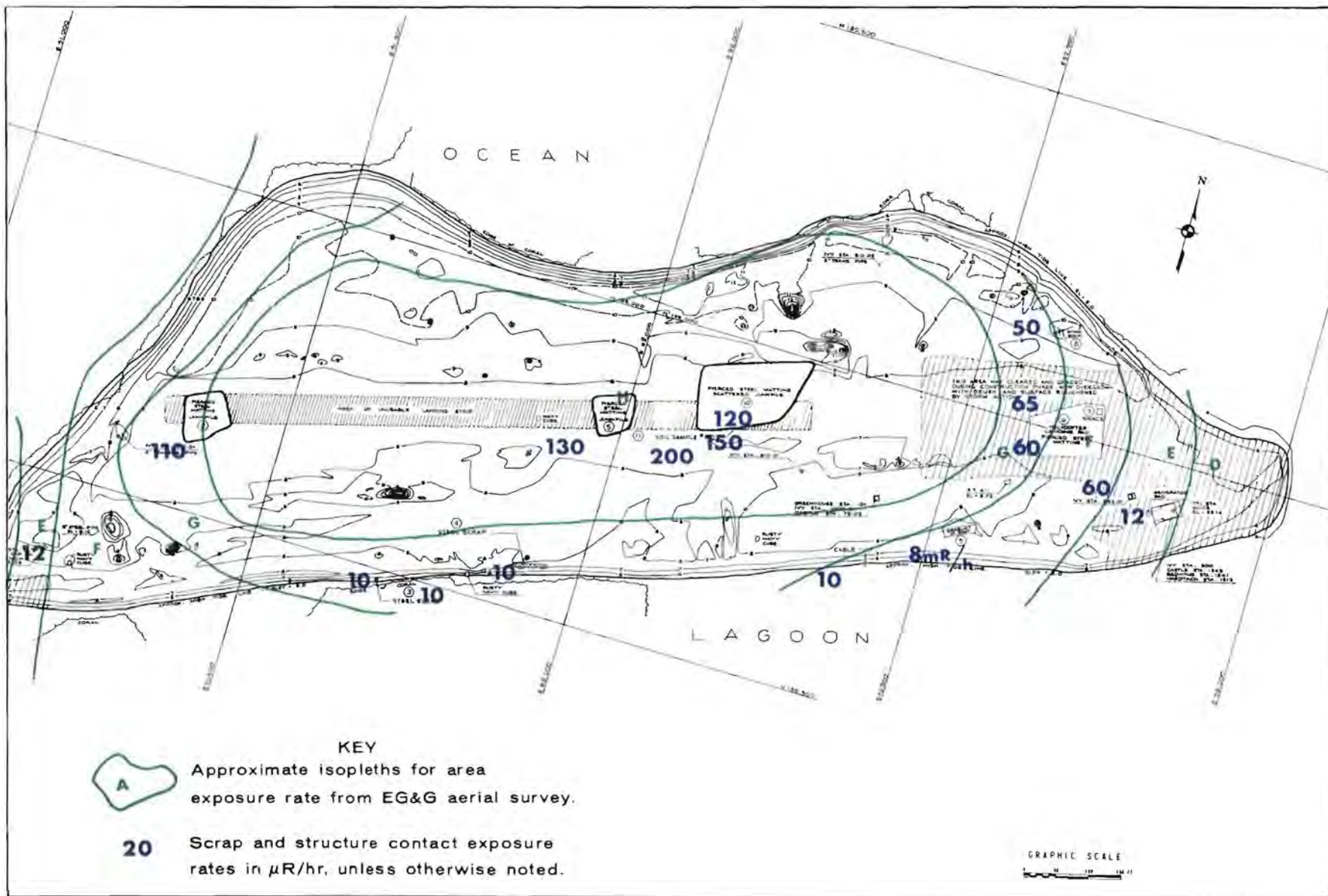


Fig. 90. Scrap and structure radiation measurements, ALICE, EAST.



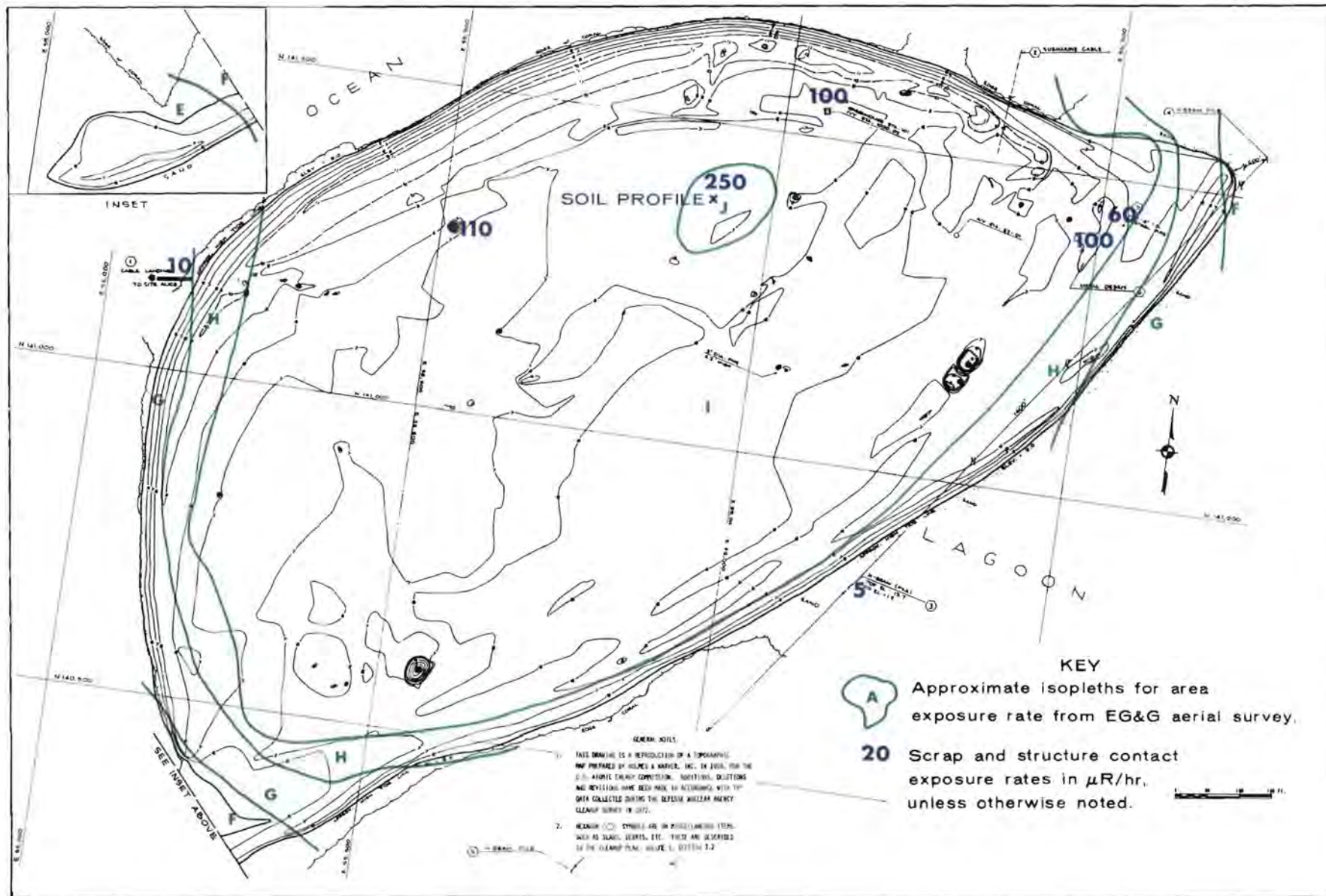


Fig. 91. Scrap and structure radiation measurements, BELLE.





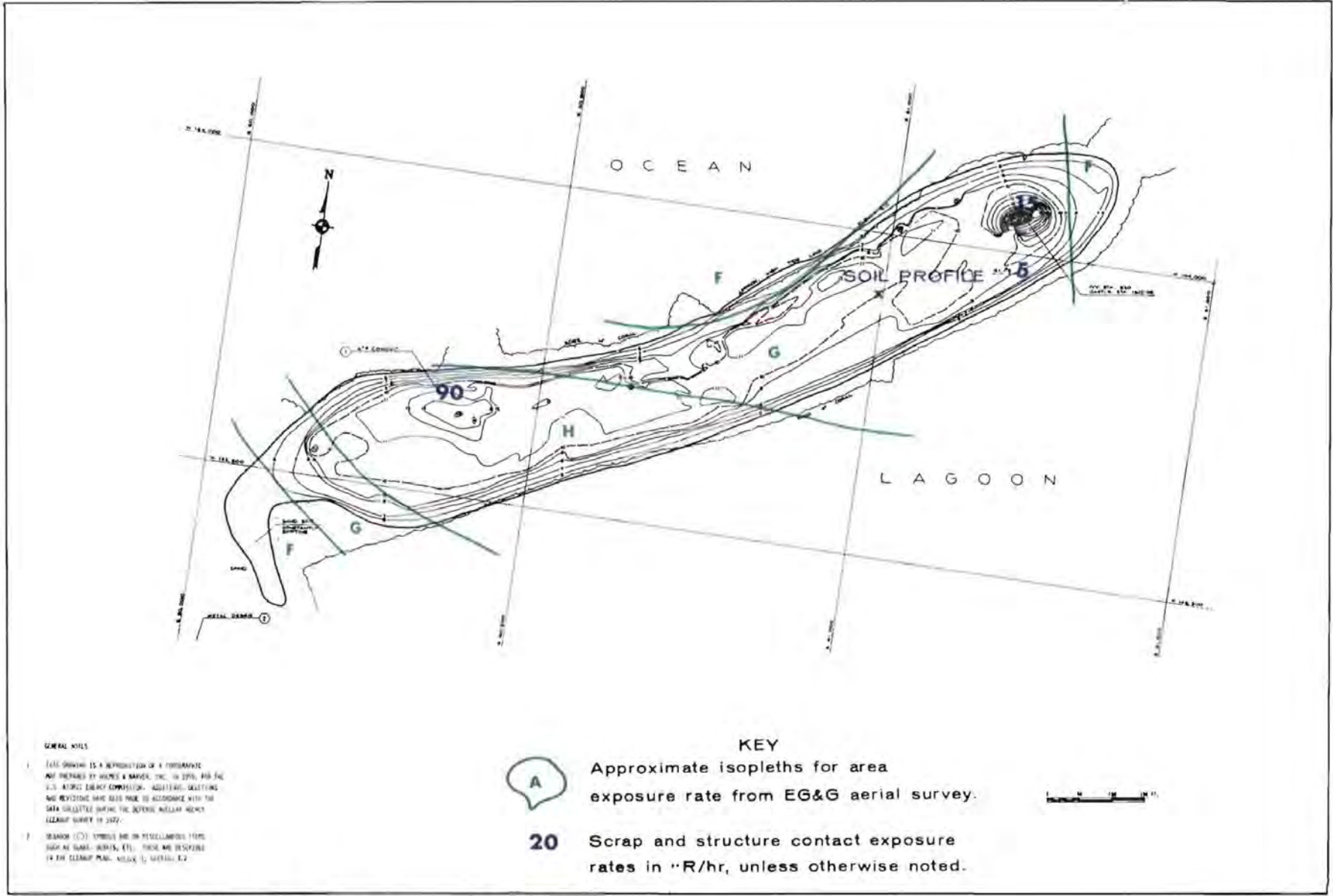


Fig. 92. Scrap and structure radiation measurements, CLARA.



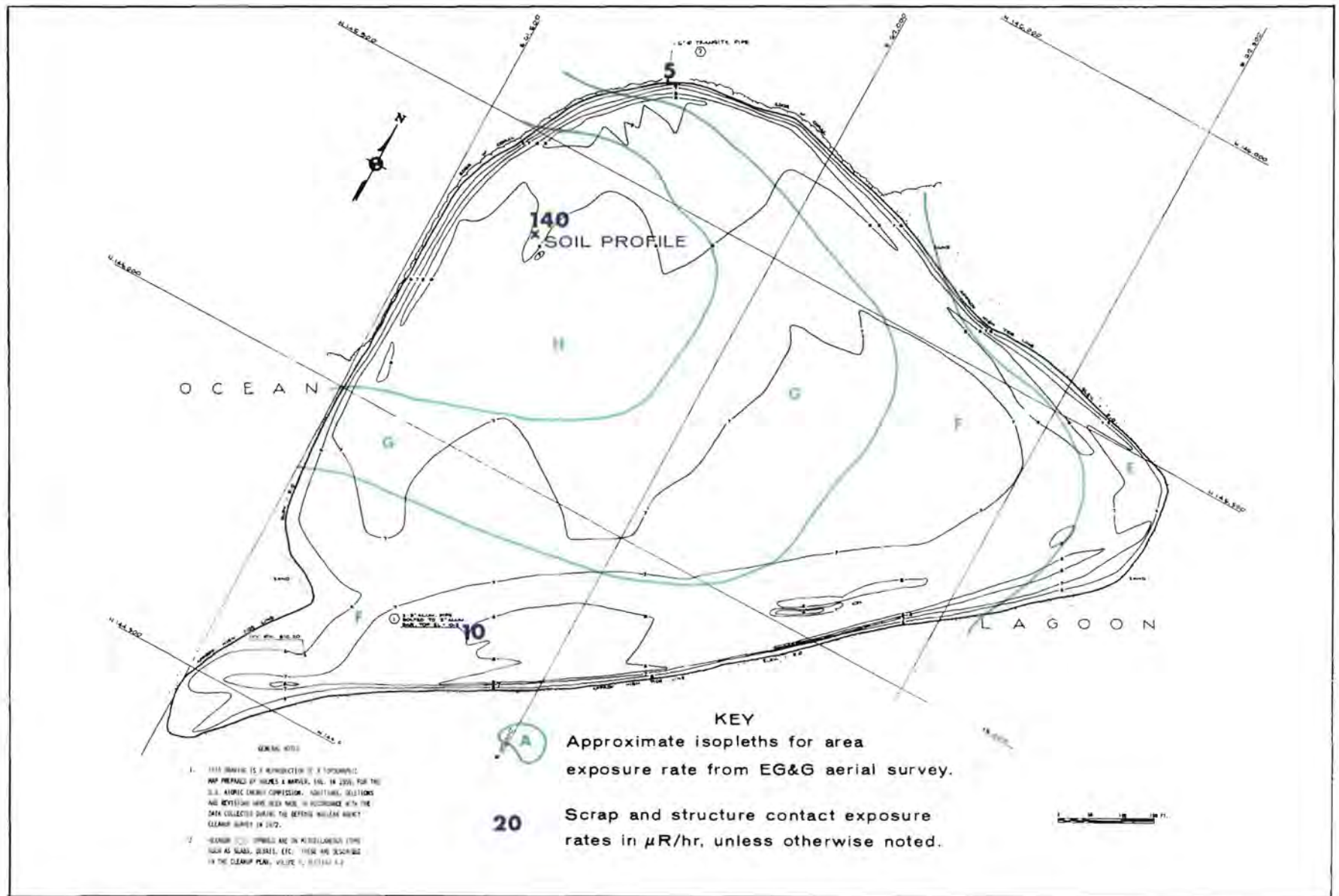


Fig. 93. Scrap and structure radiation measurements, DAISY.



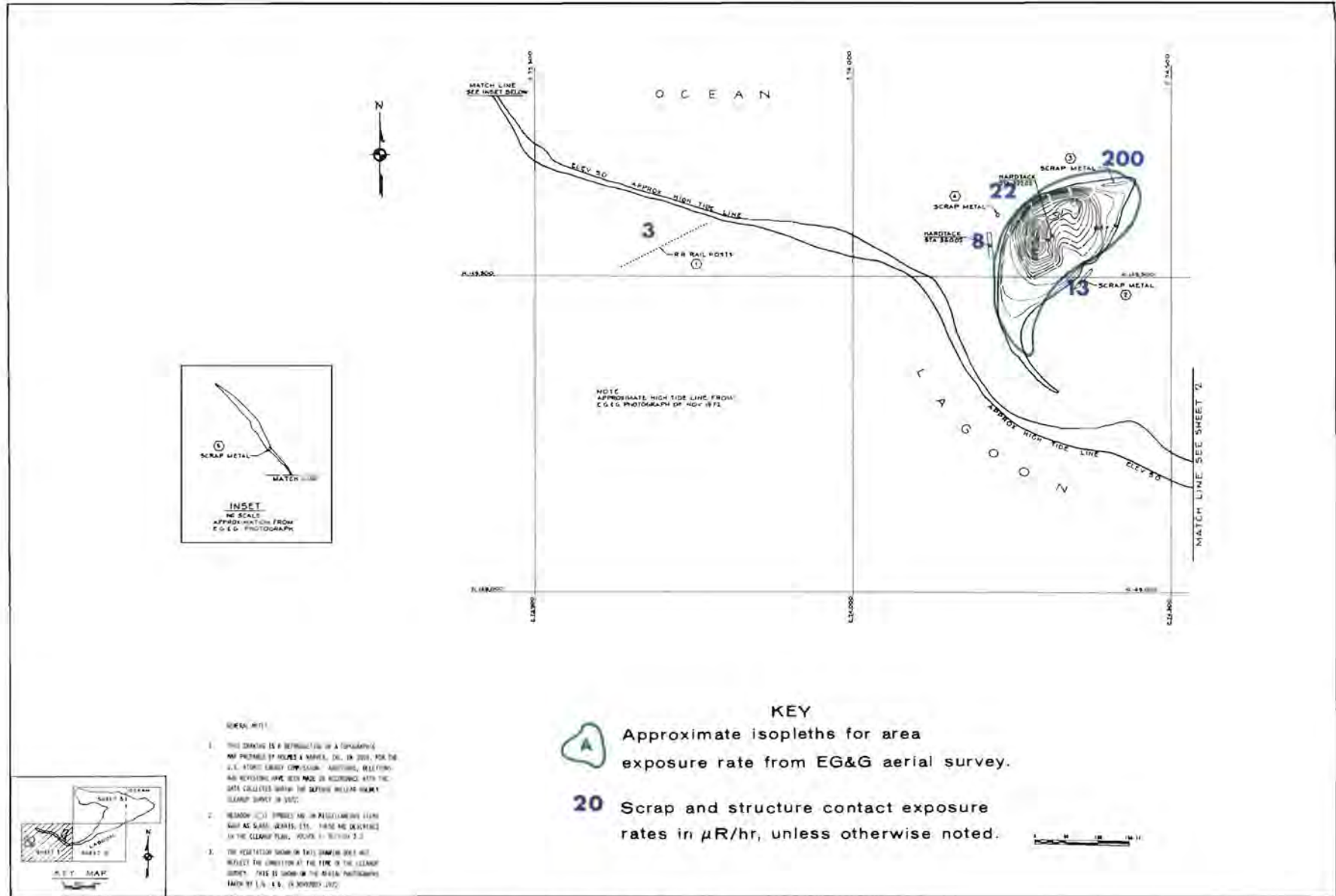


Fig. 94. Scrap and structure radiation measurements, HELEN and IRENE.



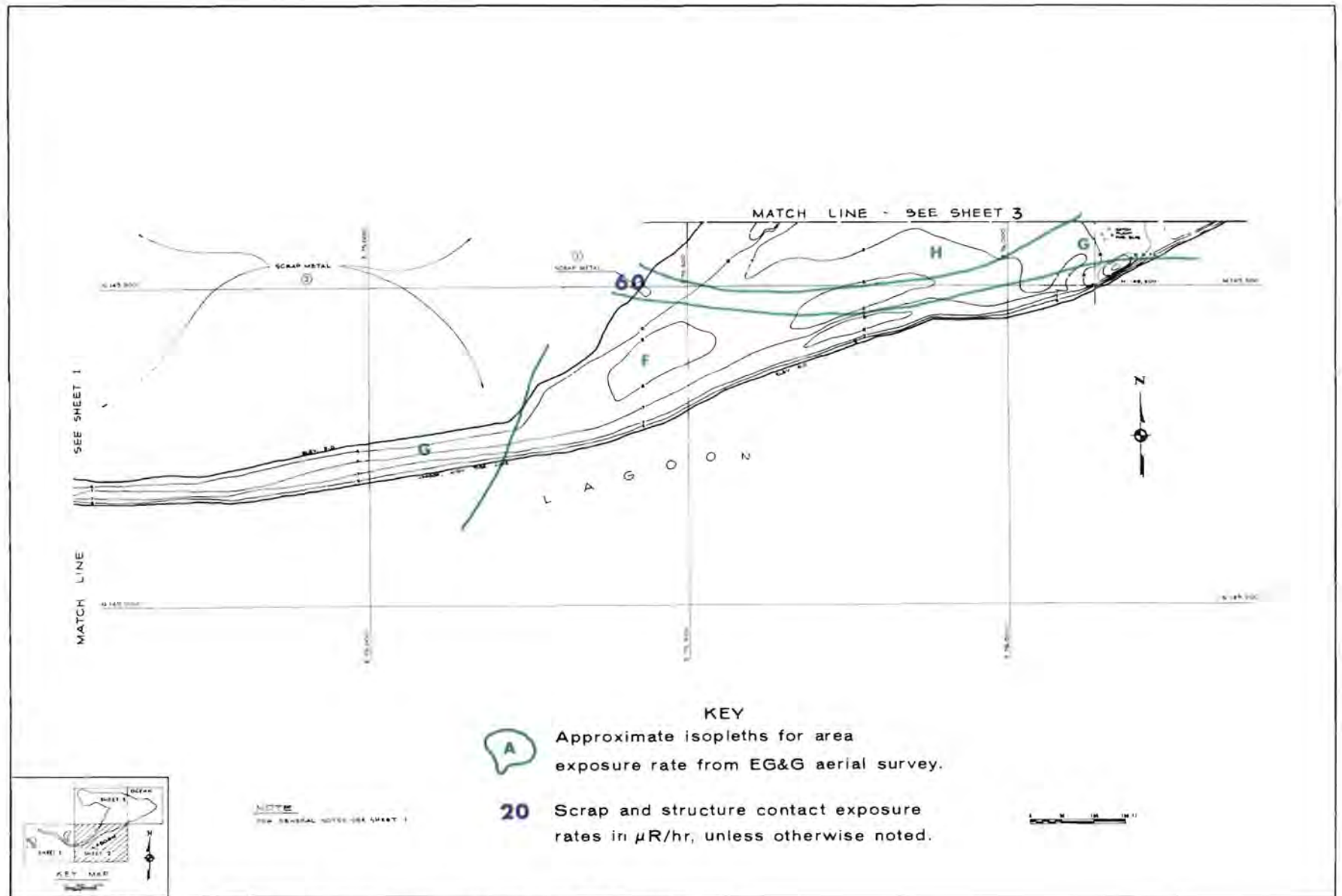


Fig. 95. Scrap and structure radiation measurements, HELEN and IRENE.





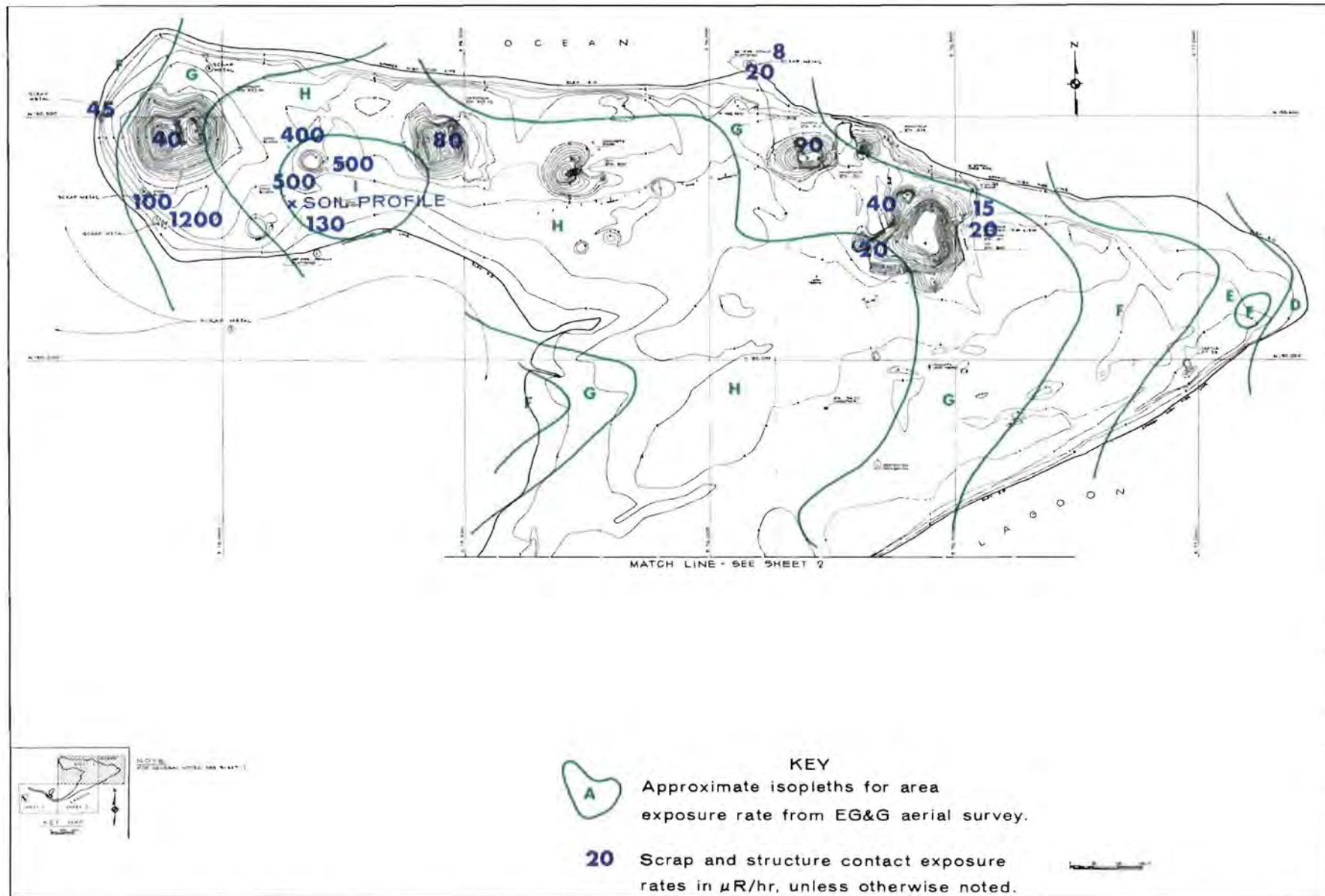


Fig. 96. Scrap and structure radiation measurements, HELEN and IRENE.



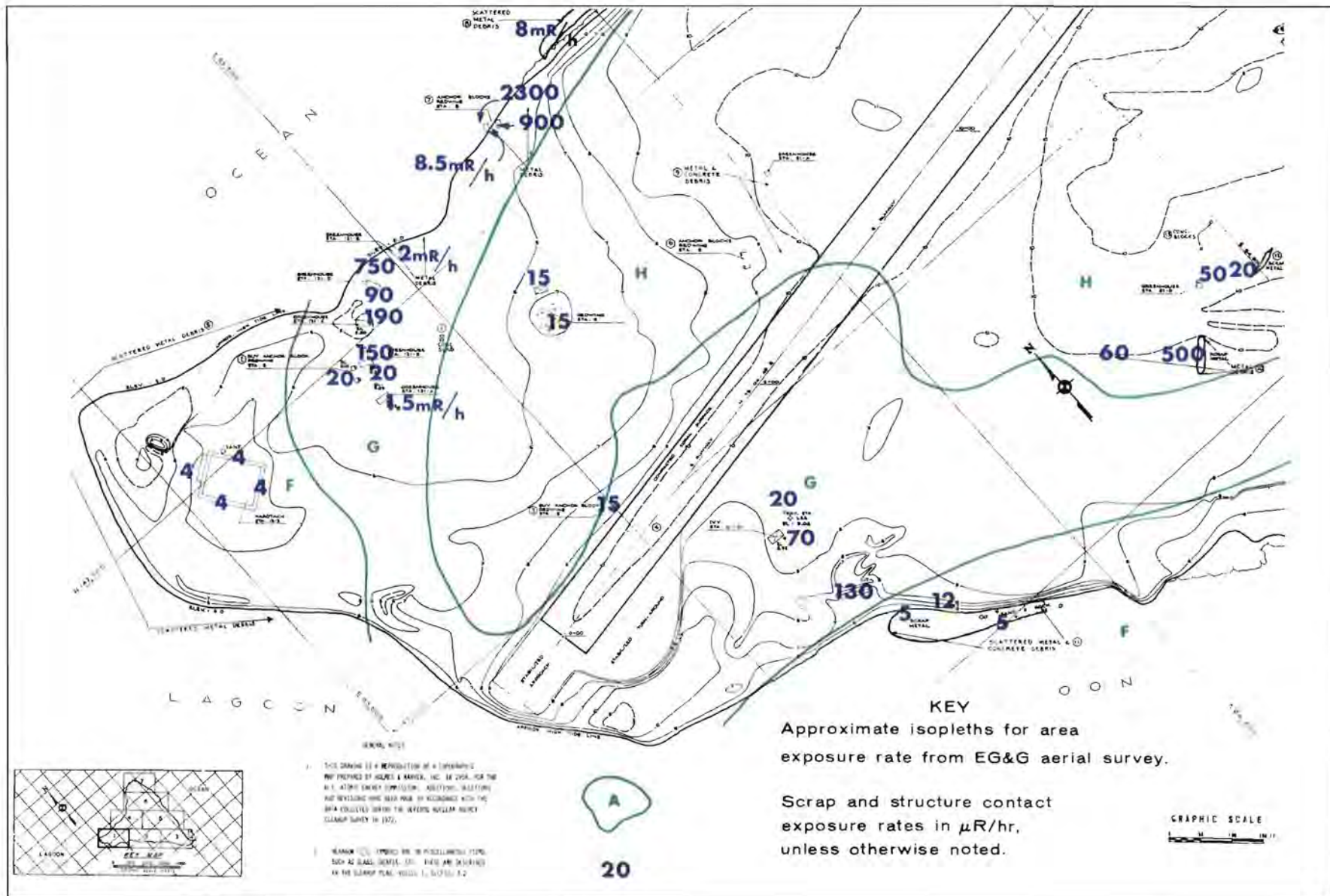


Fig. 97. Scrap and structure radiation measurements, JANET.



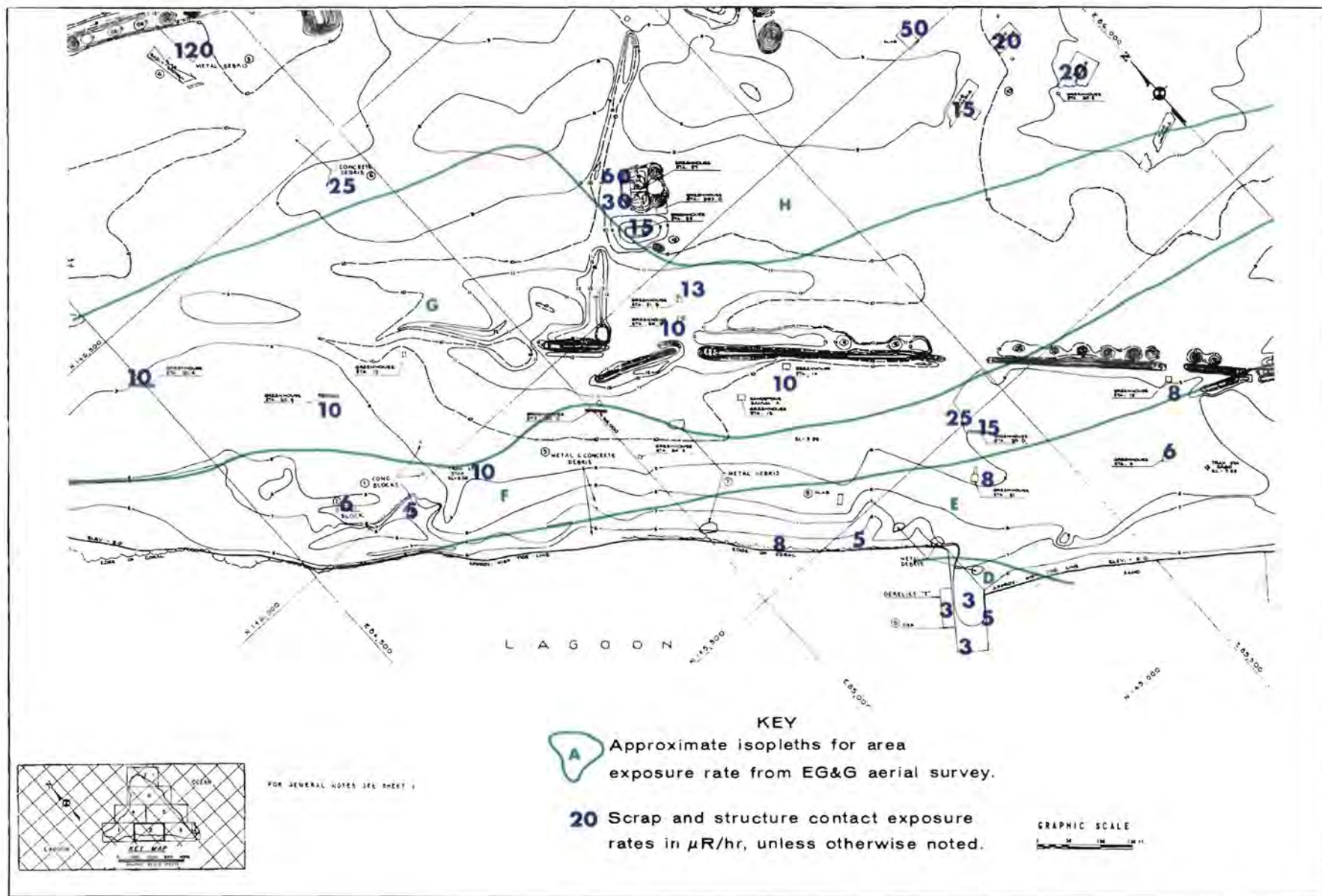


Fig. 98. Scrap and structure radiation measurements, JANET.



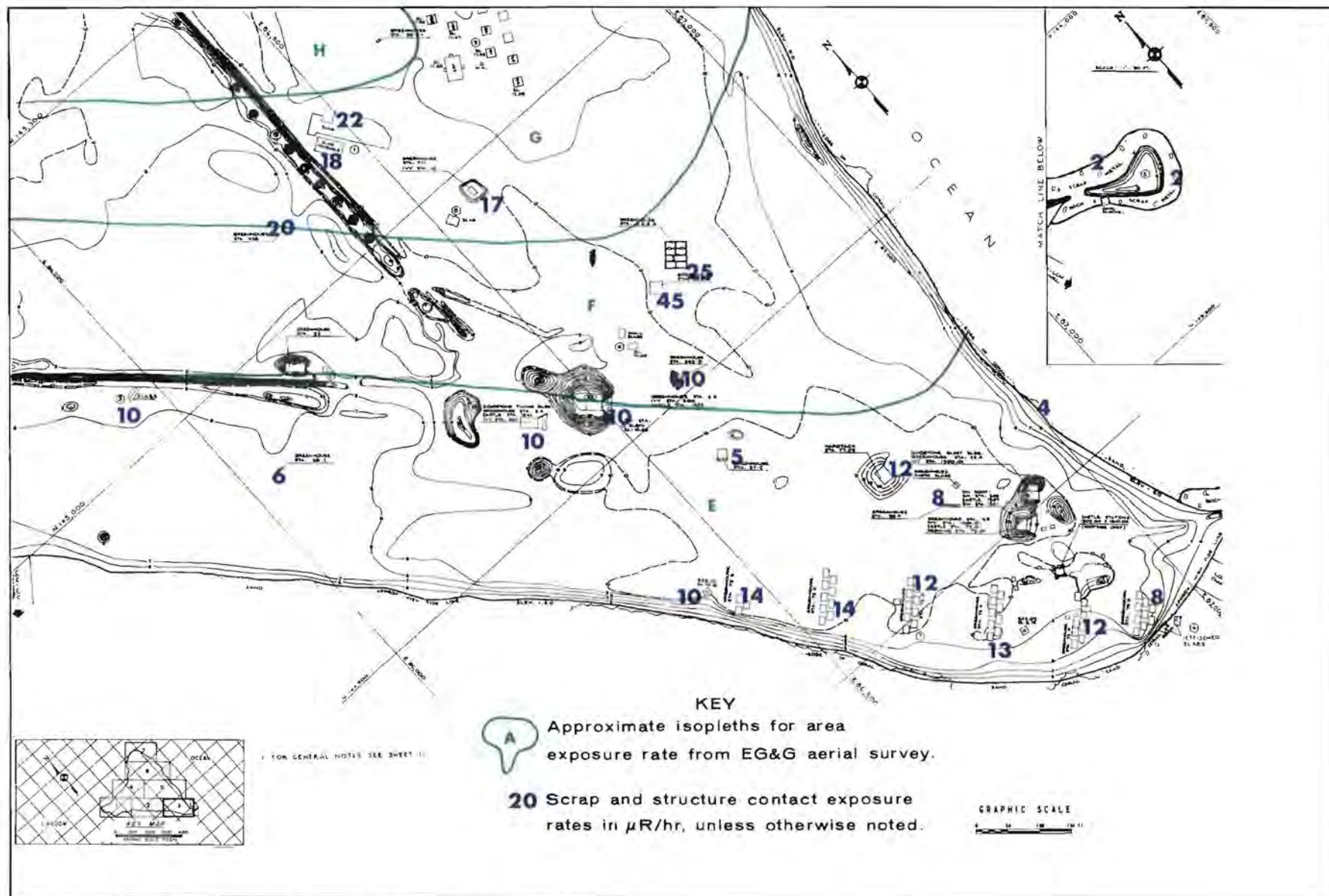


Fig. 99. Scrap and structure radiation measurements, JANET.





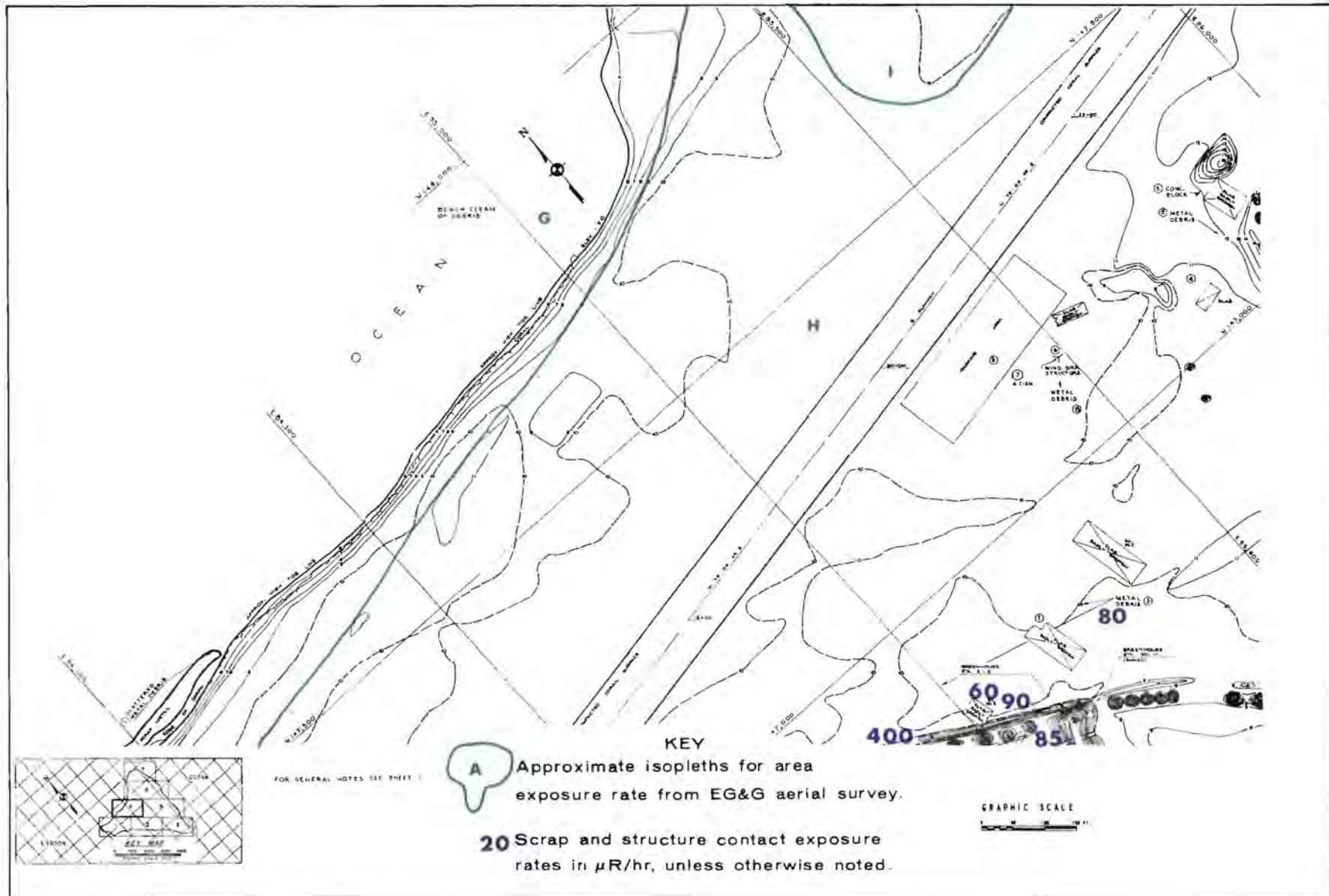


Fig. 100. Scrap and structure radiation measurements, JANET.



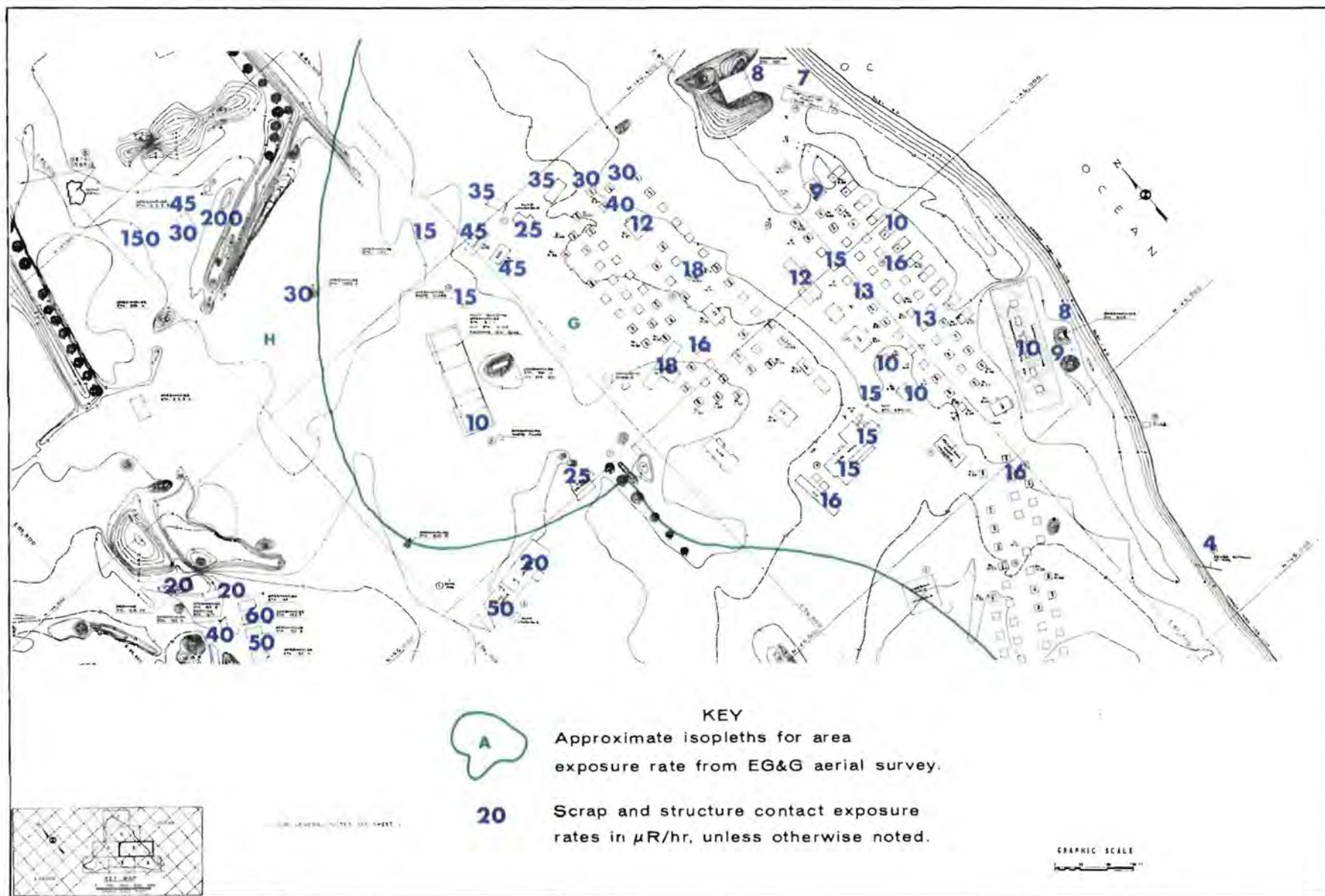


Fig. 101. Scrap and structure radiation measurements, JANET.



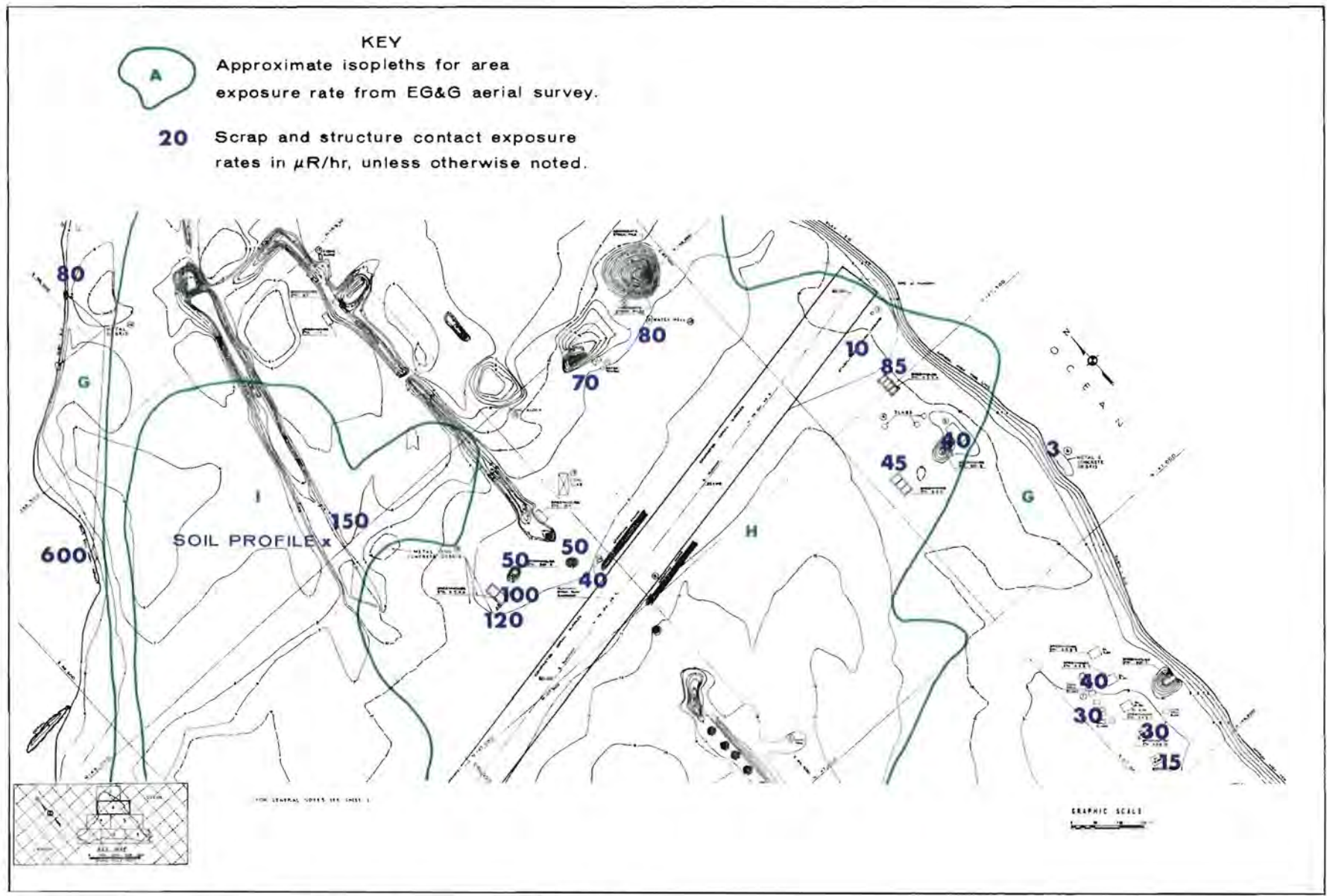


Fig. 102. Scrap and structure radiation measurements, JANET.



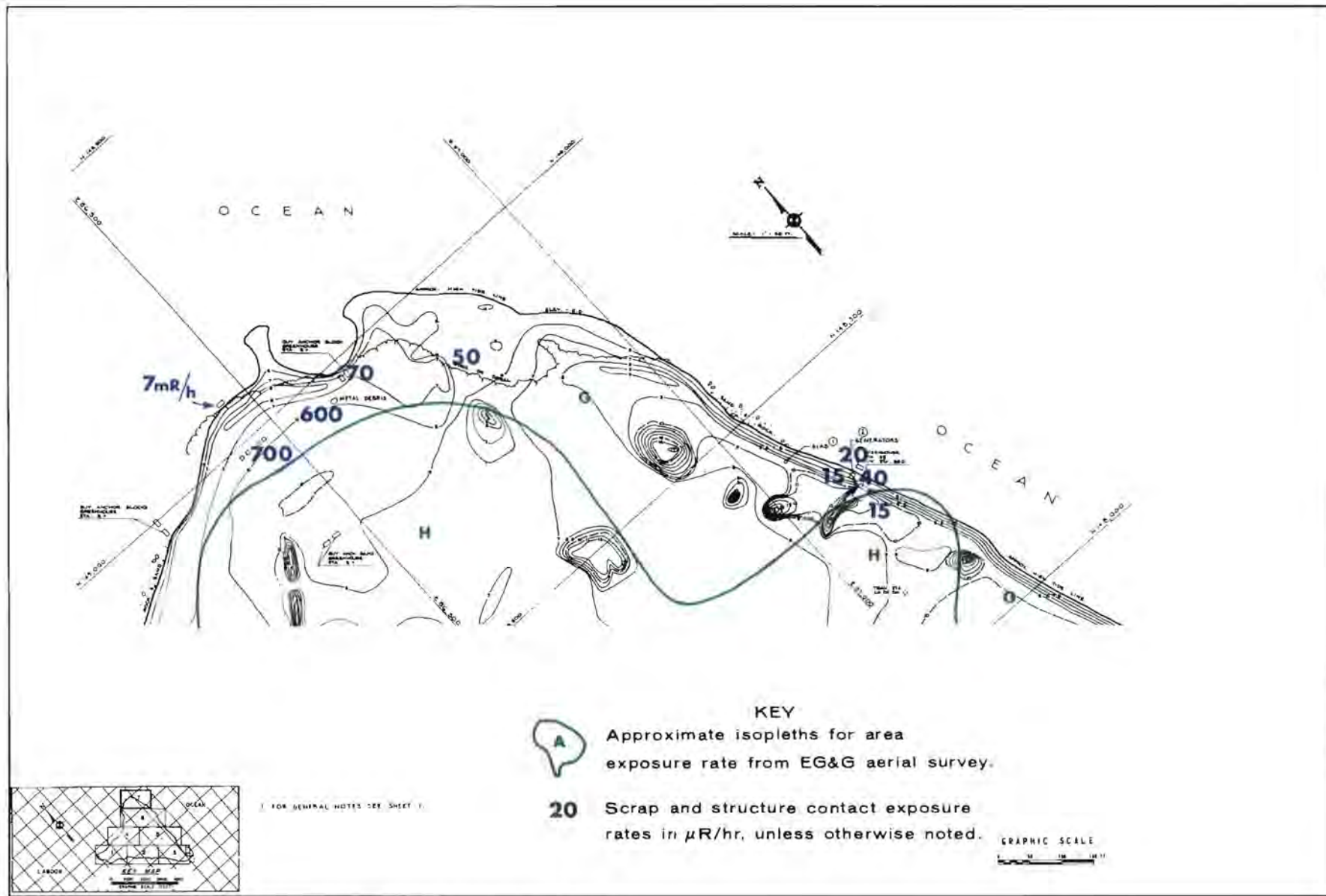


Fig. 103. Scrap and structure radiation measurements, JANET.





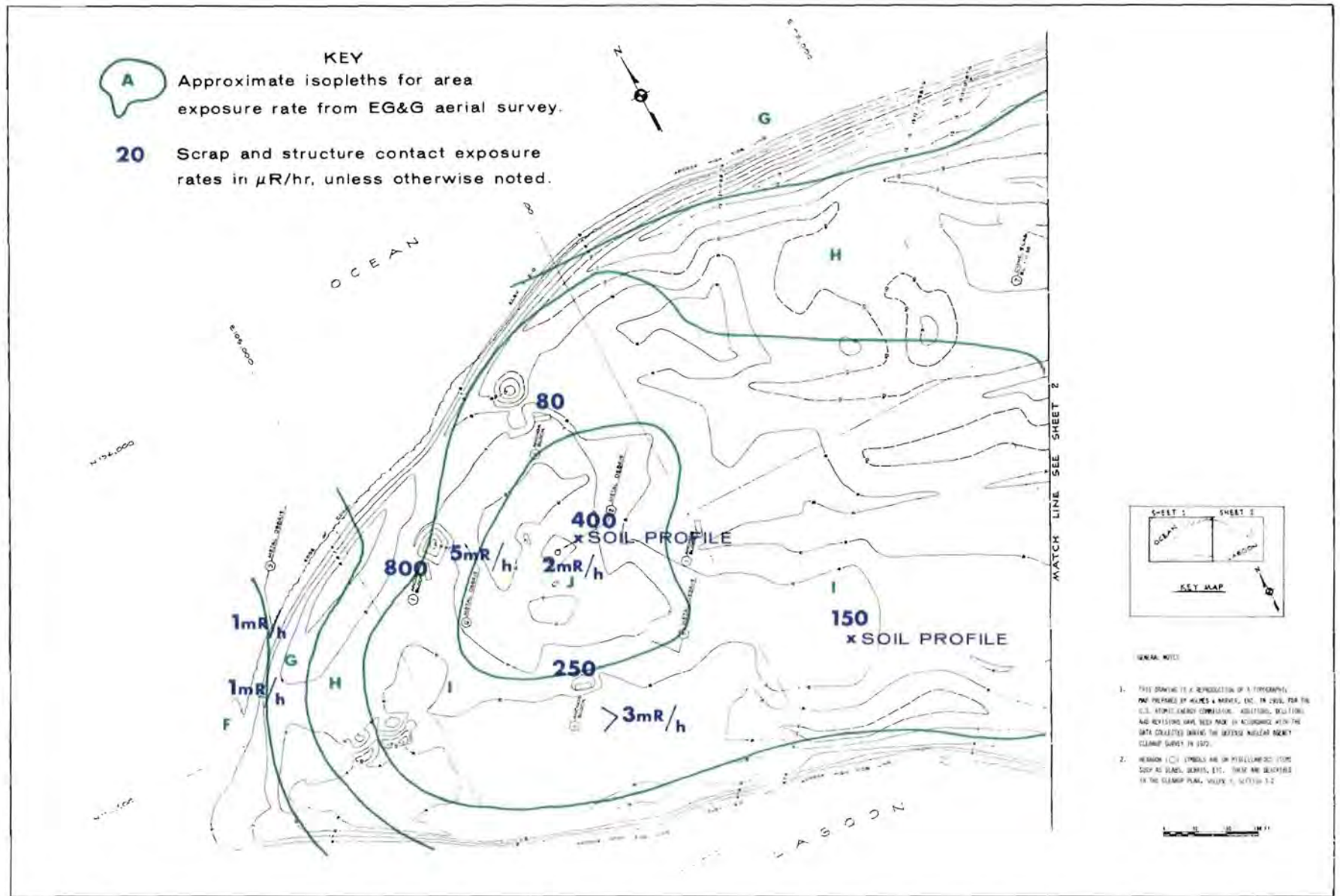


Fig. 104. Scrap and structure radiation measurements, PEARL.



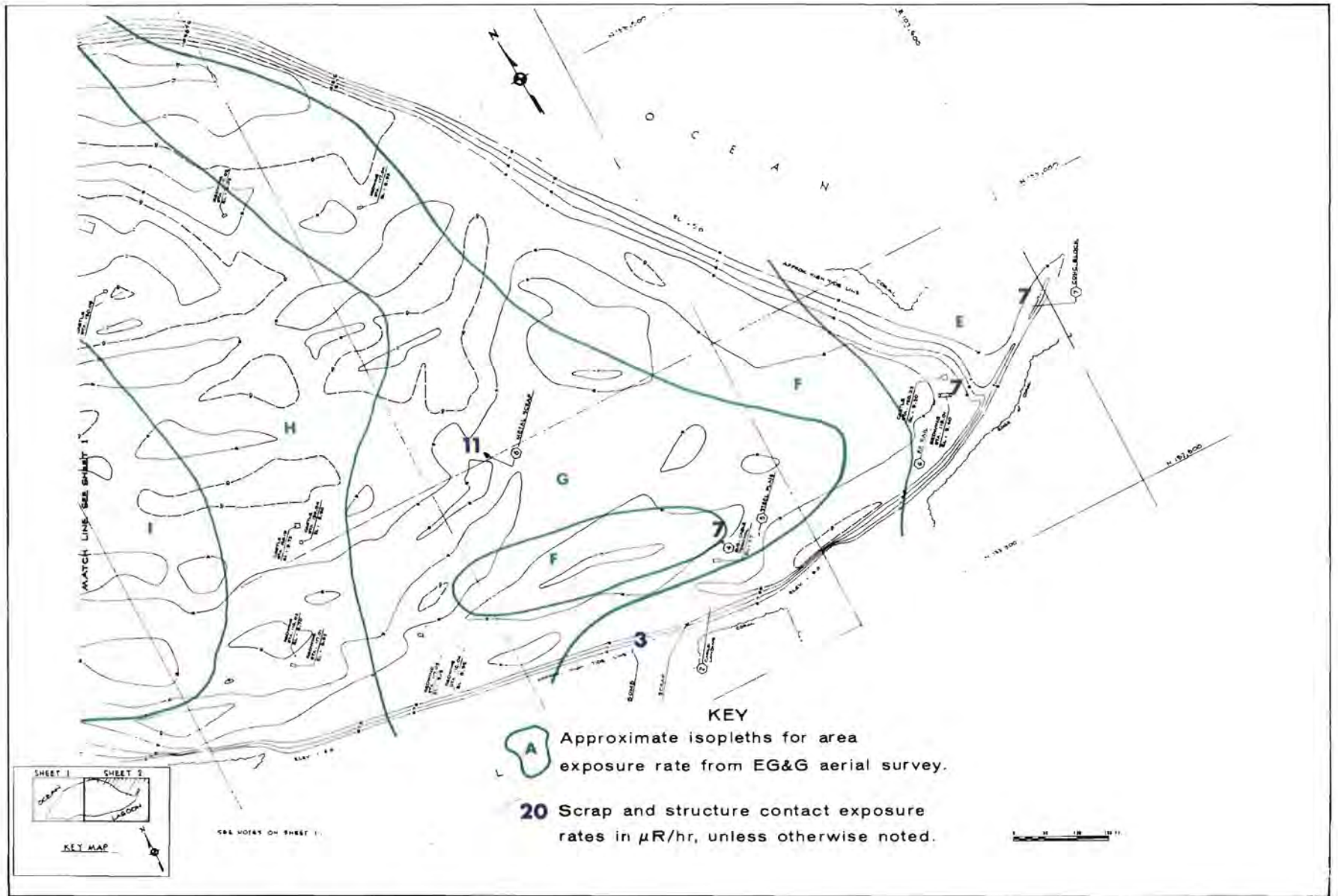


Fig. 105. Scrap and structure radiation measurements, PEARL.



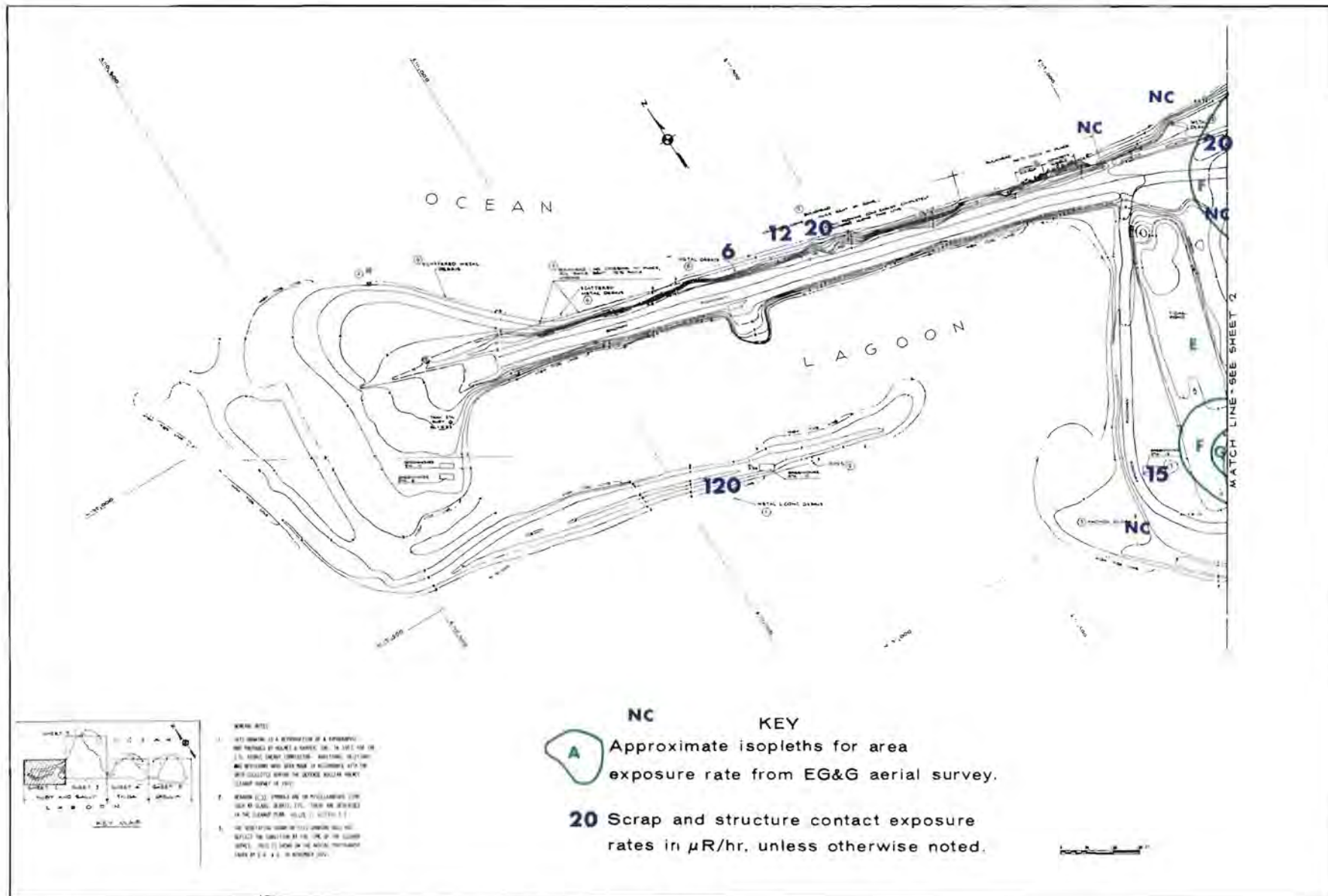


Fig. 106. Scrap and structure radiation measurements, RUBY and SALLY.



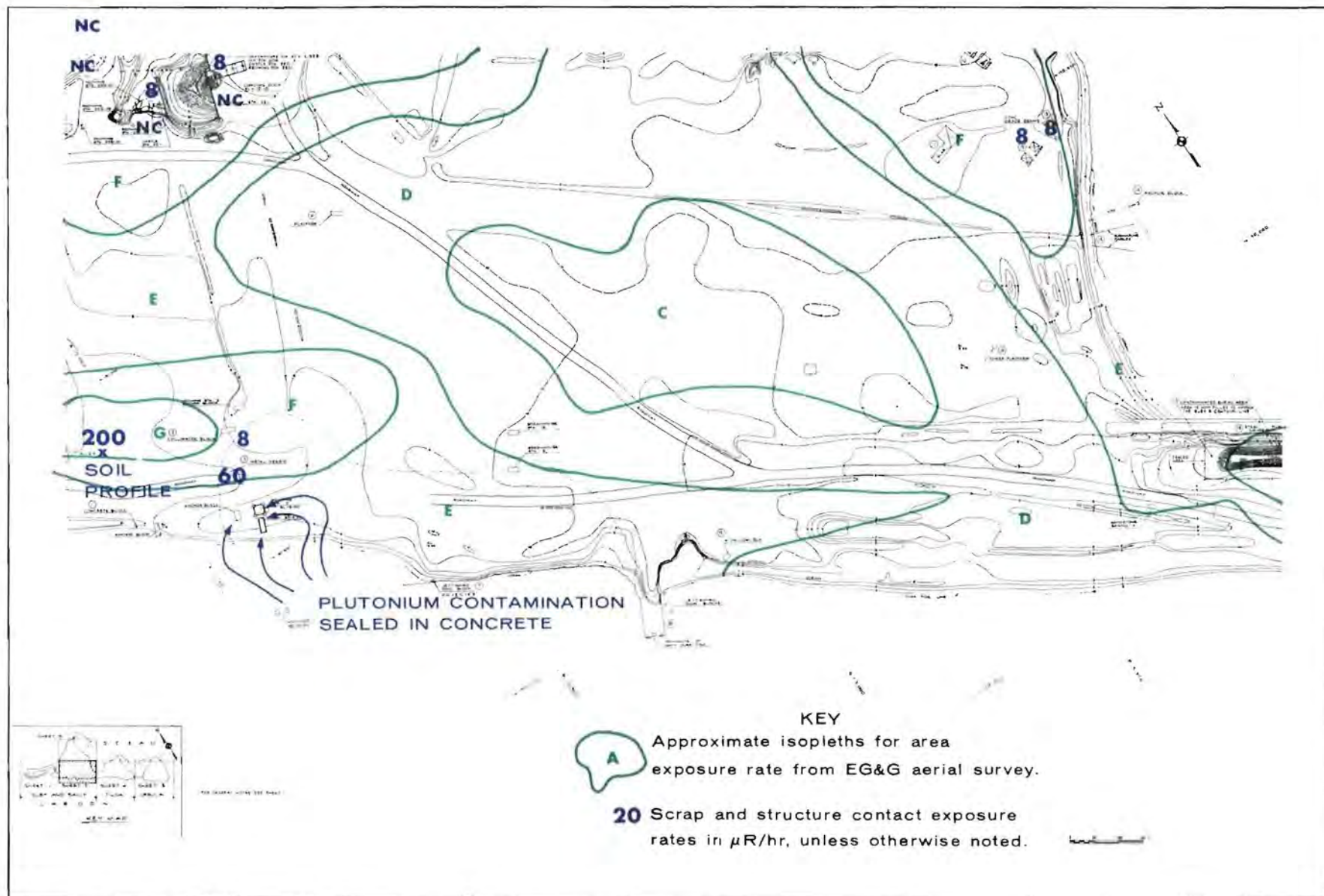


Fig. 107. Scrap and structure radiation measurements, RUBY and SALLY.





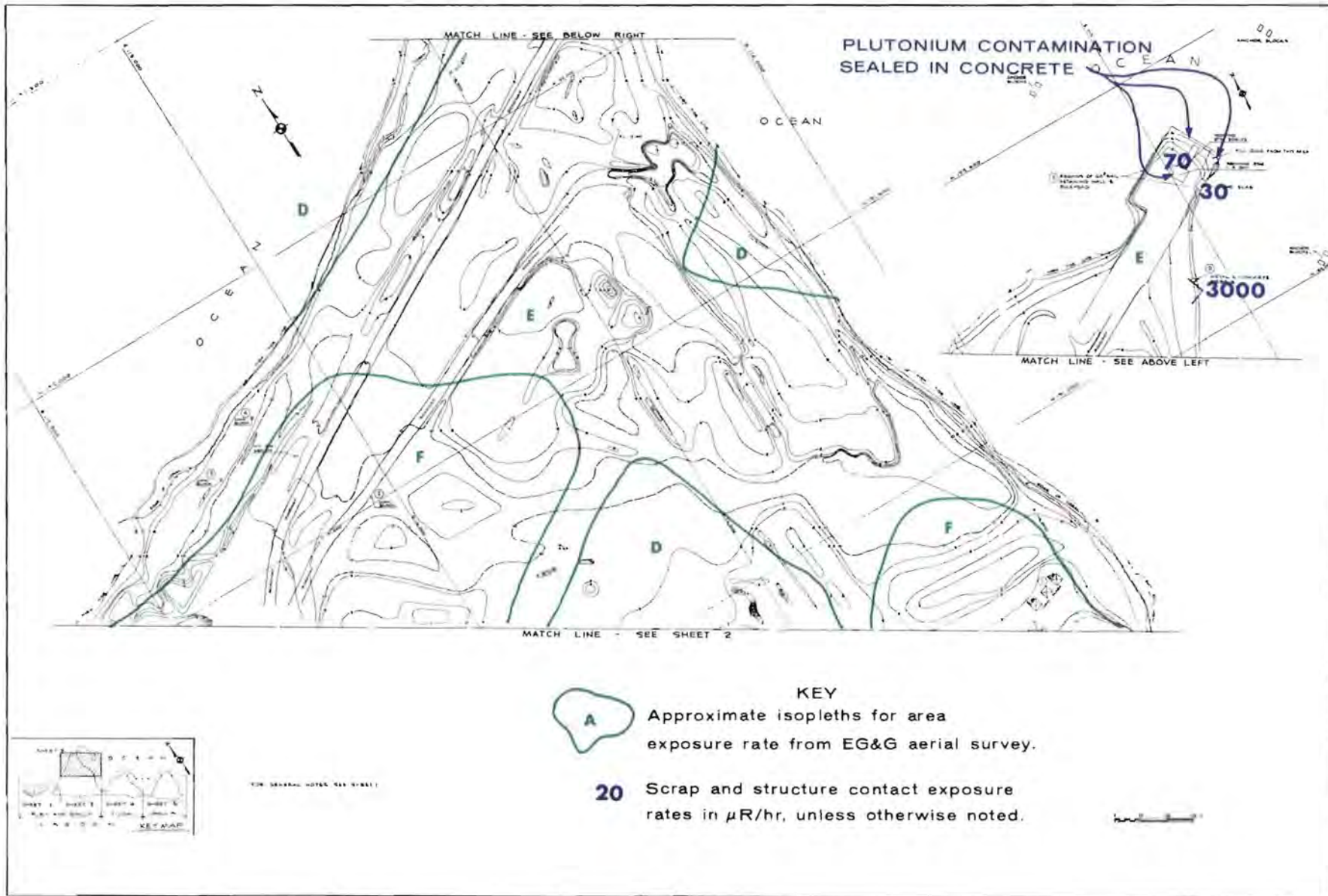


Fig. 108. Scrap and structure radiation measurements, RUBY and SALLY.



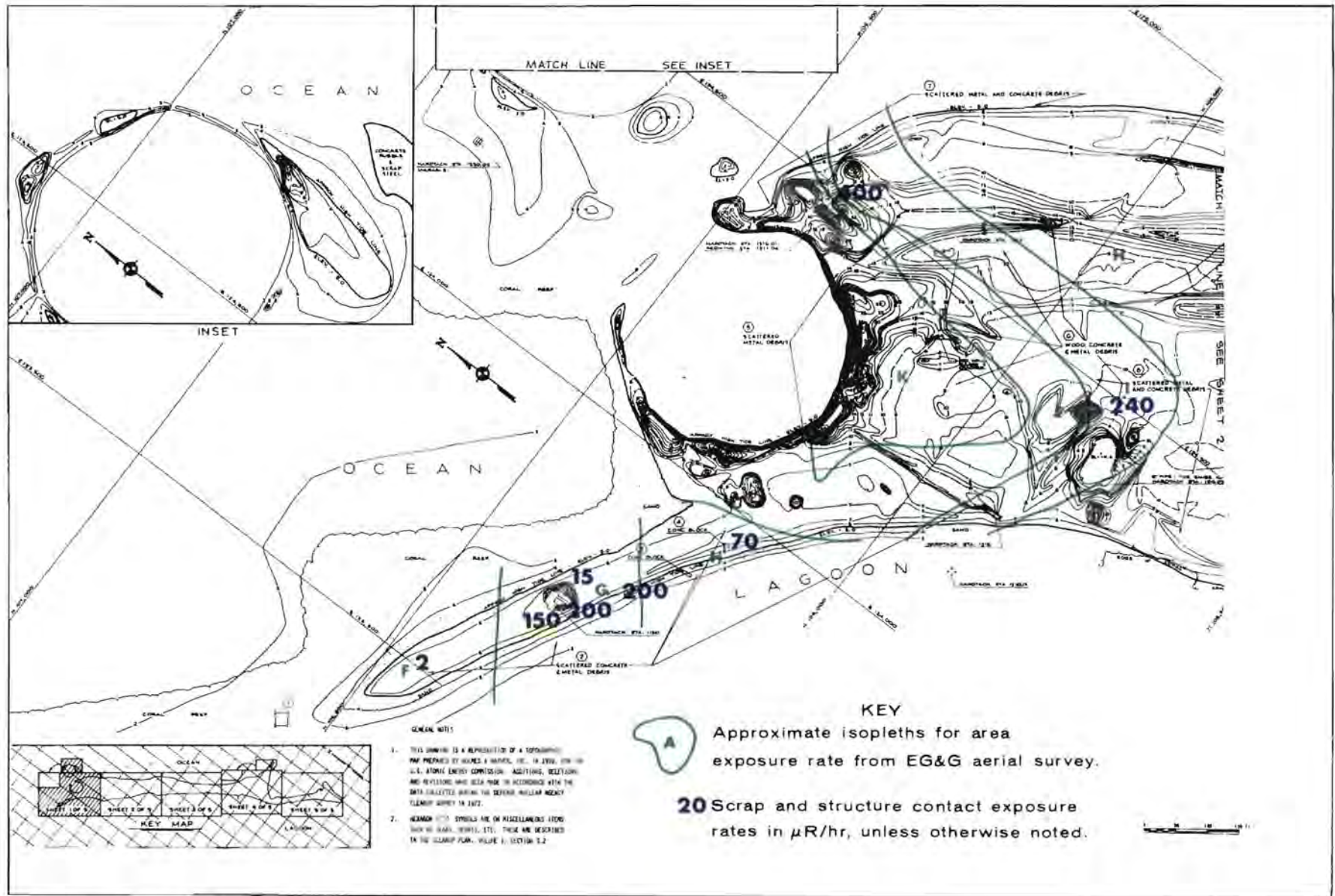


Fig. 109. Scrap and structure radiation measurements, YVONNE.



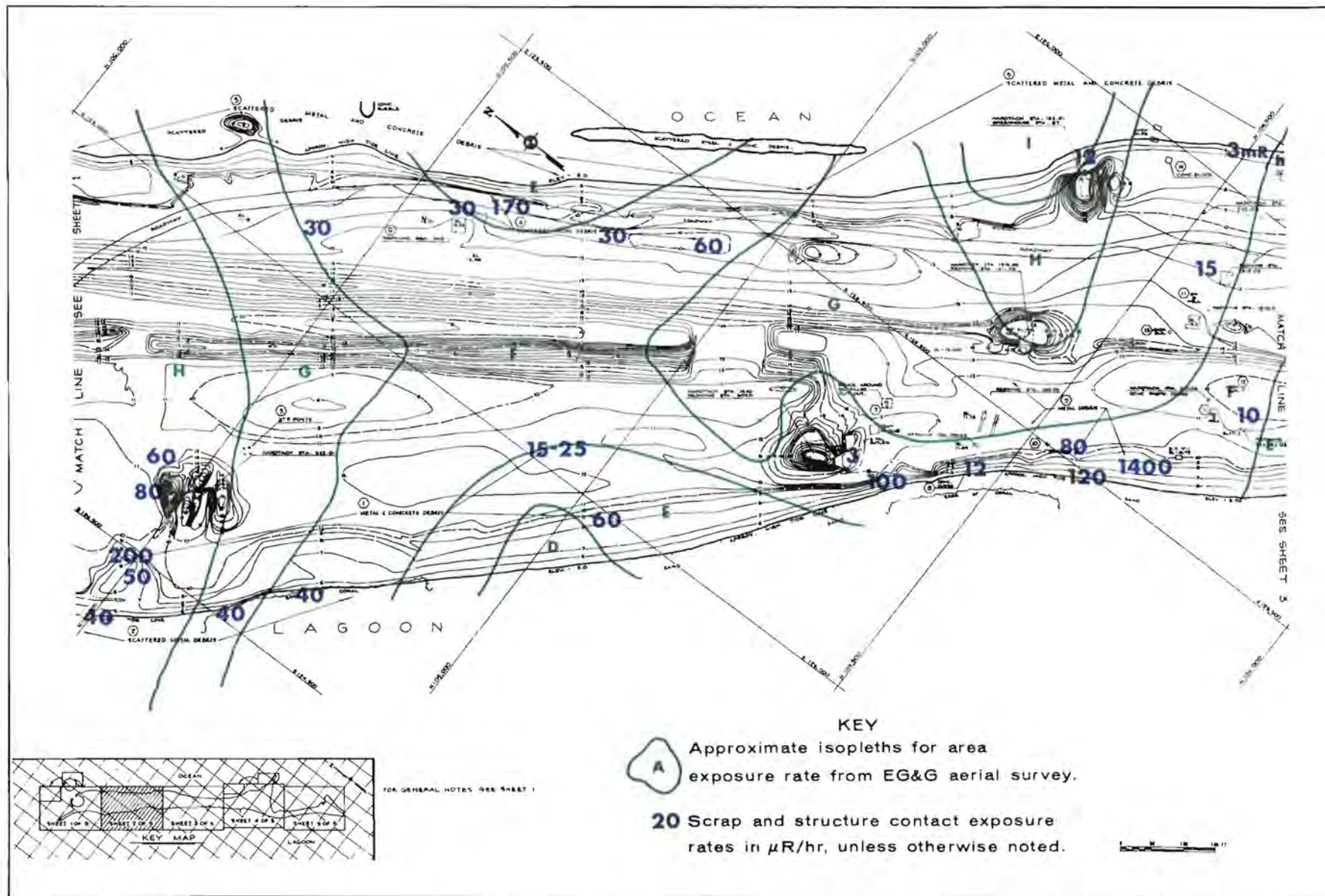


Fig. 110. Scrap and structure radiation measurements, YVONNE.



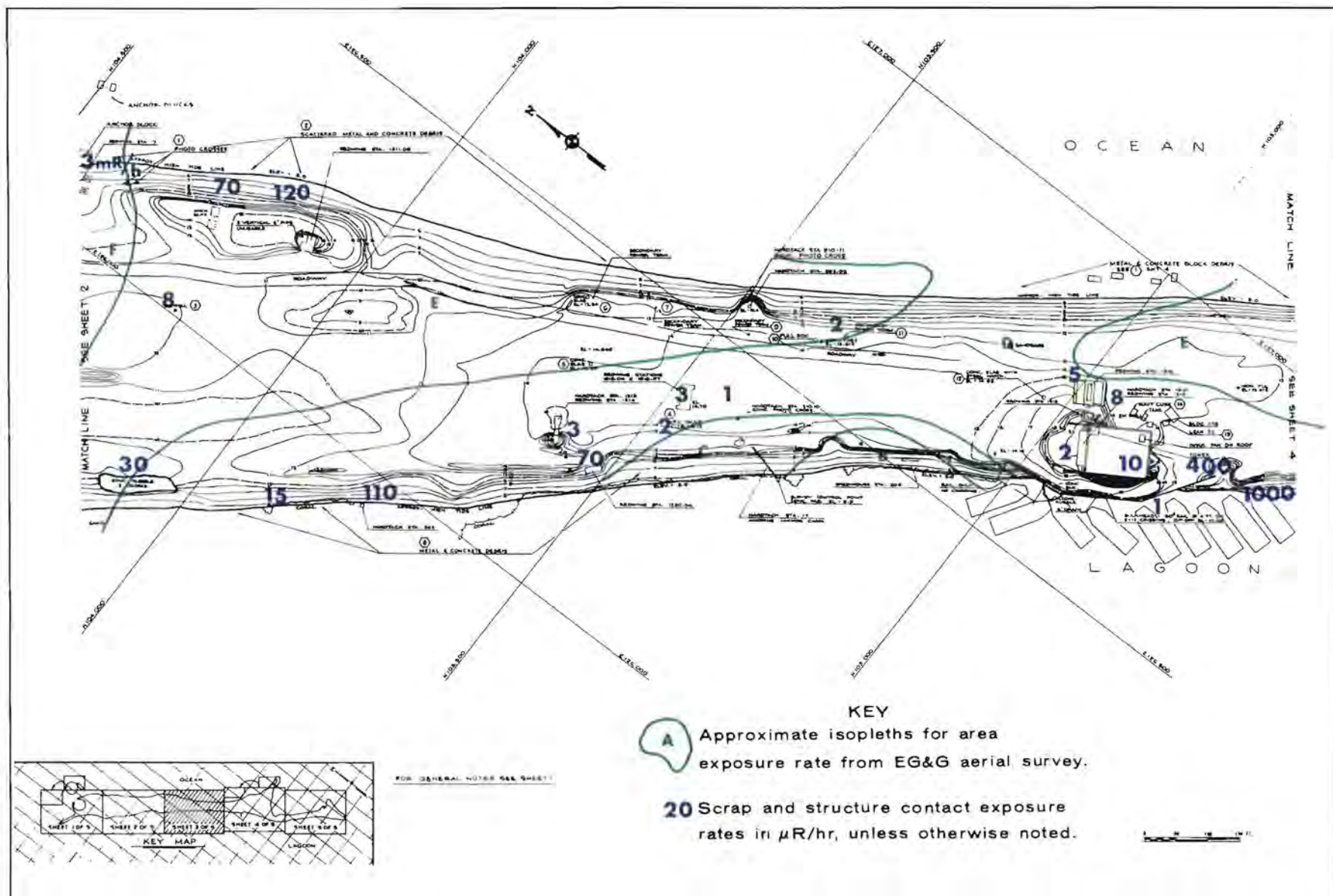


Fig. 111. Scrap and structure radiation measurements, YVONNE.





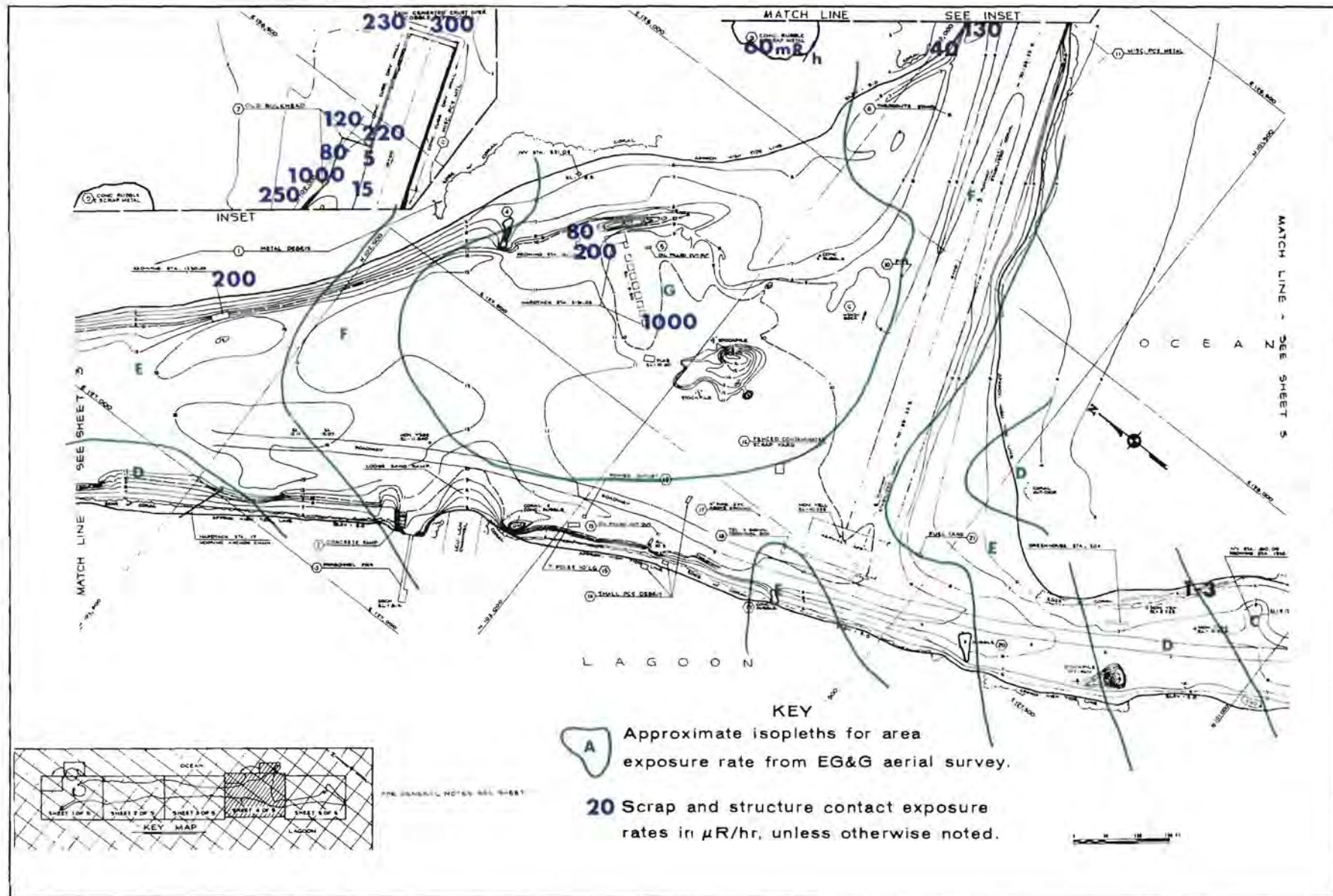


Fig. 112. Scrap and structure radiation measurements, YVONNE.



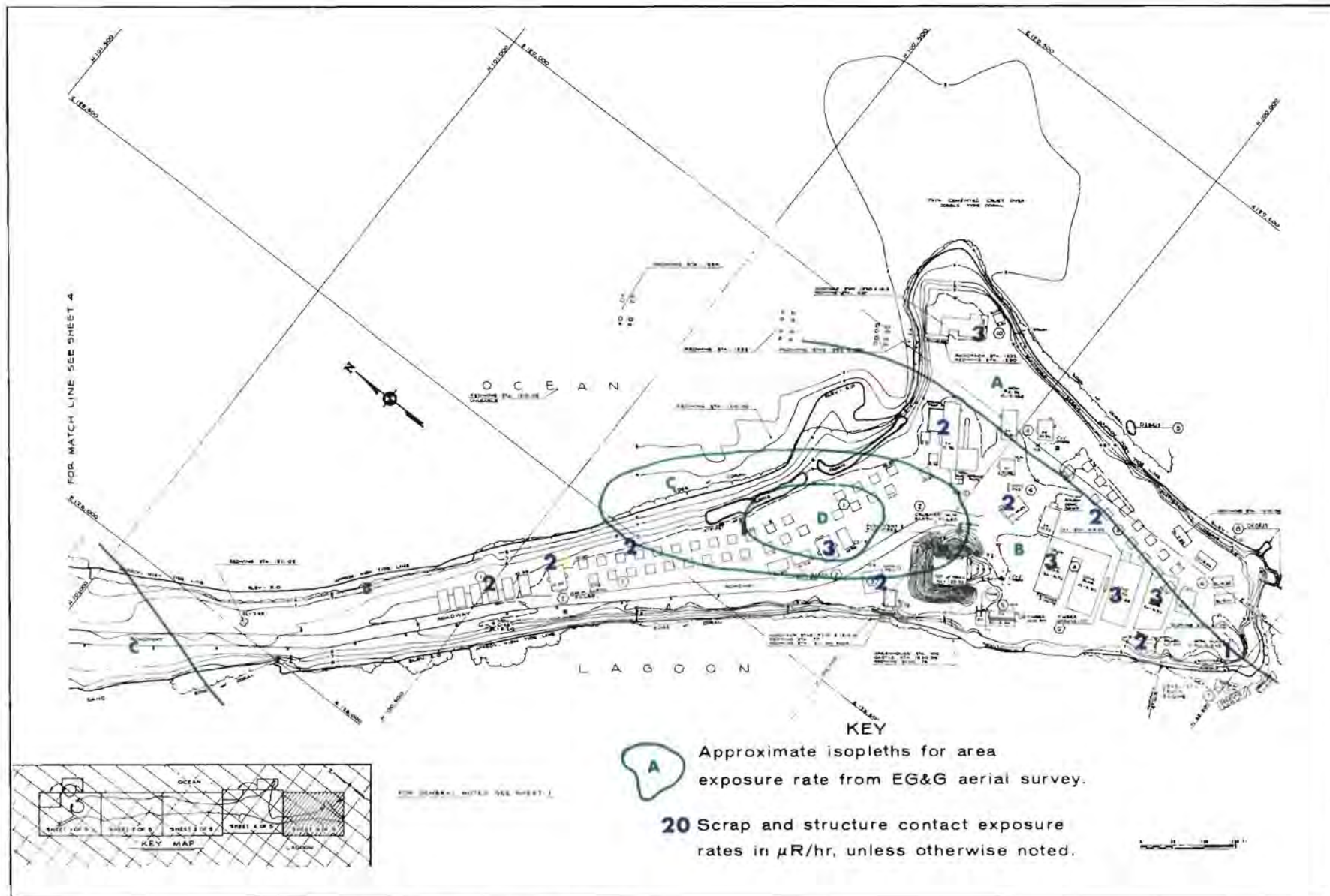


Fig. 113. Scrap and structure radiation measurements, YVONNE.



taminated above the area background levels (up to 250  $\mu\text{R/hr}$ ), if at all. The only exception appears to be the wrecked M-boat on the east end of the lagoon beach of ALICE. The contact exposure rate measured on this scrap was about 8 mR/hr.

The island of JANET has large quantities of radioactive scrap metal and debris scattered all over it. Contact exposure rate measurements of up to 8 mR/hr were observed at the old ITEM SGZ on the north end of the island. Near the EASY SGZ, scrap piles and individual pieces of metal read several mR/hr. Structures on the island exhibit some residual surface contamination (below 100 $\mu\text{R/hr}$ ) which seems to be on the SGZ-oriented and upper surfaces of the concrete.

PEARL has a small quantity of scrap material, all near the SGZ. The metal is measurably activated, with contact measurements of up to 5 mR/hr. The concrete blocks near the SGZ also exhibit surface contamination of several hundred  $\mu\text{R/hr}$ .

SALLY has large quantities of scrap, most of which is near the shoreline on the northern sides of the islands. Most of this is apparently not contaminated. On the other hand, several small concrete blocks and other structures apparently contain plutonium-contaminated debris. At least six such structures have been identified.

The most contaminated island in the Atoll is YVONNE. Large quantities of scrap metal are found on the beaches, the ocean reef, and in the interior of the island. Nearly all of this scrap is activated and/or contaminated. A very large pile of scrap metal near the

ERIE SGZ, just north of the airstrip, exhibited contact readings of 60 mR/hr.

Concrete structures on YVONNE, north of the airstrip, exhibit surface contamination with levels of several hundred  $\mu\text{R/hr}$ . South of the airstrip, scrap metal and structures do not appear to be contaminated.

### Limitations on Results

Although the H&N Engineering Survey was thorough, there are several limitations which must be placed on any interpretation of this evaluation of radioactive scrap and structures:

- It must be kept in mind that the survey covered only structures and scrap which were on the surface, visible and accessible. No attempt was made to search for any buried scrap or unknown structures. No known buried contaminated debris was unearthed or surveyed.
- Except for grossly obvious structures, only structures which appeared on the H&N as-built drawings were examined.
- If a precise estimate or evaluation of the amount of radioactive scrap is desired, it must be realized that it was not possible to survey each piece of scrap nor seek out the location of all scrap piles. Therefore, additional radioactive scrap may still be hidden in the dense vegetation.

### Conclusion

Scrap-metal debris found on those islands which did not have surface ground zeros is probably not contaminated to any significant degree. The only exception to this would be the wrecked M-boat on ALICE, which presumably drifted there

after a test.

Scrap metal on those islands which had SGZs was found to be radioactive to some degree. Some of this scrap was contaminated or activated to levels as high as 60 mR/hr.

The possibility of having buried scrap is very real on the SGZ islands. It should not be overlooked when developing cleanup estimates for Enewetak Atoll.

## ANALYTICAL PROGRAM

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### Introduction

More than 5000 samples were collected during field operations of this survey, and approximately 4500 samples were selected for analysis. This chapter describes the analytical program required to provide measurements of significant nuclides in these samples. A breakdown of the samples submitted for analysis is given in Table 109a.

Sample treatment can be described in a general way as consisting of three phases: initial processing, gamma counting, and so-called "wet-chemistry" analyses. The latter phase involved dissolution of a sample, followed by chemical isolation of specific elements and radiation counting of elemental samples.

For most samples, initial processing consisted of selecting appropriate parts of a field sample, drying, homogenizing, and packaging. The selection process was provided by dissection of fish, rats, birds, etc., whereas it was unnecessary

for soil samples. Drying was accomplished by heating in ordinary ovens for soils, vegetation, and fish specimens, or by the freeze-dry process for rat, bird, and crab samples. During initial processing, samples were converted to forms appropriate for gamma counting.

All of the samples were counted on Ge(Li) detector systems to determine their gamma-emitting constituents.

Most of the samples were put through a wet chemical analysis, either by destructive analysis of a sample which had been gamma-counted first (as was the case for most of the fish, vegetation, animal and air-filter samples) or by submission for wet chemistry of a separate aliquot of sample (as was the case for most of the soil samples). The latter approach required reasonably homogeneous samples at the end of initial preparation. Minor exceptions to this general scheme of treatment are the seawater samples, where extensive chemical separation procedures were required during initial preparation before any gamma counting could be performed. Wet chemical analyses were needed to measure concentrations of certain nuclides that cannot be detected with acceptable sensitivity by gamma counting; examples of such nuclides are  $^{239}\text{Pu}$  and  $^{240}\text{Pu}$ , predominantly alpha emitters (with almost identical energies), and  $^{90}\text{Sr}$ - $^{90}\text{Y}$ , both beta emitters with no accompanying gamma radiation.

Because complete analysis of these 4500 samples was a very large undertaking, scientists from a number of organizations participated in the analytical program. A listing of these organizations and some of the scientists who were

responsible for this analytical program are as follows: Messrs. E. L. Geiger and E. A. Sanchez, Eberline Instrument Corporation (EIC), Santa Fe, New Mexico; Messrs. W. J. Major, R. A. Wessman, and L. Leventhal, Laboratory for Electronics, Environmental Analysis Laboratories Division (LFE), Richmond, California; Lawrence Livermore Laboratory (LLL), Livermore, California; Drs. V. A. Nelson, W. R. Schell, and A. H. Seymour, Laboratory of Radiation Ecology (LRE), University of Washington, Seattle, Washington; and Colonel R. C. McBryde, Major W. A. Myers, Major W. A. Rush, Captain J. R. Baca, and Captain H. T. Hawkins, McClellan Central Laboratory (MCL), Sacramento, California (a U. S. Air Force organization). A listing of laboratory participation in each phase of the analytical program is given in Table 109a. Initial processing of samples was performed at LLL and at LRE. All gamma counting was done at LLL. The wet-chemistry effort was split between MCL,

LFE, EIC, and LRE, with some special analyses performed at LLL.

Samples were initially numbered at Enewetak at the time of collection. In addition, personnel working at a sample-receiving station on Enewetak assigned each sample a survey ID number according to the scheme listed in Table 109b. The first two digits of this number indicate type of sample, the next four digits are sequential and identify a sample uniquely, and the last two digits identify the island (or area nearby) from which a sample was collected. Thus, each sample usually had two numbers associated with it, the survey ID number and a field-collection number. The latter category is comprised of numbers chosen by different field-collection teams and with varying formats. Considerable care was exercised in identifying samples; instances of confusion were relatively rare. The analytical data for each sample are identified by the appropriate survey ID number. Data for each sample are listed in Appendix II on microfiche.

Table 109a. Enewetak sample analysis — sample listing and laboratories.

Sample type	Number of samples analyzed	Initial processing	Gamma counting	Wet chemistry
Soils, total		LLL	All samples were gamma-counted at LLL.	MCL, LFE, EIC
Surface, 0-15 cm (and 0-5 cm)	870			
Profile samples	2135			
TLD samples	14			
Biota group samples	20			
Standards, background samples	18			
Sediments	} 345	LLL		MCL, LFE, EIC
Cores		LLL		MCL, LFE, EIC
Marine samples	410	LRE		MCL, LFE, LRE
Invertebrates and vertebrates				
Algae	3	LRE		LFE
Plankton	16	LLL		MCL
Vegetation (terrestrial)	216	LLL		MCL, LFE
Animals (terrestrial)	274	LLL		MCL, LFE
Rats, crabs, birds, eggs, etc.				
Seawater	54	LLL		LLL, LFE
Hydroxide fraction, Cs fraction— gamma counting				
Pu, Sr fractions — wet chemistry				
Freshwater	4	LLL		MCL, LFE
Water samples, distillation, plant residue				
Air samples	67	LLL		MCL
High volume (20), low volume (23), Anderson cascade impactor (24)				
Seawater filters, UW	28	LRE		None required
Total samples analyzed	4,474			



Table 109b. Survey ID number scheme.

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General form: AB-XXXX-CD  
 where AB are two digits which indicate sample type,  
 XXXX are four digits which were assigned sequentially and which identify the sample uniquely, and  
 CD are two digits which indicate location of sample collection.

Specific example: 09-0577-20

where 09 indicates a marine sample, vertebrate (in fact, the sample is bone from a snapper fish),  
 0577 identifies this sample, and  
 20 indicates collection in proximity of TILDA.

Sample-type identifier, first two digits:

01 General soil classification, used where depth information is not known or for biota soil samples.

Soil samples, classified according to depth:

29	0-10 cm	44	75-85 cm	74	40-50 cm
30	0-2 cm	45	85-95 cm	75	50-60 cm
31	0-5 cm	46	95-105 cm	76	60-70 cm
32	0-15 cm	47	105-115 cm	77	70-80 cm
33	2-5 cm	48	115-125 cm	78	80-90 cm
34	5-10 cm	49	125-135 cm	79	90-100 cm
35	10-15 cm	50	135-145 cm	80	100-110 cm
36	15-20 cm	51	145-155 cm	81	110-120 cm
37	15-25 cm	52	155-165 cm	82	120-130 cm
38	20-25 cm	53	165-175 cm	83	130-140 cm
39	25-35 cm	54	175-185 cm	84	140-150 cm
40	35-45 cm	70	0-10 cm	85	150-160 cm
41	45-55 cm	71	10-20 cm	86	160-170 cm
42	55-65 cm	72	20-30 cm	87	170-180 cm
43	65-75 cm	73	30-40 cm	88	180-190 cm

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Table 109b (continued)

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02	Algae
03	(designation not in use)
04	Plankton
05	Samples from lagoon floor, sediments, cores, dredge samples, etc.
06	Seawater
07	Coral (pieces broken from living coral heads)
08	Marine, invertebrate
09	Marine, vertebrate
10	Vegetation
11	Animal, terrestrial
12	Potable water
13	Air, high-volume sampler
14	Air, low-volume sampler
15	Air, Anderson cascade impactor

## Location identifier, last two digits:

01	ALICE	19	SALLY	37	FRED
02	BELLE	20	TILDA	38	GLENN
03	CLARA	21	URSULA	39	HENRY
04	DAISY	22	VERA	40	IRWIN
05	EDNA	23	WILMA	41	JAMES
06	FLORA	24	YVONNE	42	KEITH
07	(Mike crater) GENE	25	(not in use)	43	LEROY
08	HENRY	26	SAM	44	MACK
09	IRENE	27	TOM	45	OSCAR
10	JANET	28	URIAH	46	LLL Whaler
11	KATE	29	VAN	47	LCU, Navy vessel
12	LUCY	30	ALVIN	48-51	(not in use)
13	PERCY	31	BRUCE	52	<u>Palumbo</u> , AEC research vessel
14	MARY	32	CLYDE	53	Wide passage
15	NANCY	33	DAVID	54	Deep passage
16	OLIVE	34	REX	60	Kwajalein
17	PEARL	35	ELMER	61	Meck-Kwajalein
18	RUBY	36	WALT	62	Enewetak-Kwajalein
				70	Midway island
				77	Ujilang atoll
				78	Sacramento, California

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## Initial Processing of Field Samples

### Soil and Sediment Samples

This class of sample, by far the largest category, was treated at LLL in a part of Building 412 devoted entirely to this task. The treatment consisted of drying, pulverizing, blending, packaging, and doing a preliminary gamma count. With sufficient sample, three packages were produced, an aluminum "tuna can" containing 300-350 g and two vials containing 50 g each.

The facility was set up and equipped in the following manner. Since the area used for this work is adjacent to a hot-cell facility, and although this area had been used very little in the past two years, the laboratory space was carefully surveyed for possible radioactive contamination. Swipe samples were taken from the floors, and particulate matter in the air was collected on small filters. These samples were checked for  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ , and  $^{239+240}\text{Pu}$  content; there was no detectable contamination. The area was considered suitable for initial processing of soils. This monitoring program was continued throughout operation of the facility; activity above background levels was detected in only a few instances.

Drying ovens were designed and built to permit initial drying of samples at  $\sim 70^\circ\text{C}$ . Two ovens were constructed of asbestos board with steel shelves inside; two 300-W air heaters were used to blow warm air into each unit, along with a fan in the vent pipe. Final drying was accomplished in a large commercial drying oven at  $150^\circ\text{C}$ .

Grinding of samples was accomplished by placing a sample in a 1-gal paint can

along with a number of 1-in. steel balls. The cover of each can was taped securely; then the entire can was covered with a galvanized-steel jacket which was held in place by two large rubber "O" rings. This arrangement eliminated problems encountered early in the operation when can lids fell off during ball milling. Machines were built to permit rolling of 48 samples at a time and were usually operated overnight to provide 15-24 hr of grinding.

Packaging, weighing, and labeling of samples were performed by hand. Within the laboratory space there were three hoods which provided a flow of air into and up the hood. All work with finely divided soil was performed in these hoods. Before each sample was packaged, clean paper was laid out on the hood bench. Care was taken to prevent cross-contamination of samples. A series of low-level coral soils was treated at various times during operation of the facility; results of these background samples are presented in the quality control section of this chapter.

The following is a detailed description of the operations in the Building 412 facility:

- The samples were first unpackaged from the shipping container and logged. Notes were taken on the appearance of each sample (e. g. , amount of organic matter, color, presence of large chunks, etc. ). If samples contained appreciable water (e. g. , certain sediments were quite wet), the solid material was allowed to settle, and the water was carefully decanted without loss of fine particles.

- The samples were then transferred to a disposable aluminum cake pan and covered with aluminum foil. Holes were punched in the top of the foil to permit evaporation.
- The samples were then transferred to preliminary drying ovens that were designed to handle about 200 samples. These ovens were set at a temperature of  $\sim 70^{\circ}\text{C}$  and run continuously. The average residence time per sample was 48 hr.
- To assure that the samples reached complete dryness, a second oven was used. This oven was set at  $\sim 150^{\circ}\text{C}$ , and the sample residence time averaged  $\sim 3$  hr.
- The samples were then transferred to a 1-gal paint can and a dry weight established. The weights of the samples varied from 100 g to 2 kg.
- The samples were then ball-milled using eight 1-in. steel grinding balls. The average sample residence time in the ball mill was  $\sim 15\text{-}24$  hr.
- The finely ground soil\* was then prepared for gamma spectrometry and wet-chemistry analysis using two different containers. The gamma-spectrometry samples consisted of tightly sealed tuna cans made of 0.25-mm thick aluminum. The large can was 3.9 cm high, 8.3 cm in diameter, with a cross-sectional area of  $53.8\text{ cm}^2$  and a volume of  $210\text{ cm}^3$ . The small can was 3.3 cm high, 6.0 cm in diameter,

\*Finely ground soil is a goal which was not always attained. In a few cases, the presence of chunk of coral over 1 cm in diameter was reported by the participating analytical facilities.

with a cross-sectional area of  $28.5\text{ cm}^2$  and a volume of 95 cc. Soil-sample weights in these cans ranged from 100 to 375 g.

The wet chemical samples consisted of two vials, each containing soil weighing  $\sim 50$  g. One of the vials was shipped out for chemical analysis, and one held as a backup sample.

- The gamma-spectroscopy "tuna cans" were counted for gross gammas with a  $3 \times 3$ -in. NaI detector; a 512-channel NaI gamma spectrum was measured for those samples which exceeded 100 counts/min. These preliminary NaI data served as a guide in scheduling more precise measurements with Ge(Li) detectors.

Approximately 3400 samples were processed in the soil-preparation facility between November 15, 1972 and June 1, 1973 by an average working force of 4-1/2 people. We wish to acknowledge the dedicated effort of Messrs. Bern J. Qualheim and James S. Schweiger in supervising operation of the Building 412 facility. In addition to LLL personnel, two experienced technicians were supplied by Reynolds Electrical and Engineering Company (NTS) for this work.

#### Other Samples and Specimens

Initial processing of other samples, marine specimens, algae, plankton, vegetation, terrestrial animals, and air filters has been described in chapters which also describe collection of these samples in the field. For each type of sample, the product of this processing was a package suitable for gamma counting — either an aluminum "tuna can"

where sufficient sample was available or, in the case of small samples, a plastic package which was a right circular cylinder. Because of the versatility of our gamma-spectroscopy data processing code, it was unnecessary to require that all of the small plastic packages be of standardized dimensions and they could be varied according to sample size.

### Gamma Spectrometry

Gamma-spectrometric measurements were made on all samples at LLL. The work was accomplished by personnel in the Radiochemistry and Biomedical Divisions. In the Radiochemistry Division effort, 4100 samples (90%) were counted with eight Ge(Li) detector systems, three of which included an automatic sample-change feature. In the Biomedical Division effort, 400 samples (10%) were counted with four Ge(Li) detector systems. The latter systems were devoted to counting marine, vegetation, and animal samples, all of which required long counts (1/2 - 1 day each). Most of the largest sample category, soils, were counted with the Radiochemistry systems which had automatic sample changers; counting times were a minimum of 133 minutes each for the soils. All data were taken with single detectors; no anti-coincidence shielded detector systems were used to count samples in this survey.

### Description of Equipment

The gamma counting in Radiochemistry Division was accomplished with a variety of Ge(Li)-diode detector systems which are listed in Table 110a. The diodes varied in volume from 19 to 50 cc. Three of the counting systems were automated. The automated systems, interfaced to a

PDP-8 computer, were capable of handling 16 samples per system, thus allowing 24-hr/day counter use. The remainder of the systems could analyze one sample at a time, and the data were removed either by a manual dump onto a PDP-8 computer or by paper tape output. All data were transferred to magnetic tape and analyzed on a CDC-7600 computer as described later in this section under Identification of Nuclides.

The Biomedical Division Ge(Li) detector systems are listed in Table 110b. Data taken with these systems were transferred from memory storage in a pulse-height analyzer to magnetic tape. Analysis of the data was performed on a CDC-7600 computer with a separate code (ANALYSE 5) whose operation has been described by Phelps and Hamby\*.

### Calibration of Detectors

It was necessary to calibrate each of the detector systems used on an absolute basis. During the course of the Enewetak survey, more than 20 different geometries were encountered. Several of these containers were checked for calibration on an individual basis, while others were submitted to the GAMANAL code (see paragraph below on Identification of Nuclides) as right circular cylinders. GAMANAL is capable of making the proper corrections on cylindrical geometries.

The majority of the samples were packaged in aluminum cans with nominal volumes of 95 and 210 cc. To check the

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\*P. L. Phelps and K. O. Hamby, "Experience in the Use of an Anti-coincidence Shielded Ge(Li) Gamma-Ray Spectrometer for Low Level Environmental Radionuclide Analysis", IEEE Transactions on Nuclear Science, NS-19 (1), 155, (1972).

Table 110a. Summary of Ge(Li) detectors and systems used for gamma-counting Enewetak samples by Radiochemistry Division, LLL.

Detector and system identification	Description
C2	Canberra 45-cc "down-looker," automatic counting chamber No. 2, PDP-8 control and dump.
N1	Nuclear Diodes 40-cc "down-looker," automatic counting chamber No. 1, PDP-8 control and dump.
T3	Princeton Gamma Tech 50-cc "down-looker," automatic counting chamber No. 3, PDP-8 control and dump.
S4	Nuclear Diodes 48-cc "up-looker," manual change, PDP-8 control and dump.
M5	LLL 19-cc "down-looker," manual change, paper tape output.
U8	Nuclear Diodes 25-cc "up-looker," manual change, paper tape output.
W7	Nuclear Diodes 48-cc "side-looker," manual change, paper tape output.
V7	Nuclear Diodes 48-cc "side-looker," manual change, paper tape output.

All systems except U use 4096-channel analyzers. System U uses a 2048-channel analyzer.

aluminum can geometry, a solution containing accurately known amounts of  $^{60}\text{Co}$ ,  $^{106}\text{Ru}$ ,  $^{137}\text{Cs}$ ,  $^{152}\text{Eu}$ ,  $^{155}\text{Eu}$ , and  $^{241}\text{Am}$  was prepared. Aliquots of this solution were dried and mixed with powdered coral from Midway Atoll. The powdered coral was packaged in the aluminum cans and used as a calibration standard. All of the standard solutions used for calibration were cross-checked with standards from the International Atomic Energy Authority

and Laboratoire de Métrologie des Rayonnements Ionisants. Some standard samples for the dried marine materials were supplied by the University of Washington.

Since large, fairly dense samples were being counted, it was necessary to derive self-absorption parameters. Self-absorption is a function of mass and atomic composition. The Enewetak survey samples were primarily calcium

Table 110b. Summary of Ge(Li) detectors and systems used for gamma-counting Enewetak samples by Biomedical Division, LLL.

Detector and system identification	Description
M7	18-cc detector operated at two different gains; 1 keV/channel, 2048 channels, and 0.25 keV/channel, 1024 channels.
W1	16.5-cc detector, gain 0.5 keV/channel, 4096 channels.
20	17-cc detector, gain 0.5 keV/channel, 4096 channels.
28	19-cc detector, gain 1 keV/channel, 2048 channels.

All of the above detectors were housed in 4-in. lead shields.

carbonate and the composition was approximated as a mixture of calcium and water. A special counter was built to obtain a good approximation of the calcium content of each sample. The counter consisted of a collimated 60-keV gamma-ray beam with a thin NaI scintillation detector in the beam path. Count-rate measurements were made on the unattenuated beam. A count-rate measurement was then made with a sample in the beam path. With calibration samples of known composition and with a sample of known density, the count rates with and without the sample in place could be used to calculate the percentage of calcium in the sample.

All of the background peaks in each detector system were loaded into a special subroutine in GAMANAL cross-referenced by detector. The computer then subtracted backgrounds at these energies before proceeding with the regular analysis described below under Identification of Nuclides. During and at

the end of the Enewetak program, detailed backgrounds were again measured to verify that counters had not been contaminated during the program.

#### Sensitivity of Counters

The sensitivity of a counter for a given nuclide depends on the sample size, counter efficiency, the branching intensity of the gamma rays, the length of the count, and the counter background. On a typical Enewetak coral sample (100-375 g) we found that a count time of 133 min on the larger diodes was sufficient to establish a limit of less than 1 dpm/g for most gamma-emitting nuclides. In the case of marine, vegetation, animal, and air-filter samples, the sensitivity was limited by sample size. For these samples the minimum count time was 666 min and ranged up to several thousand minutes.

#### Identification of Nuclides - Interference Between Various Nuclides

A general-purpose computer program

called GAMANAL was used for the data reduction and interpretation of all Radio-chemistry-generated spectra. It examines the pulse-height data for "background" and "peak" regions, fits these peaks with the proper shape functions, and corrects for the effects of geometry, attenuation, and detector efficiency in evaluating the photon emission rate. The program then proceeds to search a "library" of decay-scheme information in order to make tentative assignments for each of the observed peaks. A matrix of equations is formed so that the intensity of each peak is described as a linear addition of the identified nuclides present. The quantitative value, as well as the degree of interference, is the result of a least-squares solution of this set of equations. Unlikely components are also weeded out in this process. A more complete description is given in UCRL-51061, Volume 1, \*

For the Enewetak program, a special library of nuclides was loaded into GAMANAL. Table 111 lists the half-lives, energies, and branching intensities for these nuclides. These nuclides were chosen because they are long-lived products of nuclear explosions or are naturally occurring radionuclides.

#### Uncertainties

There are many sources of error in the measurement of gamma spectra; generally only a few dominate and determine the accuracy of the reported values.

Sources of error in the interpretation of gamma-ray spectra include the intensity of the observed peaks, the level of the surrounding background, interference of neighboring peaks, natural background activities in the counting chambers, attenuation of gamma rays in the sample matrix or container, the calibration of detectors, the effects of sample geometry and positioning, and decay-scheme information. For low-activity-level samples, the dominant factor contributing to the error is the low net count in the observed peaks. In assessing the error on the net counts of the observed peaks, GAMANAL takes into account the background level, interference problems, and attenuation of the radiations by the sample matrix and container. No additional error is added due to incorrect calibrations or to the effects of geometry and positioning. Since the samples were counted in very "close-in" geometry, the last-mentioned sources of error can be appreciable. All errors which could be determined were added in quadrature. Again, a more complete description is presented in UCRL-51061, Vol. 1.

To establish the relationship between uncertainties in the input parameters for the GAMANAL code and the final answers as output from the computer, a series of tests was made. Each of the input values (density, atomic composition, geometry, and weight) was purposely changed by  $\pm 5\%$ . In no case did this alter the final answer by more than  $\pm 10\%$ .

\*R. Gunnink and J. B. Niday, Computerized Quantitative Analysis by Gamma-Ray Spectrometry, Vol. 1. Description of the Gamanal Program, Lawrence Livermore Laboratory, Rept. UCRL-51061, Vol. 1 (1972).

#### Method for Setting Upper Limits on Detection of a Given Nuclide

A request was made to calculate an upper-limit amount for certain nuclides,



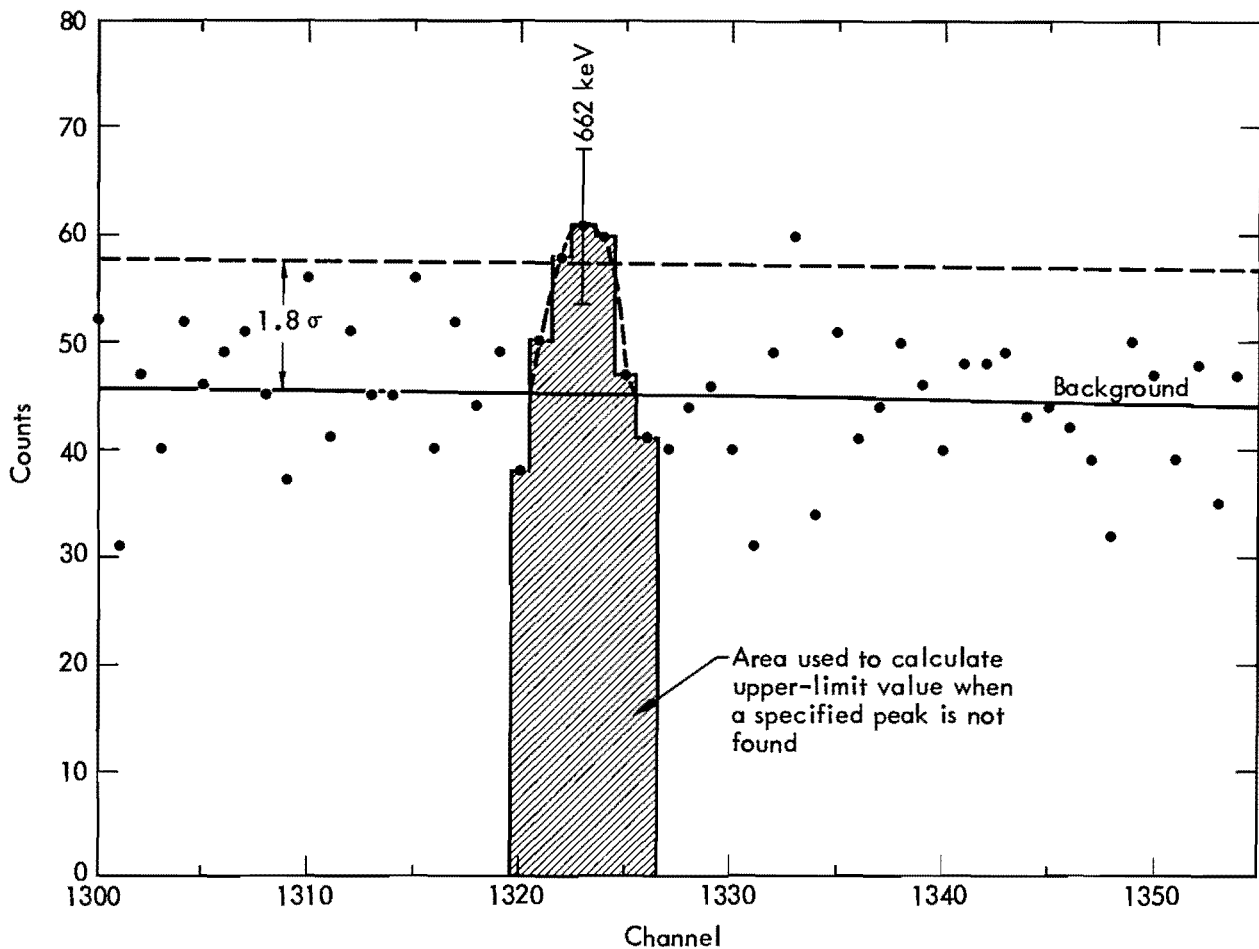


Fig. 114. GAMANAL spectral analysis of a weak  $^{137}\text{Cs}$  photopeak.

based on those spectra regions where signals would be seen if the species were present in detectable quantities.

In order to describe the process by which GAMANAL calculates an upper limit for the presence of a given photopeak, we must discuss the method used in detecting photopeaks. The method of detecting peaks cannot be described explicitly because it cannot be described by a simple algorithm. However, the process can be described qualitatively with the aid of Fig. 114. GAMANAL first finds a "background" continuum line. It then proceeds to locate each peak grouping by searching for a minimum of two

successive data points which are greater than 1.8 standard deviations above this background. This value was obtained as a result of experience and insures that most of the reported peaks are real. Figure 114 illustrates a case where a peak was detected by GAMANAL and reported as 51 counts with an assigned error of 63%. This peak is just above the threshold of detection.

If the peak in Fig. 114 had not been detected and an upper limit analysis was requested, the calculation would be done as follows: First, the peak region would be located and a number of data points proportional to the expected peak width

(seven in this case) would have been integrated. Then the upper-limit area would have been calculated to be twice the square root of this count. In the illustration, this upper-limit value would have been 36 counts. In practice, spectral regions of two gamma rays per nuclide were investigated (if two were available), and limits were calculated for each. Only the lower of the values was retained.

The method used by ANALYSE 5 (Biomedical Division) to calculate peak areas is to specify channel intervals that define both the peak and the baseline on either side of the peak. The latter is used to make a baseline subtraction from the gross peak area. If the net peak area is negative or zero or if one standard deviation is greater than 50%, ANALYSE 5 calculates an upper limit equal to twice the square root of the gross peak area.

Comments on Identification and Measurement of Each Nuclide in the Complete Sample Set

The GAMANAL code searched each spectrum for photopeaks from all of the nuclides listed in Table 111 and reported all positive signals. In addition, in the case of nonobservation of certain nuclides, upper limits were calculated according to the procedure given in the previous section of this chapter. The nuclides for which upper limits were calculated routinely are:  $^{60}\text{Co}$ ,  $^{102\text{m}}\text{Rh}$ ,  $^{106}\text{Ru}$ ,  $^{125}\text{Sb}$ ,  $^{133}\text{Ba}$ ,  $^{137}\text{Cs}$ ,  $^{152}\text{Eu}$ ,  $^{155}\text{Eu}$ ,  $^{207}\text{Bi}$ ,  $^{235}\text{U}$ , and  $^{241}\text{Am}$ .

In looking over the nuclides listed in Table 111, one finds entries with relatively short half-lives, some even shorter

than 1 yr. Remembering that Table 111 lists a library of possible nuclides, the following comments summarize the question of observation of gamma emitters listed in the library.

$^7\text{Be}$   $t_{1/2} = 53.5 \text{ da}$   
 Observation: Measured in 32 vegetation samples and in 30 air samples.  
 Comments: Commonly occurs in air due to cosmic ray interactions.

$^{22}\text{Na}$   $t_{1/2} = 942 \text{ da} = 2.58 \text{ yr}$   
 Observation: No  $^{22}\text{Na}$  identified in any sample.

$^{40}\text{K}$   $t_{1/2} = 1.26 \times 10^9 \text{ yr}$   
 Observation: Measured and reported in a large fraction of the samples. Naturally occurring radioactivity; origin not related to weapons testing.

$^{54}\text{Mn}$   $t_{1/2} = 312 \text{ da}$   
 Observation: Identified in a Tridacna kidney sample (08-0556-11) taken from KATE at  $0.61 \pm 0.23 \text{ pCi/g}$  (collected December 8, 1972) and in a Guettarda sample (10-2250-23) taken on WILMA at  $0.05 \pm 0.02 \text{ pCi/g}$  (collected January 1973). Also observed in 29 air samples.  
 Comments: Existence in air samples and short half-life suggests the origin of this nuclide is worldwide fallout.

$^{60}\text{Co}$   $t_{1/2} = 1,920 \text{ da} = 5.26 \text{ yr}$   
 Observation: Positive signals in a large fraction of the samples; upper limits set for all remaining samples.

$^{65}\text{Zn}$   $t_{1/2} = 245$  da

Observation: Identified in a few samples, one soil, 16 marine samples at 0.4-5 pCi/g (collected November-December 1972) with uncertainties 6-44%, and in five animal samples at 0.22-0.55 pCi/g (collected January 1973) with uncertainties 23-42%.

$^{95}\text{Zr}$   $t_{1/2} = 65$  da

Observation: Identified only in high-volume air samples (9).

Comment: Origin is recent weapons-test debris which is transported as worldwide fallout.

$^{103}\text{Ru}$   $t_{1/2} = 40$  da

Observation: Identified in only one sample, a high-volume air filter (13-1189-24).

Comment: Origin is presumably worldwide fallout.

$^{106}\text{Ru}$   $t_{1/2} = 369$  da = 1.01 yr

Observation: Identified only in six air samples; five are from high-volume samplers.

Comment: Origin is presumably worldwide fallout.

$^{101}\text{Rh}$   $t_{1/2} = 1100$  da = 3.01 yr

Observation: Identified in 24 soil samples scattered over the northern half of the Atoll, in 58 sediment samples, and in two marine samples, Tridacna viscera and kidney (08-0504-02) at  $0.12 \pm 0.03$  pCi/g (collected December 11 1972) and Tridacna viscera (08-0536-02) at  $0.18 \pm 0.03$  pCi/g (collected November 29, 1972), with both samples taken near BELLE.

$^{102\text{m}}\text{Rh}$   $t_{1/2} = 1060$  da = 2.90 yr

Observation: Identified in 218 soil samples scattered over the northern half of the Atoll, in 12 samples from LEROY, in 162 sediment samples, and in the following seven marine samples:

08-0476-01, Tridacna kidney,  $0.8 \pm 0.2$  pCi/g (collected December 11, 1972), ALICE.

08-0504-02, Tridacna viscera and kidney,  $0.51 \pm 0.14$  pCi/g (collected December 11, 1972), BELLE.

08-0535-02, Tridacna kidney,  $1.0 \pm 0.3$  pCi/g (collected November 29, 1972), BELLE.

08-0536-02, Tridacna viscera,  $0.54 \pm 0.06$  pCi/g (collected November 29, 1972), BELLE.

08-0789-10, Tridacna viscera,  $0.14 \pm 0.05$  pCi/g (collected December 4, 1972), JANET.

08-0676-10, Tridacna kidney,  $3.0 \pm 0.9$  pCi/g (collected December 5, 1972), JANET.

09-8048-24, Goatfish viscera,  $0.11 \pm 0.02$  pCi/g (collected December 6, 1972), YVONNE.

$^{108\text{m}}\text{Ag}$   $t_{1/2} = 127$  yr

Observation: Identified in the following three marine samples:

08-0348-38, Tridacna, muscle and mantle,  $0.05 \pm 0.01$  pCi/g, GLENN.

09-0466-37, Sea turtle, liver,  $0.56 \pm 0.09$  pCi/g, FRED.

09-0264-53, Bonito, liver,  $0.28 \pm 0.04$  pCi/g, wide passage.

$^{110\text{m}}\text{Ag}$   $t_{1/2} = 253$  da

Observation: Not identified in any sample.

$^{125}\text{Sb}$   $t_{1/2} = 1010$  da = 2.77 yr

Observation: Identified in a large fraction of soil samples, predominantly from northern

half of the Atoll. Also identified in 130 sediment samples and in the following eight marine, one vegetation, and one air-filter samples:

- 08-0359-38, Sea cucumber, viscera and gut content,  $1.55 \pm 0.15$  pCi/g (collected October 18, 1972), GLENN.
- 09-8018-24, Parrotfish, viscera,  $0.35 \pm 0.11$  pCi/g (collected December 4, 1972), YVONNE.
- 09-0376-37, Goatfish, eviscerated whole,  $1.58 \pm 0.10$  pCi/g (collected December 1, 1972), FRED.
- 09-0466-37, Sea turtle, liver,  $1.85 \pm 0.31$  pCi/g (collected December 9, 1972), FRED.
- 09-0467-37, Turtle,  $1.24 \pm 0.20$  pCi/g (collected December 9, 1972), FRED.
- 09-0344-43, Mullet, muscle,  $1.72 \pm 0.18$  pCi/g (collected October 20, 1972), LEROY.
- 09-0346-43, Mullet, viscera,  $1.83 \pm 0.25$  pCi/g (collected October 20, 1972), LEROY.
- 09-0591-61, Yellowfin tuna, muscle,  $1.11 \pm 0.15$  pCi/g (collected December 9, 1972), Kwajalein.
- 10-0085-38, *Scaevola* leaf,  $0.12 \pm 0.05$  pCi/g (collected January 1973), GLENN.
- 13-1189-24, High-volume air filter,  $0.27 \pm 0.06$  fCi/m<sup>3</sup> (collected December 1972), YVONNE.

<sup>133</sup>Ba  $t_{1/2} = 2630$  da = 7.21 yr  
 Observation: Identified in 34 soil samples from JANET (7), PEARL (6), SALLY (13), and YVONNE (8).

<sup>134</sup>Cs  $t_{1/2} = 745$  da = 2.04 yr  
 Observation: Identified in seven soil samples (BELLE, IRENE, LUCY, GLENN, and HENRY), one sediment sample, and the following

marine and animal samples:

- 09-8041-24, Convict surgeon, viscera,  $0.53 \pm 0.07$  pCi/g (collected December 6, 1972), YVONNE.
- 09-0466-37, Sea turtle, liver,  $0.44 \pm 0.12$  pCi/g (collected December 9, 1972), FRED.
- 11-9118-24, Roof rat, viscera,  $1.3 \pm 0.3$  pCi/g (collected January 15, 1973), YVONNE.
- 11-9135-24, Roof rat, lung,  $1.0 \pm 0.3$  pCi/g (collected February 3, 1973), YVONNE.
- 11-9167-24, Roof rat, bone,  $0.8 \pm 0.2$  pCi/g (collected January 15, 1973), YVONNE.
- 11-9168-24, Roof rat, bone,  $1.0 \pm 0.2$  pCi/g (collected February 3, 1973), YVONNE.
- 11-9269-33, Sooty tern, bone,  $0.29 \pm 0.06$  pCi/g (collected January 15, 1973), DAVID.

<sup>137</sup>Cs  $t_{1/2} = 30.0$  yr

Observation: Positive signals in a large fraction of the total samples; upper limits set for all remaining samples.

<sup>144</sup>C  $t_{1/2} = 285$  da

Observation: Identified in soil (7), sediment (26), marine (11), vegetation (10), and air-filter (12) samples. With the exception of the air filters (all from high-volume samplers), all observations are considered questionable since they are based upon the observation of a single gamma ray at 133 keV. Confirmation of these data would require chemical separation of cerium and further counting. The air-filter data are considered authentic.

<sup>152</sup>Eu  $t_{1/2} = 5120$  da = 14.0 yr

Observation: Identified in roughly

half of soil samples from northern half of the Atoll and in about a third of the sediments. Also identified in the following samples:

- 08-0556-11, Tridacna, kidney, 0.52 ± 0.11 pCi/g, KATE.  
 09-0494-02, Mullet, viscera, 0.33 ± 0.10 pCi/g, BELLE.  
 09-0496-02, Mullet, viscera, 0.26 ± 0.06 pCi/g, BELLE.

$^{154}\text{Eu}$   $t_{1/2} = 2860 \text{ da} = 7.83 \text{ yr}$

Observation: Identified in 101 soil samples from ALICE (7), BELLE (14), CLARA (4), DAISY (4), IRENE (6), JANET (3), PEARL (28), SALLY (12), and YVONNE (23), and in 36 sediment samples. There were no other authenticated observations.

$^{155}\text{Eu}$   $t_{1/2} = 1850 \text{ da} = 5.08 \text{ yr}$

Observation: Identified in a large fraction of the soil samples and in most of the sediment samples. Also identified in 7 (of 16) plankton samples, in 10 (of 54) seawater samples, in 68 (of 410) marine samples, in 3 (of 216) vegetation samples, and 1 (of 274) animal samples.

10-2265-02, Messerschmidia, 0.06 ± 0.02 pCi/g (collected January 1973), BELLE.

10-1892-11, Messerschmidia, 0.05 ± 0.02 pCi/g (collected January 1973), KATE.

10-3275-24, Scaevola, 0.05 ± 0.02 pCi/g (collected January 1973), YVONNE.

11-9082-17, Rice rat, hide, 0.22 ± 0.07 pCi/g (collected January 1973), PEARL.

$^{207}\text{Bi}$   $t_{1/2} = 32.0 \text{ yr}$

Observation: Identified in soil

samples in localized regions, especially on DAISY, EDNA, IRENE, JANET, IRWIN, JAMES, and KEITH. Also identified in most of the sediment samples, in 14 (of 16) plankton samples, in 22 (of 54) seawater samples, in approximately half of the marine samples, in the following five vegetation samples and four animal samples:

10-2455-04, Coconuts, 0.06 ± 0.03 pCi/g, DAISY.

10-3700-10, Pandanus, 0.11 ± 0.03 pCi/g, JANET.

10-0199-33, Messerschmidia, 0.05 ± 0.02 pCi/g, DAVID.

10-0081-38, Pisonia leaf, 0.06 ± 0.03 pCi/g, GLENN.

10-2430-42, Messerschmidia, 0.07 ± 0.03 pCi/g, KEITH.

10-2434-42, Pandanus, 0.04 ± 0.01 pCi/g, KEITH.

11-9133-21, Rice rat, liver, 0.38 ± 0.11 pCi/g, URSULA.

11-9150-21, Rice rat, lung, 0.90 ± 0.32 pCi/g, URSULA.

11-9087-24, Roof rat, hide, 0.21 ± 0.08 pCi/g, YVONNE.

11-9026-38, Hermit crab, pancreas and gonad, 0.15 ± 0.06 pCi/g, GLENN.

$^{226}\text{Ra}$   $t_{1/2} = 1620 \text{ yr}$

Observation: Identified in 102 soil samples spread throughout the entire Atoll and 130 sediment samples.

$^{228}\text{Th}$   $t_{1/2} = 698 \text{ da} = 1.91 \text{ yr}$

Observation: Identified locally in YVONNE soil samples (32). No other positive identification.

$^{235}\text{U}$   $t_{1/2} = 7.13 \times 10^8 \text{ yr}$

Observation: Identified fairly infre-

quently (about 6.5%) among soil samples. Measured concentrations in the samples averaged in the range 0.014-0.026 ppm  $^{235}\text{U}$ . If one assumed the  $^{235}\text{U}$  abundance to be that of natural uranium (not necessarily a valid assumption at Enewetak), these averages correspond to a natural uranium content of 1.9-3.6 ppm. Also identified in 96 sediment samples. There was no positive identification in any other type of sample.

$^{239}\text{Pu}$   $t_{1/2} = 24,360$  yr

Observation: Identified by gamma detection in just two samples (sensitivity for detection is greatly increased in wet-chemistry analysis). Comparison of gamma counting and wet-chemistry results is given below:

Sample	$^{239}\text{Pu}$ , dpm/g (gamma)	$^{239+240}\text{Pu}$ , dpm/g (alpha)
73-5235-24	469±145	1020±50
05-1096-24	290±160	714±28

Note that gamma counting measures only  $^{239}\text{Pu}$  whereas alpha counting measures the sum of  $^{239}\text{Pu}$  and  $^{240}\text{Pu}$  activity. One can deduce 240/239 atom ratios

from the above data which have values of  $0.32 \pm 0.19$  and  $0.40 \pm 0.38$ , respectively.

The precision of these values is poor; mass-spectrometric analyses of 240/239 ratio yield more precise data.

$^{241}\text{Pu}$   $t_{1/2} = 5110$  da = 14.0 yr

Observation: No  $^{241}\text{Pu}$  detected in any sample by gamma counting.

$^{241}\text{Am}$   $t_{1/2} = 433$  yr

Observation: Identified in many of the soil samples from most of the islands, although in greatest abundance and frequency in the northern half of the Atoll. Also prevalent in sediments. Identified elsewhere in 5 (of 16) plankton samples, 7 (of 54) seawater samples, in 38 (of 410) marine samples, in 2 (of 216) vegetation samples, and in 1 (of 67) air filters. There was no positive identification in animal samples.

Comments: Comparison of  $^{241}\text{Am}$  determination by gamma counting with that by wet-chemistry analysis is given in the last section of this chapter.

Table 111. Half-lives, energies, and branching intensities for nuclides loaded into GAMANAL.

Nuclide	Half-life days ,	Energy, keV	Branching intensity
1. 4 BE 7	5.350E+01	477.400	1.030E-01
2. 11 NA 22	9.417E+02	511.000 1274.550	1.800E+00 1.000E+00
3. 19 K 40	4.610E+11	1460.760	1.083E-01
4. 25 MN 54	3.123E+02	834.823	1.000E+00
5. 27 CO 60	1.922E+03	1173.230 1332.510	1.000E+00 1.000E+00
6. 30 ZN 65	2.450E+02	1115.520	4.900E-01
7. 40 ZR 95	6.500E+01	724.200 756.720	4.300E-01 5.460E-01
8. 41 NB 95	3.510E+01	765.800	9.900E-01
9. 44 RU 103	3.960E+01	497.090 610.310	9.000E-01 5.600E-02
10. 45 RH 101	1.100E+03	127.200 197.900 325.100	8.400E-01 9.000E-01 1.800E-01
11. 45 RH 106	3.514E-04	511.800 616.300 622.100 873.800 1050.700	2.050E-01 8.100E-03 9.800E-02 4.400E-03 1.400E-02
12. 45 RH 102M	1.059E+03	418.800 475.100 628.200 631.400 697.600 767.000 1046.800 1103.300 1112.900	1.120E-01 9.300E-01 7.000E-02 5.200E-01 4.320E-01 3.300E-01 3.100E-01 4.500E-02 1.800E-01
13. 47 AG 108M	4.635E+04	79.120 433.610 614.040 632.740 722.730	5.200E-02 9.200E-01 9.200E-01 1.140E-03 9.200E-01
14. 47 AG 110M	2.530E+02	446.200 620.100 657.600 677.500 686.800 706.600 744.200 763.800 817.900 884.500 937.300	3.500E-02 2.500E-02 9.300E-01 1.220E-01 7.500E-02 1.600E-01 4.330E-02 2.200E-01 6.950E-02 7.100E-01 3.360E-01

Table 111 (continued)

	Nuclide	Half-life days,	Energy, keV	Branching intensity
14.	47 AG 110M	2.530E+02	1384.300	2.400E-01
			1475.900	3.700E-02
			1505.200	1.260E-01
			1562.500	1.100E-02
15.	51 SB 125	1.012E+03	176.430	7.200E-02
			380.440	1.520E-02
			427.880	3.040E-01
			463.380	1.070E-01
			600.600	1.810E-01
			606.700	5.150E-02
			635.920	1.150E-01
			671.410	1.820E-02
16.	55 CS 134	7.450E+02	475.340	1.540E-02
			563.220	8.820E-02
			569.330	1.580E-01
			604.700	9.800E-01
			795.790	8.900E-01
			801.870	9.500E-02
			1038.610	1.060E-02
			1167.910	1.850E-02
			1365.130	3.000E-02
17.	55 CS 137	1.096E+04	661.646	8.500E-01
18.	56 BA 133	2.630E+03	53.170	1.950E-02
			79.590	3.040E-02
			81.010	3.600E-01
			160.620	7.600E-03
			276.290	7.500E-02
			302.710	1.960E-01
			355.860	6.700E-01
			383.700	9.400E-02
19.	58 CE 144	2.846E+02	80.100	1.480E-02
			133.500	1.100E-01
			696.500	1.330E-02
20.	63 EU 152	5.117E+03	121.780	3.010E-01
			244.700	7.740E-02
			295.970	4.700E-03
			329.300	1.490E-03
			344.270	2.740E-01
			367.760	9.000E-03
			411.100	2.270E-02
			416.000	1.140E-03
			443.940	3.200E-02
			488.700	3.900E-03
			503.450	1.500E-03
			586.200	4.400E-03
			656.400	1.400E-03
			674.350	1.660E-03
			678.600	4.400E-03
			688.800	8.500E-03
			712.900	1.000E-03
			719.300	2.900E-03



Table 111 (continued)

	Nuclide	Half-life days ,	Energy, keV	Branching intensity
20.	63 EU 152	5.117E+03	764.900	1.400E-03
			778.850	1.300E-01
			810.240	3.150E-03
			841.400	2.100E-03
			867.300	4.260E-02
			919.100	4.000E-03
			964.000	1.480E-01
			1005.100	6.500E-03
			1085.700	1.025E-01
			1089.500	1.750E-02
			1111.900	1.400E-01
			1212.800	1.400E-02
			1249.700	2.030E-03
			1292.600	1.140E-03
			1298.970	1.640E-02
			1407.920	2.150E-01
			1457.600	5.000E-03
			1528.200	2.830E-03
21.	63 EU 154	2.863E+03	123.140	4.050E-01
			248.040	6.590E-02
			591.740	4.840E-02
			692.410	1.696E-02
			723.300	1.970E-01
			756.870	4.340E-02
			873.190	1.150E-01
			996.320	1.030E-01
			1004.760	1.730E-01
			1274.390	3.350E-01
			1596.480	1.670E-02
22.	63 EU 155	1.855E+03	60.010	1.320E-02
			86.550	3.220E-01
			105.320	2.280E-01
23.	83 BI 207	1.169E+04	569.620	9.800E-01
			1063.650	7.700E-01
			1770.180	7.150E-02
24.	88 RA 226	5.917E+05	186.140	4.000E-02
			241.960	7.900E-02
			295.200	2.020E-01
			351.920	4.010E-01
			609.270	4.840E-01
			665.400	1.650E-02
			742.480	PAIR PEAK
			768.350	5.320E-02
			785.800	1.210E-02
			806.160	1.310E-02
			934.060	3.340E-02
			1120.280	1.600E-01
			1155.170	1.820E-02
			1238.130	6.200E-02
			1280.980	1.560E-02
			1377.640	4.180E-02

Table 111 (continued)

	Nuclide	Half-life days,	Energy, keV	Branching intensity
24.	88 RA 226	5.917E+05	1401.440	1.440E-02
			1407.980	2.600E-02
			1509.220	2.300E-02
			1661.240	1.210E-02
			1729.550	3.070E-02
			1764.490	1.660E-01
			1838.330	4.100E-03
			1847.440	2.200E-02
			2118.520	1.230E-02
			2204.140	5.300E-02
			2447.630	1.650E-02
25.	90 TH 228	6.976E+02	74.817	9.530E-02
			74.970	1.303E-01
			77.108	1.620E-01
			84.380	1.330E-02
			84.450	1.580E-03
			86.830	1.930E-02
			87.350	3.600E-02
			238.626	4.480E-01
			240.982	4.140E-02
			277.340	2.300E-02
			300.110	3.420E-02
			510.720	8.340E-02
			583.139	3.090E-01
			727.270	6.650E-02
			785.460	1.100E-02
			860.490	4.530E-02
			1592.690	PAIR PEAK
			1620.620	1.510E-02
			2614.710	3.596E-01
26.	92 U 235	2.604E+11	143.770	1.070E-01
			163.370	4.850E-02
			185.720	5.610E-01
			202.100	1.070E-02
			205.330	4.870E-02
27.	94 PU 239	8.908E+06	94.665	9.830E-05
			98.439	1.900E-04
			129.280	6.420E-05
			203.520	5.630E-06
			375.020	1.585E-05
			413.690	1.506E-05
28.	94 PU 241	5.110E+03	148.600	1.900E-06
			164.590	4.500E-07
			207.970	5.120E-06
29.	95 AM 241	1.582E+05	59.536	3.590E-01
			99.000	2.100E-04
			103.000	2.020E-04

## Wet-Chemistry Analyses

### Nuclides Measured; Laboratories Making Measurements

Nuclides that could not be detected by gamma spectroscopy and that were judged to be of potential significance to this survey were analyzed for by dissolution of a sample, chemical separation of a desired element, and quantification by an appropriate radiation-counting technique. An integral part of this technique is the addition of a known amount of elemental carrier or tracer at the beginning of the procedure to permit determination of chemical yield in the final sample. These nuclides, their half-lives, principal radiation, and technique for counting are listed in Table 112. In this list, the nuclides analyzed for most generally were  $^{90}\text{Sr}$ ,  $^{238}\text{Pu}$ ,  $^{239,240}\text{Pu}$ , and  $^{55}\text{Fe}$ . Wet-chemistry analysis for  $^{241}\text{Am}$  was performed on a small fraction of the samples; gamma counting was the major method used to determine this nuclide. The purposes of wet-chemistry analyses for  $^{241}\text{Am}$  were either to check results obtained by gamma counting or, in the case of some marine, vegetation, and animal samples, to extend the sensitivity for  $^{241}\text{Am}$  detection to lower levels. The remaining nuclides in Table 112 were measured in relatively small numbers of samples to provide an approximate indication of levels existing in various biological samples. In addition to the radioactive species, analyses for stable iron, calcium, and iodine were required on certain samples. The kinds and numbers of analyses performed at each laboratory are listed in Table 113.

## Separation Schemes

For application to coralline soils and sediments, chemical dissolution, separation, and purification schemes for  $^{90}\text{Sr}$  and Pu determination as performed at MCL, LFE, and EIC are shown in Tables 114, 115, and 116.

These procedures are given in basic outline form; no details on manipulation, quantities of reagents, or fine points of analytical technique are included. Each laboratory received 50-g samples of finely divided coral soil. At MCL, quantities of 10-20 g were dissolved, while at LFE and EIC, entire 50-g samples were put in solution.

Some variation in dissolving technique is seen among the laboratories; each reported coralline soil to be readily soluble in appropriate mineral acids. Both MCL and LFE procedures feature a sequential separation of Sr-Y and Pu from a single aliquot, while EIC chose to isolate these elements from separate aliquots.

Determination of  $^{90}\text{Sr}$  and Pu in other types of samples required some modifications of procedures given in Tables 114 and 115. For MCL, the required variations are summarized in Table 117. Corresponding procedures in use at LFE are summarized in Table 118.

The isolation of  $^{55}\text{Fe}$  was based upon the extraction of iron carrier into diethyl ether from 6 M HCl solution at all four laboratories. Following further purification, samples were electrodeposited in preparation for gamma counting. An aliquot of each sample to which no carrier had been added was reserved for determination of stable iron via atomic absorption spectrometry. This information

Table 112. Nuclides measured in wet-chemistry analyses.

Nuclide	$T_{1/2}$	Principal radiation	Type of detection
$^{55}\text{Fe}$	2.7 y	5.95 keV x ray	Gamma counting: NaI(Tl), Ge(Li) detectors.
$^{90}\text{Sr}$	28.5 y	$\beta$ particle of $^{90}\text{Y}$ daughter ( $E_{\text{max}} = 2.27$ MeV)	Beta counting: gas-filled proportional counter.
$^{239,240}\text{Pu}$	24,400 y (239) 6,540 y (240)	5.16 MeV $\alpha$	Alpha pulse-height analysis, (solid state, Frisch-grid chamber), mass spectrometry.
$^{238}\text{Pu}$	87.8 y	5.50 MeV $\alpha$	Alpha pulse height analysis.
$^{241}\text{Am}$	433 y	5.49 MeV $\alpha$	Alpha pulse height analysis.
$^3\text{H}$	12.35 y	$\beta$ particle ( $E_{\text{max}} = 18.5$ keV)	Gas-filled proportional counter.
$^{14}\text{C}$	5,730 y	$\beta$ particle ( $E_{\text{max}} = 156$ keV)	Liquid scintillation counter.
$^{63}\text{Ni}$	92 y	$\beta$ particle ( $E_{\text{max}} = 65.9$ keV)	Liquid scintillation counter.
$^{65}\text{Zn}$	245 d	Gamma ray (1.116 MeV)	Gamma spectrometry of separated samples.
$^{113\text{m}}\text{Cd}$	14 y	$\beta$ particle ( $E_{\text{max}} = 580$ keV)	Beta counting: gas-filled proportional counter.
$^{129}\text{I}$	$1.57 \times 10^7$ y	$\beta$ particle ( $E_{\text{max}} = 150$ keV) Xenon K x rays (29.7, 33.7 keV)	Liquid scintillation counter, x-ray detection (Si diode).
$^{144}\text{Ce}$	285 d	$\beta$ particle of $^{144}\text{Pr}$ daughter ( $E_{\text{max}} = 2.99$ MeV)	Beta counting: gas-filled proportional counter.
$^{147}\text{Pm}$	2.62 y	$\beta$ particle ( $E_{\text{max}} = 225$ keV)	Beta counting: gas-filled proportional counter.
$^{151}\text{Sm}$	87 y	$\beta$ particle ( $E_{\text{max}} = 76$ keV)	Liquid scintillation counter.
Fe, Ca, I, Sr	stable	None	(Atomic absorption)

Table 113. Summary of wet-chemistry analyses.

Type of samples	Laboratory, number of samples	Analyses performed	
		Major nuclides ( <sup>55</sup> Fe, <sup>90</sup> Sr, <sup>238,239,240</sup> Pu)	Minor nuclides ( <sup>3</sup> H, <sup>14</sup> C, <sup>63</sup> Ni, <sup>65</sup> Zn, <sup>113m</sup> Cd, <sup>144</sup> Ce, <sup>147</sup> Pm, <sup>151</sup> Sm, <sup>241</sup> Am)
Soil, sediment, core	MCL 1923	<sup>90</sup> Sr, <sup>238</sup> Pu, <sup>239,240</sup> Pu (all), <sup>55</sup> Fe (2)	<sup>65</sup> Zn (4), <sup>113m</sup> Cd (9), <sup>144</sup> Ce (4), U (2), <sup>241</sup> Am(24)
	LFE 1007	<sup>90</sup> Sr, <sup>239,240</sup> Pu (all), <sup>238</sup> Pu (29)	
	EIC 486	<sup>90</sup> Sr, <sup>239,240</sup> Pu (all)	
Marine	MCL 121	<sup>55</sup> Fe, <sup>90</sup> Sr, <sup>238</sup> Pu, <sup>239,240</sup> Pu (all)	<sup>63</sup> Ni (9), <sup>65</sup> Zn (2), <sup>113m</sup> Cd(14), <sup>147</sup> Pm(9), <sup>151</sup> Sm (9), <sup>241</sup> Am(9)
	LFE 196	<sup>55</sup> Fe, <sup>90</sup> Sr, <sup>239,240</sup> Pu (all)	<sup>63</sup> Ni(4), <sup>113m</sup> Cd(3), <sup>147</sup> Pm(4), <sup>151</sup> Sm(4), <sup>241</sup> Am(8)
	LRE 114	<sup>55</sup> Fe, <sup>90</sup> Sr, <sup>239,240</sup> Pu (all), <sup>238</sup> Pu (all)	
	LLL 10		<sup>3</sup> H(10), <sup>14</sup> C(10)
Plankton	MCL 16	<sup>90</sup> Sr, <sup>238</sup> Pu, <sup>239,240</sup> Pu (all)	
Algae	LFE 3	<sup>55</sup> Fe(1), <sup>90</sup> Sr(1), <sup>239,240</sup> Pu(2)	
Vegetation	MCL 130	<sup>55</sup> Fe(28), <sup>90</sup> Sr, <sup>238</sup> Pu, <sup>239,240</sup> Pu (all)	<sup>63</sup> Ni(8), <sup>113m</sup> Cd(8), <sup>147</sup> Pm(8), <sup>151</sup> Sm(7), <sup>241</sup> Am(8)
	LFE 51	<sup>55</sup> Fe(11), <sup>90</sup> Sr, <sup>239,240</sup> Pu (all)	
	LLL 11		<sup>3</sup> H(10), <sup>14</sup> C(11)
Animal	MCL 53	<sup>55</sup> Fe(53), <sup>90</sup> Sr, <sup>238</sup> Pu, <sup>239,240</sup> Pu (all)	<sup>113m</sup> Cd(4)
	LFE 163	<sup>55</sup> Fe(116), <sup>90</sup> Sr, <sup>239,240</sup> Pu (all)	<sup>63</sup> Ni(3), <sup>113m</sup> Cd(2), <sup>147</sup> Pm(5), <sup>151</sup> Sm(5), <sup>241</sup> Am(6)
	LLL 15		<sup>3</sup> H(15)
Seawater	LLL 47	<sup>238</sup> Pu, <sup>239,240</sup> Pu (47)	
	LFE 62	<sup>90</sup> Sr(62)	
Air filter	MCL 58	<sup>238</sup> Pu, <sup>239,240</sup> Pu (all)	

Table 114. McClellan Central Laboratory: Chemistry scheme for determination of  $^{90}\text{Sr}$  and Pu in coralline soils and sediments.

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<u>Dissolution</u>	<p>Fire coral at 950°C for 8 hr.  Dissolve 12 <u>M</u> HCl + 5.5 <u>M</u> HI; dilute with H<sub>2</sub>O.<sup>a</sup>  Working solution for aliquots, combined Sr-Pu.</p>
<u>Separation</u>	<p>To aliquot, add Y carrier, <math>^{236}\text{Pu}</math> or <math>^{242}\text{Pu}</math> tracer.<sup>b</sup>  Ppt Y(OH)<sub>3</sub> by adding NH<sub>4</sub>OH. (Note Sr-Y separation time).  Wash ppt H<sub>2</sub>O; dissolve 16 <u>M</u> HNO<sub>3</sub>, dilute with H<sub>2</sub>O.  Ppt Y(OH)<sub>3</sub> by adding NH<sub>4</sub>OH.  Wash ppt H<sub>2</sub>O; dissolve satd HCl + few drops HNO<sub>3</sub>.  Load on Dowex 1 × 8 column (Pu-Y separation).  Wash column 12 <u>M</u> HCl. (Load and wash to Y purification).  Elute Pu with 12 <u>M</u> HCl + satd NH<sub>4</sub>I. (To Pu purification).</p>
<u>Y purification</u>	<p>Evaporate column load and wash fractions to dryness.  Dissolve in 0.1 <u>M</u> HCl.  Extract twice with 10% HDEHP (toluene).  Back-extract 3 <u>M</u> HCl.  Ppt Y(OH)<sub>3</sub> by adding NH<sub>4</sub>OH.  Wash H<sub>2</sub>O; dissolve 12 <u>M</u> HCl + H<sub>2</sub>O, filter.  Ppt Y oxalate by adding satd oxalic acid, digestion.  Filter ppt, dry, fire to Y<sub>2</sub>O<sub>3</sub> at 900°C, 1 hr.  Weigh, beta count <math>^{90}\text{Y}</math>.</p>
<u>Pu purification</u>	<p>To column eluant, add 5 <u>M</u> NH<sub>2</sub>OH HCl, LaCl<sub>3</sub> carrier,  satd NH<sub>4</sub>I, ZrO(NO<sub>3</sub>)<sub>2</sub> carrier.  Boil to reduce volume.  Ppt LaF<sub>3</sub> by adding HF.  Dissolve HNO<sub>3</sub> + H<sub>3</sub>BO<sub>3</sub>.  Ppt La(OH)<sub>3</sub> by adding NH<sub>4</sub>OH.  Dissolve 16 <u>M</u> HNO<sub>3</sub>, boil.  Ppt La(OH)<sub>3</sub> by adding NH<sub>4</sub>OH.  Wash H<sub>2</sub>O; dissolve 12 <u>M</u> HCl + few drops HNO<sub>3</sub>.</p>

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Table 114 (continued).

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<u>Pu purification</u> (continued)	Load on Dowex 1 × 8 column. Wash 12 <u>M</u> HCl, 12 <u>M</u> HCl-dilute HF, more 12 <u>M</u> HCl. Elute Pu with 12 <u>M</u> HCl-HI. Add two drops H <sub>2</sub> SO <sub>4</sub> ; fume to SO <sub>3</sub> evolution. Electroplate in 10% (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> solution. Determine Pu by either α pulse-height analysis or mass-spectrometric analysis.
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<sup>a</sup>The addition of HI is necessary to insure equilibration of plutonium tracer with the plutonium in the aliquot of the working solution.

<sup>b</sup><sup>236</sup>Pu was used as an alpha-PHA tracer; <sup>242</sup>Pu could be used either as an alpha-PHA tracer or as a mass tracer. Note that <sup>238</sup>Pu could be determined only on those samples which were assayed via alpha-PHA.

Table 115. Laboratory for Electronics - Environmental Analysis Laboratories:  
Chemistry scheme for determination of  $^{90}\text{Sr}$  and Pu in coralline soils  
and sediments.

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<u>Dissolution</u>	<p>Fire coral at <math>900^{\circ}\text{C}</math> for 12 hr.          Add Y carrier, <math>^{236}\text{Pu}</math> tracer.          Dissolve 6 <u>N</u> <math>\text{HNO}_3</math>, adjust solution to 0.05 <u>M</u> HF.</p>
<u>Separation</u>	<p>Evaporate near dryness, add <math>\text{H}_3\text{BO}_3</math>.          Evaporate near dryness, add 6 <u>N</u> <math>\text{HNO}_3</math> + 30% <math>\text{H}_2\text{O}_2</math>.          Boil down, add more 6 <u>N</u> <math>\text{HNO}_3</math>, cool, add 5% <math>\text{NaNO}_2</math>.          Load on Dowex 1 <math>\times</math> 4 column. (Pu, Sr-Y separation).          Wash column 6 <u>N</u> <math>\text{HNO}_3</math>. (Load and wash to Sr-Y purification).          Elute Pu with 4 <u>N</u> <math>\text{HNO}_3</math> - 0.1 <u>N</u> HF. (To Pu purification).</p>
<u>Sr-Y purification</u>	<p>Evaporate column load and wash near dryness.          Add <math>\text{H}_2\text{O}</math>; adjust to pH 1.          Extract with 20% HDEHP (toluene). (Note Sr-Y separation time).          Wash three times with 0.5 <u>N</u> <math>\text{HCl}</math>.          Back-extract three times with 12 <u>M</u> <math>\text{HCl}</math>.          Evaporate to dryness (adding fuming <math>\text{HNO}_3</math>).          Dissolve 12 <u>M</u> <math>\text{HCl}</math> + <math>\text{H}_2\text{O}</math>.          Ppt <math>\text{YF}_3</math> by adding HF.          Dissolve <math>\text{HNO}_3</math> + <math>\text{H}_3\text{BO}_3</math>.          Ppt <math>\text{Y}(\text{OH})_3</math> by adding <math>\text{NH}_4\text{OH}</math>.          Dissolve 6 <u>N</u> <math>\text{HCl}</math> + <math>\text{H}_2\text{O}</math>.          Ppt <math>\text{Y}(\text{OH})_3</math> by adding <math>\text{NH}_4\text{OH}</math>.          Wash twice with <math>\text{H}_2\text{O}</math>; dissolve min. 6 <u>N</u> <math>\text{HCl}</math>.          Ppt Y oxalate by adding satd oxalic acid + <math>\text{H}_2\text{O}</math>, digestion.          Filter, fire to <math>\text{Y}_2\text{O}_3</math>.          Weigh, beta count <math>^{90}\text{Y}</math>.</p>
<u>Pu purification</u>	<p>Evaporate eluant to low volume, adding <math>\text{H}_3\text{BO}_3</math> + Fe carrier.          Ppt <math>\text{Fe}(\text{OH})_3</math> by adding <math>\text{NH}_4\text{OH}</math>.          Wash dilute <math>\text{NH}_4\text{OH}</math>.          Dissolve 6 <u>N</u> <math>\text{HNO}_3</math>; cool, add 5% <math>\text{Na}_2\text{NO}_2</math>.          Load on Dowex 1 <math>\times</math> 4 column.          Wash 6 <u>N</u> <math>\text{HNO}_3</math>, 12 <u>M</u> <math>\text{HCl}</math>.          Elute Pu with 12 <u>M</u> <math>\text{HCl}</math> - HI.          Evaporate solution.          Electrodeposit on stainless steel disk for alpha pulse-height analysis.</p>

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Table 116. Eberline Instrument Company: Chemistry scheme for determination of  $^{90}\text{Sr}$  and Pu in coralline soils and sediments.

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<u>Dissolution</u>	Fire coral at 500°C for 12 hr. Dissolve 8 <u>N</u> $\text{HNO}_3$ , filter. Working solution for aliquots, separate Sr and Pu.
<u>Sr-Y aliquot</u>	Add $^{85}\text{Sr}$ tracer, evaporate dry. Dissolve 0.08 <u>N</u> $\text{HCl}$ . Extract twice with 20% HDEHP (toluene). (Note Sr-Y separation time). Discard organic each time. Add Y carrier to aqueous. Count sample for $^{85}\text{Sr}$ with gamma spectrometer. Store sample 2 wk ( $^{90}\text{Y}$ growth period). Extract 5% HDEHP (toluene). Wash 0.08 <u>N</u> $\text{HCl}$ . Back-extract 3 <u>N</u> $\text{HNO}_3$ . Ppt $\text{Y}(\text{OH})_3$ by adding $\text{NH}_4\text{OH}$ . Dissolve 1 <u>N</u> $\text{HCl}$ . Ppt Y oxalate by adding $\text{H}_2\text{O}$ , $\text{NH}_4$ oxalate, digestion. Filter; wash ppt with $\text{H}_2\text{O}$ , alcohol. Dry, cool, weigh. Beta count $^{90}\text{Y}$ .
<u>Pu aliquot</u>	Add $^{236}\text{Pu}$ tracer, few drops 25% $\text{Na}_2\text{NO}_2$ . Extract with Aliquat 336 (quaternary amine). Wash twice with 8 <u>N</u> $\text{HNO}_3$ , four times with 10 <u>M</u> $\text{HCl}-\text{H}_2\text{O}_2$ . Back-extract Pu twice with $\text{HClO}_4$ -oxalic acid solution. Add $\text{NaHSO}_4$ , evaporate dry. Add 12 <u>M</u> $\text{HCl}$ , evaporate dry. Electroplate from $\text{HCl}-\text{NH}_4$ oxalate solution. Wash $\text{H}_2\text{O}$ , dry. Determine Pu by alpha pulse-height analysis.

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Table 117. McClellan Central Laboratory: Supplemental chemistry schemes required to process biological samples.

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1. Fish, bird, rat samples - bones present:

After ashing at 900°C and dissolution in 12 M HCl - 5.5 M HI, the amounts of phosphate present prevented effective carrying on a hydroxide precipitate. The following procedure was followed:

Evaporate HCl-HI dry.

Add 12 M HCl, evaporate dry.

Dissolve 12 M HCl, centrifuge insolubles.

Load on Dowex 1 × 8 column in 12 M HCl + few drops HNO<sub>3</sub>.

Wash column with 12 M HCl.

Combine load, wash, insolubles; evaporate dry, proceed with Y purification shown in Table 114.

Elute Pu from column with 12 M HCl + satd NH<sub>4</sub>I.

Proceed with Pu purification shown in Table 114.

2. Fish, bird, rat samples - muscles, kidneys, liver, viscera (no bones present):

Ash at 900°C, dissolve in 12 M HCl - 5.5 M HI.

Proceed with Y(OH)<sub>3</sub> pptn as shown in Table 114.

3. Bird eggs: Ash, process as with coralline soils.

4. Plankton: Ash, process as with coralline soils.

5. Vegetation samples, coconut meat only:

Ash at 600°C.

Dissolve 12 M HCl + 5.5 M HI.

Treat insolubles with HClO<sub>4</sub>-HF.

Proceed as with soil procedure in Table 114.

6. Vegetation samples, all others:

Dissolve in HNO<sub>3</sub> and HClO<sub>4</sub>.

Bake to dryness.

Dilute with 6 M HCl plus 2 ml HI.

Proceed as with soil procedure in Table 114.

7. Polystyrene air filters:

Distill styrene off at 450°C.

Dissolve residue in 12 M HCl + 5.5 M HI.

Proceed as with soil procedure in Table 114.

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Table 118. Laboratory for Electronics - Environmental Analysis Laboratories:  
Supplemental chemistry schemes required to process biological samples.

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1. Fish, crab samples.

Dissolution Ash at 600°C for 12 hr.  
Dissolve ash in 12 M HCl, filter.  
Ash filter plus solids at 600°C.  
Dissolve in 12 M HCl; combine with filtrate.  
Add <sup>236</sup>Pu and appropriate carriers (Y, Fe, others).  
Add few drops HF; evaporate to near dryness.  
Add HNO<sub>3</sub>, H<sub>3</sub>BO<sub>3</sub>; evaporate to near dryness.  
Add HNO<sub>3</sub>, H<sub>2</sub>O<sub>2</sub>; evaporate to near dryness.  
Dissolve in 12 M HCl.

Separation Load on Dowex 1 × 4 column.  
Column load to Sr-Y purification.  
Elute Fe with 6 N HNO<sub>3</sub>. (Fe separation - to Fe purification).  
Elute Pu with 4 N HNO<sub>3</sub>-0.1 N HF. (To Pu purification).

2. Vegetation, bird, and egg samples.

Dissolution Ash at 600°C for 12 hr.  
Dissolve ash in 12 M HCl, filter.  
Ash filter plus solids at 600°C.  
Dissolve in 12 M HCl; combine with filtrate.  
Add <sup>236</sup>Pu and appropriate carriers.  
Add few drops HF; evaporate to near dryness.  
Add HNO<sub>3</sub>, H<sub>3</sub>BO<sub>3</sub>; evaporate to near dryness.  
Add HNO<sub>3</sub>, H<sub>2</sub>O<sub>2</sub>; evaporate to near dryness.  
Dissolve in 6 N HNO<sub>3</sub>.

Separation Evaporate to near dryness.  
Add 6 N HNO<sub>3</sub> and NH<sub>4</sub>NO<sub>3</sub> until saturated.  
Extract Pu with hexone. (Pu separation).  
Back-extract with 0.1 N HNO<sub>3</sub>.  
Evaporate to dryness; dissolve in 6 N HNO<sub>3</sub>.  
Load on Dowex 1 × 4 column.  
Proceed with Pu purification at appropriate step in procedure given in  
Table 115.  
Adjust aqueous phase to pH 1 with NH<sub>4</sub>OH.  
Extract Y with 20% HDEHP (toluene). (Sr-Y separation).  
Proceed with Y purification at appropriate step in procedure given in  
Table 115.

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permitted correction to the recovered amount of iron carrier for any iron originally present in the sample.

Chemically bound tritium measurements were made on 35 selected marine, vegetation, and animal samples. A 10-g sample of dried material was taken for each determination. The chemical procedure for this determination is as follows: The sample is ignited in the presence of 300-psi O<sub>2</sub> in a Parr bomb. Water formed by this oxidation is distilled in vacuum into a methanol-dry ice trap. After the sample is warmed, NaOH is added to neutralize the solution. The sample is redistilled. The water is then reduced with magnesium at 600°C to produce hydrogen gas which is put through a molecular sieve trap and then collected on a charcoal trap at liquid nitrogen temperature. The sample is ready for counting.

Carbon-14 measurements were made on 21 selected marine and vegetation samples. The desired sensitivity was obtainable with a sample size of only 300 mg of dried material. The chemical procedure for this determination is as follows: The sample is placed in a 2-liter, heavy-walled flask which has been flushed with oxygen. Following ignition of the sample and complete oxidation, the flask is cooled to freeze out water. A trapping solution (15 ml) of phenylethylamine, toluene, and methanol is introduced into the flask to quantitatively absorb any CO<sub>2</sub> present. Aliquots of this solution are taken for counting.

Various chemical procedures were devised at MCL and LFE to isolate and purify fractions containing <sup>63</sup>Ni, <sup>113m</sup>Cd,

<sup>147</sup>Pm, <sup>151</sup>Sm, and <sup>241</sup>Am. Chemical yields were determined by the addition of known amounts of either carrier solutions (Ni, Cd, Sm) or tracers (<sup>143,144,146</sup>Pm, <sup>243</sup>Am). Several precipitations of nickel dimethylglyoxime were the key purification steps for a nickel fraction. Cadmium was isolated by precipitation of CdS and purified by absorption on (in 2 M HCl) and elution from (in 1.5 M H<sub>2</sub>SO<sub>4</sub>) a Dowex 1 × 8 column. The two rare earths and americium were carried through common chemistry; elemental separation was achieved by use of a Dowex 50 column eluted with α-hydroxyisobutyric acid, a standard technique for intra-group separation of lanthanides and actinides.

#### Counting Techniques

Techniques for measuring nuclides in samples which were purified by wet chemistry are summarized in Table 112.

Although all of the nuclides of interest (Table 112) have half-lives long enough that decay of a counting sample cannot be used conveniently as a means of identification, determination of <sup>90</sup>Sr by chemically "milking" the 64-hr <sup>90</sup>Y daughter does permit one to follow decay of the energetic Y beta particles. Interference from other radioactivities can be readily identified and correction made. It is a highly specific technique for <sup>90</sup>Sr-<sup>90</sup>Y. All laboratories used this method to determine <sup>90</sup>Sr.

Plutonium-238, plutonium-(239, 240), and americium-241 were determined by the addition of an appropriate tracer, <sup>236</sup>Pu, <sup>242</sup>Pu, or <sup>243</sup>Am, at the beginning of analysis, and by measurement of an isotope ratio in a purified sample. Isotope ratios were usually determined

by a comparison of areas under alpha groups of characteristic energies from pulse-height analysis data, although some of the plutonium samples were spiked with  $^{242}\text{Pu}$  for measurement by mass spectrometry at MCL. These methods, observation of a characteristic alpha energy or a characteristic mass-to-charge ratio for an ion, are highly specific for the nuclides in question. Most of the  $^{238}\text{Pu}$  data were measured at MCL where it was determined routinely. Some additional  $^{238}\text{Pu}$  measurements were made at LFE and LRE. Measurements of  $^{238}\text{Pu}$  were made on about 60% of the samples.

Determination of  $^{55}\text{Fe}$  was based upon detection of a 6-keV Mn K x ray which arises from the electron capture of  $^{55}\text{Fe}$ . Most often, samples were counted with thin NaI(Tl) detectors, although some were measured with planar Ge(Li) diode detectors. Pulse-height analysis was used to provide energy discrimination. Good chemical purity of an iron fraction is required to eliminate interference from other nuclides. The quantitative determination of the 6-keV manganese K x ray also required a correction to account for self-absorption in the iron carrier. This correction varies from sample to sample and may lead to difficulties in comparing data from different laboratories.

Tritium was counted at LLL by introducing the purified sample, as hydrogen gas, into an evacuated proportional counter (2.6-liter volume), adding 380-mm  $\text{CH}_4$  and raising the absolute pressure to 1500 mm with tritium-free hydrogen. Acceptable pulses are determined by discrimination in rise time and anticoincidence with a guard counter arranged coaxially

around the tritium sample counter.

Counting of  $^{14}\text{C}$  samples was performed at LLL in the following manner: Two equal aliquots of purified  $\text{CO}_2$  from a sample, absorbed in a mixture of phenylethylamine, toluene, and methanol, were mixed with liquid scintillator solution (dimethyl POPOP and PPO in toluene). Samples were counted at an optimum  $^{14}\text{C}$  channel on an LS spectrometer for 100 min each. Energy discrimination was used to screen out low-energy betas, e.g., those from tritium decay. When a sample count rate did not exceed background within statistical limits, an upper limit was set at twice the value of the standard deviation.

Another group of nuclides,  $^{63}\text{Ni}$ ,  $^{113\text{m}}\text{Cd}$ ,  $^{147}\text{Pm}$ , and  $^{151}\text{Sm}$ , all long-lived beta emitters, were determined by measuring beta activity in purified samples. Those nuclides with less energetic betas,  $^{63}\text{Ni}$  and  $^{151}\text{Sm}$ , were measured by liquid scintillation counting. Aliquots of the purified sample were added to a scintillation mixture (dimethyl POPOP and PPO in toluene); each sample was counted with a Tracerlab scintillation spectrometer. The  $^{113\text{m}}\text{Cd}$  and  $^{147}\text{Pm}$  samples were measured with gas-flow (pure methane) proportional counters. The  $^{147}\text{Pm}$  samples required gamma counting [Ge(Li) detector] as well to provide chemical yield data from the  $^{143}, ^{144}, ^{146}\text{Pm}$  tracer. Because this group of nuclides has long half-lives, so that samples cannot be conveniently followed for decay, preparation of the samples was done with considerable care to insure good chemical purity.

Quality-Control Program

Soil Samples

An initial set of soil samples was distributed to the laboratories for calibration purposes. These samples were produced by blending varying proportions of two coral batches with different specific activities. Analytical results for  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$  are listed in Table 119. The plutonium content of these samples ranged from 0.41 to 17.8 dpm/g; the  $^{90}\text{Sr}$  content was uniform in all samples, with a mean value of  $3.96 \pm 0.10$  dpm/g. Plutonium

analyses for sample 4 showed a large spread and replicates did not agree; presumably, this sample was nonhomogeneous due to inadequate blending. This finding is consistent with the  $^{90}\text{Sr}$  results because  $^{90}\text{Sr}$  was present only in one of the two ingredients, that which comprised the major portion of each sample. (Included in the table are entries for MCL with the date, 5/73. These three samples were blind standards submitted for analysis in the middle of the analytical program.)

The plutonium results for sample 1 measured in January 1973 are quite con-

Table 119. Interlaboratory calibration, coral soil samples,  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$ .

	Concentration, dpm/g				
	<u>No. 0001</u>	<u>No. 0002</u>	<u>No. 0003</u>	<u>No. 0004</u>	<u>No. 0005</u>
<u><math>^{239,240}\text{Pu}</math></u>					
LLL 1/73	18.0±1.7	0.51±0.04	0.45±0.02	2.52±0.91	0.41±0.02
MCL 1/73	17.6±1.0	0.46±0.02	0.47±0.05	1.90±0.11	0.41±0.02
MCL 5/73	14.6±0.8	0.48±0.02	----	1.54±0.08	----
LFE 1/73	18.7±0.8	----	----	3.01±0.12	0.44±0.03
EIC 1/73	16.9±1.1	0.60±0.15	0.54±0.14	1.48±0.16	0.53±0.14
<u><math>^{90}\text{Sr}</math></u>					
LLL 1/73	----	----	----	----	3.40±0.17
MCL 1/73	4.13±0.12	4.14±0.58	4.15±0.23	3.90±0.12	4.00±0.12
MCL 5/73	4.04±0.40	3.64±0.17	----	4.26±0.21	----
LFE 1/73	3.43±0.21	3.49±0.21	3.52±0.18	3.68±0.18	3.58±0.21
EIC 1/73	4.83±0.39	3.90±0.33	4.92±0.29	4.29±0.33	3.92±0.29
<u><math>^{90}\text{Sr}</math></u>					
Mean (all results)	= 3.96±0.43				
LLL (av)	= 3.40±0.17; LLL/mean = 0.86 (1 sample)				
MCL (av)	= 4.03±0.19; MCL/mean = 1.02				
LFE (av)	= 3.54±0.10; LFE/mean = 0.89				
EIC (av)	= 4.37±0.49; EIC/mean = 1.10				

sistent and give a mean value,  $17.8 \pm 0.4$  dpm/g, with 10% spread. Laboratory comparisons for samples 2, 3, and 5 showed a greater spread than for sample 1, with EIC reporting results systematically higher than the mean of LLL, MCL, and LFE by 17-26%, although the relatively large error limits set by EIC encompass the mean of the other laboratories. The  $^{90}\text{Sr}$  data from all

laboratories showed acceptable agreement.

Another plutonium interlaboratory calibration was performed by distributing a standard solution to each laboratory. The results are listed in Table 120. The best value for the solution concentration is probably given by the mean derived from equally weighted values,  $1278 \pm 14$  dpm/ml, because the mass-spectrometric data from LLL and MCL

Table 120. Interlaboratory calibration,  $^{239}\text{Pu}$  standard solution (No. 1100).

Date	Concentration of $^{239,240}\text{Pu}$ , dpm/ml	Technique	Reference tracer
<u>LLL</u>			
6/4/73	1303±28	Direct assay, counter efficiency = 49.6%	Counting standard: H. E. $^{241}\text{Am II}$
6/4/73	1320±20	Pulse-height analysis	$^{242}\text{Pu}$ : Environmental standard
6/4/73	1265±5	Mass spectrometry	$^{242}\text{Pu}$ : Mass spectrometry standard
<u>MCL</u>			
10/9/73	1255±15	Pulse-height analysis	$^{236}\text{Pu}$
5/9/73	1272±6	Mass spectrometry	$^{242}\text{Pu}$
<u>LFE</u>			
4/25/73	1330±27	Pulse-height analysis	$^{236}\text{Pu}$
<u>LRE</u>			
6/29/73	1273±64	Pulse-height analysis	$^{236}\text{Pu}$ (HASL calibration)
<u>EIC</u>			
3/6/73	1207±54	Pulse-height analysis	$^{236}\text{Pu}$ (LLL calibration)
	Mean (equiv wt) = $1278 \pm 14$	$\sigma$ (single detn) = $\pm 39$	
		$\sigma$ (mean) = $\pm 14$	
	Mean (weighted) = $1270 \pm 4$	$\sigma$ (single detn) = $\pm 12$	
		$\sigma$ (mean) = $\pm 4$	

may have unrealistically low errors quoted. These errors are derived only from counting statistics and do not include any estimates of error from calibration of  $^{242}\text{Pu}$  tracers. Differences between pulse-height analysis of plutonium alpha activity and mass-spectrometric analyses with  $^{242}\text{Pu}$  tracer would include any error in the half-life of  $^{242}\text{Pu}$ . The total spread of the determinations was 9.7%.

Pairs of soil aliquots from common field samples were distributed to MCL, LFE, and EIC over the course of the analytical program. Thus, performance of a given laboratory relative to the others was monitored. In most cases, LFE and EIC results were compared with MCL results. It should be noted that in this comparison nonhomogeneity of any given sample could cause an observed difference between laboratories. However, we have some confidence in this question of homogeneity based upon results obtained by gamma-counting  $^{137}\text{Cs}$ . Analysis of the data for 24 pairs of soil aliquots shows an estimated difference of 6% between duplicate soil aliquots which can be ascribed to lack of homogeneity.

Data for laboratory comparisons of  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$  results are given in Tables 121 and 122. Entries in these tables include measured concentrations and errors from each laboratory and a ratio of concentrations with the error on the ratio derived by propagating the measurement errors. Entries in Tables 121 and 122 in parentheses are results which have been discarded before calculating laboratory ratios. The ratios are listed again in Tables 123-126 according to laboratory and nuclide, along with a statistical analysis of each set. Loga-

rithms of the ratios were averaged to produce a mean value for a given set of data. The significance of a mean value differing from unity (i. e., indication of possible bias), was tested by calculating the standard deviation,  $s_{\bar{\mu}}$ , of the mean,  $\bar{\mu}$  (logarithmic mean), multiplying  $s_{\bar{\mu}}$  by a factor  $t$  which is based upon the 95% confidence level and is obtained from standard tables, and comparing the value of  $t \cdot s_{\bar{\mu}}$  with  $\bar{\mu}$ . If the logarithmic means exceeds  $t \cdot s_{\bar{\mu}}$ , the observed bias is said to be significant with a 95% level of confidence.

In the LFE/MCL comparisons, the plutonium results (Table 123) show that if one includes all samples (29), a mean laboratory ratio of  $1.06 \pm 0.04$  is calculated with no evidence for significant bias. If we exclude the two most deviant members of the set, a mean laboratory ratio of  $1.02 \pm 0.03$  is calculated; again, there is no evidence for significant bias. The  $^{90}\text{Sr}$  comparison (Table 124) shows a mean laboratory ratio (LFE/MCL) of  $0.943 \pm 0.033$  if one includes all samples; a statistical test indicates the bias is not significant in this set of data (the value of  $t \cdot s_{\bar{\mu}}$  exceeds that of  $\bar{\mu}$ ). If we exclude the two most deviant members of the set, a pair of ratios which are nearly twice the mean value, a mean laboratory ratio of  $0.901 \pm 0.012$  is calculated. This reduced set of ratios exhibits much less variation; statistically, the observed bias is significant at the 95% confidence level.

In the EIC/MCL comparisons, the plutonium data (Table 125) have had only one very low ratio excluded; the remainder produces a mean laboratory ratio of  $0.85 \pm 0.02$ , with statistically significant bias indicated. The range of values and



Table 121. Interlaboratory comparison,  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$  data for soil samples, LFE vs MCL.

Sample No.	Concentration of $^{239,240}\text{Pu}$ , dpm/g		LFE/MCL	Concentration of $^{90}\text{Sr}$ , dpm/g		LFE/MCL
	LFE data	MCL data		LFE data	MCL data	
<u>BELLE 100 profile</u>						
30-0834-02	524±21	480±10	1.09±0.05	1940±19	2140±39	0.91±0.02
33-0835-02	132±3 (196±8)	123±12 124±2 <sup>a</sup> 126±5 <sup>a</sup> Av 124±2	1.06±0.03	868±87	959±19 900±16 <sup>a</sup> 928±15 <sup>a</sup> Av 929±17	0.93±0.09
34-0836-02	20.3±0.2	19.7±2.2	1.03±0.11	515±5	586±8	0.88±0.01
35-0837-02	5.77±0.12 (15.4±0.5)	7.85±0.34 9.12±0.35 <sup>a</sup> 8.24±0.31 <sup>a</sup> Av 8.40±0.65	0.69±0.06	222±2	234±1 243±2 <sup>a</sup> 242±2 <sup>a</sup> Av 240±5	0.92±0.02
36-0838-02	1.87±0.06 (1.58±0.03)	2.15±0.11 2.27±0.15 Av 2.21±0.09	0.85±0.04	138±3	75.1±1.3 80.8±1.0 Av 78.0±4.0	1.77±0.10
38-0839-02	1.01±0.04 (1.49±0.03)	1.02±0.03 <sup>a</sup> 1.07±0.04 <sup>a</sup> (0.75±0.03) Av 1.04±0.03	0.97±0.05	31.5±0.3	33.6±0.4 35.0±0.4 <sup>a</sup> 34.8±0.4 <sup>a</sup> Av 34.5±0.3	0.91±0.01
39-0840-02	0.68±0.01	0.57±0.02 <sup>a</sup> 0.52±0.02 <sup>a</sup> (0.41±0.03) Av 0.54±0.03	1.26±0.07	13.1±0.1	13.0±0.1 13.6±0.2 <sup>a</sup> 13.3±0.2 <sup>a</sup> Av 13.3±0.2	0.98±0.01
40-0841-02	0.28±0.09	0.145±0.013 (0.064±0.015)	1.93±0.63	4.75±0.09	2.73±0.10 2.96±0.21 Av 2.85±0.16	1.67±0.10
41-0842-02	0.077±0.003	0.046±0.005 0.057±0.008 Av 0.052±0.008	1.48±0.23	1.44±0.72	1.42±0.71	1.01±0.07

<sup>a</sup>MCL replicates on 0835, 0837, 0839, and 0840 were determined from a new soil sample.

Table 121 (continued).

Sample No.	Concentration of $^{239,240}\text{Pu}$ , dpm/g			Concentration of $^{90}\text{Sr}$ , dpm/g		
	LFE data	MCL data	LFE/MCL	LFE data	MCL data	LFE/MCL
<u>CLARA 100 profile</u>						
30-0843-03	191±6	164±18	1.16±0.13	305±3	355±14	0.86±0.04
33-0844-03	163±15	143±12	1.14±0.14	247±5	255±6	0.97±0.03
34-0845-03	62.8±2.5	58.2±5.6	1.08±0.11	220±9	242±4	0.91±0.04
35-0846-03	15.8±0.5	14.2±1.0	1.11±0.09	125±6	138±1	0.91±0.05
					138±1	
					Av 138±1	
37-0847-03	3.69±0.15	3.57±0.19	1.03±0.09	150±5	166±1	0.90±0.03
39-0848-03	1.10±0.09	0.84±0.05	1.21±0.18	50.1±1.5	54.4±0.6	0.94±0.04
		0.99±0.08			51.9±0.7	
		Av 0.91±0.11			Av 53.2±1.8	
<u>DAISY 100 profile</u>						
30-0852-04	380±11	413±8	0.92±0.03	1400±30	1700±30	0.82±0.02
33-0853-04	91.5±3.7	86.6±5.8	1.06±0.08	431±9	509±8	0.85±0.02
34-0854-04	44.6±1.8	46.8±6.1	1.05±0.15	221±4	239±6	0.92±0.03
		38.5±1.7				
		Av 42.6±5.9				
35-0855-04	23.3±0.7	25.1±1.6	0.93±0.07		191±5	
36-0856-04	6.21±0.19	7.69±0.43	0.81±0.05	103±1	120±5	0.86±0.04
38-0857-04	2.97±0.06	2.52±0.19	1.18±0.09	71.7±3.6	73.8±2.5	0.97±0.06
39-0858-04	0.80±0.02	0.86±0.05	0.93±0.06	45.0±0.9	47.3±0.6	0.95±0.02
40-0859-04	0.33±0.01	0.33±0.03	1.00±0.10	37.2±0.4	41.9±0.4	0.89±0.01
		(0.57±0.16)				

Table 121 (continued).

Sample No.	Concentration of $^{239,240}\text{Pu}$ , dpm/g			Concentration of $^{90}\text{Sr}$ , dpm/g		
	LFE data	MCL data	LFE/MCL	LFE data	MCL data	LFE/MCL
<u>JANET surface samples</u>						
32-3793-10	37.7±1.5	36.0±0.4	1.05±0.04	115±2	153±3	0.75±0.02
JAN 051-000-015						
31-3850-10	79.9±3.2	71.1±0.7	1.12±0.05	302±6	358±9	0.84±0.03
JAN 066-000-005						
32-3856-10	45.3±2.3	39.3±0.4	1.15±0.06	196±2	211±7	0.93±0.03
JAN 069-000-015						
32-4514-10	39.5±2.0	38.2±0.7	1.03±0.05	136±4	150±5	0.91±0.04
JAN 084-000-015						
32-3922-10	49.0±1.0	54.0±0.5	0.91±0.02	271±5	336±9	0.81±0.03
JAN 101-000-015						
32-3926-10	49.0±1.5	48.0±2.0	1.02±0.05	215±11	232±7	0.93±0.06
JAN 103-000-015						

Table 122. Interlaboratory comparison,  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$  data for soil samples, EIC vs MCL.

Sample No.	Concentration of $^{239,240}\text{Pu}$ , dpm/g			Concentration of $^{90}\text{Sr}$ , dpm/g		
	EIC data	MCL data	EIC/MCL	EIC data	MCL data	EIC/MCL
<u>ALICE 100 profile</u>						
33-0826-01	58.0±2.7	58.7±2.9	0.99±0.07	290±14 299±6	336±3	0.88±0.03
34-0827-01	2.32±0.14	2.46±0.18 2.64±0.23 Av 2.55±0.16	0.91±0.08	96.9±7.2 90.7±3.6 84.6±3.2 Av 295±11	101±1	0.90±0.04
35-0828-01	0.65±0.06	0.66±0.03 0.65±0.05 Av 0.65±0.04	1.00±0.11	83.0±5.7 72.2±3.1 75.1±2.8 Av 90.7±3.6	89.2±0.6	0.86±0.04
37-0829-01	0.36±0.05	0.30±0.03	1.20±0.21	64.0±4.8 61.5±2.6 66.9±3.0 Av 76.8±3.2	74.8±0.4	0.86±0.05
39-0830-01	0.12±0.02	0.073±0.015	1.64±0.34	46.9±2.7 48.8±1.9 Av 64.1±3.6	50.9±0.3	0.94±0.05
40-0831-01	0.09±0.03	0.092±0.018	0.98±0.38	30.2±2.2 Av 47.9±2.3	37.0±0.3	0.82±0.06
<u>IRENE 050 profile</u>						
30-4720-09	23.3±1.0	20.3±1.8	1.15±0.11	93.1±1.0	105±4	0.89±0.04
33-4721-09	24.1±1.5	17.2±1.2	1.40±0.13	82.5±0.9	87.4±3.3	0.94±0.04
34-4722-09	14.2±0.6	16.2±1.2	0.88±0.08	76.4±0.8	90.2±2.5	0.85±0.03
35-4723-09	16.5±0.7	21.4±0.3	0.77±0.04	95.4±1.0	114±5	0.84±0.04
37-4724-09	15.2±0.7	19.8±0.3	0.77±0.04	85.0±0.9	114±2	0.75±0.02
39-4725-09	24.1±1.0	26.3±0.3	0.92±0.04	104±1	107±6	0.97±0.05
40-4726-09	16.8±0.9	19.3±0.3	0.87±0.05	90.3±1.0	91.3±7.9	0.99±0.09
41-4727-09	7.32±0.52	7.73±0.71	0.95±0.11	53.4±0.6	69.0±2.5	0.77±0.03
42-4728-09	4.09±0.29	6.03±0.60	0.68±0.08	57.2±0.6	54.1±2.5	1.06±0.05

Table 122 (continued).

Sample No.	Concentration of $^{239, 240}\text{Pu}$ , dpm/g			Concentration of $^{90}\text{Sr}$ , dpm/g		
	EIC data	MCL data	EIC/MCL	EIC data	MCL data	EIC/MCL
<u>PEARL 101 profile</u>						
33-0876-17	269±5 206±5 289±7	350±33 356±9	0.72±0.17	116±1 115±1	149±7 122±21	0.85±0.12
	Av 255±43	Av 353±9		Av 116±1	Av 136±19	
34-0877-17	11.0±0.5 12.6±0.5	11.4±0.9	1.04±0.13	47.2±0.5	51.6±2.1	0.91±0.04
	Av 11.8±1.1					
35-0878-17	9.82±0.47 (4.49±0.30) (5.91±0.36)	12.8±1.2 11.8±0.8	0.80±0.06	21.6±0.4 25.9±0.3	68.9±2.7 60.1±1.0	0.37±0.06
		Av 12.3±0.7		Av 23.8±3.0	Av 64.5±6.2	
<u>IRENE 100 profile</u>						
33-0861-09	9.05±0.27 8.79±0.46 7.96±0.50	231±17 219±11	0.038±0.003	206±2	315±8 315±9	0.65±0.02
	Av 8.60±0.57	Av 225±9			Av 315±6	
34-0862-09	267±9 269±7	375±29 348±14	0.74±0.04	672±7 570±11	509±12 522±18	1.20±0.14
	Av 268±6	Av 362±19		Av 621±72	Av 516±9	
35-0863-09	1486±18	2100±120 1920±90	0.74±0.04	3980±80	2960±50 2950±220	1.34±0.04
		Av 2010±130			Av 2960±50	
37-0864-09	1367±18	1900±110 1760±35	0.75±0.04	2260±23 1967±20	977±32 1420±90	2.05±0.35
		Av 1830±90		Av 2115±210	Av 1030±140	
39-0865-09	535±16	719±40 691±32	0.76±0.04	1135±11 1075±21	731±12 697±20	1.55±0.08
		Av 705±25		Av 1105±40	Av 714±24	
40-0866-09	305±9	385±25 379±17	0.80±0.04	1785±18 1809±36	1420±14 1140±18	1.41±0.22
		Av 382±14		Av 1800±20	Av 1280±200	

Table 122 (continued).

Sample No.	Concentration of <sup>239, 240</sup> Pu, dpm/g		EIC/MCL	Concentration of <sup>90</sup> Sr, dpm/g		EIC/MCL
	EIC data	MCL data		EIC data	MCL data	
<u>JANET 100 profile</u>						
30-0978-10	128±4 129±2 Av 128±2	147±5	0.87±0.04	1027±8 1043±8 Av 1035±8	1220±20 (332±4)	0.85±0.02
33-0979-10	44.2±1.5 42.5±0.8 Av 43.3±0.9	47.0±1.7	0.92±0.03	498±5 475±5 Av 486±12	471±9	1.03±0.03
34-0980-10	5.43±0.37 4.76±0.18 Av 5.10±0.33	5.45±0.25	0.94±0.07	170±3	168±1	1.01±0.02
<u>PEARL 100 profile</u>						
30-0867-17	18.1±0.8 18.9±0.8 Av 18.5±0.6	22.8±1.1	0.81±0.05	25.2±1.2 24.4±1.0 Av 24.8±0.6	23.3±2.1 (7.92±1.74)	1.06±0.10
33-0868-17	9.03±0.43 10.69±0.58 Av 9.86±0.83	8.65±0.31	1.14±0.10	25.5±1.1 18.2±0.8 Av 21.8±5.2	18.0±0.8 19.8±1.5 Av 18.9±1.3	1.15±0.29
34-0869-17	8.45±0.48 11.89±0.84 Av 10.17±1.72	8.91±0.41	1.14±0.20	31.7±1.3	33.5±2.8	0.95±0.09
<u>SALLY 200 profile</u>						
30-0884-19	9.09±0.48 9.09±0.27 Av 9.09±0.27	11.1±0.4	0.82±0.04	71.5±2.3	71.2±0.9	1.00±0.03
30-0885-19	12.75±0.73 12.75±0.37 Av 12.75±0.37	12.9±0.6	0.99±0.05	104±2	81±5 (143±5)	1.29±0.08

Table 122 (continued).

Sample No.	Concentration of $^{239,240}\text{Pu}$ , dpm/g			Concentration of $^{90}\text{Sr}$ , dpm/g		
	EIC data	MCL data	EIC/MCL	EIC data	MCL data	EIC/MCL
<u>ALICE 024 profile</u>						
30-2044-01	148±5	208±11	0.71±0.04	1230±12	1360±41	0.90±0.03
33-2045-01	377±12	637±70	0.59±0.07	2210±22	2500±98	0.88±0.04
34-2046-01	109±4	139±7	0.78±0.05	751±8	797±25	0.94±0.03
<u>IRENE 047 profile</u>						
30-4693-09	50.6±1.0	65.2±3.2	0.78±0.04	236±2 179±2 Av 208±40	205±7	1.01±0.20
33-4694-09	55.0±1.0	82.6±3.9	0.67±0.03	189±2 169±2 Av 179±14	215±7	0.83±0.07
34-4695-09	50.0±0.9	77.4±7.1	0.65±0.06	159±2 173±2 Av 166±10	82.3±5.6	2.02±0.18
35-4696-09	57.6±1.2	88.7±5.0	0.65±0.04	265±3 236±2 Av 250±20	95.0±5.1	2.63±0.25
34-4697-09	89.4±2.1	141±9	0.63±0.04	300±3 320±3 Av 310±14	122±7	2.54±0.19
39-4698-09	294±6	379±33	0.78±0.07	576±6 496±5 Av 536±57	592±27	0.91±0.11
40-4699-09	197±4	280±16	0.70±0.04	402±4 322±3 Av 362±57	433±21	0.84±0.14
41-4700-09	139±3	219±10	0.63±0.03	270±3 226±2 Av 248±30	370±13	0.67±0.08
42-4701-09	175±4 189±5 Av 182±5	272±14	0.67±0.04	283±3 222±2 Av 252±43	312±11	0.81±0.14

Table 123. Interlaboratory comparison, Enewetak soil samples.

Ratios of measured $^{239,240}\text{Pu}$ concentrations, LFE/MCL			
<u>BELLE 100 profile</u>	1.09±0.05	<u>JANET surface</u>	1.05±0.04
	1.06±0.03		1.12±0.05
	1.03±0.11		1.15±0.06
	0.69±0.06		1.03±0.05
	0.85±0.04		0.91±0.02
	0.97±0.05		1.02±0.05
	1.26±0.07		
	(1.93±0.63)	<u>DAISY 100 profile</u>	0.92±0.03
	(1.48±0.23)		1.06±0.08
			1.05±0.15
<u>CLARA 100 profile</u>	1.16±0.13		0.93±0.07
	1.14±0.14		0.81±0.05
	1.08±0.11		1.18±0.09
	1.11±0.09		0.93±0.06
	1.03±0.09		1.00±0.10
	1.21±0.18		

No.	= 29	27
$\bar{\mu}$	= 0.05731	0.02268
$s_1$	= 0.1846	0.1315
$s_1^2$	= 0.03408	0.01729
$s_{\bar{\mu}}$	= 0.03428	0.02530
$t \cdot s_{\bar{\mu}}$	= 0.07010	0.05192
$e^{\bar{\mu}}$	= 1.06±0.04	1.02±0.03
Range	0.69-1.93	0.69-1.26
Significant bias?	No	No



Table 124. Interlaboratory comparison, Enewetak soil samples.

Ratios of measured <sup>90</sup> Sr concentrations, LFE/MCL			
<u>BELLE 100 profile</u>	0.91±0.02	<u>JANET surface</u>	0.75±0.02
	0.93±0.09		0.84±0.03
	0.88±0.01		0.93±0.03
	0.92±0.02		0.91±0.04
	(1.77±0.10)		0.81±0.03
	0.91±0.01		0.93±0.06
	0.98±0.01		
	(1.67±0.10)	<u>DAISY 100 profile</u>	0.82±0.02
	1.01±0.07		0.85±0.02
			0.92±0.03
<u>CLARA 100 profile</u>	0.86±0.04		0.86±0.04
	0.97±0.03		0.97±0.06
	0.91±0.04		0.95±0.02
	0.91±0.05		0.89±0.01
	0.90±0.03		
	0.94±0.04		

No.	= 28	26
$\bar{\mu}$	= - 0.05863	-0.1048
$s_1$	= 0.1811	0.06548
$s_1^2$	= 0.03280	0.004287
$s_{\bar{\mu}}$	= 0.03423	0.01284
$t \cdot s_{\bar{\mu}}$	= 0.07010	0.02640
$e^{\bar{\mu}}$	= 0.943±0.033	0.901±0.012
Range	= 0.75-1.77	0.75-1.01
Significant bias?	No	Yes

Table 125. Interlaboratory calibration, Enewetak soil samples.

Ratios of measured <sup>239,240</sup> Pu concentrations, EIC/MCL			
<u>ALICE 100 profile</u>	0.99±0.07	<u>JANET 100 profile</u>	0.87±0.04
	0.91±0.08		0.92±0.03
	1.00±0.11		0.94±0.07
	1.20±0.21		
	1.64±0.34	<u>SALLY 200 profile</u>	0.82±0.04
	0.98±0.38		0.99±0.05
<u>ALICE 024 profile</u>	0.71±0.04	<u>PEARL 100 profile</u>	0.81±0.05
	0.59±0.07		1.14±0.10
	0.78±0.05		1.14±0.20
<u>PEARL 101 profile</u>	0.72±0.17	<u>IRENE 050 profile</u>	1.15±0.11
	1.04±0.13		1.40±0.13
	0.80±0.06		0.88±0.08
			0.77±0.04
<u>IRENE 047 profile</u>	0.78±0.04		0.77±0.04
	0.67±0.03		0.92±0.04
	0.65±0.06		0.87±0.05
	0.65±0.04		0.95±0.11
	0.63±0.04		0.68±0.08
	0.78±0.07		
	0.70±0.04	<u>IRENE 100 profile</u>	(0.038±0.003)
	0.63±0.03		0.74±0.04
	0.67±0.04		0.74±0.04
			0.75±0.04
			0.76±0.04
			0.80±0.04

No. = 43  
 $\bar{\mu}$  = 0.1670  
s = 0.2223  
s<sup>2</sup> = 0.0491  
 $s_{\bar{\mu}}$  = 0.03390  
t ·  $s_{\bar{\mu}}$  = 0.06846  
e $\bar{\mu}$  = 0.85±0.02

Range 0.59-1.64

Significant bias? Yes

Table 126. Interlaboratory calibration, Enewetak soil samples.

Ratios of measured <sup>90</sup> Sr concentrations, EIC/MCL			
<u>ALICE 100 profile</u>	0.88±0.03	<u>IRENE 100 profile</u>	0.65±0.02
	0.90±0.04		1.20±0.14
	0.86±0.04		1.34±0.04
	0.86±0.05		(2.05±0.35)
	0.94±0.05		1.55±0.08
	0.82±0.06		1.41±0.22
<u>ALICE 024 profile</u>	0.90±0.03	<u>IRENE 047 profile</u>	1.01±0.20
	0.88±0.04		0.83±0.07
	0.94±0.03		(2.02±0.18)
			(2.63±0.25)
<u>PEARL 101 profile</u>	0.85±0.12		(2.54±0.19)
	0.91±0.04		0.91±0.11
	(0.37±0.06)		0.84±0.14
			0.67±0.08
<u>JANET 100 profile</u>	0.85±0.02		0.81±0.14
	1.03±0.03		
	1.01±0.02	<u>IRENE 050 profile</u>	0.89±0.04
			0.94±0.04
<u>PEARL 100 profile</u>	1.06±0.10		0.85±0.03
	1.15±0.29		0.84±0.04
	0.95±0.09		0.75±0.02
			0.97±0.05
<u>SALLY 200 profile</u>	1.00±0.03		0.99±0.09
	1.29±0.08		0.77±0.03
			1.06±0.05
No.	= 44	39	
$\bar{\mu}$	= -0.0004	-0.0601	
$s_1$	= 0.3486	0.1837	
$s_1^2$	= 0.1215	0.03375	
$s_{\bar{\mu}}$	= 0.05256	0.02942	
$t \cdot s_{\bar{\mu}}$	= 0.1061	0.05942	
$e^{\bar{\mu}}$	= 1.00±0.05	0.94±0.03	
Range	0.37-2.63	0.65-1.55	
Significant bias?	No	Yes	

the standard deviation of a single member of the set are both comparable with values derived for the LFE/MCL plutonium comparisons; however, this EIC/MCL set exhibits significant bias. The EIC/MCL  $^{90}\text{Sr}$  comparison (Table 126) is characterized by somewhat greater variation in values than observed in the preceding tables. If we include all values listed in Table 126, the mean laboratory ratio is  $1.00 \pm 0.05$ , with no indication of significant bias. If we exclude the five most deviant ratios, the range of values and the standard deviation of a single member of the set are reduced to values comparable to those encountered in the other comparisons. The mean laboratory ratio for this reduced set is  $0.94 \pm 0.03$ , with statistically significant bias indicated.

Of the four comparisons just discussed, only the LFE/MCL plutonium data showed both satisfactory mean values and no evidence for bias. If one wants to derive a most consistent set of data, the derived values for interlaboratory bias can be used to adjust all of the plutonium and strontium soil data to a common calibration. However, considering the urgency for completion of the survey report and the general nature of the schedule of the analytical program, we have not made any arbitrary adjustment of data. If one considers  $\leq 10\%$  bias as acceptable for the purposes of this survey, only the EIC/MCL plutonium comparison remains a problem. Although the data presented in this report are as reported by each laboratory, we have identified the source of wet-chemistry analyses for each sample in the general data bank given in Appendix II, if there is need for data adjustment.

### Marine Samples

Among the marine samples, inter-laboratory comparison was made by distributing aliquots of dried and homogenized material to more than one laboratory. These comparisons were made to check laboratory results for bias, recognizing that some samples may present difficulties due to incomplete homogenization, e.g., eviscerated whole fish which show pieces of bone, etc. Comparisons between LRE and MCL for  $^{239,240}\text{Pu}$ ,  $^{90}\text{Sr}$ , and  $^{55}\text{Fe}$  are listed in Table 127. In many cases a comparison is labeled either consistent or inconsistent. Consistent comparisons usually involve an upper limit set by one laboratory and an actual measurement by the other laboratory, where the measured concentration is lower than the upper limit. Those comparisons where a measured concentration exceeded an upper limit are labeled inconsistent. The results are summarized in Table 128.

The effectiveness of this comparison is reduced because  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$  results from MCL for many samples are upper-limit values. Positive signals from both laboratories were obtained for only a few samples. One factor which led to this situation was generally low concentrations of plutonium and strontium in marine samples; given additional time and effort, additional measurements for interlaboratory calibration would be appropriate.

For  $^{239,240}\text{Pu}$ , five valid comparisons gave a mean laboratory ratio, LRE/MCL =  $1.01^{+0.06}_{-0.05}$ , with no evidence of significant bias. There were four comparisons where the results were inconsistent; the worst of these cases was for 09-0381-37

Table 127. Interlaboratory comparison, marine samples - LRE and MCL.

Sample		Concentration of $^{239,240}\text{Pu}$ , dpm/g dry	Concentration of $^{90}\text{Sr}$ , dpm/g dry	Concentration of $^{55}\text{Fe}$ , dpm/g dry
08-0787-10 Tridacna, mantle	LRE	0.129±0.007	LRE 0.16±0.04	LRE 4.49±0.06
	MCL	0.122±0.017	MCL <0.37	MCL 4.65±0.10
		0.130±0.007 0.126±0.007 av LRE/MCL = 1.02±0.07	Consistent	4.57±0.11 av MCL 4.24±0.93 4.78±0.32 4.51±0.73 av LRE/MCL = 1.01±0.16
09-0427-20 Goatfish, eviscerated whole	LRE	0.07±0.007	LRE 0.123±0.012	LRE 21.7±0.2
	MCL	<0.036 Inconsistent	MCL <0.55 Consistent	MCL 24.9±2.5 LRE/MCL = 0.87±0.09
09-0374-37 Goatfish, eviscerated whole	LRE	0.013±0.003	LRE 0.029±0.008	LRE 13.0±0.1
	MCL	<0.019	MCL <0.66	MCL (54.9±3.7)
		Consistent	Consistent	13.9±2.1 13.0±0.1 av 14.4±1.6 12.8±1.4 13.6±1.1 av LRE/MCL = 0.96±0.08
09-0376-37 Goatfish, eviscerated whole	LRE	0.026±0.013	LRE 0.090±0.011	LRE 5.21±0.06
	MCL	<0.016 Consistent	MCL 0.58±0.08 LRE/MCL = 0.16±0.03	MCL 12.0±1.4 12.7±1.9 (57.9±4.8) 11.5±1.6 12.1±0.60 av LRE/MCL = 0.43±0.02
09-0381-37 Convict surgeon, eviscerated whole	LRE	0.406±0.090	LRE <0.07	LRE 1.49±0.10
	MCL	0.311±0.079 0.358±0.084 av <0.013 <0.005 Inconsistent	MCL <0.27	MCL <4.3
		Inconsistent	Consistent	Consistent
09-0383-37 Convict surgeon, eviscerated whole	LRE	0.088±0.008	LRE <0.02	LRE 0.68±0.03
	MCL	<0.014 Inconsistent	MCL <0.71 Consistent	MCL <5.4 Consistent
09-0385-37 Convict surgeon, eviscerated whole	LRE	0.040±0.004	LRE 0.03±0.01	LRE 0.60±0.08
	MCL	<0.016 Inconsistent	MCL <0.68 Consistent	MCL <5.6 Consistent

Table 127 (continued).

Sample		Concentration of $^{239,240}\text{Pu}$ , dpm/g dry		Concentration of $^{90}\text{Sr}$ , dpm/g dry		Concentration of $^{55}\text{Fe}$ , dpm/g dry
09-0493-02	LRE	0.141±0.024	LRE	0.300±0.020	LRE	18.9±0.3
Mullet,						16.8±0.2    17.9±1.5 av
eviscerated whole	MCL	0.031±0.003	MCL	0.394±0.034	MCL	17.9±1.0
		LRE/MCL = 4.5±0.9		LRE/MCL = 0.76±0.08		LRE/MCL = 1.00±0.10
09-0497-02	LRE		LRE	0.443±0.013	LRE	21.8±0.20
Mullet,	MCL	0.042±0.008	MCL	0.654±0.044	MCL	21.7±0.54
eviscerated whole				LRE/MCL = 0.68±0.05		LRE/MCL = 1.00±0.03
09-0498-02	LRE	19.5±0.6	LRE	17.9±0.2	LRE	184±1
Mullet, viscera	MCL	18.6±0.7	MCL	< 2.6	MCL	402±6
		LRE/MCL = 1.05±0.05		Inconsistent		LRE/MCL = 0.46±0.01
09-0499-02	LRE	0.013±0.003	LRE	0.049±0.015	LRE	4.61±0.04
Mullet, muscle	MCL	0.012±0.002	MCL	< 0.22	MCL	18.7±0.5
		LRE/MCL = 1.12±0.31		Consistent		LRE/MCL = 0.25±0.01
09-0448-09	LRE		LRE		LRE	104±1
Snapper	MCL	0.146±0.012	MCL	1.84±0.08	MCL	170±4
						LRE/MCL = 0.61±0.02
09-0451-09	LRE	0.045±0.007	LRE	0.097±0.016	LRE	33.5±0.4
Mullet, muscle	MCL	0.54±0.08	MCL	< 0.33	MCL	39.2±1.6
		LRE/MCL = 0.083±0.018		Consistent		LRE/MCL = 0.85±0.04
09-0453-09	LRE	0.415±0.031	LRE	2.05±0.03	LRE	26.9±0.2
Mullet	MCL	0.388±0.028	MCL	1.96±0.10	MCL	37.4±1.4
		LRE/MCL = 1.07±0.11		LRE/MCL = 1.05±0.06		LRE/MCL = 0.72±0.03
09-0511-10	LRE		LRE	0.022±0.004	LRE	3.08±0.03
Mullet,	MCL	< 0.064	MCL	< 0.68	MCL	< 4.0
eviscerated whole				Consistent		Consistent
09-0575-20	LRE		LRE		LRE	10.4±0.1
Snapper, muscle	MCL	< 0.004	MCL	< 0.24	MCL	13.3±0.9
						LRE/MCL = 0.78±0.05

Table 127 (continued).

Sample	Concentration of $^{239,240}\text{Pu}$ , dpm/g dry		Concentration of $^{90}\text{Sr}$ , dpm/g dry		Concentration of $^{55}\text{Fe}$ , dpm/g dry	
09-0516-21	LRE	< 0.13	LRE	0.224±0.021	LRE	5.39±0.04
Convict surgeon, eviscerated whole	MCL	0.037±0.010 Consistent	MCL	< 0.28 Consistent	MCL	4.63±0.42 LRE/MCL = 1.16±0.10
09-0481-36	LRE		LRE		LRE	191±2
Skipjack, light muscle	MCL	< 0.009	MCL	< 0.22	MCL	203±3 LRE/MCL = 0.94±0.02
09-0685-37	LRE	< 0.043	LRE	0.05±0.02	LRE	4.17±0.05
Parrotfish, muscle	MCL	< 0.038 Consistent	MCL	< 0.54 Consistent	MCL	7.45±1.79 LRE/MCL = 0.56±0.13
09-0687-37	LRE	0.40±0.05	LRE	0.16±0.04	LRE	289±3
Parrotfish, viscera	MCL	0.49±0.09 LRE/MCL = 0.82±0.19	MCL	< 0.99 Consistent	MCL	473±32 LRE/MCL = 0.61±0.04
09-0531-47	LRE	0.016±0.003	LRE	< 0.10	LRE	116±2
Skipjack, light muscle	MCL	< 0.014 < 0.011 Consistent	MCL	< 0.17 Consistent	MCL	124±11 av 131±2 142±1 137±3 142±5 av 147±4 LRE/MCL = 0.87±0.10
09-0693-54	LRE	< 0.0025	LRE	< 0.14	LRE	6.88±0.10
Yellowfin tuna, light muscle	MCL	< 0.0048 Consistent	MCL	< 0.75 Consistent	MCL	8.84±0.13 LRE/MCL = 0.78±0.02

Table 128. Interlaboratory calibration, marine samples, ratios of concentrations, LRE/MCL.

$^{239,240}\text{Pu}$	$^{90}\text{Sr}$	$^{55}\text{Fe}$	$^{55}\text{Fe}$
1.02±0.07	(0.16±0.03)	1.01±0.16	0.85±0.04
(4.5±0.9)	0.76±0.08	0.87±0.09	0.72±0.03
1.05±0.05	0.68±0.05	0.96±0.08	0.78±0.05
1.12±0.31	1.05±0.06	0.43±0.02	1.16±0.10
(0.083±0.018)		1.00±0.10	0.94±0.02
1.07±0.11		1.00±0.03	0.56±0.13
0.82±0.19		0.46±0.01	0.61±0.04
		0.25±0.01	0.87±0.10
		0.61±0.02	0.78±0.02
No. = 5	3	18	
$\bar{\mu}$ = 0.01023	-0.2038	-0.3214	
s = 0.1215	0.2257	0.3855	
$s^2$ = 0.01476	0.05093	0.1486	
$s_{\bar{\mu}}$ = 0.05434	0.1303	0.09086	
$t \cdot s_{\bar{\mu}}$ = 0.1397	0.560	0.1909	
$e^{\bar{\mu}}$ = 1.01 <sup>+0.06</sup> <sub>-0.05</sub>	0.82 <sup>+0.11</sup> <sub>-0.10</sub>	0.72±0.07	
No significant bias	No significant bias	Significant bias	

(convict surgeon, eviscerated whole) where the observed plutonium concentration at LRE was  $0.36 \pm 0.08$  dpm/g and upper limits set at MCL were  $<0.013$  and  $<0.005$  dpm/g. Duplicate samples were run at both laboratories. There is no obvious explanation for this discrepancy. Various possibilities, such as a nonhomogeneous sample, mixup in sample designation, plutonium contamination in the laboratory, or loss of plutonium in chemistry may be invoked as explanations. In the other three instances, measured plutonium concentration values from LRE exceeded upper limits set at MCL by factors of 2, 2.5, and 6.

For  $^{90}\text{Sr}$ , much of the data were consistent but very often LRE reported a low-level measurement while MCL tended to report an upper limit at some higher concentration. Four valid comparisons were obtained, three of which gave moderate agreement between laboratories. The laboratory ratio, LRE/MCL, derived from these three samples was  $0.82 \pm 0.11$ ; the evidence is insufficient for determining significant bias. For the fourth sample, a laboratory ratio of  $0.16 \pm 0.03$  was obtained. Also, one sample (09-0498-02, mullet viscera) produced inconsistent results; LRE reported  $17.9 \pm 0.2$  dpm/g  $^{90}\text{Sr}$  and MCL set a



limit of < 2.6 dpm/g. Comments regarding possible explanations for inconsistent results as stated in the previous paragraph apply here as well.

For  $^{55}\text{Fe}$ , the largest set of interlaboratory comparison data for marine samples was obtained. From 18 samples, a mean laboratory ratio of LRE/MCL =  $0.72 \pm 0.07$  was obtained, with indication of significant bias. No inconsistent results were observed. Additional effort on calibration of detectors at LRE and MCL for counting 6-keV x rays from  $^{55}\text{Fe}$  decay is going on at this time. Relative to calibration data included with a standard  $^{55}\text{Fe}$  solution obtained from Amersham, the MCL detector is in agreement, while the LRE detector calibration is apparently low. Although this investigation of interlaboratory bias is not finished, the data could be made more self-consistent (and, apparently, more accurate) by adjusting the LRE  $^{55}\text{Fe}$  results upward by  $1/0.72$  (or 1.39). Incidentally, interlaboratory calibrations between LFE and MCL carried out in 1969 and 1971 for other programs have shown good agreement for  $^{55}\text{Fe}$  results (LFE/MCL = 0.968). However, data for  $^{55}\text{Fe}$  in marine samples from LRE listed in the data bank (Appendix II) have not been given any arbitrary adjustment because: (1) The problem has not been entirely resolved as to which measurements are most accurate, and (2)  $^{55}\text{Fe}$  plays an insignificant role in dose estimates for the marine food chain; the major sources of biological dose in this pathway are  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{90}\text{Sr}$ . We concluded that adjustment of the LRE  $^{55}\text{Fe}$  data would cause no detectable

change in dose estimates from the marine pathway.

Comparison was made between LFE and MCL on four marine samples; the results are listed in Table 129. The first sample in the table (08-0782-20, viscera and gut contents of sea cucumber) was judged to be quite nonhomogeneous, based upon the  $^{90}\text{Sr}$  data and the amount of coral found as gut content. The second sample (09-0393-33, convict surgeon, eviscerated whole) did not produce agreement between laboratories; concentrations of  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$  measured at LFE are factors of 5-7 times higher than those measured at MCL. Consistent results were observed for the last two entries for  $^{239,240}\text{Pu}$  and  $^{90}\text{Sr}$  and moderately good agreement was obtained between laboratories for  $^{55}\text{Fe}$ .

#### Replicate Analyses

A question of importance to the analytical program was whether soil samples, having been dried, ground, and blended, were homogeneous enough to allow meaningful comparison of analyses from separate aliquots of finely divided soil. In order to investigate this question, about 100 pairs of replicate soil samples were prepared and gamma-counted. Measured concentrations of  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  in each pair were compared. From this set of data, a group of 24 pairs was selected where both samples of a given pair were counted with the same Ge(Li) detector system. Estimates of the variance for this set of 24 replicate analyses were calculated in two different ways. The first,  $s_1^2$ , is derived from the spread of replicate measurements and is calculated as indicated in Table 130.

Table 129. Interlaboratory comparison, marine samples - LFE and MCL.

Sample		Concentration of $^{239,240}\text{Pu}$ , dpm/g dry	Concentration of $^{90}\text{Sr}$ , dpm/g dry	Concentration of $^{55}\text{Fe}$ , dpm/g dry
08-0782-20	LFE	1.18±0.01	LFE 4.15±0.17	LFE 1.77±0.30
Sea cucumber,	MCL	0.93±0.06		
viscera and gut		1.42±0.05    1.18±0.35 av	MCL 1.85±0.26; 0.12±0.03	MCL < 19.2
contents		LFE/MCL = 1.00±0.30	LFE/MCL = 2.2±0.3; 35	LFE/MCL: Consistent
09-0393-33	LFE	0.096±0.003	LFE 0.52±0.02	LFE 4.02±0.28
Convict surgeon,	MCL	0.013±0.002	MCL < 0.77; 0.11±0.02	MCL < 8.5
eviscerated whole		LFE/MCL = 7.2±1.1	LFE/MCL = 4.7±0.9	LFE/MCL: Consistent
09-0300-43	LFE	0.0046±0.0006	LFE 0.20±0.01	LFE 49.2±0.5
Goatfish,	MCL	< 0.032	MCL < 0.85	MCL 53.3±4.0
eviscerated whole		LFE/MCL: Consistent	LFE/MCL: Consistent	LFE/MCL = 0.92±0.07
09-0345-43	LFE	0.011±0.001	LFE 0.15±0.01	LFE 9.3±0.6
Mullet,	MCL	< 0.024	MCL < 0.65	MCL 13.7±2.7
eviscerated whole		LFE/MCL: Consistent	LFE/MCL: Consistent	LFE/MCL = 0.68±0.14

Table 130. Gamma-spectroscopy replication, A vs D samples. Two soil aliquots counted with same detector system.

		<sup>60</sup> Co		<sup>137</sup> Cs	
		Uncorrected	Corrected	Uncorrected	Corrected
$s_1^2 = \frac{\sum \left[ \frac{2(x_i - y_i)}{(x_i + y_i)} \right]^2}{2n}$	=	0.00408	0.00464	0.00475	0.00468
$s_1$	=	0.0639	0.0681	0.0689	0.0684
$s_2^2 = \frac{\sum (\sigma_{x_i}^2 + \sigma_{y_i}^2)}{2n}$	=	0.00321		0.00119	
$s_2$	=	0.0567		0.0345	
$n$	=	24		24	
$s_1^2/s_2^2$	=	1.27	1.44	4.0	3.9
$F$	=	2.0		2.0	
$\left[ s_1^2 - s_2^2 \right]^{1/2}$	=	0.030		0.060	0.059

The second,  $s_2^2$ , is derived from experimental uncertainties quoted for each measurement ( $\sigma_{x_i}$  and  $\sigma_{y_i}$  are expressed as percentage uncertainty) and is calculated as indicated in Table 130.

The two estimates of variance are compared to see if there is a statistically significant difference between them. Should this be the case — and assuming that  $s_1^2$  will be greater than  $s_2^2$  — the source of the difference can be ascribed to nonhomogeneity of samples. If the samples are homogeneous,  $s_1^2$  and  $s_2^2$  should be the same statistically. In order to test this question, we perform an F-test on the ratio,  $F = s_1^2/s_2^2$ , where  $s_1^2$  has  $n_1$  degrees of freedom and  $s_2^2$  has  $n_2$  degrees of freedom. Standard

tables of values for F as a function of  $n_1$ ,  $n_2$ , and confidence level are available. Should the ratio,  $s_1^2/s_2^2$ , exceed a value of F extracted from the table, the estimates of variance differ in a statistically significant way.

Tests were made with our data at a 95% confidence level. Results are shown in Table 130. For <sup>60</sup>Co, with data in the first column marked "Uncorrected," we find that  $s_1^2$  values do not differ significantly.

A refinement to the data was added because some of the replicate pairs were packaged in different-sized cans due to lack of sample. The counting results for these pairs were corrected for any difference in counting efficiency between

can sizes observed when a series of standard soil samples was counted at the beginning of the program. The data, with these corrections, are listed in columns labeled "Corrected." For  $^{60}\text{Co}$ , there was little change in the result; in fact, corrected results showed slightly greater imprecision.

The  $^{137}\text{Cs}$  data, which exhibit greater precision in experimental uncertainties due to higher concentrations than the  $^{60}\text{Co}$  data, indicate a statistically significant difference in estimates of variance. Standard deviation for a single pair in the set is 6.9%, based upon the spread of duplicates; standard deviation based upon quoted experimental uncertainties is 3.5%. An estimate of imprecision due to non-homogeneity is derived by taking the square root of  $(s_1^2 - s_2^2)$ . We obtain an average contribution of 6% imprecision in duplicates due to sample inhomogeneity. There is no difference between results for corrected and uncorrected data. Thus, we have an estimate of effectiveness in the sample homogenization procedure.

#### Measurement of $^{241}\text{Am}$ Concentration — Alpha Detection vs Gamma Detection

In addition to measurement of  $^{241}\text{Am}$  content in every sample by gamma assay, wet-chemistry analyses were performed on a selected number of samples, and  $^{241}\text{Am}$  concentrations were determined by alpha counting. In practice,  $^{243}\text{Am}$  tracer is added to permit measurement of chemical yield, and a 241/243 activity ratio is measured by pulse-height analysis techniques. These measurements served two purposes: (1) To permit com-

parison of two different methods for measuring  $^{241}\text{Am}$ , and, for other samples, (2) to provide greater sensitivity for detecting  $^{241}\text{Am}$  than available from routine gamma counting.

Comparison data for 24 soil samples are shown in Table 131. A mean value for the ratio between wet-chemistry determination and gamma counting, MCL/LLL, is  $1.20 \pm 0.05$ , with evidence for significant bias. Since relatively large errors, 25-35%, were quoted for about half of these samples, we have calculated a value for the MCL/LLL ratio,  $1.21 \pm 0.04$ , based upon samples with more precise  $^{241}\text{Am}$  data (first 11 entries in table). As with the entire set, there is evidence for significant bias. Comparison of a variance for this set of 11 calculated from variation of samples from the mean ( $s_1^2$ ) with a variance calculated from experimental uncertainties quoted for individual measurements shows no significant difference between them (based upon an F test at a 95% confidence level). Thus, the variation of values in this set of 11 results can be accounted for by experimental uncertainties.

Accurate determination of  $^{241}\text{Am}$  in soil samples of nominal 300-g mass and at counting geometries (flush against the detector housing face) typical of this program's gamma spectrometry is judged to be difficult. Questions of self-absorption, changes in geometry due to settling of soil in the can, incomplete grinding of certain samples, lack of homogeneity, and other problems can be raised in discussing ultimate accuracy of the method. Chemical isolation of americium and assay via alpha pulse-height analysis is expected to be more accurate for this kind of sample. Thus, it appears that

Table 131. Comparison of alpha count and gamma-spectrometric analyses for  $^{241}\text{Am}$  in separate batches of soil (MCL vs LLL).

Sample No.	Alpha count (MCL), dpm/g	Gamma spectrometry (LLL), dpm/g	MCL/LLL
33-2039-01	4.13±0.38	4.32±0.29	0.96±0.11
34-2040-01	5.55±0.45	4.28±0.37	1.30±0.15
37-2042-01	7.06±0.48	5.42±0.35	1.30±0.12
32-2141-01	4.56±0.33	4.18±0.32	1.09±0.11
35-2017-02	51.2±4.3	39.6±3.7	1.29±0.16
32-2113-02	49.7±3.2	43.7±3.3	1.14±0.11
32-2115-02	64.4±4.6	55.5±3.6	1.16±0.08
32-2850-03	27.3±3.0	19.3±1.4	1.41±0.18
35-2716-05	22.3±2.7	17.2±1.4	1.30±0.19
37-2717-05	25.6±3.3	19.0±1.3	1.35±0.20
32-2856-05	14.1±1.0	12.7±0.9	1.11±0.11
32-2860-05	30.4±6.1	17.9±1.3	1.70±0.36
32-2189-01	66.0±13.2	43.7±2.7	1.51±0.32
30-4720-09	7.68±0.41	7.12±2.58	1.08±0.40
33-4721-09	5.57±0.22	3.95±1.26	1.41±0.45
34-4722-09	5.17±0.23	3.88±1.04	1.33±0.36
35-4723-09	7.18±0.48	6.70±1.72	1.07±0.28
37-4724-09	7.22±0.46	5.17±1.41	1.40±0.39
39-4725-09	10.2±0.7	10.3±3.1	0.99±0.31
40-4726-09	8.96±0.66	10.0±2.9	0.90±0.27
41-4727-09	3.61±0.27	3.31±0.98	1.09±0.33
42-4728-09	2.73±0.20	3.48±1.20	0.78±0.28
31-3720-10	40.6±2.6	27.7±5.9	1.47±0.33
31-3333-14	82.7±3.9	70.3±14.4	1.18±0.25

$$\begin{aligned}
 \bar{\mu} &= 0.1496 & t \cdot s_{\bar{\mu}} &= 0.1315 \\
 s_1 &= 0.2090 & e^{\bar{\mu}} &= 1.16 \pm 0.07 \\
 s_1^2 &= 0.04369 & s_2^2 &= 0.08393 \\
 s_{\bar{\mu}} &= 0.06034 & s_1^2/s_2^2 &= 1.57 \\
 & & F &= 2.7
 \end{aligned}$$

Table 132. Comparison of alpha count and gamma-spectrometric analyses for  $^{241}\text{Am}$  in marine samples (MCL vs LLL and LFE vs LLL).

Sample No.		Alpha count, dpm/g	Gamma spectrometry (LLL), dpm/g	MCL/LLL or LFE/LLL
08-0504-02	MCL	1.53±0.09	0.78±0.42	2.0±1.1
09-0449-09	MCL	7.8±0.4	8.3±1.0	0.94±0.13
09-0473-02	MCL	3.3±0.2	3.2±1.6	1.0±0.5
09-0506-02	MCL	1.86±0.09	1.62±0.51	1.15±0.36
09-0494-02	LFE	6.0±0.1	10.0±1.0	0.60±0.06
				Factor of improvement in sensitivity or value of limit
08-0476-01	MCL	0.50±0.04	< 1.5	3.0
08-0535-02	MCL	0.92±0.05	< 1.2	1.3
09-0597-09	MCL	0.52±0.03	< 0.63	1.2
09-0326-33	MCL	< 0.019	< 0.61	32
09-0483-36	MCL	< 0.031	1.85±0.20	Inconsistent
08-0358-38	LFE	< 2.9	< 0.063	No improvement
08-0304-39	LFE	< 0.48	< 1.9	4.0
08-0353-39	LFE	0.19±0.04	< 2.5	13
09-0271-39	LFE	0.092±0.023	< 0.35	3.8
09-0312-43	LFE	0.32±0.04	< 2.4	7.5
09-0338-43	LFE	7.0±3.7	< 0.88	Inconsistent
		( $^{239}, ^{240}\text{Pu} = 0.47$ dpm/g)		
09-0462-60	LFE	0.16±0.02	< 1.0	6.2

the body of  $^{241}\text{Am}$  data for soil samples reported in this survey may be systematically low by about 20%. However, since this check for bias involved a relatively small number of samples and the magnitude of the bias is somewhat uncertain, the body of  $^{241}\text{Am}$  data for soils is just as reported, based upon gamma spectrometry. A possible bias of 20% in the  $^{241}\text{Am}$  data for soils has negligible effect on estimated external dose due to gamma emitters in soil since  $^{241}\text{Am}$  contributed a very small fraction of the total dose.

Another comparison of  $^{241}\text{Am}$  deter-

minations by alpha counting and gamma counting was made on a group of 17 marine samples. The data are listed in Table 132. Ratios which compare methods were obtained for the first five entries in the table. The ratio for the most precisely measured sample, 09-0494-02, is  $0.60 \pm 0.06$ . The other four show satisfactory agreement between methods; the ratios have large enough uncertainties that none varies significantly from unity. Data for the remaining samples in Table 132 demonstrate improvement in sensitivity with factors in the range, 1.2-32.

Table 133. Comparison of alpha count and gamma-spectrometric analyses for  $^{241}\text{Am}$  vegetation and animal samples (MCL vs LLL and LFE vs LLL).

Sample No.	Alpha count (MCL), dpm/g	Gamma spectrometry (LLL), dpm/g	Factor of improvement in sensitivity
<u>Vegetation samples</u>			
10-2256-03	< 0.10	< 0.26	2.6
10-3293-09	0.010±0.002	< 0.16	16
10-3297-09	0.020±0.003	0.32±0.14	MCL/LLL = 0.062±0.028
10-2438-15	0.012±0.002	< 0.074	6.2
10-2447-16	0.025±0.003	< 0.19	7.6
10-3275-24	0.325±0.016	0.25±0.11	MCL/LLL = 1.33±0.58
10-0205-33	< 0.006	< 0.19	32
10-0081-38	< 0.006	< 0.17	28
Sample No.	Alpha count (LFE), dpm/g	Gamma spectrometry (LLL), dpm/g	Factor of improvement in sensitivity
<u>Animal samples</u>			
11-9094-10	0.009±0.006	< 0.97	110
11-9130-10	< 0.025	< 4.3	170
11-9099-24	< 0.017	< 1.3	80
11-9136-24	< 0.016	< 0.21	13
11-9127-10	0.11±0.09	< 1.0	9.1
11-9115-24	< 0.004	< 2.3	580

Other comparable  $^{241}\text{Am}$  data for vegetation and animal samples are given in Table 133. The data emphasize improvements in sensitivity available from wet-chemical analysis and alpha counting. For vegetation samples, increases in sensitivity were factors in the range, 2.6-32, while for animal samples, increases were factors in the range, 9-580.

#### Background Samples

A series of coral soil samples for background determination were put

through the entire system, from initial processing to wet-chemistry analysis, at varying intervals during the processing period. These samples were given identical treatment to neighboring samples as they were prepared and analyzed. Results from this series, given in Table 134, were expected to bear on questions of cross-contamination in the analytical sequence. Since the main sample load was processed in approximate sequence from low-level contamination to higher levels, cross-contamination if detectable at all, would

Table 134. Background samples, Midway coral.

Sample No.	Processed with samples from island	Wet chemistry performed by	Concentration, pCi/g			
			$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$
01-1305-70	LUCY	LFE	< 0.014	----	< 0.010	0.046±0.002
01-1306-70	JANET	MCL	< 0.015	< 0.32	< 0.010	0.010±0.002
01-1307-70	FRED	MCL	< 0.034	< 0.34	< 0.016	0.013±0.004
01-1308-70		LFE	----	0.018±0.002	----	0.012±0.001
01-1309-70		LFE	----	0.016±0.006	----	0.013±0.001
01-1310-70	IRENE	LFE	< 0.018	0.042±0.009	< 0.017	0.012±0.002
01-1314-70	YVONNE	LFE	< 0.018	0.024±0.006	< 0.014	0.015±0.001
01-1315-70	YVONNE	LFE	< 0.008	0.023±0.003	< 0.007	0.118±0.005
	(YVONNE 122 profile)					
01-1316-70	YVONNE	MCL	< 0.003	< 0.43	0.012±0.003	0.013±0.004
01-1317-70	YVONNE	MCL	< 0.010	< 0.27	< 0.007	0.011±0.002
	(YVONNE 145 profile)					
01-1318-70		LFE				
	Mean value		< 0.015	0.025	< 0.012	0.012
	Range		< (0.003-0.034)	0.016-0.042	< (0.007-0.017)	0.010-0.015 (exclude 1305,1315)



become more obvious in later samples of the series. The material used for background measurements came from a single batch of coral sand taken from Midway Island and was supplied to us by Major W. A. Myers of MCL. It was known not to be significantly contaminated.

The data in Table 134 show very little evidence for any cross-contamination with batches of highly contaminated Enewetak coral. The gamma emitters give no evidence of contamination. No  $^{60}\text{Co}$  was detected in any of the samples; an average upper limit value was  $<0.015$  pCi/g. For  $^{137}\text{Cs}$ , one sample yielded detectable cesium at  $0.012 \pm 0.003$  pCi/g, while the remainder gave upper limits averaging  $<0.012$  pCi/g. For  $^{90}\text{Sr}$ , MCL reported upper limits ranging from  $<0.27$  to  $<0.43$  pCi/g, while LFE reported five measurements with a mean value of  $0.025$  pCi/g and a range of  $0.016$ - $0.042$  pCi/g. For  $^{239,240}\text{Pu}$ , two of the results from LFE showed very slightly elevated levels; the

values were  $0.046 \pm 0.002$  and  $0.118 \pm 0.005$  pCi/g. The remaining analyses, from both LFE and MCL, produce a tightly clustered set with a mean of  $0.012$  pCi/g and a range of  $0.010$ - $0.015$  pCi/g. Sample 1315 was processed with samples from YVONNE which contained high levels of plutonium, ranging up to  $500$  pCi/g. These plutonium results for 1305 and 1315 are the only indication of cross-contamination given by the data for background samples. The constant levels of  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  measured for most of the samples can be ascribed to fallout on Midway Island during the years since atmospheric testing began. Since this batch of soil was collected on a beach and has been subjected to the leaching action of seawater, one should not try to read any significance into the absolute amounts of strontium and plutonium observed.

We are grateful for guidance from Dr. H. B. Levy in the statistical treatment of data.

## ENEWETAK SURVEY RADIOLOGICAL CONTROLS

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### Introduction

In the planning of the precleanup survey effort, it was recognized that radiation fields and radioactive contamination existed on various islands in the Atoll; however, at the time the survey began, the radiological conditions of all of the islands had not been evaluated. From previous surveys, it was known that the island of YVONNE had significant plutonium contamination problems, while SALLY, IRENE, and JANET were known to have activated/contaminated scrap metal or buried plutonium-contaminated debris. The radiological conditions on KATE, LUCY, MARY, NANCY, OLIVE, PEARL, VERA, and WILMA were unknown but could be inferred. PEARL had a surface ground zero and the other islands were near contaminated locations.

### General Radiological Controls

For the safety of the survey personnel, general radiological safety requirements were formally established by Roger Ray, Survey Manager. These requirements provided for personnel dosimetry and radiological support for all survey-related personnel.

All survey personnel leaving FRED (Enewetak Island) for other areas within Enewetak Atoll and personnel utilizing radioactive materials or handling potentially contaminated soil samples on FRED were required to wear a personnel dosimeter (TLD). These dosimeters were issued upon arrival at the Atoll and

were returned to the LLL Hazards Control representative upon departure from the Atoll. The personnel dosimeter utilized by the survey was the LLL TLD unit, which consisted of three TLD chips [Harshaw TLD 100 (LiF), TLD 200 (CaF<sub>2</sub>), and TLD 700 (LiF, depleted in Li)] mounted separately in a numbered plastic disk. An aluminum beta-shield was provided with an open window over the TLD 100 chip. Control TLDs were carried to the Atoll and returned, with the personnel dosimeters, to LLL for reading and interpretation.

Because of the possibility that contaminated soil samples might be brought back to FRED, all sample processing, counting, and storage areas were monitored with portable survey instruments for beta-gamma and alpha emitters. Swipe tests were also made; the swipes were counted on portable swipe counters fielded for that purpose.

A monitor accompanied all survey parties landing on the islands designated by the Survey Manager as requiring radiological support. Portable survey instruments specifically designed to detect alpha, beta-gamma, and gamma-only emissions were used. The high humidity at Enewetak Atoll makes alpha detection a problem because condensation not only masks alpha emitters in soil, but also causes electrical problems with all portable survey instruments.

- 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, leaving the PAC-1S as the

only alternative. This instrument uses an alpha scintillation detector with an active area of  $59 \text{ cm}^2$  and an aluminized Mylar window with a thickness of  $1.5 \text{ mg/cm}^2$ . The scintillation crystal is silver-activated zinc sulfide.

- LLL "Blue Alpha Meter." As the field effort progressed, an LLL modification of a well-known, air-chamber-type alpha survey instrument became available to the Enewetak survey teams. Although not ruggedized like the PAC-1S, the instrument was much more sensitive; it had an air chamber with an effective area of  $100 \text{ cm}^2$  and an aluminized (on both sides) Mylar window with an effective thickness of  $0.85 \text{ mg/cm}^2$ . Also, the probe guard was half as thick as the PAC-1S probe enabling near-contact measurements of surfaces to be made. The air chamber was subject to damage by sharp objects, more so than the PAC-1S; however, unless a large hole had been torn in the Mylar, it was still serviceable.

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

The following beta-gamma detectors were used to obtain contact readings on contaminated/activated radioactive scrap:

- E-400B. This instrument is a portable Geiger counter used for conducting beta-gamma radiation surveys. A tube sensitive to 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 cutoff at approximately  $0.31 \text{ MeV}$  and was calibrated with the  $662\text{-keV}$  radiation from  $^{137}\text{Cs}$ .

- 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 effective window thickness of  $1.5$  to  $2 \text{ mg/cm}^2$  (mica) and diameter of  $1.75 \text{ in.}$  The window thickness was increased to  $7 \text{ mg/cm}^2$  by applying plastic tape to the probe face. This instrument was calibrated for gamma radiation using  $^{60}\text{Co}$  and for beta emissions using  $^{90}\text{Sr}$ , but it was intended to be for low-energy beta-gamma.

The following gamma detectors were used:

- NE-148 Scintillation Monitor 904-148. This is the Baird-Atomic portable survey instrument which was used in the soil survey and terrestrial radiation measurement program. The Model 904-148 scintillation monitor is a highly sensitive instrument capable of measuring extremely fine gradations of gamma-radiation levels in three ranges, up to  $3 \text{ mR/hr.}$  The detecting element is a smaller version ( $1 \times 1 \text{ in.}$ ) of the NaI(Tl) crystal scintillator used in the aerial radiation survey. The instrument was calibrated using  $^{137}\text{Cs}$  for gamma fields. It proved to be a reliable device which was very rugged and well suited for use in the field.
- Fidler probe. The Fidler, a low-

energy x-ray detector, consists of a 5-in. diam  $\times$  1/16 in. -thick NaI(Tl) crystal optically coupled through a quartz light pipe to a selected RCA 8055 photomultiplier tube. The detector entrance window is 10-mil beryllium, and the entire assembly is encased in a 5/32-in. stainless steel can. A portable regulated high-voltage power supply and single-channel analyzer with integral count rate meter are used for the detection of plutonium x rays and the americium gamma ray. Field calibration was accomplished with  $^{241}\text{Am}$ .

#### Results of General Radiological Controls

A total of 125 TLD personnel dosimeters were issued to 84 people between October 13, 1972 and February 17, 1973. Only one dosimeter indicated any positive exposure above the minimum detectable dose (10 mrem). This dosimeter was not turned in when the individual to whom it was assigned left the Atoll. When recovered by mail in the continental United States, it indicated a total exposure of 18 mrem

(8 mrem above the minimum detectable dose). The 8-mrem difference is comparable to the exposure one would receive during a high-altitude passenger flight in a commercial aircraft flying from Enewetak to the continental United States and was probably accumulated during this individual's flight and subsequent mailing of the dosimeter.

The monitoring program conducted on FRED to prevent and control cross-contamination of soil samples was apparently successful. All swipes were negative, and no significant contamination was detected in the sample areas by portable survey instruments.

#### Special Radiological Controls

Special controls were established for the soil-collection and terrestrial-radiation survey efforts on the northern half of YVONNE, where pieces of plutonium were known to be randomly distributed on or near the surface north of the Tower Bunker (HARDTACK Station 1310). In addition, the area immediately south of the CACTUS crater was known to have

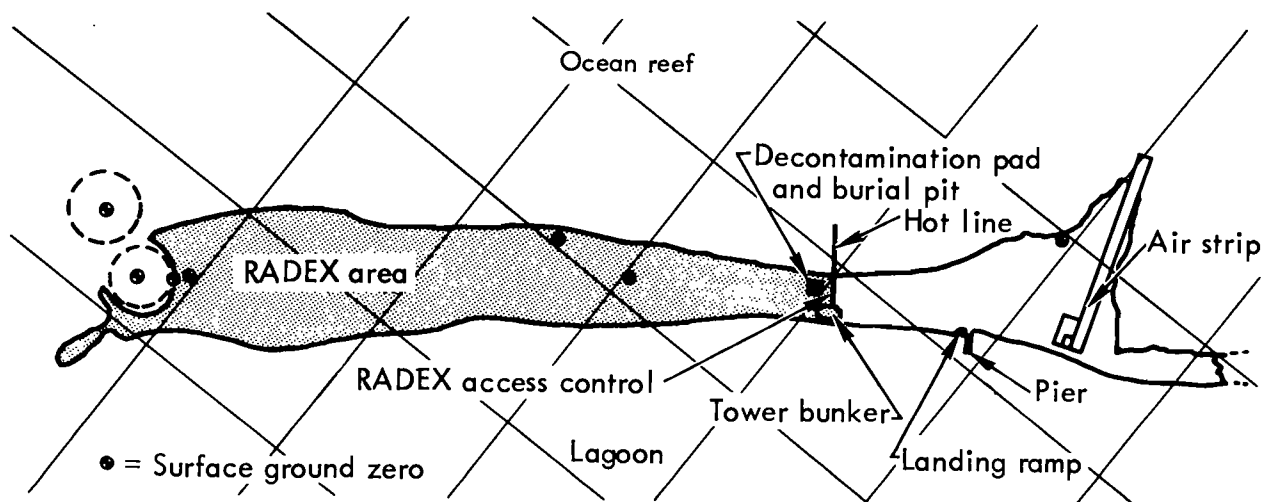


Fig. 115. Locations of the soil-sampling RADEX area and radiological control operation, YVONNE (Runit).

gamma levels of approximately 1 mR/hr, the highest in the Atoll.

For the purpose of this survey, a radiation exclusion (RADEX) area was established from the Tower Bunker north to the CACTUS crater (Fig. 115). Complete radiation safety controls were in effect within this RADEX area. A decontamination pad for equipment was set up on the ocean side of this RADEX area immediately adjacent to the hot line. A personnel decontamination facility and hot line were established on the east side of the tower; they controlled the sole access route for personnel going into the survey area.

#### Air Monitoring

Air samples were taken continuously in the area immediately downwind from the soil-disturbing activities in order to detect any resuspension of radioactivity. The airborne contaminants were collected on filters which were changed at the end of each work day. Additionally, two lapel-type, low-volume air samplers were used. One was placed on the backhoe operator, and the other on a profile monitor for more realistic evaluation of breathing zone concentrations. Samples were counted at Enewetak at the end of the day for gross activity and forwarded to LLL for further analysis. Daily gross results were available to the sampling team leaders.

#### Personnel Monitoring

The LLL TLD system was used to monitor personnel on YVONNE for external exposure to beta-gamma radiation. All individuals engaged in survey activities on YVONNE were issued the TLD packet

which was worn on the upper body in the same manner as a film badge.

Swipe tests using disks of filter paper were used to evaluate and detect removable surface contamination on equipment and area surfaces.

#### Contamination Controls

Every effort was made to prevent radioactive contamination of personnel. All personnel entering the YVONNE RADEX area or working at the hot line were suited out in full anticontamination (anti-C) clothing, consisting of one pair of coveralls, totes, cotton gloves, and cloth hood. All seams were taped. Those personnel collecting soil samples, displacing soil, or downwind from soil displacing activities, wore an Acme full-face mask, or equivalent, equipped with an Acme OAPR 282 high-efficiency canister.

All personnel left the area through the hot-line station and were monitored for alpha and beta-gamma contamination before, during, and after removing anti-C gear. Nose swipes were collected from selected individuals after all anti-C gear was removed. Decontamination capability was available at the hot line. Smoking and eating were not permitted in the RADEX area.

All contaminated anti-C gear was removed and suitably packaged at the hot line. Contaminated waste produced by the survey effort was collected, bagged, and buried on YVONNE in a marked area just east of the Tower Bunker.

All equipment used in the RADEX area was monitored with portable survey instruments and swipe tested. It was decontaminated when necessary.

Soil samples taken from the northern

part of YVONNE could have contained considerable amounts of  $^{239}\text{Pu}$ , therefore care was taken to prevent not only cross-contamination between individual samples but also contamination of personnel, equipment, and storage areas used in the recovery and processing of these samples.

Profile samples, collected from pits dug by backhoe (4- to 6-ft-deep profiles), were carefully removed from the pits with special side-wall sampling tools in approximately 10-cm-depth increments. Each individual sample was bagged and numbered at the time of collection. The sample was then bagged once more in a heavy plastic bag to guard against breakage of bags and leakage of material. All samples from a single profile location were again bagged in a single large plastic bag to keep all contents together for transfer to Enewetak.

To reduce airborne contamination during this windy and relatively dry season, all soil collection areas were wet down with salt water prior to any soil-disturbing activities.

All samples passing over the hot line on YVONNE were monitored for external alpha contamination. Samples found contaminated were bagged again and marked as having surface contamination on the inner bags. Soil samples from the northern portion of YVONNE were segregated from samples taken from other locations and kept in a special storage area where the floors were covered with a plastic sheet to provide for easy removal of contamination in case of leakage.

#### Decontamination

A personnel decontamination facility, which included a freshwater shower and

washstand, was provided at the hot line. Personnel were monitored crossing the hot line and were decontaminated as necessary.

A final equipment decontamination pad was set up on the concrete landing ramp. Saltwater washdown capability was provided. All digging equipment used in the RADEX area was decontaminated at the landing ramp. Effluent flowed back into the ground and into the lagoon.

Although every effort was made to prevent personnel contamination, a comprehensive bioassay program was followed to ascertain any internal contamination, to document either its absence or presence for the record, and to evaluate the effectiveness of control measures. Samples were taken in the following ways:

- Nose swipes were taken from selected personnel working in the area of airborne contamination immediately after the end of the work period when they removed their anti-C apparel.
- A 24-hr collection sample of urine was submitted by each YVONNE survey participant at the completion of the survey effort. These samples were forwarded to the United States for analysis.
- Selected individuals known to be involved in the YVONNE sampling effort had base-line whole-body (lung) counts prior to their arrival on Enewetak. These individuals were whole-body counted again upon the completion of the survey to evaluate any internal deposition acquired during the survey effort.

## Results

Only one individual required personal decontamination during the YVONNE soil-sampling effort. In this case, simple washing with soap and water removed the alpha contamination (less than 100 dpm). Anticontamination clothing did become contaminated with low-level alpha emitters (a few hundred dpm).

Equipment used to dig the sampling trenches also became contaminated. The low-level alpha contamination was removed by high-pressure saltwater spray before the equipment left the island. Vehicles used for transportation within the RADEX area did not need decontamination.

Air samplers, running continuously during the sampling operation showed positive indications of plutonium activity. The maximum observed values were  $1.6 \text{ pCi/m}^3$  on one lapel monitor and  $9.5 \times 10^{-2} \text{ pCi/m}^3$  on the downwind low-volume air sampler, approximately 10 ft from the sampling trench. The background high-volume air sampler, operated behind the hot line, indicated a maximum of  $7.4 \times 10^{-3} \text{ pCi/m}^3$ .

TLD personnel dosimeters did not indicate any significant beta-gamma exposures due to this final soil-collection effort. The results of analysis of urine samples and whole-body counts, taken after the field effort, were negative.

It is concluded that the radiological safety controls used for the Enewetak pre-cleanup survey field effort were adequate and effective.

## DOSE ASSESSMENT AND EVALUATION

### Introduction

The potential dosages to the returning population on Enewetak Atoll are developed and discussed in this chapter. The data base for the analysis is derived from all the information collected during the survey portion of the program. Four major pathways are considered: (1) external gamma exposure, (2) inhalation, (3) marine food chain, and (4) terrestrial food chain. Models used for assessment of each pathway are described in the section of the chapter dealing with that specific pathway. Living patterns, i. e., dietary habits, location of villages, and daily habits which influence time distributions at various geographical locations in the Atoll, are of primary importance in determining the relative significance of each exposure pathway to the total dose. Six living patterns have been constructed and evaluated to determine the sensitivity of these factors and the possible range of dosages. Each section describes the relative impact of the complete living patterns, and specific components within living patterns, upon the dose contribution via the four pathways. The chapter is organized as follows:

- (1) Dietary and living patterns
- (2) External dose pathway
- (3) Inhalation pathway
- (4) Marine food chain
- (5) Terrestrial food chain
- (6) Summary of dose assessment and evaluation





Table 135. Living patterns describing the geographical locations for activities involved in daily living.

	<u>Pattern I</u>	<u>Pattern II</u>
<u>Residence</u>	Enewetak, Parry	Enewetak, Parry
<u>Agriculture</u>	ALVIN through KEITH	KATE through WILMA + LEROY
<u>Fishing</u>	Entire Atoll	Entire Atoll
	<u>Pattern III</u>	<u>Pattern IV</u>
<u>Residence</u>	JANET	BELLE
<u>Agriculture</u>	JANET	BELLE
<u>Fishing</u>	Entire Atoll	Entire Atoll
	<u>Pattern V</u>	<u>Pattern VI</u>
<u>Residence</u>	JANET	JANET
<u>Agriculture</u>	KATE through WILMA + LEROY	ALICE through IRENE
<u>Fishing</u>	Entire Atoll	Entire Atoll

based upon these islands as the village areas, with visits to other islands for planting and collection of food. Generally, people living on Engebi own land on the neighboring islands, i. e., in the northern half of the Atoll, while those living on Parry and Enewetak own land on the islands in the southern half of the Atoll. These nearby islands would be used for additional agriculture and food collection by the two respective groups.

As a result of the above-mentioned de-

sires of the Enewetak people, the six different living patterns shown in Table 135 have been synthesized for estimating the potential dose to the returning population. For estimating the dose via the terrestrial food chain, islands are grouped according to a common range of external exposures and radionuclide concentrations in the soil; these groups are shown in Fig. 117. JANET and YVONNE are listed individually (Groups II and IV) and LEROY is included in the Group III islands, KATE through WILMA.

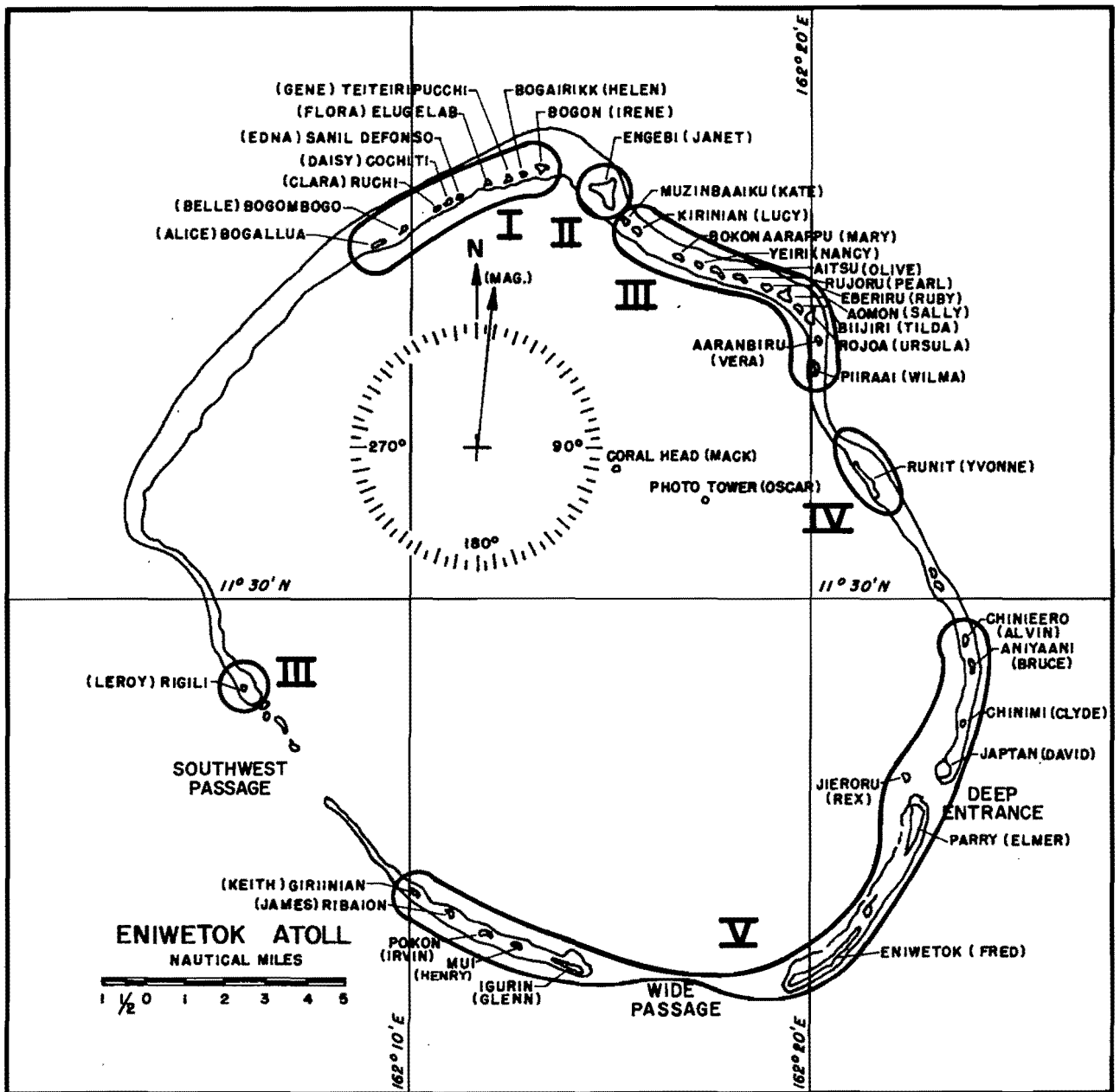


Fig. 117. Island groups used for assessing the dose via the terrestrial food chain.

The living patterns are designed to include the most probable circumstances which will occur when the inhabitants return (patterns I, II, III, V, and VI), as well as a more extreme exposure situation which could occur (pattern IV). The effects on total dose of these various living patterns will be discussed in the sections dealing with the external exposure,

the exposure via food chains and in the section describing the total doses via all pathways.

The distribution of time between village, interior, beach, lagoon, and other islands is shown in Tables 136 and 137. The breakdown is based upon reports by Jack Tobin from his years of experience in the Marshall Islands and from Ken

Table 136. Estimated time distribution (in percent) for men, women, children, and infants, with emphasis on residence island. Pattern A.

	Village area	Beaches	Interior	Lagoon	Other islands
Men	50	5	15	10	20
Women	60	10	10	0	20
Children	55	10	15	5	15
Infants	85	5	0	0	10

Table 137. Estimated time distribution (in percent) for men, women, children, and infants with emphasis on additional time spent on nonresidence islands. Pattern B.

	Village area	Beaches	Interior	Lagoon	Other islands
Men	40	5	20	10	25
Women	50	5	15	5	25
Children	50	5	15	10	20
Infants	70	5	5	0	20

Table 138. Population distribution of Enewetak.

Age groups	Percentage of total population	
Infants (0-5 yr)	Male	12
	Female	10
Children (6-18 yr)	Male	21
	Female	21
Adults (19-50 yr)	Male	18
	Female	14
Adults (over 50)	Male	2
	Female	2

Total population 432

On Ujilang now 340

Table 139. Postulated diet for the returning adult Enewetak population for time of return and for 10 yr after initial return.

Food item	Diet, g/day	
	At time of return	10 yr after return
Fish	600	600
Domestic meat	60	100
Pandanus fruit	0	200
Breadfruit	0	150
Wild birds	100	20
Bird eggs	20	10
Arrowroot	0	40
Coconut	100	100
Coconut milk	100	300
Coconut crabs	25	25
Clams	25	25
Garden vegetables	0	0
Imports	200-1000	200-1000
	1030 plus imports	1570 plus imports

Marsh who observed the Enewetak people on Ujilang and interviewed them as to their probable habits upon return to Enewetak Atoll.

Table 137 differs from Table 136 in that it increases the time spent in locations other than the residence island; this may be the situation during the first years of return while the inhabitants are cultivating and reestablishing the agricultural islands.

The population distribution of the Enewetak people, as determined by a census conducted by Dr. Jack Tobin in the fall of 1973, is shown in Table 138.

#### Diet

The composition of the diet shown in Table 139, both at the time of initial re-inhabitation of the Atoll and 10 yr after return, was compiled from reports and interviews of Jack Tobin of the Trust

Territories, Ken Marsh of LLL, Vic Nelson of the University of Washington, and Dr. Mary Murai, a nutritionist at the University of California, Berkeley, who spent a number of years living on Majuro and visited several of the atolls in the Marshall Islands. The reports by Tobin, Marsh, and Nelson are included in this report. Dr. Murai contributed through private discussion and through her publication "Nutrition Study in Micronesia," Atoll Research Bulletin No. 27 (1954), issued by the Pacific Science Board National Academy of Sciences — National Research Council.

The diets listed are intended to represent the average diet if the Atoll resources and Atoll agriculture are pursued in a manner similar to that prior to removal of the people from the Atoll for the testing program. The diet from 0 to 10 yr reflects the current lack of significant

quantities of pandanus, breadfruit and coconuts, all of which will have to be planted upon return and all of which have 7- to 10-yr development periods before contributing edible fruit to the diet.

The general opinion of all the sources listed above is that imports of rice, flour, tea, canned fish (tuna, mackerel, salmon, etc.) and canned meats will probably be major components in the diet of the Enewetakese because they are now accustomed to such living. They prefer to establish a cash economy and purchase most of their needed food items. It would therefore appear that dose calculations based upon the dietary intake per se shown in Table 139 may overestimate the total dose via the food chains; however, a brief comment on each of the items listed for both diets is in order.

Fish — The 600-g/day average intake, both initially and 10 yr after return, is probably a high estimate in view of the dietary and living habits of the people today. Bones and viscera of fish, dark muscle of tuna, and invertebrates such as sea cucumbers are not eaten by the natives.

Domestic Meat — This commodity is likely to be in shorter supply upon return than later because the people do not have sufficient room to raise many head of livestock where they presently live and it will take time to increase the pig and chicken population.

Pandanus Fruit — There are fewer than 10 pandanus plants on the entire Atoll at present. New plants will have to be started and will bear fruit about 8-10 yr

after planting.

Breadfruit — No breadfruit trees were encountered in the survey. Again a program of replanting will be necessary, with a subsequent period of approximately 8-10 yr before edible fruit is available.

Wild Birds and Bird Eggs — Wild birds are plentiful now, but the population will probably be depleted when the 400 people return.

Arrowroot — Very small patches of arrowroot were observed on the southern islands, with one larger patch observed on DAVID. Arrowroot will therefore have to be planted. However, the people have indicated that they much prefer imported white wheat flour and would only use arrowroot as a second choice.

Coconut and Coconut Milk — Islands in the southern half of the Atoll, especially Parry, FRED, and GLENN, have a large enough coconut crop to supply the people who first return. More coconut groves will be established on the other islands; however it takes approximately 8-10 yr for coconut trees to become productive and useful.

Coconut Crabs — The crab population now parallels that of the coconut trees in distribution. As more trees are planted, the coconut crab can be reintroduced to the other islands. The only question may be how rapidly the returning people harvest the available crabs and how well they practice conservation of this species. The people consider the crab a delicacy and could easily decimate the population.

Clams — Giant clams (*Tridacna*) are eaten raw and almost exclusively by the men during fishing trips. If the clams are not harvested under controlled conditions, they could be depleted to a stage where there would be few available in 10 yr.

Garden Vegetables — Very few garden vegetables will probably be available if current agricultural practices are continued. Terrestrial plants and garden crops, if planted, are allowed to grow in natural surroundings with very little organized gardening, i. e., no fencing or protected areas. The people prefer not to have high-maintenance agricultural situations. At the same time, their livestock, mostly pigs and chickens, are allowed complete freedom to roam as they please. The combination of low-intensity open agriculture and the uncontrolled meandering of the livestock tends to make fresh garden vegetables an unlikely component of the diet.

Imports — A large part of the diet is expected to consist of imported products. It is possible that imports will supply nearly the whole diet, with local marine and terrestrial products serving only in a limited way and on special festive occasions. If this should be the case, then the doses incurred by the returning population via the marine and terrestrial food chains will be far below those listed in this report.

#### External Dose Determination

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As described in the earlier sections on the EG&G aerial survey and photography, the terrestrial soil and radiation survey, and external dose estimates, gamma-ray exposure rates have been measured in this program by aerial survey, hand-held instruments, and thermoluminescent dosimeters. The three techniques yield the same results within  $\pm 10\%$ ; in the section on external dose estimates it was stated that the aerial-survey data would be used for those estimates. Average dose rates as obtained from the aerial survey are summarized in Table 140.

Even though wide variations in gamma-ray exposure rates were measured throughout the northern islands, it was necessary, for the purpose of the dose calculation, to derive the most reasonable values of the current mean exposure rates for each specific geographical area under consideration. These values are shown in Table 141 for the living patterns of Table 135. The mean exposure rates for specific areas of JANET were obtained by examination of the  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  exposure-rate contour maps provided by the aerial survey. The village area was assumed to lie along the lagoon side of the island. The mean values given for the northern islands were obtained by weighting the mean exposure rates for each individual island with the area of each island. Since the minor contamination of the southern islands is relatively uniform, the mean  $^{137}\text{Cs}$  and  $^{60}\text{Co}$  ex-

Table 140. Summary of average dose rates for islands in Enewetak Atoll.

Island	Average dose rate, $\mu\text{R/hr}$ at 1 m <sup>a</sup>			
	<sup>137</sup> Cs	<sup>60</sup> Co	Total $\gamma$ (0-3 MeV)	Range <sup>b</sup>
ALICE	42	36	81	4-170
BELLE	61	50	115	5-200
CLARA	20	19	42	5-100
DAISY	6.8	14.4	21.3	5-140
EDNA	2.8	2.4	6	5-8
IRENE	14	63	80	3-560
JANET	25	13	40	2-150
KATE	11	7	19	3-22
LUCY	6	7	14	1-20
PERCY	2	2	5	2-11
MARY	5.5	4	10	2-12
NANCY	6	5	12	1-50
OLIVE	6.5	4.5	11	1-15
PEARL	12	45	70	1-400
RUBY	2	12	14	1-42
SALLY	3.5	3	7	3-110
TILDA	4	2	6	2-11
URSULA	3	1.8	5	1-7
VERA	2.8	2	5	1-6
WILMA	1	1	2	1-3
YVONNE	5.6	22.4	33	1-750
SAM	<0.3 (0.20)	<0.6 (0.11)	<0.9	0-1
TOM	<0.3 (0.18)	<0.6 (0.13)	<0.9	0-1
URIAH	<0.3 (0.06)	<0.6 (0.43)	<0.9	0-1
VAN	<0.3 (0.08)	<0.6 (0.25)	<0.9	0-1
ALVIN	N. D. (0.06)	<0.6 (0.25)	<0.9	0-1
BRUCE	0.4 (0.22)	0.8 (0.34)	1.2	0-1
CLYDE	<0.3 (0.04)	<0.6 (0.11)	<0.9	0-1
DAVID	N. D. (0.21)	N. D. (0.10)	<0.9	0-5
REX	<0.3 (0.28)	<0.6 (0.25)	<0.9	0-1
ELMER	N. D. (0.19)	N. D. (0.12)	<0.9	0-2
WALT	<0.3 (0.08)	<0.6 (0.10)	<0.9	0-1
FRED	N. D. (0.14)	N. D. (0.12)	<0.9	0-1
GLENN	0.4 (0.33)	<0.6 (0.20)	<0.9	0-1
HENRY	<0.3 (0.14)	<0.6 (0.20)	<0.9	0-1

Table 140 (continued).

Island	Average dose rate, $\mu\text{R/hr}$ at 1 m <sup>a</sup>			
	<sup>137</sup> Cs	<sup>60</sup> Co	Total $\gamma$ (0-3 MeV)	Range <sup>b</sup>
IRWIN	<0.3 (0.08)	<0.6 (0.46)	<0.9	0-1
JAMES	<0.3 (0.05)	2.8	3.0	0-5
KEITH	<0.3 (0.15)	<0.6 (0.49)	<0.9	0-2
LEROY	2.8	4.8	7.6	3-8

<sup>a</sup>Average dose rates given are derived from aerial-survey data. On islands where activity levels are at the lower limit of sensitivity of the aerial-survey equipment, dose rates derived from the soil sample data are given in parentheses.

<sup>b</sup>As measured with the Baird-Atomic instrument.



Table 141. Estimated mean exposure rates ( $\mu\text{R/hr}$ ) used for dose calculations.

Major geographical area	Source	Exposure rate, $\mu\text{R/hr}$		
		Village	Interior	Beach
JANET	$^{137}\text{Cs}$	9.0	33	1.0
	$^{60}\text{Co}$	5.0	14	0.5
	Cosmic and natural	3.5	3.5	3.5
BELLE	$^{137}\text{Cs}$	61	61	1.0
	$^{60}\text{Co}$	50	50	0.5
	Cosmic and natural	3.5	3.5	3.5
FRED, ELMER, or DAVID	$^{137}\text{Cs}$	0.2	0.2	0.2
	$^{60}\text{Co}$	0.1	0.1	0.1
	Cosmic and natural	3.5	3.5	3.5
Lagoon	Cosmic and natural	3.5	3.5	3.5

		Area-weighted mean exposure rates, $\mu\text{R/hr}$
Northern islands (ALICE-WILMA, but excluding JANET)	$^{137}\text{Cs}$	14
	$^{60}\text{Co}$	21
	Cosmic and natural	3.5
Northern islands (ALICE-WILMA, but excluding BELLE)	$^{137}\text{Cs}$	15
	$^{60}\text{Co}$	16
	Cosmic and natural	3.5
Northern islands (ALICE-IRENE)	$^{137}\text{Cs}$	34
	$^{60}\text{Co}$	47
	Cosmic and natural	3.5
Northern islands (KATE-WILMA)	$^{137}\text{Cs}$	5.9
	$^{60}\text{Co}$	11
	Cosmic and natural	3.5
Southern islands (ALVIN-KEITH)	$^{137}\text{Cs}$	0.2
	$^{60}\text{Co}$	0.1
	Cosmic and natural	3.5

posure rates were chosen by inspection of the individual aerial-survey contour maps and of the soil data. The cosmic-ray contribution was estimated to be  $3.3 \mu\text{R/hr}$  at this latitude, and the naturally occurring radionuclides in the soil and sea water were expected to contribute an additional  $0.2 \mu\text{R/hr}$ .

The relative gamma-ray exposure rate contributions from  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  obtained from the aerial survey agrees well with values independently inferred from the soil activity-depth profile measurements. Although the soil measurements indicate trace amounts of other gamma emitters, such as  $^{125}\text{Sb}$ ,  $^{155}\text{Eu}$ , and  $^{241}\text{Am}$ , calculations of exposure rates based upon the observed soil activities indicate that these radionuclides contribute at most an additional 3 to 5% of the total exposure rate. The contribution due to these radionuclides was therefore neglected. Thus, the mean exposure rates shown in Table 141 are felt to be the most reasonable values available for computing integrated dose values. In fact, these mean values may be somewhat conservative, even though the aerial-survey data agree well with the TLD data, because the latter may have slightly overestimated the exposure rates due to the minimal beta-ray shielding afforded by the TLD badges.

Integral 5-, 10-, 30-, and 70-yr gamma-ray doses for each age group were calculated for each case or living pattern described in Table 135. The results were then combined by "folding" in the present population distribution shown in Table 138. Corrections were made for radioactive decay but not for possible weathering and subsequent

deeper penetration of the radionuclides in the soil. The results of these calculations are given in Table 142 and are labeled "unmodified." Additional calculations were made to ascertain the effect of reasonable attempts to reduce the exposure rates on the Atoll.

The first modification, labeled "village graveled" in Table 142, reflects the effect of covering the village areas with about 2 in. of coral gravel — a common practice throughout Micronesia.\* This action can be expected to reduce the gamma exposure rates in the village area by approximately a factor of two. The second and third modifications are based upon the assumption that clearing the islands for agricultural use and housing will result in some mixing of the topsoil. It appears that it would be practical during this period to also plow many of the more contaminated islands to a depth of 1 ft. Assuming that plowing results in mixing rather than burying the topsoil, an average reduction in exposure rates of about a factor of three may be obtained. This reduction factor is based upon the present 3- to 5-cm relaxation lengths (the depth at which the activity is  $e^{-1}$ , or 37% of the surface activity) for activity depth distribution in the uppermost soil layers of the more contaminated areas. This value, however, is highly variable from site to site. In Table 142 modification (2) indicates the effect of plowing only JANET or BELLE, while modification (3) reflects the additional effect of plowing all the northern islands. Deeper plowing or turning over the soil rather than mixing

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\*J. A. Tobin, private communication, 1973.

Table 142. Estimated integral external free-air gamma doses.

Case	Living pattern	Gamma dose, rad			
		Time interval, yr			
		5	10	30	70
I	Village: Enewetak/Parry Visits to ALVIN-KEITH Time distribution: Table 137				
<u>Unmodified</u>		0.14	0.28	0.83	1.92
II	Village: Enewetak/Parry Visits to ALICE-WILMA Time distribution: Table 137				
<u>Unmodified</u>		0.38	0.68	1.59	2.97
3. Northern islands plowed		(0.22)	(0.41)	(1.08)	(2.26)
III	Village: JANET No visits to other islands Time distribution: Table 137 with "other islands" time spent in interior of JANET				
<u>Unmodified</u>		0.94	1.71	3.95	6.66
1. Village graveled		(0.82)	(1.49)	(3.48)	(5.96)
2. JANET plowed		(0.36)	(0.68)	(1.70)	(3.24)
IV	Village: BELLE Visits to ALICE-WILMA Time distribution: Table 137				
<u>Unmodified</u>		2.72	4.78	10.06	15.50
1. Village graveled		(1.78)	(3.14)	(6.69)	(10.53)
2. Plus BELLE plowed		(0.83)	(1.47)	(3.26)	(5.47)
3. Plus northern islands plowed		(0.68)	(1.23)	(2.77)	(4.76)
V	Village: JANET Visits to KATE-WILMA Time distribution: Table 137				
<u>Unmodified</u>		0.71	1.28	2.94	5.06
1. Village graveled		(0.59)	(1.07)	(2.48)	(4.36)
2. Plus JANET plowed		(0.36)	(0.66)	(1.59)	(3.02)
3. Plus KATE-WILMA plowed		(0.29)	(0.54)	(1.36)	(2.71)

Table 142 (continued).

Case	Living pattern	Gamma dose, rad			
		Time interval, yr			
		5	10	30	70
VI	Village: JANET Visits to ALICE-IRENE Time distribution: Table 137				
<u>Unmodified</u>		1.15	2.03	4.39	7.13
1. Village graveled		(1.02)	(1.81)	(3.93)	(6.43)
2. Plus JANET plowed		(0.80)	(1.41)	(3.05)	(5.09)
3. Plus ALICE-IRENE plowed		(0.43)	(0.78)	(1.85)	(3.39)
VIa	Village: JANET Visits to ALICE-WILMA Time distribution: Table 136				
<u>Unmodified</u>		0.76	1.37	3.12	5.33
1. Village graveled		(0.62)	(1.12)	(2.58)	(4.51)
2. Plus JANET plowed		(0.41)	(0.75)	(1.77)	(3.27)
3. Plus northern islands plowed		(0.30)	(0.56)	(1.40)	(2.76)
VIb	Village: JANET Visits to ALVIN-KEITH Time distribution: Table 136				
<u>Unmodified</u>		0.60	1.10	2.60	4.60
1. Village graveled		(0.48)	(0.88)	(2.14)	(3.90)
2. Plus JANET plowed		(0.25)	(0.48)	(1.26)	(2.56)
Mean population dose (Average of Cases I, II, III, V, and VI)					
<u>Unmodified</u>		0.66	1.20	2.74	4.75
1. Village graveled		(0.59)	(1.07)	(2.46)	(4.33)
2. Plus JANET plowed		(0.41)	(0.74)	(1.75)	(3.25)
3. Plus all northern islands plowed		(0.29)	(0.54)	(1.36)	(2.70)
Sea level, U.S.A. (80 mrad/yr) Typical					
		0.40	0.80	2.40	5.60

it would, of course, result in even greater exposure-rate reductions. For example, mixing to a depth of 2 ft would reduce the exposure rates by an additional factor of two, while covering the sources with approximately 1 ft of uncontaminated soil would essentially reduce the exposure rates to negligible values similar to those observed on the southern islands. Removing the top 6 in. of soil, which often contains about two-thirds of the activity, would result in a threefold reduction in the exposure rates. The advantages of plowing or removing the topsoil should, however, be considered on a case-by-case basis because of the highly variable distributions of activity with depth. In fact, plowing IRENE could possibly increase the exposure rates in specific areas due to the elevated activity levels beneath the surface.

A review of Table 142 reveals that extensive modifications may not be required in order to reduce the dose levels to values comparable to typical U. S. values. Keeping in mind that Cases I, II, III, V, and VI represent approximations to the most likely living patterns, one observes that even for Cases V and VI, the unmodified 70-yr integral doses are comparable to U. S. values\*, while Cases I and II lead to considerably lower doses. The mean integrated doses to the entire population, shown in Table 142, were derived by averaging those for Cases I, II, III, V, and VI. This implies that half of the returning population live on JANET, and the other half live on FRED, ELMER, or

\*H. L. Beck, W. J. Lowder, B. G. Bennett, and W. J. Condon, Further Studies of External Environmental Radiation, USAEC, Rept. HASL-170 (1966).

DAVID, and that trips to the northern or southern islands are equally likely for both groups. The unmodified mean population doses are all quite comparable to U. S. values. At most, implementation of modifications 1 and 2 should be sufficient to assure mean population exposures well below the U. S. levels. Case IV represents a "worst credible" type of living pattern which, of course, leads to appreciably higher doses. However, even in this situation, the modifications can bring the levels down to the range of U. S. values.

Because of the low amount of natural radioactivity normally present in the coral atolls, the external dose levels calculated for Cases III, V, and VI are still appreciably higher than corresponding levels found elsewhere in the Marshall Islands (essentially Case I). The results for Cases I and II indicate that restricting the permanent villages to "clean" southern islands at least temporarily would result in lower exposures. Note that for Case IIb almost as much exposure is accumulated in the first 10 years as in the succeeding 20 years.

As illustrated in Table 143 for Case VIa, the differences in radiation exposure of the various population groups are minor, particularly for the longer time periods. Similar results were obtained for the other living patterns, indicating that the exact breakdown among age groups is not highly important. Table 144 illustrates the distribution of dose with respect to geographical area for Cases I, II, V, VIa, and VIb. The large fraction received while working in the interior or on other islands reflects, of course, the higher exposure rates present in these areas.

Table 143. Illustration of dose breakdown among population groups (Case VIa - unmodified).

Group	Total integrated dose, rad			
	5 yr	10 yr	30 yr	70 yr
Infants	0.64	1.15	2.66	4.63
Children	0.79	1.43	3.24	5.52
Men	0.82	1.47	3.32	5.61
Women	0.79	1.42	3.20	5.42

Table 144. Percentage of unmodified exposure received from various locales.<sup>a</sup>

Case	Village	Beach	Interior	Lagoon	Other islands
VIa	47	2	27	1	23
V and VI	36	1	33	2	28
II	22	2	8	4	64
VIb	58	2	33	1	5
I	50	5	17	8	20

<sup>a</sup>For 30-yr intervals averaged over population distribution. Percentages for other time periods are similar.

All of the doses discussed so far are due to free-air gamma plus cosmic-ray exposures. The effect of shielding by structures or the body itself on gonadal or bone doses has been ignored. To convert from free-air dose (rads) to gonadal dose (rem), a body-shielding factor of 0.8 may be used\*.

The free-air dose will be additionally enhanced by the presence of beta rays, originating primarily from <sup>90</sup>Sr and <sup>90</sup>Y in the soil. In radiation fields produced by global fallout, where the <sup>90</sup>Sr/<sup>137</sup>Cs activity ratio in the soil is normally

about 0.67, the free-air beta dose at 1 m above the ground is expected to be about four times that due to the <sup>137</sup>Cs gamma rays. At Enewetak, however, the <sup>90</sup>Sr/<sup>137</sup>Cs activity ratios in the soil samples showed a wide range of values, with an average ratio of about three. Thus, the free-air beta dose rates may average about 600  $\mu$ rad/hr in the interior of JANET and about 200  $\mu$ rad/hr in the village area. The resulting beta-ray doses to the skin, eye lenses, and gonads will be about 50, 25, and 1%, respectively, of the free-air values†. Thus, appreciable

\*Report of the United Nations Scientific Committee on The Effects of Atomic Radiation, 27th Session, Vol. 1, Suppl. No. 25 (1973).

†K. O' Brian, Health and Safety Laboratory, USAEC, New York, private communication (1973).

increases in skin and eye-lens doses due to the beta contribution could be expected. The gonadal dose, on the other hand, would be insignificant.

Very little information is available to verify these calculated beta-ray air doses, but indications are that they may be unrealistically high. This is based upon data obtained from two LiF TLD badges that were equipped with aluminum shields, one of which was situated within the interior of JANET. These shielded badges only showed an approximate 10% reduction in exposure rates from those measured by the unshielded badges at the same location, thus leading one to suspect that the beta air doses are considerably less than the calculated values.

#### Evaluation of the Inhalation Pathway

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The purpose of this analysis is to determine the significance of radioactivity in soils of the Atoll for their potential to inhalation exposures and to provide data necessary for making decisions regarding cleanup and future habitation.

It has been well documented that radioactivity in soils can resuspend in the atmosphere and be available for inhalation. For most radionuclides this pathway contributes an insignificant dosage compared with dosages derived from other pathways. For example, analysis of dosages from  $^{137}\text{Cs}$  in the U. S. environment has shown that, as an upper limit, resuspension is no more than 0.003% of the infinite-time dosage from all pathways to an individual\*. The results of

such an analysis would be similar for  $^{60}\text{Co}$  and  $^{90}\text{Sr}$ , but not for plutonium and other actinide elements. These latter radionuclides contribute negligibly to external exposures to the whole body and move inefficiently through food chains, resulting in an increased relative importance of the inhalation pathway.

Comparison of the maximum permissible concentrations in air ( $\text{MPC}_a$ 's), shows that  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ , and  $^{137}\text{Cs}$  contribute little to the dosages derived from inhalation as compared with plutonium (see Table 145). The  $\text{MPC}_a$  for  $^{90}\text{Sr}$  in the soluble form comes closest to being significant. The ratio of the  $\text{MPC}_a$  for soluble  $^{90}\text{Sr}$  to insoluble  $^{239}\text{Pu}$  is 40, for example. These radionuclides would be of equal significance if  $^{90}\text{Sr}$  levels in soil are 40 times those of  $^{239}\text{Pu}$ .  $^{90}\text{Sr}$  levels in the Atoll are generally only 2-3 times those of  $^{239}\text{Pu}$ . The ratio will decrease with time due to more rapid radioactive decay of  $^{90}\text{Sr}$  and its preferential runoff to the aquatic environment.  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$  dosages via inhalation are expected to contribute less than 5% to the total inhalation exposure.

Average values for  $^{241}\text{Am}$  on the islands ranged from 0.07 to 8.2 pCi/g in the top 15 cm of soil (see chapter on terrestrial soil and radiation survey). The  $^{241}\text{Am}$  to  $^{239,240}\text{Pu}$  ratio, island by island, ranged from approximately 0.25 to 3.5. Highest  $^{241}\text{Am}$  values were associated with the lowest  $^{239,240}\text{Pu}$

\*Y. Ng, W. Robison, and D. Wilson, "Modeling Radiation Exposures to Populations from Radioactivity Released to the Environment," in IAEA/NEA/WHO Symposium on Environmental Behavior of Radionuclides Released in the Nuclear Industry, Aix-en-Provence, France, May 14-18, 1973.

Table 145. MPC<sub>a</sub> for radionuclides found in Enewetak soils.<sup>a</sup>

Radionuclide	MPC <sub>a</sub> , μCi/cm <sup>3</sup>		
	Soluble form	Insoluble form	Reference
<sup>60</sup> Co	1 × 10 <sup>-7</sup> (total body)	3 × 10 <sup>-9</sup> (lung)	2
<sup>90</sup> Sr	4 × 10 <sup>-10</sup> (bone)	2 × 10 <sup>-9</sup> (lung)	3
<sup>137</sup> Cs	2 × 10 <sup>-8</sup> (total body)	5 × 10 <sup>-9</sup> (lung)	2
<sup>238</sup> Pu	7 × 10 <sup>-13</sup> (bone)	1 × 10 <sup>-11</sup> (lung)	2
<sup>239</sup> Pu	6 × 10 <sup>-13</sup> (bone)	1 × 10 <sup>-11</sup> (lung)	2
<sup>241</sup> Am	2 × 10 <sup>-12</sup> (bone, kidney)	4 × 10 <sup>-11</sup> (lung)	2

<sup>a</sup>The concentration in air computed as leading to the maximum allowable dose rate in the organ of reference, noted in the table, when an individual is continuously exposed to the contaminant in air.

values on an island-by-island basis. On the basis of the MPC<sub>a</sub> values and these soil data, it is concluded that <sup>241</sup>Am presently in soil would be a small contributor to the inhalation dosages. An additional amount of <sup>241</sup>Am activity will grow in from further decay of <sup>241</sup>Pu. Since the testing period, the <sup>241</sup>Pu has gone through almost two half-lives. Therefore, <sup>241</sup>Am values measured now are almost as high as will be obtained by further decay of the remaining <sup>241</sup>Pu.

Three approaches may be used to evaluate the inhalation pathway:

- Consider only the results of the air sampling during the survey as the basis for the evaluation.

Air sampling of the Atoll during the survey showed resuspension levels to be so low as to be masked in the "background" of atmospheric radioactivity present from fallout of stratospheric origin (see chapter on air-sampling program). The only exceptions were noted on northern YVONNE. These findings are encourag-

ing since they show that the atmosphere of the Atoll, in general, is not influenced by the burden of radioactivity present in the soils.

Air-sampling data taken during the survey may be unrepresentative of air levels under actual living conditions since they were obtained on uninhabited islands. A high level of human activity can be expected to alter the levels of re-suspended activity, particularly near the individuals who create the disturbances of the soil surface. Such circumstances could not easily be simulated during the survey.

- Use measured soil concentrations and published resuspension factors.

A considerable amount of information has been reported on resuspension factors, e.g., the ratio of air concentration expressed as activity per unit volume, to soil concentration expressed as activity per unit area (see Appendix A of this Chapter). Resuspension factors, so calculated, show a wide range of variation,



demonstrating that soil-atmosphere distributions depend upon complex relationships not accounted for very accurately by a bulk measurement of activity per unit area in soil.

- Use measured soil concentrations and estimates of maximum dust loading in the air.

The problems of using resuspension factors derived from data on radioactivity are circumvented by an approach which uses measurements of the amounts of dust in the nonurban atmosphere. The origin of the dust loading of the nonurban atmosphere is assumed to be from soil and to consist of particles in the respirable range of particle size (for our calculations we assume a mean particle of  $0.4 \mu\text{m}$  aerodynamic diameter). An additional assumption is required, namely that radioactivity in the soil will behave similarly to the resuspendable soil surface. This set of assumptions allows one to predict the ambient levels of radioactivity in air, knowing the concentration of radioactivity in the soil and the amount of soil in air:

$$C_a = C_s \cdot L_a \quad (1)$$

In Eq. (1), the air concentration ( $C_a$ ) in  $\text{pCi}/\text{m}^3$ , equals the concentration in soil, ( $C_s$ ) in  $\text{pCi}/\text{g}$ , times the concentration of dust in the atmosphere ( $L_a$ ) in  $\text{g}/\text{m}^3$ .

Estimation of dosage,  $D_t$ , as a function of soil levels can be made by combining dose conversion factors,  $R_t$ , with Eq. (1), yielding:

$$D_t = C_s \cdot L_a \cdot R_t \quad (2)$$

Using Eq. (2) to predict dosages requires:

- Knowledge of the activity in soil ( $C_s$ ) in  $\text{pCi}/\text{g}$ .
- Knowledge of the dust loading in the atmosphere ( $L_a$ ) in  $\text{g}/\text{m}^3$ .
- Dose conversion factors ( $R_t$ ) in rems per  $\text{pCi}/\text{m}^3$ , for cumulative dose to organs of the body through the inhalation pathway for  $t = 5, 10, 30, 50,$  and  $70$  yr of continuous exposure.

#### Plutonium in Enewetak Soils

The soil-sampling program provides information on the plutonium activity in the top 15 cm of soil on each island and, to a somewhat lesser extent, measurements of the vertical distribution of activity. Soil-profile data indicate that soil concentrations decrease with depth, although there are exceptions to this generalization. Two sets of soil-concentration data will be used in the inhalation-pathway evaluation (see Table 146). The activity in the top 2 cm of soil will be used to calculate dosages for conditions of the "unmodified" environment. It is expected that this environment will not exist to a large extent in the rehabilitated Atoll, but will exist in the transition period between now and the time when construction and agricultural rehabilitation is completed. At that time, much of the land will have been turned over by plowing, and large areas will be covered with buildings, coral, and cultivated vegetation. Under these conditions, it is expected that the soil surface radioactivity will be no greater than the average found now in the top 15 cm of soil. The median values for  $^{239}\text{Pu}$  in soil are considered to be representative of this latter case. This evaluation is based on the survey data for  $^{239}\text{Pu}$

Table 146.  $^{239,240}\text{Pu}$  in Enewetak soils, pCi/g.

Island	In top 15 cm		In top 2 cm		
	Median	Range	Median	Range	No. of samples
ALICE	12	3.9-68	56	3.9-105	5
BELLE	--	----	96	12-230	5
Dense	26	7.2-130	--	----	--
Sparse	11	5.8-26	--	----	--
CLARA	22	3.8-88	40	11-80	4
DAISY	--	----	50	8-180	6
Dense	41	22-98	--	----	--
Sparse	15	3.8-33	--	----	--
EDNA	18	13-24	18	--	1
IRENE	11	2.4-280	13	2.3-43	21
JANET	8.5	0.08-170	21	2.8-100	14
KATE	--	----	28	1.8-62	3
Dense	17	8.6-50	--	----	--
Sparse	2.3	0.17-14	--	----	--
LUCY	7.7	2.4-22	34	8.0-49	5
MARY	8.0	2.0-35	18	2.0-26	3
NANCY	9.1	2.3-28	23	9.6-35	4
PERCY	3.5	1.5-23	11	5.5-16	2
OLIVE	--	----	54	2.8-87	4
Dense	7.7	2.2-30	--	----	--
Sparse	2.8	1.9-4.1	--	----	--
PEARL	--	----	70	4.0-400	7
Hot spot	51	15-530	--	----	--
Remainder	11	0.85-100	--	----	--
RUBY	7.3	3.0-24	2.7	----	1
SALLY	4.3	0.21-130	18	1.7-62	11
TILDA	--	----	5.8	2.0-16	4
Dense	7.6	1.4-17	--	----	--
Sparse	2.5	1.1-34	--	----	--
URSULA	1.3	0.26-7.3	1.5	0.6-2.7	3
VERA	2.5	0.60-25	22	1.5-35	3
WILMA	1.1	0.1-5.3	3.3	1.2-7.0	4
Southern YVONNE	3.2	0.02-50	10	0.24-32	5

Table 146 (continued).

Island	In top 15 cm		In top 2 cm		No. of samples
	Median	Range	Median	Range	
Northern beaches	2.7	0.34-18	--	----	--
DAVID, ELMER, FRED	0.04	0.004-0.31	0.12	0.01-0.90	17
LEROY	0.63	0.02-2.0	1.7	1.1-2.6	3
All other southern islands	0.07	0.004-1.1	0.12	0.01-0.45	22

and  $^{240}\text{Pu}$  together. The small contribution from  $^{238}\text{Pu}$  and  $^{241}\text{Pu}$  could not influence the results of the evaluation.

#### Predicting the Atmospheric Levels of Plutonium

It is important to provide an evaluation which considers, as far as is possible, the potential for exposure to a returned population which accounts for the population distribution on the Atoll and the patterns of living. Under conditions of habitation, large areas of soil surface will become stabilized by cultivated vegetation, coral layering in the village areas, and by buildings. These activities will tend to reduce the possibility for resuspension of soil particles. However, human activities such as construction, earth moving, agricultural activities, and children playing, tend to stir up dust. Exposure levels to individuals will depend on such local sources.

Population exposure levels due to plutonium via the inhalation pathway have been developed on the basis of a model of dust loading. Details of the model used are discussed in Appendix A of this chapter. The assumptions made, and the

values for all parameters used, are chosen to be as realistic as possible but to contain an element of caution so as not to underestimate possible effects.

As shown in Appendix A, arithmetic mean values for dust loading for nonurban U.S. locations range from 9 to  $79 \mu\text{g}/\text{m}^3$ ; the average of all locations is  $38 \mu\text{g}/\text{m}^3$ . For urban Honolulu, Hawaii the arithmetic mean mass loading is  $35 \mu\text{g}/\text{m}^3$ . It seems reasonable to assume that ambient levels at Enewetak, away from sources of soil disturbance, are similar to these values for nonurban locations.

Therefore, a value of  $40 \mu\text{g}/\text{m}^3$  is taken to represent the ambient dust loading in Enewetak air under "quiet" atmospheric conditions, assumed to be approximately 60% of the time. For 35% of the time, levels are assumed to be as high as  $80 \mu\text{g}/\text{m}^3$  close to an active population. Finally, to account for extremely dusty conditions, due either to high winds or artificial agitation of the soil, levels as high as 10 times the ambient, or  $400 \mu\text{g}/\text{m}^3$ , are assumed to apply 5% of the time.

With these arguments one can derive a time-weighted value for dust loading:  $40(0.6) + 80(0.35) + 400(0.05) = 72 \mu\text{g}/\text{m}^3$ .

It is instructive to examine how high a value could be obtained to gain perspective on the sensitivity of the result to each component. The latter two components are components which might change with individuals who spend a good deal of time in dusty atmospheres as a result of their occupation or habits. This individual might spend 30% of the time in an atmosphere three times the ambient, and 10% of the time in an atmosphere ten times the ambient. This person would experience an average atmosphere containing  $100 \mu\text{g}/\text{m}^3$  of particles in air of soil origin. We will use this figure for computing the expected population dosages.

Predicting Inhalation Exposure from Atmospheric Levels

Prediction of inhalation dosages has been carried out using dose conversion factors derived by Bennett\* from calculations using the ICRP lung dynamics model. These factors are calculated for a class-y particle,  $0.4 \mu\text{m}$ , and low in solubility. Bennett has found that  $^{239}\text{Pu}$  distributions in the U. S. population are most closely explained by the lung dynamics model using the characteristics of the class-y particles.

Dose conversion factors used in this evaluation are developed for continuous exposure to  $1 \text{ pCi}/\text{m}^3$  of  $^{239}\text{Pu}$  in surface air. The factors are in units of cumulative rems to the lung, liver, and bone at the end of 5, 10, 30, 50, and 70 yr of exposure (see Table 147).

Dose Estimates

Using the soil data of Table 146, the dose conversion factors of Table 147, and an average dust loading of  $100 \mu\text{g}/\text{m}^3$ , cumulative dose estimates for each of the six living patterns of Table 135 have been made for the lung (Table 148), liver (Table 149), and bone (Table 150). In the living pattern analysis, it is assumed that the population spends 60% of the time on the island of residence, 20% on other islands in food gathering and agriculture, and 20% in the beach areas of the Atoll and on the water for fishing purposes.

Weighted  $^{239,240}\text{Pu}$  concentrations in soil were developed for each living pattern for both the "modified" and "unmodified" environment. For the "unmodified" environment, the 0-2 cm concentrations of  $^{239,240}\text{Pu}$  were used. The "modified"

\*B. Bennett, Fallout Plutonium-239 Dose to Man, Fallout Program Quarterly Summary Report, HASL-278, Health and Safety Laboratory, U. S. Atomic Energy Commission, New York (1974).

Table 147. Cumulative dose to the organs from continuous inhalation of  $1 \text{ pCi}/\text{m}^3$  of  $^{239}\text{Pu}$  in air.

<u>Organ</u>	<u>Dose, rem, after</u>				
	<u>5 yr</u>	<u>10 yr</u>	<u>30 yr</u>	<u>50 yr</u>	<u>70 yr</u>
Lung	8.6	22.0	76	130	180
Liver	0.4	2.4	33	93	170
Bone	0.6	4.2	61	180	360

Table 148. Cumulative rems to organs from <sup>239,240</sup>Pu via inhalation pathway, lung.

LIVING PATTERN	DOSE IN SOIL	5 YRS	EXPOSED 10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.75	0.0000	0.0001	0.0004	0.0006	0.0009
UNMODIFIED	0.12	0.0001	0.0003	0.0009	0.0016	0.0022
II. MODIFIED	2.00	0.0017	0.0044	0.0152	0.0260	0.0360
UNMODIFIED	4.70	0.0040	0.0103	0.0357	0.0611	0.0846
III. MODIFIED	7.30	0.0063	0.0161	0.0555	0.0949	0.1314
UNMODIFIED	17.00	0.0146	0.0374	0.1292	0.2210	0.3060
IV. MODIFIED	15.00	0.0129	0.0330	0.1140	0.1950	0.2700
UNMODIFIED	77.00	0.0662	0.1694	0.5852	1.0010	1.3860
V. MODIFIED	7.30	0.0063	0.0161	0.0555	0.0949	0.1314
UNMODIFIED	17.60	0.0151	0.0387	0.1339	0.2288	0.3168
VI. MODIFIED	9.50	0.0082	0.0209	0.0722	0.1235	0.1717
UNMODIFIED	14.70	0.0126	0.0323	0.1117	0.1911	0.2646

environment is represented by the 0-15 cm soil data, on the assumption that use of the land will result in a "turnover" of soil.

The southern islands are characterized by uniformly low levels of plutonium in soil. Living patterns, such as case I, which involve a predominant use of the southern part of the Atoll, can be expected to result in insignificant dosages from plutonium via inhalation. Highest dosages were computed for unmodified conditions in living pattern IV, which is an upper-limit case of living on BELLE in the northwest portion of the Atoll. For this living pattern, modifications which homogenize the topsoil would result in reducing

exposures by a factor of five.

The range of plutonium concentrations in soil in the northern half of the Atoll is large, with levels of the order of 1 to 10 pCi/g in the top 15 cm of soil, 10 to 50 pCi/g in the top 2 cm of soil, and isolated high values of 100 to 500 pCi/g. The limited number of such high values does not constitute a separate, significant condition with regard to evaluation of potential population dosage. All such data has been incorporated into the development of average soil values, island by island, and are therefore accounted for in the calculations of dose. The only conditions of potential significance, unaccounted for in the evaluation, would be those conditions which

Table 149. Cumulative rems to organs from  $^{239,240}\text{Pu}$  via inhalation pathway, liver.

LIVING PATTERN	PCi/G IN SOIL	5 YRS	EXPOSED 10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.05	0.0000	0.0000	0.0002	0.0005	0.0008
UNMODIFIED	0.12	0.0000	0.0000	0.0004	0.0011	0.0020
II. MODIFIED	2.00	0.0001	0.0005	0.0065	0.0186	0.0340
UNMODIFIED	4.70	0.0002	0.0011	0.0155	0.0437	0.0799
III. MODIFIED	7.30	0.0003	0.0010	0.0241	0.0679	0.1241
UNMODIFIED	17.00	0.0007	0.0041	0.0561	0.1581	0.2890
IV. MODIFIED	15.00	0.0006	0.0036	0.0495	0.1395	0.2550
UNMODIFIED	77.00	0.0031	0.0185	0.2541	0.7161	1.3090
V. MODIFIED	7.30	0.0003	0.0018	0.0241	0.0679	0.1241
UNMODIFIED	17.60	0.0007	0.0042	0.0581	0.1637	0.2992
VI. MODIFIED	9.50	0.0004	0.0023	0.0313	0.0883	0.1615
UNMODIFIED	14.70	0.0006	0.0035	0.0485	0.1367	0.2499

time-weight the activities and residence of people toward areas of elevated plutonium in soil. Thus, if a large portion of the population spends a large fraction of the time in the specific areas of elevated levels of plutonium in soil, population dosages would be increased. These factors should be considered in examining the need for remedial actions, such as soil removal. An extreme example, the hypothetical occupation of the area on DAISY with up to 500 pCi/g, can be used for perspective. Under these maximum, hypothetical conditions, use of this area might lead to dosages of the order of 4 rems to the lungs in 30 yr of exposure, and a similar dosage to the bone.

YVONNE is a unique island with respect to plutonium contamination, in particular the northern part of the island (see the chapter on terrestrial soil and radiation survey for a description of the distribution of plutonium in soils). This part of the Atoll has the highest plutonium levels observed in the survey, and was the only area in which positive identification of resuspended plutonium was made in the air-sampling program. YVONNE is characterized by a nonuniformity of contamination, a large inventory of plutonium, and the existence of pure particles of plutonium metal. Unrestricted land use of YVONNE, without remedial action, would produce the highest potential for

Table 150. Cumulative rems to organs from <sup>239,240</sup>Pu via inhalation pathway, bone.

LIVING PATTERN	PC/G IN SOIL	5 YRS	EXPOSED 10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.05	0.0000	0.0000	0.0003	0.0009	0.0018
UNMODIFIED	0.12	0.0000	0.0001	0.0007	0.0022	0.0043
II. MODIFIED	2.00	0.0001	0.0008	0.0122	0.0360	0.0720
UNMODIFIED	4.70	0.0003	0.0020	0.0287	0.0846	0.1692
III. MODIFIED	7.30	0.0004	0.0031	0.0445	0.1314	0.2628
UNMODIFIED	17.00	0.0010	0.0071	0.1037	0.3060	0.6120
IV. MODIFIED	15.00	0.0009	0.0063	0.0915	0.2700	0.5400
UNMODIFIED	77.00	0.0046	0.0323	0.4697	1.3860	2.7720
V. MODIFIED	7.30	0.0004	0.0031	0.0445	0.1314	0.2628
UNMODIFIED	17.60	0.0011	0.0074	0.1074	0.3168	0.6336
VI. MODIFIED	9.50	0.0006	0.0040	0.0579	0.1710	0.3420
UNMODIFIED	14.70	0.0009	0.0062	0.0897	0.2646	0.5292

population dosages from plutonium. The level of radiological significance, however, depends upon land-use plans as well as radionuclide inventory.

Bringing the radiological significance of YVONNE into line with the rest of the Atoll will require either restriction against habitation of the island, or removal of large amounts of contaminated soil.

In summary, the levels of plutonium observed in soils of the Atoll, excluding YVONNE, can be expected to lead to long-term, average air concentrations of plutonium which are the order of a millionth up to a thousandth of the MPC<sub>a</sub>. These estimates have been made with such

assumptions that it is very doubtful that they could be underestimates of the potential population dosages. Population dosages derived from YVONNE would probably exceed ICRP guidelines if this island is used for habitation without prior soil removal.

#### Appendix A

##### Relationship Between Resuspended Plutonium in Air and Plutonium in Soil

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There are no general models that may be used with confidence to predict the resuspended air activity in the vicinity of an area contaminated with plutonium.

However, two approximate methods may be used — the resuspension factor approach and an argument based upon ambient air particulate concentrations, with the assumption that the particulates are derived from the contaminated surface. The former method has been frequently used, but almost always in the context of a fresh surface deposit. The latter method is inappropriate to the fresh deposit situation, but should be reasonably valid after enough time has elapsed for the surface-deposited material to become fairly well mixed with a few centimeters of the soil surface.

#### Resuspension Factor Approach

The resuspension factor,  $K$ , is defined as

$$K = \frac{\text{Air concentration (Ci/m}^3\text{)}}{\text{Surface deposition (Ci/m}^2\text{)}},$$

and thus has units of  $\text{m}^{-1}$ . It is almost always implied that both measurements are made at the same location. The difficulties with this approach are fairly obvious — no allowance is made for the geometrical configuration of the source, the particle-size distributions of the contaminant and the soil surface, vegetation cover, etc. Stewart<sup>1</sup> and Mishima<sup>2</sup> have tabulated values of  $K$  from many experiments including those involving laboratory floors as well as native soils. As would be expected, the tabulated values cover an enormous range and vary from  $10^{-2}$  to  $10^{-13}/\text{m}$ . Most of the high values, however, are derived from experiments with laboratory floor surfaces and/or with artificial disturbance.

For outdoor situations, Stewart<sup>1</sup> suggests as a guide for planning purposes that a value for  $K$  of  $10^{-6}/\text{m}$  be used

"under quiescent conditions, or after administrative control has been established in the case of an accident." A value of  $10^{-5}/\text{m}$  is suggested under conditions of moderate activity. Stewart states, however, that exceptionally higher values (mean of  $10^{-5}/\text{m}$ ) were observed during the Hurricane Trial (Monte Bello Islands) and credited this to the nature of the small islands exposed to sea breezes. Values approaching  $10^{-3}/\text{m}$  when dust is raised by pedestrians and vehicles are also reported by Stewart.

Kathren<sup>3</sup> has also considered the resuspension factor approach and has recommended the use of  $10^{-4}/\text{m}$  as a conservative but appropriate value for setting standards for  $\text{PuO}_2$  surface contamination.

Langham<sup>4, 5</sup> has suggested that a value of  $10^{-6}/\text{m}$  is a reasonable average value to use in estimating the potential hazard of occupancy of a plutonium-contaminated area. At the same time, however, Langham notes that many measured values lie in the range of  $10^{-5}$  to  $10^{-7}/\text{m}$  and reports that his own measurements in 1956 produced a value of  $7 \times 10^{-5}/\text{m}$ .

These recommended values, however, are all intended for application during the time period immediately following deposition. Numerous studies<sup>1, 5-8</sup> have shown that air concentrations of resuspended materials decrease with time. With the assumption that this decrease can be represented by a single exponential function, half-times of 35 to 70 days have been reported<sup>5, 7, 8</sup>. This decrease in air activity is not explainable by the relatively minor loss of material from the initial site of deposition<sup>1, 6</sup>, but is



presumably caused by the migration of the initial surface-deposited material into the soil.

Attempts to use the resuspension factor approach to derive acceptable levels of soil surface contamination have included this "attenuation factor" as a simple exponential function with half-times of 35 or 45 days<sup>3, 4</sup>. There are major uncertainties in such a formulation, however. The longest study of this decrease with time extended to only 11 mo following the initial deposition<sup>8</sup>, which is extremely short compared to the half-life of a radionuclide such as <sup>239</sup>Pu. There are also published reports which indicate on experimental and theoretical bases that the decrease with time will not be adequately represented by a single exponential function, but that the rate of decrease itself will also decrease with time<sup>1, 6</sup>. Fortunately, the exact nature of this time dependence is not critical in determining the integrated exposure from the time of initial deposition due to the fairly well-documented rapid decrease at early times. However, it is obviously the controlling factor for questions concerning the reoccupation of areas many years after the contaminating event.

As an illustration, the most conservative published model (Kathren<sup>3</sup>) may be used to calculate a resuspension rate for material 15 yr after deposition:

$$K = \frac{10^{-4}}{m} \exp\left(\frac{-0.693 \times 15y \times 365d}{45d \times y}\right) \\ \simeq 10^{-41}/m.$$

If, however, the resuspension rate asymptotically approached some finite value  $10^{-6}$  of the original, then the resuspension rate 15 yr later would obviously

be  $10^{-10}/m$ . However, the total integrated air activity (from  $t = 0$  to  $\infty$ ) for <sup>239</sup>Pu would be changed only by

$$A \times 10^{-4} \int_0^{\infty} \exp(-0.693t/45d) dt \\ + A \times 10^{-10} \int_0^{\infty} \exp(-0.693t/24,400y) dt \\ = 6.5A \times 10^{-3} + 1.3A \times 10^{-3},$$

which is an increase of 20%, and more importantly, cannot be accumulated during an individual's life span.

Because the functional nature of the decrease in resuspension rate with time cannot be confidently extrapolated, previously published models should not be applied to the reoccupation of areas many years after the contaminating event.

The resuspension-factor approach can be applied in an approximate way, however, if resuspension factors are used which were derived from measurements over aged sources. Perhaps the most relevant data are unpublished results from current resuspension experiments at the GMX site in Area 5 of the Nevada Test Site. The <sup>239</sup>Pu at this location was deposited following 22 high-explosive detonations during the period from December 1954 to February 1956. Measurements of resuspended air activity levels at this site during 1971-1973 appear to be the only available data concerning resuspension of <sup>239</sup>Pu from a source of this age.

Data from two types of measurements are available and can be used to derive average resuspension factors. The first type of measurement<sup>9</sup> was accomplished by placing five high-volume cascade impactors<sup>10</sup> within the most highly contaminated area, and running them for

36 days, from July 7 to August 12, 1972. The collected  $^{239, 240}\text{Pu}$  activity was distributed lognormally with particle size with an activity median aerodynamic diameter (AMAD) of  $3.0 \mu\text{m}$  and a geometric standard deviation of 8.2. The  $^{239, 240}\text{Pu}$  concentration varied from  $1.0 \times 10^{-14}$  to  $3.9 \times 10^{-14} \mu\text{Ci}/\text{cm}^3$ , with an average of  $2.3 \times 10^{-14} \mu\text{Ci}/\text{cm}^3$  for the five samplers. At the present time only limited data are available regarding the soil activity in the area.

Four soil samples of depth 0-3 cm from approximately the same location have been analyzed with results<sup>11</sup> of 2060 to 3550 dpm/g, with a mean of 2700 dpm/g. Profile data from other locations at the same general site indicate that about 90% of the total deposition is contained within the top 2.5 cm of the soil<sup>12</sup>. Measurements of soil density in the area average  $1.8 \text{ g}/\text{cm}^3$ <sup>9</sup>. The resuspension factor is therefore

$$\frac{2.3 \times 10^{-14} \mu\text{Ci}}{\text{cm}^3} \times \frac{\text{g}}{2700 \text{ dpm}} \times \frac{\text{cm}^3}{1.8 \text{ g}} \times \frac{0.9}{3 \text{ cm}} \times \frac{10^2 \text{ cm}}{\text{m}} \times \frac{2.22 \times 10^6 \text{ dpm}}{\mu\text{Ci}} = 3 \times 10^{-10}/\text{m}.$$

Additional air samples were taken by the Reynolds Electrical and Engineering Co. (REECo) on the edge of the contaminated area during the period of February 1971 to July 1972, with a sampling time of approximately 48 hr<sup>13</sup>. Measurements were made at four locations, but the most pertinent is the one which was most frequently in the direction of strong winds from the strongly contaminated area and where the highest air activities were recorded. Here, 254 individual air-filter samples were collected and detec-

table results reported for  $^{236, 239, 240}\text{Pu}$  concentrations ranged from  $3.5 \times 10^{-17}$  to  $6.3 \times 10^{-13} \mu\text{Ci}/\text{cm}^3$ , with arithmetic and geometric means of  $6.6 \times 10^{-15}$  and  $7.9 \times 10^{-16} \mu\text{Ci}/\text{cm}^3$ , respectively. Results for four soil samples taken from approximately the same location range from 128 to 202 dpm/g, with a mean of 160 dpm/g<sup>11</sup>. Because the arithmetic mean is a better representation of average lung exposure, it is used to derive a resuspension factor at this site:

$$\frac{6.6 \times 10^{-15} \mu\text{Ci}}{\text{cm}^3} \times \frac{\text{g}}{160 \text{ dpm}} \times \frac{\text{cm}^3}{1.8 \text{ g}} \times \frac{0.9}{3 \text{ cm}} \times \frac{10^2 \text{ cm}}{\text{m}} \times \frac{2.22 \times 10^6 \text{ dpm}}{\mu\text{Ci}} = 2 \times 10^{-9}/\text{m}.$$

This value is nearly an order of magnitude higher than the one previously calculated, and reflects some of the inherent difficulties in the resuspension-factor approach, i. e., that no allowance is made for the geometrical configuration of the source and that higher ground activities may be present upwind.

It is obvious that this approach is subject to major uncertainties, but does serve as an order-of-magnitude indication of the resuspended air activities that may arise from a  $^{239, 240}\text{Pu}$  contaminated area which has weathered for 15 to 20 yr. The data discussed above also demonstrate unequivocally that resuspension of  $^{239, 240}\text{Pu}$  does in fact occur from such aged deposits and at levels many orders of magnitude higher than would be expected if the often noted decrease with time were represented by a single exponential function with a half-time of 35 to 70 days.

### Mass-Loading Approach

The other approximate prediction method is based upon measured or assumed levels of particulate matter in ambient air with the assumption that this material is derived from the contaminated soil. For fresh deposits this approach is not valid because the freshly deposited debris is much more likely to be resuspended than the remainder of the weathered soil surface. After many years of weathering since the initial deposition, however, the contaminating material should be reasonably well mixed with a centimeter or two of soil, such that the contaminant activity per gram of airborne particulate should approximate that in the upper soil. However, a major difficulty could arise if, for example,  $^{239, 240}\text{Pu}$  were preferentially associated with the smaller particle sizes more likely to become airborne. For the Nevada Test Site, such is not the case as determined by soil analyses<sup>14</sup> and by the high-volume cascade impactor study. The latter study found an AMAD of  $3.0 \mu\text{m}$  for  $^{239, 240}\text{Pu}$ , whereas the total mass median aerodynamic diameter was  $1.7 \mu\text{m}$ . The specific activity of the material collected on each stage can also be examined for a preferential association of plutonium with particle size. Average data from all five samplers are:

<u>Size, <math>\mu\text{m}</math></u>	<u><math>^{239, 240}\text{Pu}</math>, dpm/g</u>
>7	950
3.3 to 7	700
2.0 to 3.3	1030
1.1 to 2.0	1300
0.01 to 1.1	480
All stages	890
(Soil)	(2700)

Although there is considerable spread in these data, there is no indication of a preferential association of  $^{239, 240}\text{Pu}$  with a particular particle size; as would be expected as a result of dilution by inert aerosol, the specific activity is lower than that of the soil.

If we assume that this is generally true, a general and conservative method of predicting resuspended air concentrations of contaminants would be to simply multiply the ambient air mass loading by the contaminant concentration in soil. A factor of some uncertainty for a specific calculation is what value to use for the ambient air mass loading in the absence of specific data. This becomes even more uncertain because of the possibility that the people involved may be highly correlated with the source in the sense that children playing in sand, adults cultivating crops, etc., may generate their own "ambient air" which contains much more mass than would be recorded by a remote stationary sampler.

The lower and upper bounds of ambient air mass loading can be fixed rather easily for any site. There has been considerable interest in establishing a "background level" of mass loading, and this is generally believed to be about  $10 \mu\text{g}/\text{m}^3$  (15). The upper bound can be established in a reasonable way by the levels found in mine atmospheres which have led to a considerable prevalence of pneumoconiosis in the affected workers<sup>16</sup>. Examination of these data indicate that current standards for occupational dust exposure ( $\sim 1\text{-}10 \text{ mg}/\text{m}^3$ ) have a very small, or perhaps no margin of safety, such that a reasonable upper bound can be taken as  $1 \text{ mg}/\text{m}^3$ . British data<sup>17</sup>

indicate that if the general public were exposed to dust levels in excess of  $1 \text{ mg/m}^3$ , the public health problem from the dust alone might be enormous. The reasonableness of the upper limit value of  $1 \text{ mg/m}^3$  is also demonstrated by data which indicate that nonurban ambient air mass concentrations this high are usually associated with conditions described as dust storms<sup>18,19</sup>.

Measurements of ambient air mass loading can be used to further define a reasonable estimate for predictive purposes. The National Air Surveillance Network (NASN) has reported such results for several years. Data<sup>20</sup> for 1966 show that there were 217 urban and 30 nonurban stations reporting. The annual arithmetic average for the urban stations ranged from 33 (St. Petersburg, Florida) to  $254 \text{ } \mu\text{g/m}^3$  (Steubenville, Ohio), with a mean arithmetic average for all 217 stations of  $102 \text{ } \mu\text{g/m}^3$ . For the nonurban stations, the range was from 9 (White Pine County, Nevada) to  $79 \text{ } \mu\text{g/m}^3$  (Curry County, Oregon), with a mean arithmetic average for all 30 stations of  $38 \text{ } \mu\text{g/m}^3$ . No data in this report are available for nonurban locations on small islands similar to the Enewetak group; perhaps the closest analog is the urban station at Honolulu, Hawaii, which had an annual arithmetic average of  $35 \text{ } \mu\text{g/m}^3$ .

More pertinent, but limited, data have recently been published for the island of Hawaii<sup>21, 22</sup>. Data are given for three locations: Mauna Loa Observatory located at a height of 3400 m, Cape Kumukahi, and the city of Hilo. NASN data for Hilo (for an unspecified period) are given as  $18 \text{ } \mu\text{g/m}^3$ , and nephelometer measurements varied from  $18 \text{ } \mu\text{g/m}^3$

during the day to  $26 \text{ } \mu\text{g/m}^3$  at night. At Cape Kumukahi the nephelometer measurement was  $9.2 \text{ } \mu\text{g/m}^3$ . The greatest amount of data is available for Mauna Loa Observatory. Here, the NASN measurement was  $3 \text{ } \mu\text{g/m}^3$ , and the nephelometer measurements varied from  $1.7 \text{ } \mu\text{g/m}^3$  at night to  $6.5 \text{ } \mu\text{g/m}^3$  during the day. Additional measurements made by the USAEC Health and Safety Laboratory (HASL) were  $3 \text{ } \mu\text{g/m}^3$ . It is of interest in the present context that Simpson<sup>22</sup> made the following comment concerning the HASL measurements: "The HASL filter samples contain substantial dust ( $3\text{-}5 \text{ } \mu\text{g/m}^3$  of air sampled) because of the fact that the filter was located less than one meter above the ground surface near areas with substantial personnel activity at the observatory site." Thus, while this method of measurement may not have coincided with Simpson's interest, it does indicate that ambient air mass loadings may be very low on such remote islands even when considerable human activity is occurring nearby.

On the basis of the above data, it would appear reasonable to use a value of  $100 \text{ } \mu\text{g/m}^3$  as an average ambient air mass loading for predictive purposes. Indications are that this value should be quite conservative for the Enewetak Islands, and therefore allows room for the uncertainty involved because the people themselves may generate a significant fraction of the total aerosol. Therefore, they may be exposed to higher particulate concentrations than would be measured by a stationary sampler.

Supporting evidence that  $100 \text{ } \mu\text{g/m}^3$  is a reasonable value to use for predictive purposes is provided by the National Ambient Air Quality Standards<sup>23</sup>. Here

ambient air is defined as "... that portion of the atmosphere, external to buildings, to which the general public has access." The primary ambient air standards define "levels which... are necessary, with an adequate margin of safety, to protect the public health." The secondary standards define "levels which... (are)... necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant." These standards for particulate matter are given below:

National ambient air quality standards for particulate matter, $\mu\text{g}/\text{m}^3$ .	
Annual geometric mean	Max. 24-hr concentration not to be exceeded more than once a year
Primary:	
75	260
Secondary:	
60	150

Data to support these standards in terms of health effects, visibility restrictions, etc. have been provided<sup>24</sup>.

An arithmetic mean would be more desirable for predictive purposes. Data from 1966<sup>20</sup> for nonurban locations indicate that the annual arithmetic mean is (on the average) 120% of the annual geometric mean.

#### Representative Calculations

Because one of the primary objects is to derive an acceptable soil level for the Enewetak Islands, the approaches developed above were used to derive such levels for both soluble and insoluble  $^{239}\text{Pu}$ . The derived values are given in Table 151. The two methods agree within a factor of two, at least for soil distributions like those found at the Nevada Test Site. The ambient air mass loading at

Table 151. Acceptable soil levels of  $^{239}\text{Pu}$  for a source which has weathered for several years. Values are approximate and are subject to uncertainty. Permissible Concentration in Air for 168-hr occupational exposure ( $\text{MPC}_a$ )<sup>25</sup>.

	<u>Insoluble</u>	<u>Soluble</u>
Acceptable air concentration, $\mu\text{Ci}/\text{cm}^3$	$10^{-12}$	$6 \times 10^{-14}$
<u>Resuspension-factor approach</u>		
Assumed resuspension factor, $\text{m}^{-1}$	$10^{-9}$	$10^{-9}$
Acceptable soil deposition <sup>a</sup> , $\mu\text{Ci}/\text{m}^2$	$10^3$	60
Acceptable soil concentration <sup>b</sup> , $\text{nCi}/\text{g}$	20	1
<u>Mass-loading approach</u>		
Assumed mass loading, $\mu\text{g}/\text{m}^3$	$10^2$	$10^2$
Acceptable soil concentration, $\text{nCi}/\text{g}$	10	0.6

<sup>a</sup>Equivalent to approximately  $10^4 \mu\text{g}$  of insoluble  $^{239}\text{Pu}/\text{m}^2$ .

<sup>b</sup>Assumes same distribution of  $^{239}\text{Pu}$  with depth and soil density as measured at the Nevada Test Site.

NTS during the cascade impactor run was measured to be  $70 \mu\text{g}/\text{m}^3$ .

Such derived values must, of course, be used with a great deal of discretion. They are based on simple model systems which are believed to be generally conservative, but individual situations can be imagined which could exceed the predictions.

#### Other Considerations

The above calculations relate only to the resuspended air activity in ambient

air, and do not consider the additional problems of resuspension of material from contaminated clothing or the resuspension of material which has been transferred to homes.

Healy<sup>26</sup> has considered these and other problems, and has provided tables of "decision levels" for surface contamination levels and home transfer levels. A decision level is based upon National Council on Radiation Protection and Measurements (NCRP) recommended dose limitations. Because the derivations

Table 152. Decision levels <sup>26</sup> for soluble <sup>239</sup>Pu, and their equivalent in soil mass based upon the "acceptable soil concentration" from Table 151.

Pathway	Decision level	Mass equivalent
A. Direct personal contamination		
Direct inhalation <sup>a</sup>	$2 \times 10^{-5} \text{ nCi}/\text{cm}^2$	$1 \times 10^{-5} \text{ g}/\text{cm}^2$
Direct ingestion <sup>b</sup>	$0.2 \text{ nCi}/\text{cm}^2$	$0.2 \text{ g}/\text{cm}^2$
Skin absorption <sup>c</sup>	$8 \times 10^{-4} \mu\text{Ci}$	0.8 g
B. Transfer (to homes) levels		
Resuspension <sup>d</sup>	$0.01 \mu\text{Ci}/\text{day}$	10 g/day
Direct inhalation	$0.01 \mu\text{Ci}/\text{day}$	10 g/day
Direct ingestion	$100 \mu\text{Ci}/\text{day}$	$10^5 \text{ g}/\text{day}$
Skin absorption	$0.03 \mu\text{Ci}/\text{day}$	30 g/day

<sup>a</sup>"The contamination level on clothing and skin that could result in inhalation of air at the  $\text{MPC}_a$  for the public."<sup>26</sup>

<sup>b</sup>"The contamination level on skin or clothing that could result in ingestion of a quantity of radioactive material equivalent to the ingestion of water at the  $\text{MPC}_w$  for an individual in the public."<sup>26</sup>

<sup>c</sup>"The total quantity of radioactive material maintained on the skin for 24 h/day that could result in absorption of a quantity equal to that which would be absorbed from the GI tract if water at the  $\text{MPC}_w$  for "soluble" isotopes for an individual in the public were ingested."<sup>26</sup>

<sup>d</sup>"The amount transferred per day that could result in air concentrations due to resuspension in a medium-sized home averaging at the  $\text{MPC}_a$  for an individual in the public."<sup>26</sup>

are rather tenuous, Healy has used the phrase decision level and states that its use is to serve as a signal that further careful investigation is warranted.

Healy's decision levels for soluble  $^{239}\text{Pu}$  are given in column 1 of Table 152. The values in column 2 are derived from these and an acceptable soil concentration of 1 nCi/g from Table 151 to give equivalent dirt (soil) contamination and transfer levels. The results are interpreted as indicating that the potential exists for

greater dose contributions from these infrequently considered pathways than from the usually considered pathway of resuspension as calculated for ambient air. This conclusion would be the same for insoluble  $^{239}\text{Pu}$ . Therefore, if dose calculations based on the usual resuspension pathway should appear limiting compared to other pathways such as food-chain transfer, these pathways considered by Healy need to be carefully evaluated for the specific Enewetak situation.

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## Dose Estimates for the Marine Food Chain

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### Introduction

This analysis is designed to estimate the dose via the marine pathway. The dose assessment is based upon the marine diet discussed in the chapter on dietary and living patterns (Table 139).

### Data Bank

The data bank contains analytical results from slightly over 800 fish and approximately 50 edible invertebrates collected during the 1972 Enewetak survey (for a detailed description see the marine survey chapter). Data from the analysis of the radionuclide concentration in fish muscle have been summarized in several different ways to help in the interpretation and the assessment of the values to be used in the dose code. Figure 118 indicates the various forms of the summarized data.

Table 153\* lists the average radionuclide concentration — with concentrations for a nondetected nuclide set equal to the detection limit in column 4 and concentrations for nondetected nuclides set equal to zero in column 7 — for each species for samples collected at each island and in the open lagoon. Table 154 (on microfiche) presents the summary of the average radionuclide concentration for each species for the entire Atoll, regardless of location. The nuclides are identified by the

\* Because of the sheer bulk of the data, Tables 153-155 and 157 have been reproduced on microfiche film and may be found in the envelope mounted on p. 527.

sequence of numbers in the nuclide column. The first two digits give the atomic number and the last three digits give the isotope mass number; therefore 55137 is  $^{137}\text{Cs}$ . The tables also include the tissue, the number of samples in the average, the range of individual values, and, because of the skewed distribution observed in this survey and observed for trace elements and radionuclides in other populations<sup>1-3</sup>, the lognormal median for comparison with the average value.

The reef fishes are the most plentiful around the Atoll and are the easiest to catch. Therefore they make up a considerable portion of the fresh fish intake in the diet. The most plentiful reef fishes, and also three of the preferred fish in the diet, are surgeonfish, goatfish,

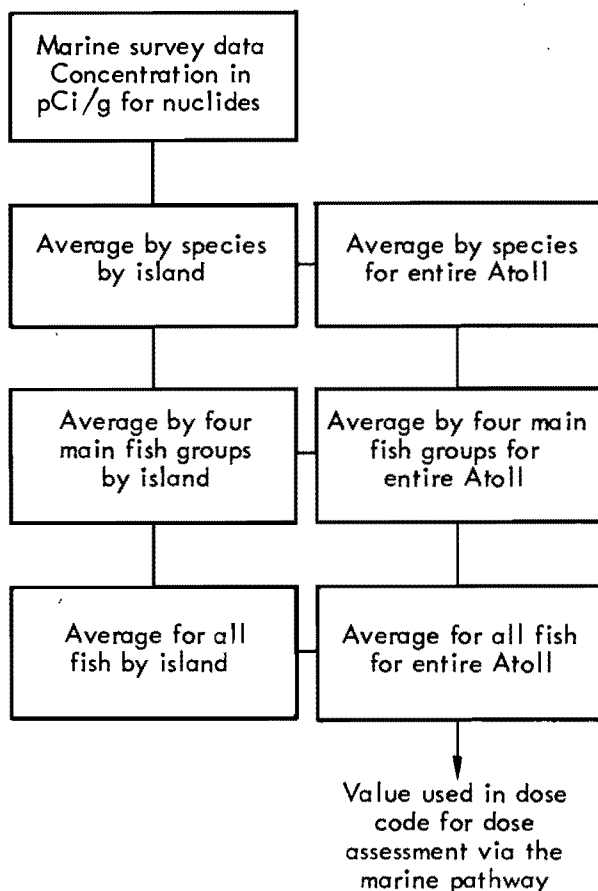


Fig. 118. Summaries of marine concentration data.

Tables 153, 154, 155, and 157.  
Radionuclide concentration in fish muscle.

**Microfiche attached  
to this page**



and mullet. Other reef fish are eaten but are not as plentiful. In addition, the larger pelagic, predator fish are eaten, but they are harder to catch and therefore supply much less of the fish diet than the reef fishes. Tridacna clams also constitute a small portion of the diet. They are considered a delicacy, are not available in large quantity, and are usually eaten raw at the time of catch. Lingusta (lobster) are also considered a delicacy but contribute a very small portion of the marine diet.

Therefore the next summary presents the average radionuclide concentration of four main fish groups — surgeonfish, goatfish, mullet and "other"— where "other" includes all species other than the three mentioned, including the tridacna clams and lingusta. The summary is shown in Table 155 (on microfiche) and is island specific.

Table 156, incorporated in the text, lists the average concentration of the radionuclides in the four fish groups for the entire Atoll. The number of samples in the average concentration, the standard deviation, and the high and low of the range are all given. The plot of the concentration of  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{90}\text{Sr}$ , the three main isotopes found in fish muscle, for the four fish groups is shown in Fig. 119. The standard deviations for each of the four fish groups were a factor of 2 to 3 times greater than the difference between the range of the mean values. There was therefore no statistically significant difference in the mean values of the four groups; however, the Kruskal-Wallis nonparametric test did indicate a difference in the total distribution for  $^{60}\text{Co}$  and  $^{90}\text{Sr}$ .

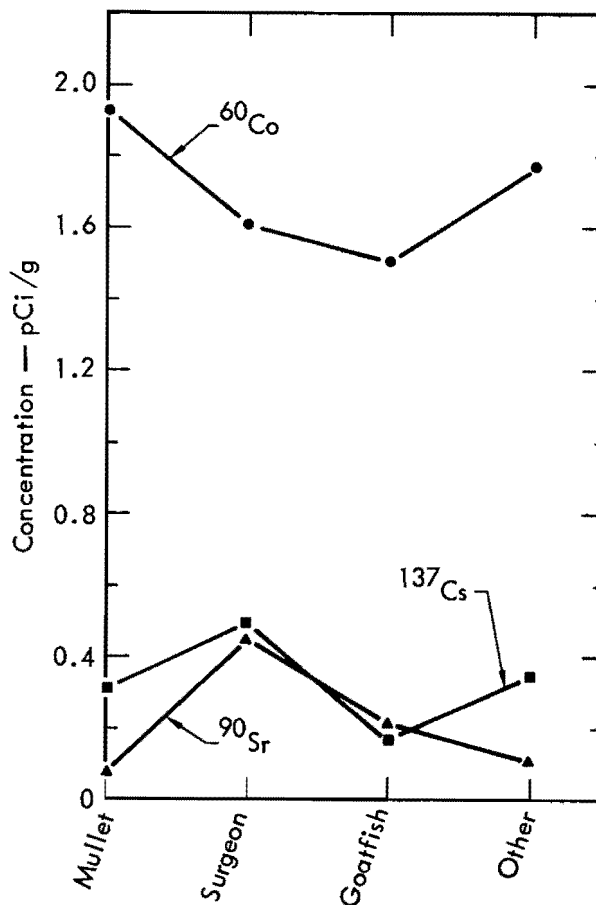


Fig. 119. Average concentration of  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{90}\text{Sr}$  for the four fish groups for the entire Atoll.

Because there were no statistically significant differences between mean values for the four major fish categories, the radionuclide concentration was averaged by island for all fish. These results are given in Table 157 (on microfiche). Figures 120-122 show a plot of the  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{90}\text{Sr}$  average nuclide concentration in all fish as a function of island location.

There appears to be a higher concentration of the three radionuclides in fish from ALICE through IRENE than from islands JANET through LEROY. Although individual samples from islands JANET through LEROY had concentrations in the

Table 156a. Summary of radionuclide concentrations for the entire Atoll for mullet.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM		AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
					HIGH	LOW		
40 K	MUSCLE	26	8.141E+00	3.697E+00	1.686E+01	2.982E+00	8.141E+00	7.402E+00
55 FE	MUSCLE	26	8.022E+00	2.114E+01	1.104E+02	5.586E-01	8.022E+00	3.289E+00
60 CO	MUSCLE	27	1.930E+00	4.132E+00	2.189E+01	1.495E-01	1.904E+00	8.237E-01
90 SR	MUSCLE	25	8.181E-02	8.926E-02	3.041E-01	3.459E-03	5.811E-02	4.216E-02
106 RU	MUSCLE	21	7.581E-01	3.077E-01	1.379E+00	3.618E-01	0.	7.003E-01
102 RH	MUSCLE	27	8.399E-02	7.316E-02	3.729E-01	2.536E-02	0.	6.557E-02
125 SB	MUSCLE	27	2.620E-01	3.782E-01	2.096E+00	7.734E-02	7.763E-02	1.871E-01
137 CS	MUSCLE	27	3.248E-01	8.185E-01	4.344E+00	2.636E-02	2.754E-01	1.400E-01
133 BA	MUSCLE	19	1.167E-01	1.003E-01	4.178E-01	2.753E-02	0.	8.557E-02
144 CE	MUSCLE	1	2.877E-01	0.	2.877E-01	2.877E-01	0.	2.877E-01
152 EU	MUSCLE	27	7.659E-02	3.908E-02	1.323E-01	3.060E-02	0.	6.716E-02
155 EU	MUSCLE	27	1.058E-01	4.897E-02	1.690E-01	3.696E-02	1.243E-02	9.333E-02
207 BI	MUSCLE	27	6.412E-02	3.964E-02	2.077E-01	2.105E-02	1.678E-02	5.517E-02
235 U	MUSCLE	26	6.505E-02	3.817E-02	1.843E-01	2.350E-02	0.	5.570E-02
239,240 PU	MUSCLE	25	9.840E-01	4.603E+00	2.306E+01	4.820E-04	9.813E-01	1.446E-02
238 PU	MUSCLE	13	1.055E-02	9.426E-03	3.036E-02	1.811E-03	3.486E-03	7.706E-03
241 AM	MUSCLE	27	9.824E-02	4.805E-02	1.722E-01	2.613E-02	0.	8.429E-02

\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM  
 \*\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

Table 156b. Summary of radionuclide concentrations for the entire Atoll for surgeon.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM		AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
					HIGH	LOW		
3 H	MUSCLE	4	3.298E-01	1.166E-01	4.698E-01	1.845E-01	3.298E-01	3.128E-01
40 K	MUSCLE	25	1.004E+01	2.552E+00	1.598E+01	7.194E+00	1.004E+01	9.758E+00
55 FE	MUSCLE	27	9.892E+00	1.364E+01	6.757E+01	2.703E-01	9.750E+00	4.718E+00
60 CO	MUSCLE	28	1.815E+00	5.789E+00	3.106E+01	6.108E-02	1.765E+00	4.647E-01
90 SR	MUSCLE	27	2.098E-01	2.801E-01	1.275E+00	6.441E-03	2.029E-01	9.282E-02
106 RU	MUSCLE	27	7.073E-01	4.951E-01	2.104E+00	3.017E-01	0.	5.938E-01
102 RH	MUSCLE	28	6.618E-02	7.081E-02	3.719E-01	1.805E-02	0.	4.894E-02
125 SB	MUSCLE	28	1.816E-01	1.243E-01	4.806E-01	7.757E-02	0.	1.515E-01
137 CS	MUSCLE	28	5.387E-01	1.271E+00	6.779E+00	4.363E-02	5.056E-01	2.222E-01
133 BA	MUSCLE	20	7.708E-02	8.988E-02	4.005E-01	2.445E-02	0.	5.292E-02
152 EU	MUSCLE	28	7.342E-02	4.802E-02	1.924E-01	3.200E-02	0.	6.184E-02
155 EU	MUSCLE	28	8.593E-02	5.551E-02	2.044E-01	3.097E-02	0.	7.105E-02
207 BI	MUSCLE	28	1.158E-01	1.529E-01	7.739E-01	1.965E-02	7.367E-02	6.825E-02
235 U	MUSCLE	28	5.434E-02	3.857E-02	1.821E-01	2.271E-02	0.	4.509E-02
239,240 PU	MUSCLE	28	7.724E-02	1.689E-01	8.874E-01	4.279E-03	7.683E-02	2.804E-02
238 PU	MUSCLE	8	8.100E-03	6.707E-03	2.207E-02	1.802E-03	4.561E-03	5.862E-03
241 AM	MUSCLE	28	8.431E-02	5.731E-02	1.920E-01	2.232E-02	0.	6.583E-02

\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM  
 \*\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

Table 156c. Summary of radionuclide concentrations for the entire Atoll for goatfish.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM		AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
					HIGH	LOW		
3 H	MUSCLE	3	4.108E-01	6.860E-02	4.622E-01	3.329E-01	4.108E-01	4.067E-01
40 K	MUSCLE	19	9.662E+00	2.464E+00	1.637E+01	5.946E+00	9.662E+00	9.374E+00
55 FE	MUSCLE	20	3.012E+01	8.358E+01	3.833E+02	1.676E+00	3.012E+01	1.002E+01
60 CO	MUSCLE	21	1.506E+00	3.087E+00	1.477E+01	1.608E-01	1.483E+00	7.914E-01
90 SR	MUSCLE	21	2.152E-01	3.527E-01	1.541E+00	1.212E-02	2.152E-01	1.036E-01
106 RU	MUSCLE	10	7.548E-01	4.684E-01	1.943E+00	3.768E-01	0.	6.633E-01
102 RH	MUSCLE	21	8.293E-02	4.513E-02	1.714E-01	2.643E-02	0.	7.234E-02
125 SB	MUSCLE	21	2.978E-01	3.943E-01	1.986E+00	9.743E-02	1.064E-01	2.242E-01
137 CS	MUSCLE	21	1.718E-01	1.963E-01	9.878E-01	4.201E-02	1.018E-01	1.324E-01
133 BA	MUSCLE	19	1.675E-01	1.052E-01	4.118E-01	2.785E-02	2.168E-02	1.275E-01
144 CE	MUSCLE	1	2.739E-01	0.	2.739E-01	2.739E-01	0.	2.739E-01
152 EU	MUSCLE	21	5.915E-02	4.338E-02	1.903E-01	2.779E-02	0.	4.942E-02
155 EU	MUSCLE	21	1.208E-01	8.445E-02	4.122E-01	3.777E-02	3.332E-02	1.018E-01
207 BI	MUSCLE	21	7.464E-01	5.320E-01	1.633E+00	1.214E-01	7.379E-01	5.555E-01
235 U	MUSCLE	20	9.357E-02	4.347E-02	1.508E-01	2.482E-02	0.	8.070E-02
239, 240 PU	MUSCLE	21	1.299E-02	1.513E-02	5.315E-02	1.608E-03	1.231E-02	7.782E-03
238 PU	MUSCLE	12	1.066E-02	7.512E-03	2.432E-02	3.153E-03	5.405E-03	8.290E-03
241 AM	MUSCLE	21	1.111E-01	4.604E-02	2.053E-01	2.774E-02	0.	9.907E-02

\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM  
 \*\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

Table 156d. Summary of radionuclide concentrations for the entire Atoll for other fish.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM		AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
					HIGH	LOW		
3 H	MUSCLE	2	5.040E-01	3.040E-01	7.189E-01	2.890E-01	5.040E-01	4.558E-01
40 K	MUSCLE	46	1.593E+01	5.369E+00	2.697E+01	3.355E+00	1.593E+01	1.481E+01
55 FE	MUSCLE	50	1.717E+01	3.209E+01	1.968E+02	1.577E-01	1.704E+01	5.012E+00
60 CO	MUSCLE	52	2.347E+00	6.448E+00	3.827E+01	4.063E-02	2.282E+00	5.167E-01
90 SR	MUSCLE	52	1.403E-01	2.207E-01	8.514E-01	1.051E-03	6.268E-02	5.129E-02
106 RU	MUSCLE	30	9.528E-01	4.861E-01	2.237E+00	3.236E-01	0.	8.466E-01
102 RH	MUSCLE	52	1.099E-01	6.257E-02	2.954E-01	2.481E-02	0.	9.180E-02
113 CD	MUSCLE	1	2.635E-01	0.	2.635E-01	2.635E-01	2.635E-01	2.635E-01
125 SB	MUSCLE	52	2.486E-01	1.424E-01	1.025E+00	7.788E-02	1.295E-02	2.212E-01
137 CS	MUSCLE	52	4.311E-01	5.679E-01	3.089E+00	2.689E-02	4.035E-01	2.539E-01
133 BA	MUSCLE	46	1.726E-01	1.342E-01	7.631E-01	2.632E-02	2.718E-02	1.284E-01
144 CE	MUSCLE	2	2.837E-01	1.949E-02	2.975E-01	2.699E-01	0.	2.834E-01
152 EU	MUSCLE	52	8.945E-02	7.507E-02	3.415E-01	2.933E-02	0.	6.866E-02
155 EU	MUSCLE	52	1.226E-01	9.119E-02	5.212E-01	3.570E-02	1.482E-02	1.019E-01
207 BI	MUSCLE	52	5.532E+00	3.499E+01	2.527E+02	2.074E-02	5.493E+00	1.776E+01
235 U	MUSCLE	48	9.569E-02	5.005E-02	2.547E-01	2.382E-02	0.	8.192E-02
239, 240 PU	MUSCLE	49	7.000E-02	2.383E-01	1.212E+00	7.883E-04	6.368E-02	9.092E-03
238 PU	MUSCLE	31	1.805E-02	2.984E-02	1.140E-01	2.063E-03	6.089E-03	7.982E-03
241 AM	MUSCLE	52	1.404E-01	1.130E-01	8.023E-01	2.700E-02	6.820E-03	1.148E-01

\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM  
 \*\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

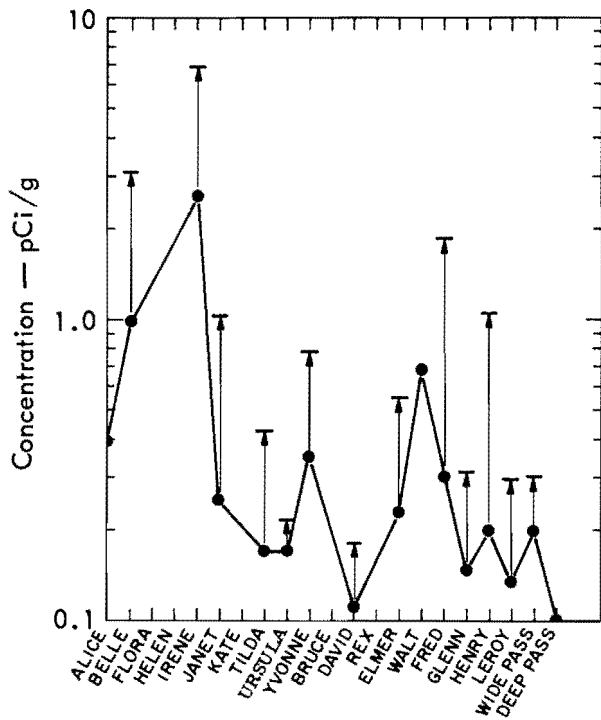


Fig. 120. <sup>137</sup>Cs concentrations in marine samples as a function of location in the Atoll. The bar above each vertical arrow indicates the maximum value for a sample included in the average. No bar or arrow indicates a single sample.

same range as individual samples for islands ALICE through IRENE, there was definitely a significant difference for the <sup>137</sup>Cs and <sup>60</sup>Co (p = 0.001 Mann-Whitney U Test) concentrations for fish from ALICE through IRENE, versus those from JANET through LEROY. There was no significant difference between these island groups for fish muscle samples for <sup>90</sup>Sr. If fish samples for eviscerated whole fish (which includes the bones) are included, then <sup>90</sup>Sr concentrations do test differently for these island groups.

However, the people living on Engebi (JANET) will fish both east and west of the island; that is, they will fish off the islands ALICE through IRENE, but will also fish off the islands KATE through

WILMA. In essence, the people living on Engebi will fish the northern half of the Atoll. Therefore, in their fish diet, they will integrate the concentrations of the fish from the northern half of the Atoll, i. e., ALICE through WILMA. Again using the Mann-Whitney U Test, concentration values for the three isotopes for all fish from islands ALICE through WILMA, i. e., the northern half of the Atoll, were tested against the concentration values for all fish from islands ALVIN through LEROY, i. e., the southern

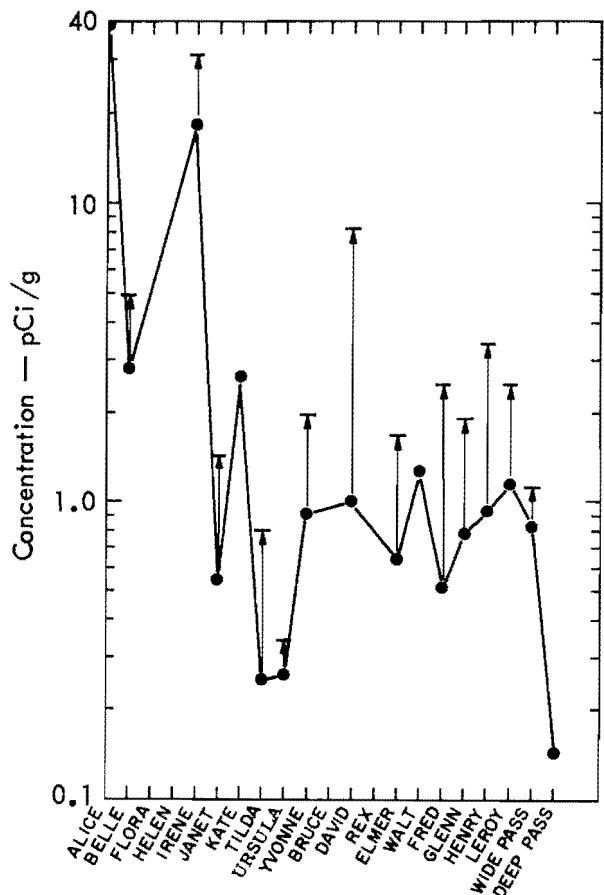


Fig. 121. <sup>60</sup>Co concentrations in marine samples as a function of location in the Atoll. The bar above each vertical arrow indicates the maximum value for a sample included in the average. No bar or arrow indicates a single sample.



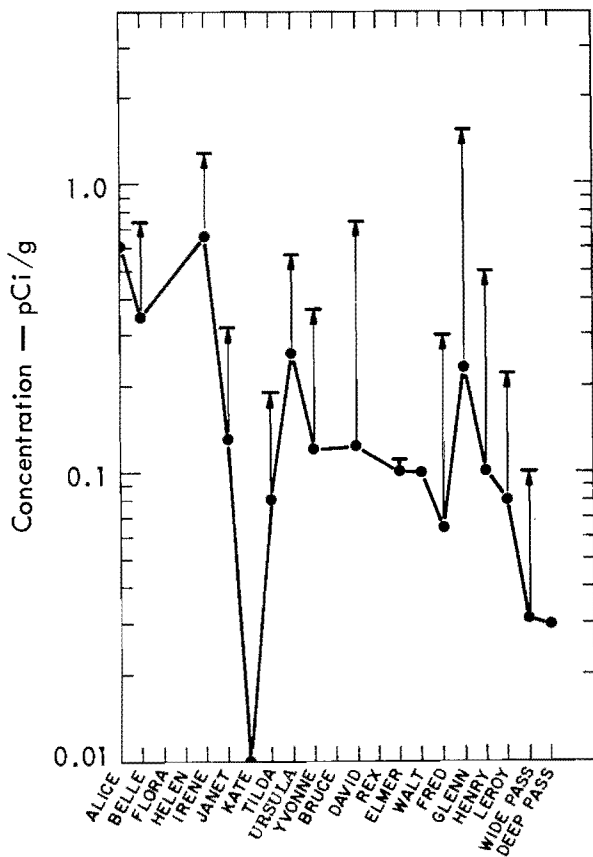


Fig. 122.  $^{90}\text{Sr}$  concentrations in marine samples as a function of location in the Atoll. The bar above each vertical arrow indicates the maximum value for a sample included in the average. No bar or arrow indicates a single sample.

half of the Atoll. The results for fish muscle show no difference between the two halves of the Atoll for  $^{90}\text{Sr}$  ( $p = 0.7$ ),  $^{137}\text{Cs}$  ( $p = 0.1$ ), and  $^{60}\text{Co}$  ( $p = 0.4$ ).  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  tested as significantly different ( $p = 0.001$ ) for eviscerated whole fish which included bone; however, the average concentration in this case for the two halves of the Atoll differs by only a factor of 3 for  $^{137}\text{Cs}$  and a factor of 2 for  $^{90}\text{Sr}$ , and the average for the entire Atoll is less by only a factor of 2 for  $^{137}\text{Cs}$  and only 30% for  $^{90}\text{Sr}$  than the average of the northern half alone.

As a result of the above analysis and the fact that the Enewetak people eat only the muscle portion of the fish, the average concentration (with concentrations for nondetected radionuclides set equal to the detection limit) for fish from the entire Atoll was used in the dose code. Table 158 lists the average concentration, the number of samples in the average, the standard deviation, and the high and low of the range for each radionuclide for all fish.

The concentration distributions for  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{60}\text{Co}$  are quite skewed (Figs. 123-125) and are consistent with other published data on radionuclide and trace-element distribution in fish, animals, and humans (1, 2, 3). The log-normal median is therefore included in the Table 158 for comparison with the average value. In general, the lognormal median is 3 to 4 times less than the average. However, to estimate the average population dose for the marine pathway

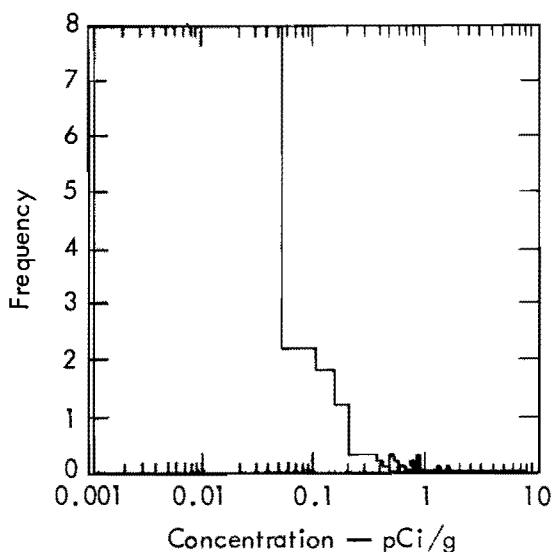


Fig. 123. Histogram plot of the  $^{90}\text{Sr}$  concentration in all fish from the entire Atoll.

Table 158. Average concentration, number of samples in the average, standard deviation, and high and low of the range for all fish in the entire Enewetak Atoll.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM		AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
					HIGH	LOW		
01003	MUSCLE	9	3.955E-01	1.517E-01	7.189E-01	1.845E-01	3.955E-01	3.712E-01
19040	MUSCLE	116	1.189E+01	5.277E+00	2.697E+01	2.982E+00	1.189E+01	1.075E+01
26055	MUSCLE	123	1.574E+01	4.108E+01	3.833E+02	1.577E-01	1.566E+01	5.063E+00
27060	MUSCLE	128	2.005E+00	5.377E+00	3.827E+01	4.063E-02	1.958E+00	5.974E-01
38090	MUSCLE	125	1.562E-01	2.460E-01	1.541E+00	1.051E-03	1.177E-01	6.308E-02
44106	MUSCLE	88	8.085E-01	4.558E-01	2.237E+00	3.017E-01	0.	7.058E-01
45102	MUSCLE	128	9.044E-02	6.601E-02	3.729E-01	1.805E-02	0.	7.165E-02
48113	MUSCLE	1	2.635E-01	0.	2.635E-01	2.635E-01	2.635E-01	2.635E-01
51125	MUSCLE	128	2.449E-01	2.581E-01	2.096E+00	7.734E-02	3.910E-02	1.970E-01
55137	MUSCLE	128	3.897E-01	7.940E-01	6.779E+00	2.636E-02	3.493E-01	1.955E-01
56133	MUSCLE	104	1.431E-01	1.205E-01	7.631E-01	2.445E-02	1.598E-02	1.004E-01
58144	MUSCLE	4	2.822E-01	1.269E-02	2.975E-01	2.699E-01	0.	2.820E-01
63152	MUSCLE	128	7.826E-02	5.899E-02	3.415E-01	2.779E-02	0.	6.329E-02
63155	MUSCLE	128	1.107E-01	7.631E-02	5.212E-01	3.097E-02	1.411E-02	9.242E-02
83207	MUSCLE	128	2.409E+00	2.233E+01	2.527E+02	1.965E-02	2.372E+00	1.358E-01
92235	MUSCLE	122	7.932E-02	4.723E-02	2.547E-01	2.271E-02	0.	6.563E-02
94000	MUSCLE	123	2.477E-01	2.083E+00	2.306E+01	4.820E-04	2.444E-01	1.257E-02
94238	MUSCLE	64	1.390E-02	2.175E-02	1.140E-01	1.802E-03	5.241E-03	7.679E-03
95241	MUSCLE	128	1.144E-01	8.462E-02	8.023E-01	2.232E-02	2.771E-03	9.298E-02

\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM

\*\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

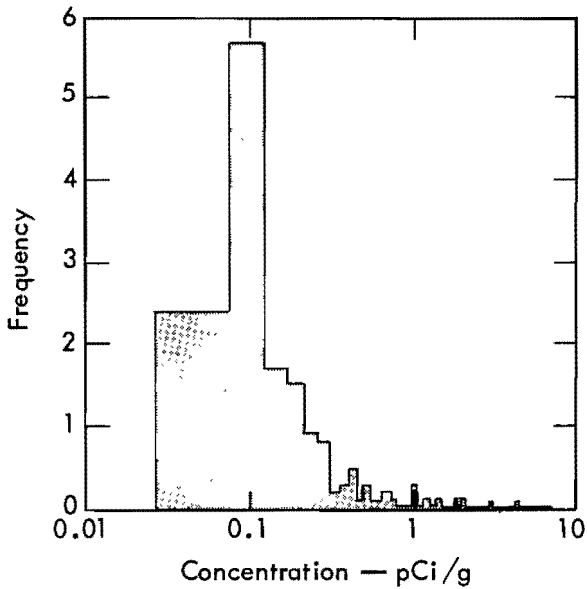


Fig. 124. Histogram plot of the  $^{137}\text{Cs}$  concentration in all fish from the entire Atoll.

we have used the average radionuclide concentration, which is conservative and leads to the higher dose estimate.

Elements other than  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ ,  $^{238}$ ,  $^{239}$ ,  $^{240}\text{Pu}$ , and  $^{55}\text{Fe}$  were for the most part nondetectable. In such cases, for the purpose of dose estimates, the concentration of the radionuclide was set equal to the detection limit. The average pCi/gram value listed in column 4 in Tables 154-158 was calculated in this manner. Using this approach produces a conservative dose estimate of the contribution from these nuclides because the actual concentration of many of these nuclides may be far below the analytical detection limit. For example, detection limits for  $^{241}\text{Am}$  established by wet-chemistry analysis of a few samples were found to be significantly lower than those previously established by gamma counting.

Tables 154-158 give an indication of

the isotopes whose concentrations were established by detection limits. The 8th column headed "average" (if nondetected concentration set equal to zero) means that if an element were not detected, the concentration value was then set equal to zero rather than equal to the detection limit. Therefore, if a zero appears in this column, it means that the isotope was not detected in any of the samples analyzed. If a number appears in this column but the concentration value is very low relative to the "average" column (if nondetected concentration set equal to detection limit), that indicates that the isotope was not detected in many of the analyzed samples. If the two columns have equal or approximately equal values, then all or nearly all of the samples analyzed had detectable amounts of the isotope. In any case, by setting the concentration equal to the detection limit for those isotopes which were nondetected

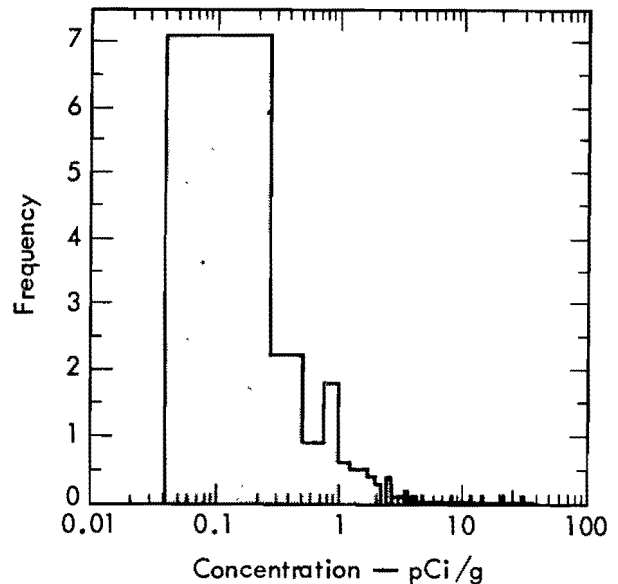


Fig. 125. Histogram plot of the  $^{60}\text{Co}$  concentration in all fish from the entire Atoll.

maximizes the dose contribution from these radionuclides.

Table 159 shows the average concentration of the three main radionuclides found in fish. The number of samples analyzed, as well as the high and low of the range, are given. These values, corrected by a factor of 3.5 to obtain wet weight, were used along with the 600-g/day intake of fish from the predicted diet to make dose estimates. The values for  $^{90}\text{Sr}$  in this table deserve special comment. Most of the reef fishes, which make up a large portion of the marine diet, are small and are not easily filleted to separate meat from bone. Therefore, the eviscerated fish were homogenized in a blender to make a uniform sample and then packaged for counting. Homogenizing the whole fish (excluding viscera) includes all the bones of the fish. A significant fraction of the  $^{90}\text{Sr}$  in fish is, of course, lodged in the bone moiety. However, the Enewetakese do not eat the bones of the fish and are, in fact, careful to eat the meat from around the bones.

The samples where the muscle was separated from the bone showed a muscle concentration of  $^{90}\text{Sr}$  of 0.075 pCi/g, which is lower by nearly a factor of 3 than that observed in the eviscerated whole fish. Therefore, the dose from  $^{90}\text{Sr}$  has been calculated using the value for fish muscle of 0.075 pCi/g dry weight (or 0.021 pCi/g wet weight).

For reference, data for the  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  content of fish from U. S. diets, from high lakes in Colorado, from around Amchitka Island, and from around Bikini Atoll are shown in Table 160. Cesium concentrations at the Atoll are quite similar or in some cases lower than those observed in other locations, while strontium concentrations are higher in the Atoll than in the U. S. diet.

#### Dose Code

The doses via the marine and terrestrial food chains were estimated using the following differential equation to describe the intake and retention by man:

Table 159. Radionuclide concentrations in fish (January 1972).

Nuclide	Sample	No. of Samples	Concentration, pCi/g dry weight		
			Average	High	Low
$^{137}\text{Cs}$	All fish <sup>a</sup>	128	0.39	6.8	0.026
$^{60}\text{Co}$	All fish <sup>a</sup>	128	2.0	38	0.041
$^{90}\text{Sr}$	All fish <sup>a</sup>	125	0.16	1.5	0.0010
$^{90}\text{Sr}$	Eviscerated whole fish	74	0.21	---	---
$^{90}\text{Sr}$	Fish muscle only	51	0.075	---	---

<sup>a</sup>All fish includes eviscerated whole fish and those fish where muscle was separated from bone and only the muscle was analyzed.

Table 160. Comparison of cesium and strontium data for marine fish muscle.

Location		Concentration, mean pCi/g, dry wt	
		<sup>137</sup> Cs	<sup>90</sup> Sr
Enewetak	1972	0.3	0.08
Amchitka	1971 <sup>a</sup>	0.1	No data
Chicago	1971 <sup>b</sup>	0.1	0.003
Chicago	1972 <sup>b</sup>	0.2	0.003
Bikini	1968 <sup>c</sup>	~1.0	0.7
Colorado mountain lakes	1972 <sup>d</sup>	2.5	No data

<sup>a</sup>Amchitka Radiobiological Program Progress Report, NVO-269-17, 1972.

<sup>b</sup>Radiation and Data Reports 1971, 1972;

Health and Safety Laboratory Quarterly Reports 1971, 1972, 1973.

<sup>c</sup>Radiological Report on Bikini Atoll, 1968.

<sup>d</sup>"Radioecology of Some Natural Organisms and Systems in Colorado,"  
Eleventh Annual Progress Report to Atomic Energy Commission, Department of  
Radiology and Radiation Biology, Colorado State University, Fort Collins,  
Colorado, Rept. COO-1156-63.

$$\frac{dC_{\text{man}}}{dt} = \frac{I f_{\text{man}} C}{M} - \lambda_{\text{man}} C_{\text{man}},$$

where  $C_{\text{man}}$  = concentration of nuclide in man, pCi/g,

$I$  = food intake, g/day,

$f_{\text{man}}$  = fraction of nuclide ingested reaching the organ of reference,

$C$  = concentration of nuclide in food product, pCi/g (i.e., fish, shellfish, coconut, land crab, etc.),

$M$  = mass of the organ of reference, g, and

$\lambda_{\text{man}}$  = effective elimination rate of nuclide from man, day<sup>-1</sup>

$$(\lambda_{\text{man}} = \lambda_{\text{biological}} + \lambda_{\text{radioactive}}).$$

The concentration  $C$  in the food products is calculated assuming that the nuclide disappears only by radioactive decay, i.e., that no other processes are in operation which reduce the nuclide availability in the food chain. Therefore

$C = C_0 e^{-\lambda_r t}$ , where  $C_0$  is the concentration observed at the time of the survey and  $\lambda_r$  is the radioactive decay constant. The concentration in man at any time  $t$  after initial consumption of the food is:

$$C_{\text{man}} = \frac{I f_{\text{man}} C_0}{M(\lambda_{\text{man}} - \lambda_r)} \left( e^{-\lambda_r t} - e^{-\lambda_{\text{man}} t} \right) \text{pCi/g.}$$

The dose at any time  $t$  after initial consumption is:

$$\begin{aligned} \text{Dose (rem)} &= KE \int_0^t C_{\text{man}} dt \\ &= KE \int_0^t \frac{I f_{\text{man}} C_0}{M(\lambda_{\text{man}} - \lambda_r)} \left( e^{-\lambda_r t} - e^{-\lambda_{\text{man}} t} \right) dt, \end{aligned}$$

where  $K$  is a conversion constant from pCi/g to rem and equals  $5.1 \times 10^{-5}$   $\frac{\text{disintegrations} \cdot \text{g} \cdot \text{rem}}{\text{pCi} \cdot \text{MeV} \cdot \text{day}}$ , and  $E$  is the disintegration energy of the nuclide in MeV, including a factor for relative bio-

logical effectiveness (RBE). The final dose is then determined from the integration of the equation, i. e.,

$$\text{Dose} = \frac{KE I f_{\text{man}} C_0}{M(\lambda_{\text{man}} - \lambda_r)} \left[ \frac{1 - e^{-\lambda_r t}}{\lambda_r} - \frac{1 - e^{-\lambda_{\text{man}} t}}{\lambda_{\text{man}}} \right] \text{rem.} \quad (6)$$

Table 161 lists the  $f_{\text{man}}$  (FMAN),  $\lambda_{\text{radioactive}}$  (LR),  $\lambda_{\text{man}}$  (LMAN), and disintegration energy (E) values for all of the isotopes in the dose calculations.

Values for the parameters  $f_{\text{man}}$  (FMAN) (a dimensionless number) and  $\lambda_{\text{man}}$  (LMAN) (in days<sup>-1</sup>) for the whole body, bone, and kidney are taken from ICRP<sup>4,5</sup> or from more recent literature reports, where such data exist. We are continually searching the literature and updating  $f$  and  $\lambda$  values for many isotopes when new information is available. The masses (in grams) used for the whole body and other reference organs are adopted from ICRP values. The disintegration energies, E, (in MeV), are obtained from either ICRP<sup>4,5</sup> or the work of the MIRD committee<sup>6</sup>. The radioactive decay constants  $\lambda_r$  (LR) (in days<sup>-1</sup>) are calculated from isotope half-life data in the Table of Isotopes<sup>7</sup>.

The intake term (I) represents the average daily consumption of various dietary components. The average diet is the result of input from Jack Tobin of the Trust Territories, discussions with Dr. Mary Murai of the University of California, Berkeley and reports which she has published<sup>8</sup>, and direct interview and observation of the Enewetak people in their present locations (see reports by Marsh and Nelson included in the chapter on Enewetak).

### Dose Estimates for the Marine Pathway

The radionuclide concentration,  $C_0$ , is the average value for all fish from the entire Atoll determined from our survey and is listed in Tables 158 and 159 for each nuclide. The average values for radionuclide concentrations listed in the tables are in pCi/g dry weight. The data are corrected to pCi/g wet weight for use in the dose code by dividing by 3.5, the average wet-to-dry ratio for fish from the Atoll.

Integral doses calculated from the marine survey data are listed in Table 162 for the whole body and bone for 5, 10, 30, and 70 yr. The major contribution to the whole-body dose comes from <sup>137</sup>Cs and <sup>60</sup>Co, while the bone dose comes from <sup>90</sup>Sr, as well as <sup>137</sup>Cs and <sup>60</sup>Co. The fourth line of the table gives the summation of the dose to each organ from the three isotopes. The bottom entry in the table lists the dose from all radionuclides which are listed in the Table 154 footnote. It is clear that almost all of the dose is contributed by <sup>137</sup>Cs, <sup>60</sup>Co, and <sup>90</sup>Sr. For example, the 30-yr integral whole-body dose is 47 mrem from <sup>137</sup>Cs and <sup>60</sup>Co, and only 6 mrem additional whole-body dose is contributed by other radionuclides. For bone, the total dose from all radionuclides is 840 mrem, with 94% contributed by <sup>90</sup>Sr, and 6% by all other nuclides.

In addition to the isotopes listed in Table 158, dose estimates for <sup>14</sup>C and <sup>129</sup>I were made and included in the summary of the marine pathway. Neither <sup>14</sup>C nor <sup>129</sup>I were detected in any of the samples, but doses were calculated on the assumption that the concentration equaled the detection limit. The 30-yr

Table 161. The disintegration energy E and the radioactive half life LR are listed for each radionuclide. The effective biological half time LMan and the fraction of ingested isotope reaching the organ of reference FMan are listed for three receptor organs, bone, liver, and whole body.

1			BONE MASS=	5.000E+03	LIVER MASS=	1.800E+03	WHOLEBODY MASS=	7.000E+04
NUCLIDE	E	LR	-LMAN-	-FMAN-	-LMAN-	-FMAN-	-LMAN-	-FMAN-
3 H	6.287E-03	1.549E-04	5.790E-02	9.100E-02	5.790E-02	2.600E-02	5.790E-02	1.000E+00
14 C	5.087E-02	3.314E-07	1.733E-02	2.500E-02	6.930E-02	2.600E-02	6.930E-02	1.000E+00
55FE	6.540E-03	7.032E-04	1.116E-03	1.000E-02	1.954E-03	1.300E-02	1.569E-03	1.000E-01
60CO	8.740E-01	3.609E-04	2.924E-02	2.000E-02	8.191E-03	8.310E-02	8.191E-03	3.000E-01
63NI	1.780E-02	2.064E-05	8.869E-04	1.500E-01	1.407E-03	2.000E-02	1.060E-03	3.000E-01
90SR	5.500E+00	6.781E-05	1.987E-03	3.000E-01	1.156E-01	7.800E-03	1.211E-04	3.000E-01
106RU	1.400E+00	1.899E-03	3.439E-03	3.300E-02	1.180E-02	6.300E-02	7.229E-03	3.000E-01
102RH	1.000E+00	6.544E-04	4.240E-02	1.000E-02	3.873E-02	8.000E-03	6.729E-02	2.000E-01
113CD	1.800E-01	1.356E-04	5.911E-03	9.000E-05	3.601E-03	1.900E-03	1.375E-04	5.900E-02
125SB	3.600E-01	7.032E-04	7.633E-03	3.000E-03	1.894E-02	6.000E-05	1.894E-02	3.000E-02
129 I	7.686E-02	1.187E-10	4.950E-02	7.000E-02	9.900E-02	1.200E-01	5.022E-03	1.000E+00
133BA	3.940E-01	2.637E-04	1.093E-02	3.500E-02	9.745E-04	3.000E-05	1.093E-02	5.000E-02
137CS	5.900E-01	6.329E-05	6.363E-03	9.100E-02	6.363E-03	2.600E-02	7.142E-03	1.000E+00
144CE	3.754E+00	2.432E-03	2.894E-03	3.000E-05	4.797E-03	2.500E-05	3.662E-03	1.000E-04
147PM	2.297E+00	7.032E-04	1.165E-03	3.500E-05	1.760E-03	6.000E-06	1.760E-03	1.000E-04
151SM	1.523E-02	2.110E-05	4.831E-04	3.500E-05	3.727E-03	3.500E-05	1.077E-03	1.000E-04
152EU	6.600E-01	1.531E-04	3.379E-04	3.600E-05	5.610E-03	2.500E-05	3.379E-04	1.000E-04
155EU	1.600E-01	1.055E-03	1.240E-03	3.600E-05	6.511E-03	2.500E-05	1.240E-03	1.000E-04
207BI	1.000E+00	6.329E-05	5.217E-02	3.000E-04	4.626E-02	1.500E-03	1.387E-01	1.000E-02
235 U	4.600E+00	2.662E-12	8.030E-03	5.400E-05	1.899E-06	1.000E-02	8.030E-03	1.000E-04
238PU	4.600E+01	2.134E-05	4.032E-05	1.350E-05	2.323E-05	1.200E-05	3.083E-05	3.000E-05
239PU	5.300E+01	7.794E-08	1.906E-05	1.350E-05	1.977E-06	1.200E-05	9.571E-06	3.000E-05
240PU	5.300E+01	2.809E-07	1.927E-05	1.350E-05	2.180E-06	1.200E-05	9.774E-06	3.000E-05
241AM	5.700E+01	4.145E-06	2.313E-05	4.500E-05	5.161E-05	4.500E-05	2.313E-05	1.000E-04

- 539 -

Table 162. Integral dose<sup>a</sup> for 5, 10, 30, and 70 yr from the marine food chain.

Nuclide	Integral dose, rem <sup>b</sup>							
	5 yr		10 yr		30 yr		70 yr	
	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
<sup>137</sup> Cs	0.0061	0.0061	0.012	0.012	0.030	0.030	0.049	0.049
<sup>60</sup> Co	0.0078	0.0078	0.012	0.012	0.017	0.017	0.017	0.017
<sup>90</sup> Sr	---	0.13	---	0.31	---	0.77	--	1.3
Sum	0.014	0.14	0.024	0.33	0.047	0.82	0.066	1.4
All nuclides <sup>c</sup>	0.016	0.14	0.028	0.34	0.053	0.84	0.089	1.6

<sup>a</sup>The dose is based upon the average concentration for fish from the entire Atoll and upon a dietary fish intake of 600 g/day. These doses apply to all six living patterns.

<sup>b</sup>The concentration data were corrected to January 1974, the earliest possible return date to the Atoll; all integral doses are calculated for periods which begin on January 1974.

<sup>c</sup>Isotopes included in the "All nuclides" calculation:

<sup>3</sup> H	<sup>60</sup> Co	<sup>102</sup> Rh	<sup>137</sup> Cs	<sup>152</sup> Eu	<sup>235</sup> U
<sup>14</sup> C	<sup>90</sup> Sr	<sup>113</sup> Cd	<sup>133</sup> Ba	<sup>155</sup> Eu	<sup>238</sup> Pu
<sup>55</sup> Fe	<sup>106</sup> Ru	<sup>125</sup> Sb	<sup>144</sup> Ce	<sup>207</sup> Bi	<sup>239</sup> Pu
					<sup>241</sup> Am

integral dose for <sup>14</sup>C, calculated in this however, there is very good reason to believe that the actual concentration is orders of magnitude below the detection

limit reported here. Therefore, neither isotope is significant in the total dose assessment via the marine pathway.



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## Evaluation of the Dosage from Terrestrial Foods

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### Introduction

This chapter describes the analysis of the biota data for evaluation of the potential dose from ingestion of terrestrial foods. Because some of the items expected in the diet were not available in abundance for adequate sampling, it was necessary to examine not only data from the edible species but also those from other constituents of the ecosystem, i. e., soil, indicator plants, and indicator animals. It was necessary to take into account radiological data reported for other locations, to examine collateral information from a variety of sources, and to use all of these data to derive quantitative relationships for predicting concentrations of radionuclides in food items. Assessment of the dosage from terrestrial foods is based on the diets and living patterns discussed earlier in this section (Tables 1,4).

### Sampling of Terrestrial Biota

The chapter on the terrestrial biota survey presents a detailed description of the terrestrial biota sampling program. Edible plants or animals collected include coconut, pandanus, tacca, various species of birds, bird eggs, and coconut crab. Indicator species include Messerschmidia, Scaevola, rice rat, and roof rat.

Table 163 lists the islands from which edible species were collected. Edible species were collected wherever they could be found but, in contrast to Messerschmidia and Scaevola, they were

not available for sampling on each island. Coconut was sampled on 16 islands distributed about the Atoll, but pandanus fruit was obtained only from BELLE and KEITH, and tacca root only from DAVID. Pandanus leaves were collected from BELLE, KEITH and eight additional islands. No breadfruit was found on the Atoll. Coconuts collected by Ken Marsh in July 1973 were the source of the coconut milk and a portion of the coconut from IRENE and MARY.

Birds were collected on 18 islands and eggs from eight islands distributed throughout the Atoll. Collection of coconut crabs was confined to islands in the south (BRUCE, GLENN, JAMES, KEITH and LEROY). Hermit crabs were collected on IRENE and on the southern islands, DAVID, REX, GLENN, HENRY and IRWIN, but they are not part of the diet. Rice rats and roof rats were collected on nine islands in the north and the south, including JANET and YVONNE. Rats are not part of the diet, but they provide useful data for assessment of the dose via poultry and livestock.

### Distribution of Radionuclides in Terrestrial Foods

Coconut — Coconut is the edible plant for which sampling was most extensive. Table 164 lists the concentrations of radionuclides in dry coconut meat. Figure 126 is a graph of the distributions of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  by island, and Fig. 127 is a graph of the distributions of the other nuclides that were above detectable limits. The term "island number" as used in Table 163 and in the figures refers to the practice of assigning consecutive numbers to each island as one proceeds around the Atoll, beginning with ALICE.

Table 163. Terrestrial biota survey. Edible plants and edible animals sampled.

Island No.	Island	Coconut meat	Coconut milk	Pandanus fruit	Pandanus leaves <sup>a</sup>	Tacca corm	Birds	Bird eggs	Coconut crab	Rat <sup>b</sup>
1.	ALICE						x			
2.	BELLE			x	x					
4.	DAISY	x	x							
9.	IRENE	x	x				x	x		
10.	JANET	x	x		x		x	x		x
12.	LUCY						x			
14.	MARY	x	x				x			
15.	NANCY	x	x							
16.	OLIVE						x			
17.	PEARL						x			x
19.	SALLY				x		x	x		x
20.	TILDA				x					
21.	URSULA									x
22.	VERA	x			x					
24.	YVONNE	x					x	x		x
29.	VAN						x			
30.	ALVIN						x			
31.	BRUCE	x					x		x	x
32.	CLYDE						x	x		x
33.	DAVID	x	x		x	x	x			x
34.	REX						x	x		
35.	ELMER	x			x					x
37.	FRED	x			x					
38.	GLENN	x							x	x
39.	HENRY	x						x		
40.	IRWIN	x					x	x		
41.	JAMES								x	
42.	KEITH	x		x	x		x		x	
43.	LEROY	x			x		x		x	

<sup>a</sup>Pandanus leaves are not eaten but serve as indicators for pandanus fruit.

<sup>b</sup>Rats are not eaten but serve as indicators for poultry and swine.

Table 164. Radionuclides in coconut meat.

Island No.	Island	Concentration, pCi/g dry wt					
		$^3\text{H}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239, 240}\text{Pu}$
4	DAISY <sup>a</sup>	0.415		<0.059	0.200	7.17	
9	IRENE			<0.067	0.067	1.77	0.0362
			86.5	<1.70	1.61	5.11	<0.034
10	JANET	0.343		<0.069	0.207	84.7	
14	MARY		1.18	<0.055	0.136	14.3	<0.0005
			76.6	<0.017	14.1	5.58	<0.43
15	NANCY	0.333	1.95	<0.054	0.167	18.8	<0.0006
22	VERA			<0.053	0.134	9.30	0.00013
24	YVONNE	0.664		0.077	0.011	3.96	
			<0.19	<0.066	<0.054	1.99	<0.0020
31	BRUCE			<0.014		0.582	
33	DAVID	0.313		<0.060	0.014	2.59	0.0027
				<0.012	0.026	0.399	0.0034
35	ELMER	0.305	<0.63	<0.028	<0.075	3.45	<0.0052
				<0.068	0.032	2.14	0.00044
37	FRED	0.390		<0.020	0.030	2.39	
		0.302	<0.35	<0.021	0.367	0.530	<0.0058
38	GLENN		<0.27	<0.053	<0.049	1.30	<0.0013
				<0.029	0.020	1.01	<0.0025
39	HENRY <sup>b</sup>		<0.11	<0.007	<0.028	0.565	<0.0010
40	IRWIN		<0.64	0.074	<0.086	0.2~9	<0.0027
42	KEITH		<0.29	<0.064	<0.056	0.952	<0.0009
43	LEROY			<0.015	0.189	3.90	0.00073

<sup>a</sup>A concentration of 0.065 pCi  $^{207}\text{Bi}$ /g was measured in the sample from DAISY.

<sup>b</sup>A concentration of 0.098 pCi  $^{155}\text{Eu}$ /g was measured in the sample from HENRY.

Coconut Milk — Table 165 is a comparison of the radionuclide content in fresh coconut meat and coconut milk collected from the same island. All of the milk samples represented were obtained from coconuts collected by Ken Marsh in July 1973. In Table 165 the meat samples of the bracketed pair of meat and milk samples from IRENE and MARY were also collected by Ken Marsh. Since most of

the milk was obtained from green nuts and most of the meat from ripe nuts, the bracketed meat and milk samples from IRENE and MARY are not representative of single pooled samples of coconuts.

Pandanus — Table 166 lists the concentrations of the radionuclides detected in fruit and leaves of pandanus. The fruit and leaves listed for BELLE and for

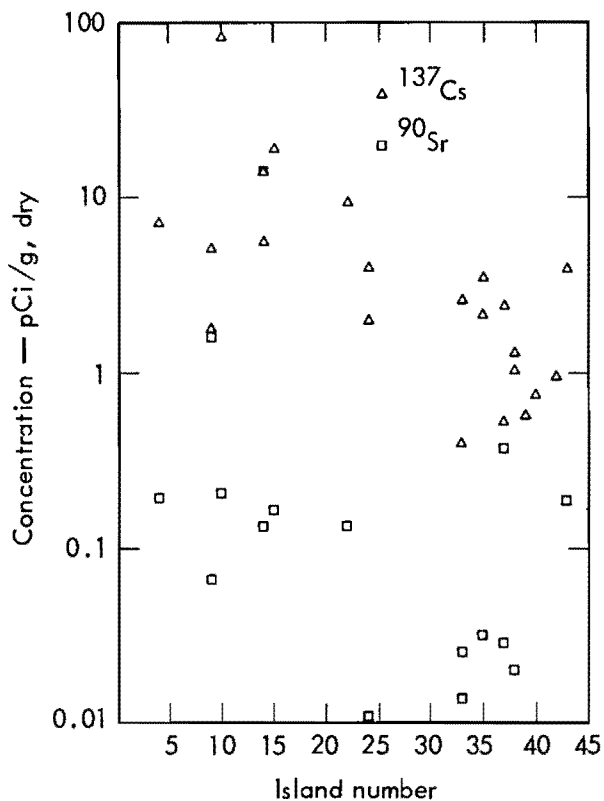


Fig. 126. Concentrations of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  in coconut meat.

KEITH are representative of the same plant. Figure 128 is a graph showing the island-by-island distribution of these concentrations.

Tacca — The concentrations of radionuclides detected in the one sample of tacca are listed in Table 166 and shown in Fig. 128.

Birds — The "edible" birds are considered to be those species that were found and collected in greatest numbers; these include the common noddy, the white-capped noddy, and the sooty tern. Table 167 lists the concentrations of radionuclides detected in muscle and liver of these species. A fourth group of pooled terns assembled from common noddies,

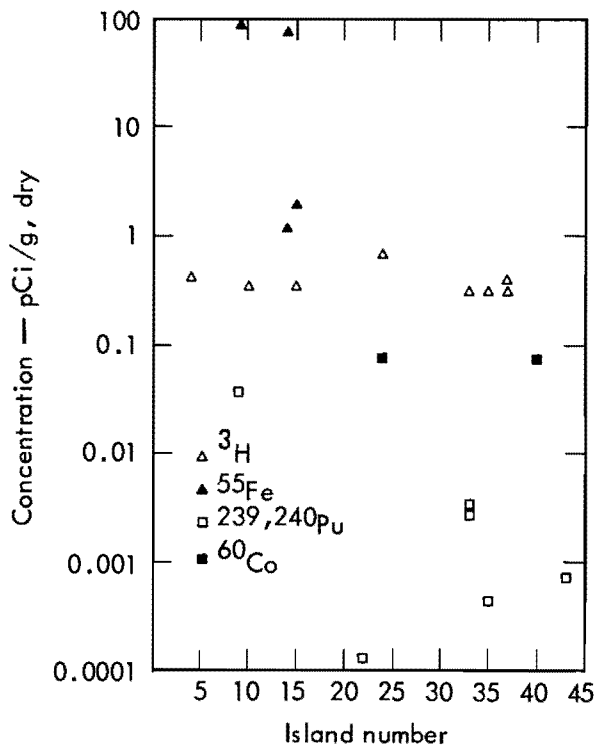


Fig. 127. Concentrations of radionuclides in coconut meat.

white-capped noddies, and sooty terns is also represented in Table 167.

Figure 129 shows the distributions of  $^{55}\text{Fe}$  and  $^{60}\text{Co}$  in muscle and liver by island, and Fig. 130 shows the distributions of  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{239,240}\text{Pu}$  in these tissues by island.

Bird Eggs — Table 168 presents the radionuclide concentrations detected in bird (common noddy or sooty tern) eggs, and Fig. 131 shows the distribution of the radionuclide concentrations by island.

Coconut Crabs — Table 169 lists the concentrations of the radionuclides detected in muscle and hepatopancreas of coconut crabs. Figure 132 is a graph of the distributions of  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ , and  $^{137}\text{Cs}$  in these tissues by island.

Table 165. Radionuclides in meat and milk of coconut.

Island No.	Island	Plant part	Concentration, pCi/g wet					$\left(\frac{\text{Dry wt}}{\text{Wet wt}}\right)^a$
			$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$	
4	DAISY	Meat		<0.029	0.100	3.58		0.50
		Milk	<0.30	<0.051	0.068	0.084	<0.0016	0.048
9	IRENE	Meat		<0.034	0.033	0.885	0.0181	0.50
		Meat	5.60	<0.11	0.104	0.331	<0.0022	0.065 <sup>b</sup>
		Milk						
10	JANET	Meat		0.035	0.103	42.3		0.50
		Milk	<0.12	<0.030	0.084	11.2	<0.0005	0.053
14	MARY	Meat	0.590	<0.027	0.068	7.14	<0.0003	0.50
		Meat	42.2	<0.009	7.79	3.07	<0.24	0.55
		Milk						
15	NANCY	Meat	0.975	<0.027	0.084	9.42	<0.0003	0.50
		Milk	0.266	<0.060	0.051	6.65	<0.0010	0.045
33	DAVID	Meat		<0.030	0.0069	1.30	0.0014	0.50
		Meat		<0.0059	0.013	0.199	0.0017	0.50
		Milk	<0.13	<0.012	<0.023	1.09	<0.0015	0.047

<sup>a</sup>Where wet and dry weights were not determined, the dry-wt/wet-wt ratio of coconut meat was assumed to be 0.50<sup>4,6</sup>.

<sup>b</sup>This coconut sample was green and hence yielded little meat.

#### Statistical Analysis of Terrestrial Biota Data

Statistical Correlations Between Plants and Soil — Soil is both a logical and convenient starting point for predicting radionuclide concentrations in terrestrial foods. First, it is the source compartment from which all the terrestrial food chains derive their radioactivity. Second, it was subjected to extensive sampling and analysis on each island of the Atoll.

The uptake of radionuclides from soil to plants can be described quantitatively in terms of the concentration factor, defined in this discussion as

$\text{pCi/g dry plant} \div \text{pCi/g dry soil}$ .

Table 170 summarizes the concentration factors of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  determined for edible and indicator plants. These two nuclides have been singled out because they were consistently detected and measured in terrestrial vegetation and they contribute most to the dosage from ingestion of terrestrial foods. The concentration factors for both  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  are seen to be widely distributed, with ranges varying by a factor of 100 or more. This is not really surprising since the pairing of plant and soil data for the same location is inherently lacking in precision and since soil is a complex substrate that does not exhibit

Table 166. Radionuclides in pandanus and tacca.

Island No.	Island	Plant type	Concentration, pCi/g dry <sup>a</sup>					
			<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239, 240</sup> Pu
2	BELLE	Pandanus fruit	0.859		0.140	206	923	0.00343
		Pandanus leaves		0.438	<0.14	391	679	<0.24
10	JANET	Pandanus leaves		2.32	<0.12	4.41	0.620	0.00204
19	SALLY	Pandanus leaves		0.703	<0.11	1.97	15.0	0.0149
20	TILDA	Pandanus leaves		2.94	<0.12	15.5	152	0.00698
22	VERA	Pandanus leaves			<0.069	4.64	17.6	0.00757
33	DAVID	Pandanus leaves		0.127	<0.11	3.56	15.9	0.00132
		Tacca corm	0.516	<1.31	<0.09	0.096	8.96	0.00114
35	ELMER	Pandanus leaves		0.416	<0.034	25.1	3.09	0.00195
37	FRED	Pandanus leaves		0.851	<0.066	0.422	4.29	0.00770
42	KEITH	Pandanus fruit	1.99	12.2	<0.10	13.1	0.860	
		Pandanus leaves		0.356	<0.027	(lost)	0.569	0.00447
43	LEROY	Pandanus leaves		0.210	<0.074	1.69	9.14	0.00222

<sup>a</sup> Additional nuclides measured at levels above detection limits: (1) <sup>125</sup>Sb, 3.01 pCi/g in pandanus fruit from BELLE; (2) <sup>102</sup>Rh, 0.114 pCi/g in tacca corm (DAVID); (3) <sup>144</sup>Ce, 0.724 pCi/g in pandanus leaves from KEITH and 0.469 pCi/g in pandanus leaves from LEROY; (4) <sup>207</sup>Bi, 0.043 pCi/g in pandanus leaves from KEITH and 0.108 pCi/g in pandanus leaves from JANET.

uniform properties at any given location. Linear regression analysis<sup>1,2</sup> was therefore carried out to identify correlations between <sup>137</sup>Cs and <sup>90</sup>Sr concentrations in plants and those in soil that would be useful for predictive purposes.

Concentrations of <sup>90</sup>Sr and <sup>137</sup>Cs in the 0-15 cm profile samples reported in the chapter on the terrestrial soil and

radiation survey were used to represent soil. Messerschmidia and Scaevola, the dominant and most widely disseminated and extensively collected plant species, were chosen as indicator plants. The following linear regression analyses were performed to determine regressions of <sup>90</sup>Sr and <sup>137</sup>Cs in plants on those in soil: (1) coconut meat on soil, (2) pandanus

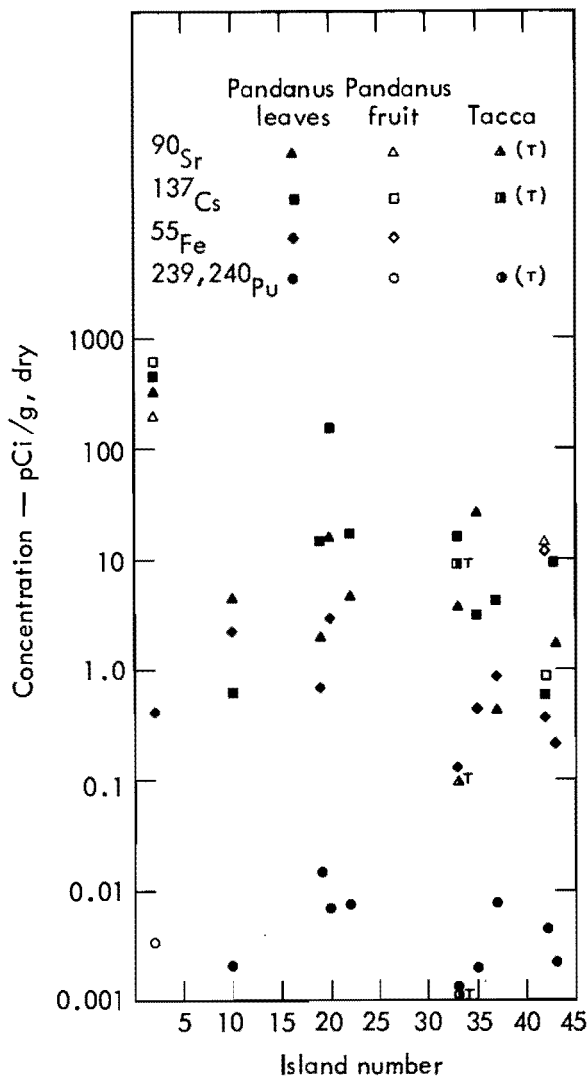


Fig. 128. Concentrations of radionuclides in pandanus and tacca.

leaves on soil, (3) *Messerschmidia* on soil, and (4) *Scaevola* on soil. The concentrations of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  associated with soil locations near a given plant location were determined using the overlay figures of Appendix II. The mean of the concentrations in soil at these locations was used as the independent variable in the regression analysis.

Coconut vs Soil — Figure 133 shows the  $^{137}\text{Cs}$  concentrations in coconut meat as a function of those in soil. Linear regression analysis<sup>1</sup> of the log-transformed

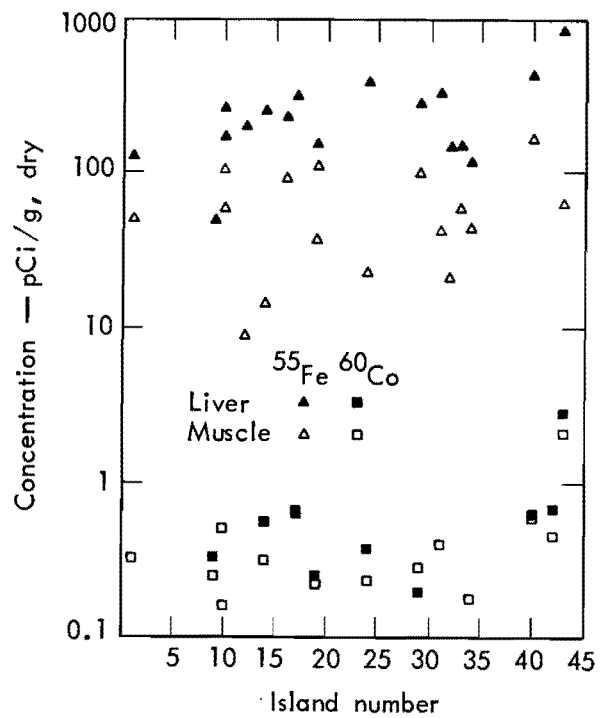


Fig. 129. Concentrations of  $^{55}\text{Fe}$  and  $^{60}\text{Co}$  in muscle and liver of birds.

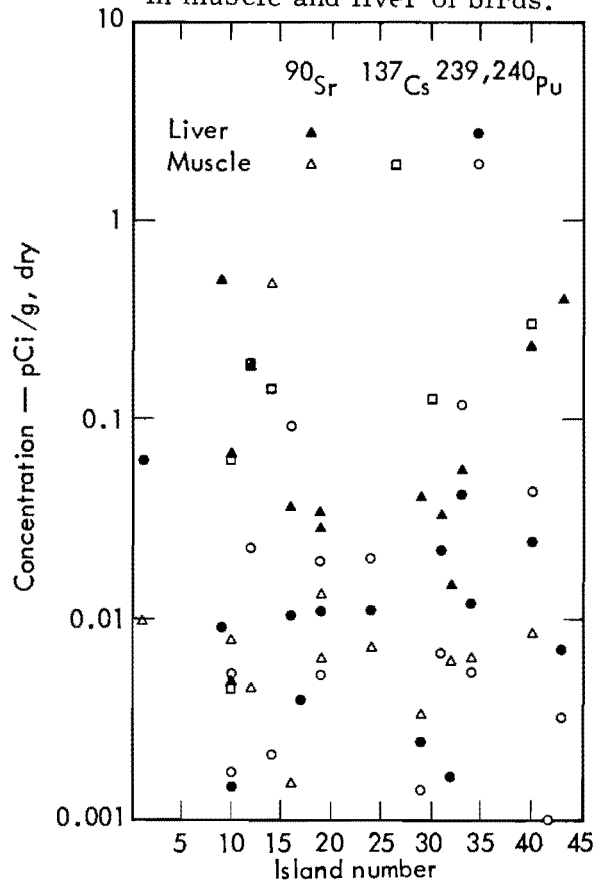


Fig. 130. Concentrations of  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ , and  $^{239,240}\text{Pu}$  in muscle and liver of birds.



Table 167. Radionuclides in muscle and liver of birds.

Island No.	Island	Sample type	Concentration, pCi/g dry									
			<sup>55</sup> Fe		<sup>60</sup> Co		<sup>90</sup> Sr		<sup>137</sup> Cs		<sup>239,240</sup> Pu	
			Muscle	Liver	Muscle	Liver	Muscle	Liver	Muscle	Liver	Muscle	Liver
1	ALICE	Common noddy	49.6	127	0.321	<0.165	0.0099	<0.0099	<0.072	<0.094		0.0622
9	IRENE	" "		49.6	0.247	0.324		0.509	<0.099	<0.057		0.0091
10	JANET	" "	105	258	0.507	<0.165	0.0078	0.0667	<0.069	<0.097	0.0018	<0.033
	JANET	Pooled terns	59.5	172	0.159	<0.514	0.0047	0.0050	0.0621	<0.406	0.0055	0.0015
12	LUCY	Common noddy	8.78	199	<0.216	<0.398	0.0046	0.187	0.192	<0.246	0.0228	<0.073
14	MARY	" "	14.2	251	0.316	0.568	0.482	<0.019	0.143	<0.093	0.0022	<0.012
16	OLIVE	" "	92.8	232	<0.151	<0.195	0.0016	0.0362	<0.092	<0.107	0.0919	0.0105
17	PEARL	Pooled terns		317	0.659	0.647		<0.049	<0.142	<0.127		0.0041
19	SALLY	White-capped noddy	110		0.214	0.235	0.0135	0.0283	<0.087	<0.055	0.0196	0.0110
	SALLY	Sooty tern	36.6	155	<0.114	<0.120	0.0064	0.0344	<0.081	<0.069	0.0054	<0.079
24	YVONNE	Common noddy	22.6	386	0.230	0.369	0.0073	<0.011	<0.086	<0.075	0.0201	0.0111
29	VAN	" "	99.6	279	0.283	0.195	0.0034	0.0403	<0.076	<0.060	0.0014	0.0025
30	ALVIN	Pooled terns			<0.167	<0.187			0.128	<0.131		
31	BRUCE	White-capped noddy	41.3	327	0.392	<0.253	<0.0080	0.0326	<0.079	<0.134	0.0069	0.0222
32	CLYDE	Sooty tern	20.4	146	<0.091	<0.549	0.0064	0.0149	<0.065	<0.054	<0.0015	0.0017
33	DAVID	" "	59.0	153	<0.108	<0.345		0.0545	<0.082	<0.230	0.119	0.0420
34	REX	Common noddy	43.5	118	0.177	<0.161	0.0065	<0.0091	<0.076	<0.091	0.0056	0.0121
40	IRWIN	" "	169	423	0.609	0.635	0.0085	0.233	0.306	<0.161	0.0434	0.0242
42	KEITH	" "			0.452	0.689	<0.0041		<0.089	<0.129	0.0010	
43	LEROY	White-capped noddy	64.4	811	2.07	2.83	<0.112	0.402	<0.134	<0.242	0.0033	0.0072

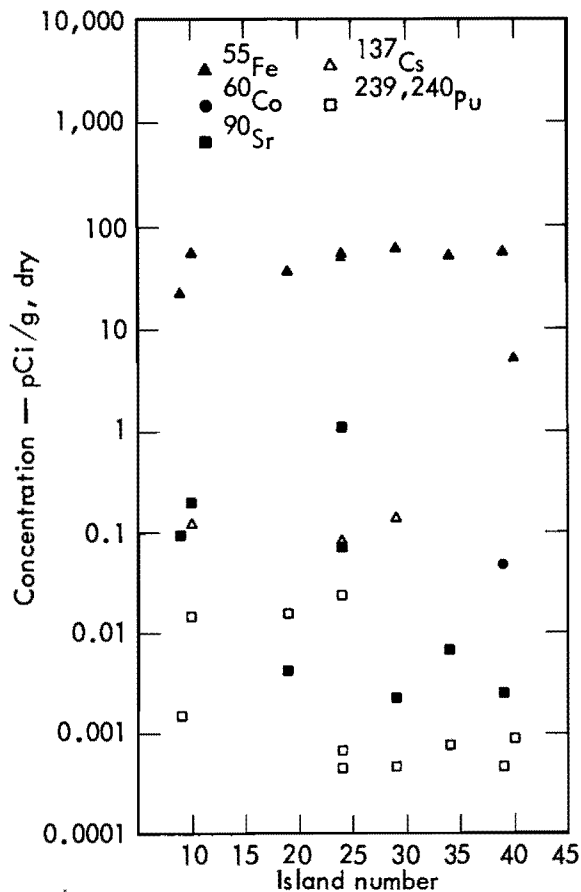


Fig. 131. Concentrations of radionuclides in bird eggs.

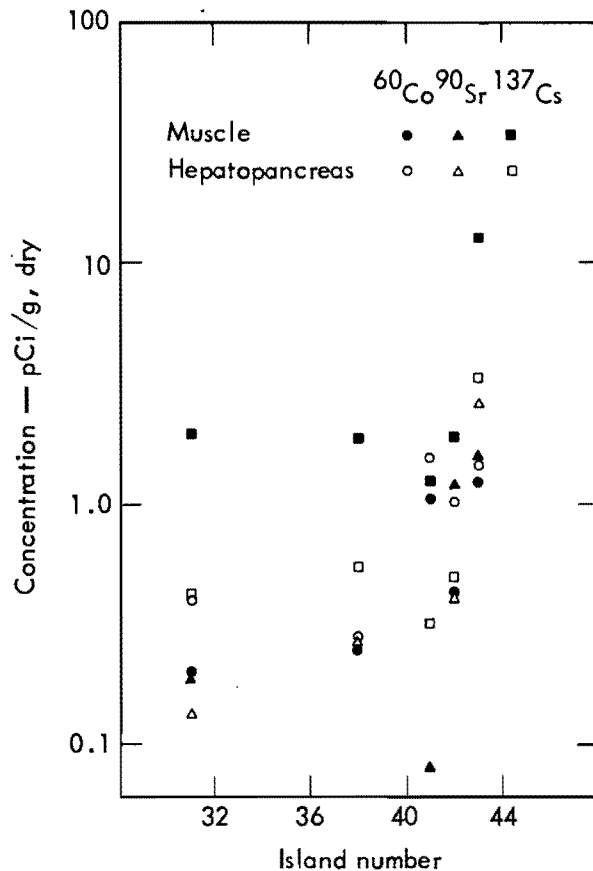


Fig. 132. Concentrations of radionuclides in coconut crabs.

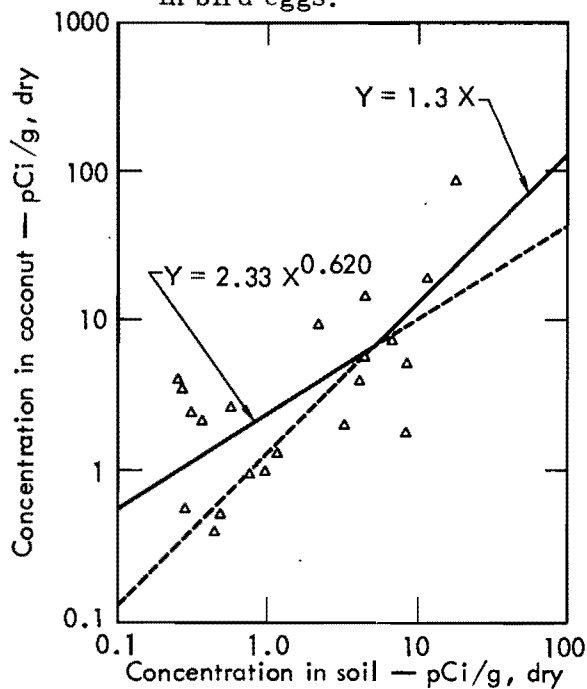


Fig. 133. Statistical correlation between  $^{137}\text{Cs}$  in coconut meat and  $^{137}\text{Cs}$  in soil.

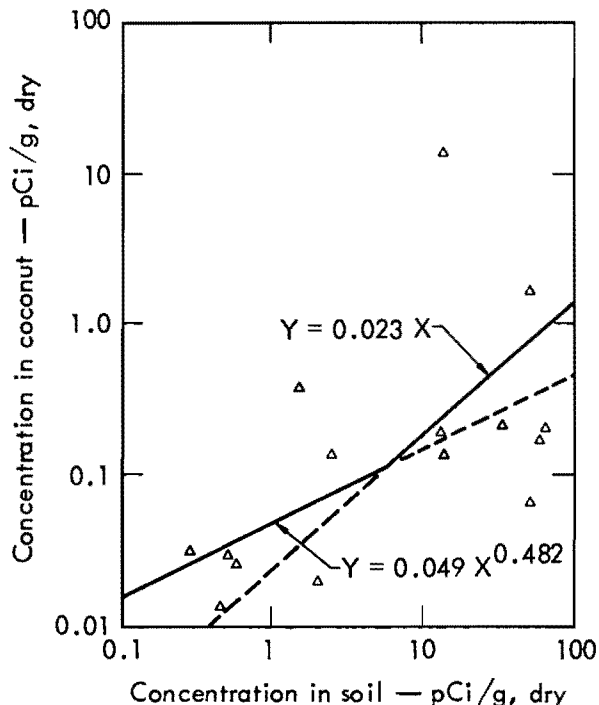


Fig. 134. Statistical correlation between  $^{90}\text{Sr}$  in coconut meat and  $^{90}\text{Sr}$  in soil.

Table 168. Radionuclides in bird eggs.

Island No.	Island	Species	Concentration, pCi/g dry				
			<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu
9	IRENE	Common noddy	23.0	<0.075	0.095	<0.051	0.0015
10	JANET	" "	57.2	<0.10	0.203	0.119	0.0148
19	SALLY	Sooty tern	37.6	<0.073	0.0043	<0.052	0.0154
24	YVONNE	Common noddy	<0.59	<0.10	1.06	<0.069	0.00045
		" "	56.8	<0.11	<0.0020	<0.079	0.0232
		" "	54.5	<0.087	0.073	0.079	0.00068
29	VAN	" "	63.5	<0.10	0.0022	0.136	0.00047
32	CLYDE	Sooty tern		<0.82		<0.057	
34	REX	Common noddy	51.4	<0.10	0.0066	<0.070	0.00077
39	HENRY	" "	54.1	0.048	0.0025	<0.015	0.00047
40	IRWIN	" "	5.14	<0.12	<0.011	<0.083	0.00088

Table 169. Radionuclides in edible parts of coconut crabs.

Island No.	Island	Tissue	Concentration, pCi/g dry				
			<sup>3</sup> H	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>152</sup> Eu <sup>239,240</sup> Pu
31	BRUCE	Muscle	0.424	0.198	0.185	1.98	0.0012
		Hepatopancreas	0.157	0.402	0.133	0.420	0.0023
38	GLENN	Muscle	0.685	0.247		1.88	0.0013
		Hepatopancreas	0.266	0.276	0.269	0.545	<0.0066
41	JAMES	Muscle		1.05	0.079	1.25	0.00076
		Hepatopancreas		1.56	0.0014	0.317	0.0019
42	KEITH	Muscle		0.420	1.19	1.92	0.0014
		Hepatopancreas		1.03	0.401	0.496	0.066 0.0098
43	LEROY	Muscle	0.867	1.23	1.58	12.6	0.0031
		Hepatopancreas	0.207	1.46	2.58	3.29	0.0038

data reveals a significant correlation ( $P < 0.001$ ) between the logarithm of the <sup>137</sup>Cs concentration in coconut and the logarithm of the <sup>137</sup>Cs concentration in soil (see Table 171C). Accordingly, the mean concentration of <sup>137</sup>Cs in coconut

can be predicted from that in soil. Figure 134 shows the <sup>90</sup>Sr concentrations in coconut meat as a function of those in soil. A similar analysis (see Table 172C) reveals a significant ( $P = 0.05$ ) correlation between the logarithm of the <sup>90</sup>Sr

Table 170. Soil-to-plant uptake of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ .

Plant type	Concentration factors (pCi/g dry plant $\div$ pCi/g dry soil)							
	No. of samples	Cesium-137			No. of samples	Strontium-90		
		Min	Median	Max		Min	Median	Max
<u>Messerschmidia</u>	47	0.051	5.4	270	42	0.031	1.2	13
<u>Scaevola</u>	45	0.059	4.7	120	39	0.023	0.74	14
Pooled <u>Messerschmidia</u> and <u>Scaevola</u>	92	0.051	5.2	270	81	0.023	0.96	14
Coconut meat	21	0.22	1.3	16	16	0.0011	0.023	1.0
Pandanus leaves	10	0.072	4.7	42	9	0.18	1.0	57
Pandanus fruit	2	1.3		21	2	2.5		7.7
Tacca corm	1		16		1		0.21	

concentration in coconut and the logarithm of the  $^{90}\text{Sr}$  concentration in soil. The mean  $^{90}\text{Sr}$  concentration in coconut can therefore be predicted from that in soil.

Pandanus Leaves vs Soil — Figure 135 shows the concentrations of  $^{137}\text{Cs}$  in pandanus leaves as a function of those in soil, and Fig. 136 shows comparable data for  $^{90}\text{Sr}$ . Both the  $^{137}\text{Cs}$  data and the  $^{90}\text{Sr}$  data scatter widely and are relatively few. Linear regression analysis (Tables 171 and 172) reveals that the correlations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  between pandanus leaves and soil are not statistically significant.

Messerschmidia, Scaevola and Pandanus Leaves vs Soil — Figure 137 presents  $^{137}\text{Cs}$  concentrations and Fig. 138,  $^{90}\text{Sr}$  concentrations in Messerschmidia and Scaevola as a function of those in soil. The data points are seen to scatter widely about the regression line, but they are far more numerous than

those obtained from the edible plants. Statistical analysis reveals for both nuclides and both indicator species significant positive correlation between the

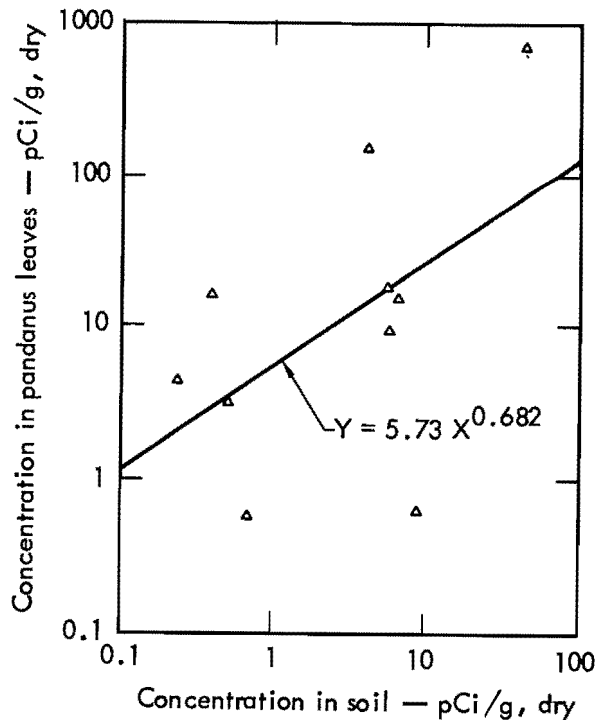


Fig. 135. Statistical correlation between  $^{137}\text{Cs}$  in pandanus leaves and  $^{137}\text{Cs}$  in soil.

Table 171. Statistical correlation between  $^{137}\text{Cs}$  in plants and  $^{137}\text{Cs}$  in soil.

Plant type	Sample size (n)	Correlation coefficient (r)	Level of significance (P)	$\ln Y = A + b \ln X$	
				A	b
<u>A. <i>Messerschmidia</i> and <i>Scaevola</i></u>					
<u>Messerschmidia</u>	48	0.79	<0.001	1.86	0.901
<u>Scaevola</u>	46	0.76	<0.001	1.52	0.823
Pooled	94	0.78	<0.001	1.69 <sup>b</sup>	0.864 <sup>a</sup>
<u>B. Pandanus leaves, <i>Messerschmidia</i>, and <i>Scaevola</i></u>					
Pandanus leaves	10	0.52	N. S. <sup>g</sup>	1.75	0.682
<u>Messerschmidia</u>	48	0.79	<0.001	1.86	0.901
<u>Scaevola</u>	46	0.76	<0.001	1.52	0.823
Pooled	104	0.76	<0.001	1.69 <sup>d</sup>	0.851 <sup>c</sup>
<u>C. Coconut meat, pandanus leaves, <i>Messerschmidia</i>, and <i>Scaevola</i></u>					
Coconut meat	22	0.69	<0.001	0.847	0.620
Pandanus leaves	10	0.52	N. S. <sup>g</sup>	1.75	0.682
<u>Messerschmidia</u>	48	0.79	<0.001	1.86	0.901
<u>Scaevola</u>	46	0.76	<0.001	1.52	0.823
Pooled	126	0.74	<0.001	1.53 <sup>f</sup>	0.824 <sup>e</sup>

<sup>a</sup> An F-test for equality of the regression slopes gives  $F = 0.28$ ,  $P = 0.597$ .

<sup>b</sup> An F-test for equality of the regression intercepts gives  $F = 1.50$ ,  $P = 0.225$ .

<sup>c</sup> An F-test for equality of the regression slopes gives  $F = 0.31$ ,  $P = 0.734$ .

<sup>d</sup> An F-test for equality of the regression intercepts gives  $F = 0.72$ ,  $P = 0.489$ .

<sup>e</sup> An F-test for equality of the regression slopes gives  $F = 0.57$ ,  $P = 0.633$ .

<sup>f</sup> An F-test for equality of the regression intercepts gives  $F = 3.32$ ,  $P = 0.22$ .

Reject null hypothesis.

<sup>g</sup> Not significant.

logarithm of the concentration in plant and the logarithm of the concentration in soil. Comparisons of the regression lines by statistical methods described in Ref. 2 support the assumption that the individual regression curves do not differ significantly and that the  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  data from Messerschmidia and Scaevola can

each be combined and represented by a common pooled regression line (Tables 171A and 172A).

Similar analyses of the three individual plant-soil correlations for  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in pandanus leaves, Messerschmidia, and Scaevola also reveal that in each case the individual correlations are statistically

Table 172. Statistical correlation between  $^{90}\text{Sr}$  in plants and  $^{90}\text{Sr}$  in soil.

Plant type	Sample size (n)	Correlation coefficient (r)	Level of significance (P)	$\ln Y = A + b \ln X$	
				A	b
<u>A. Messerschmidia and Scaevola</u>					
<u>Messerschmidia</u>	42	0.83	<0.001	0.438	0.868
<u>Scaevola</u>	39	0.81	<0.001	-0.0451	0.866
Pooled	81	0.81	<0.001	0.208 <sup>b</sup>	0.866 <sup>a</sup>
<u>B. Messerschmidia, Scaevola, and pandanus leaves</u>					
<u>Messerschmidia</u>	42	0.83	<0.001	0.438	0.868
<u>Scaevola</u>	39	0.81	<0.001	-0.0451	0.866
Pandanus leaves	9	0.49	N.S. <sup>c</sup>	1.05	0.537
Pooled	90	0.79	<0.001	0.299 <sup>e</sup>	0.836 <sup>d</sup>
<u>C. Messerschmidia, Scaevola, pandanus leaves, and coconut meat</u>					
<u>Messerschmidia</u>	42	0.83	<0.001	0.438	0.868
<u>Scaevola</u>	39	0.81	<0.001	-0.0451	0.866
Pandanus leaves	9	0.49	N.S. <sup>c</sup>	1.05	0.537
Coconut meat	16	0.50	0.05	-3.01	0.482
Pooled	106	0.62	<0.001	-0.244 <sup>g</sup>	0.798 <sup>f</sup>

<sup>a</sup>An F-test for equality of the regression slopes gives  $F = 0.00$ ,  $P = 0.989$ .

<sup>b</sup>An F-test for equality of the regression intercepts gives  $F = 3.26$ ,  $P = 0.075$ .

<sup>c</sup>Not significant.

<sup>d</sup>An F-test for equality of the regression slopes gives  $F = 0.80$ ,  $P = 0.455$ .

<sup>e</sup>An F-test for equality of the regression intercepts gives  $F = 1.76$ ,  $P = 0.179$ .

<sup>f</sup>An F-test for equality of the regression slopes gives  $F = 1.64$ ,  $P = 0.185$ .

<sup>g</sup>An F-test for equality of the regression intercepts gives  $F = 39.41$ ,  $P = 0.000$ .

Reject null hypothesis.

indistinguishable from the pooled correlation (Tables 171B and 172B). These results provide justification for using the pooled plant-soil regression curve for Messerschmidia, Scaevola, and pandanus leaves to predict  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in pandanus leaves from the respective concentrations in soil. Analysis involving the comparison of the individual regression

lines for Messerschmidia, Scaevola, pandanus leaves, and coconut meat yielded common results for  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ . The individual slopes are statistically indistinguishable (Table 171C), but the null hypothesis that the four intercepts are equal has to be rejected. Thus the pooled plant-soil regression curve cannot be used to predict

$^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in coconut from those in soil.

It must be remembered that the pandanus samples are few in number. Thus, although the pandanus-vs-soil correlations are not statistically significant, it is reasonable to expect that with a larger number of samples, this would not be the case. Use of the pooled regression line for predicting  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in pandanus leaves is a prudent procedure that leads to prediction of somewhat higher values than those using the individual pandanus vs soil regression lines. Use of the pooled regression line implies that with a larger number of pandanus samples, the data would tend to fall above the regression lines of Figs. 135 and 136 and the slopes of the regression lines would increase. The close correspondence of the median concentration factors of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in Messerschmidia, Scaevola, and pandanus leaves (see Table 170) provides additional justification for using the pooled regression.

Statistical Correlations Between Edible Plants and Indicator Plants — Indicator plants can also be used as the starting point for predicting radionuclide concentrations in food items. Linear regression analysis<sup>1,2</sup> was performed to determine regressions of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in coconut meat on those in indicator plants. It was not possible to determine regressions of pandanus leaves on other plants because other plant species were not commonly sampled at pandanus sampling sites.

Figures 139 and 140 show respectively,  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in coconut

meat as a function of those in Messerschmidia and Scaevola. Linear regression analysis<sup>1,2</sup> reveals significant correlations ( $P < 0.001$ ) between the logarithms of the  $^{137}\text{Cs}$  in coconut and those in Messerschmidia and Scaevola. Also the individual regression lines are statistically indistinguishable (see Table 173). In the case of  $^{90}\text{Sr}$ , the analysis reveals a significant correlation ( $P = 0.05$ ) between the logarithms of the concentration in coconut and those in Scaevola, but the correlation between the logarithms of the concentrations in coconut and those in Messerschmidia is not significant. The individual regression lines, however, are statistically indistinguishable (see Table 174). Thus, these results indicate that the concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in Messerschmidia

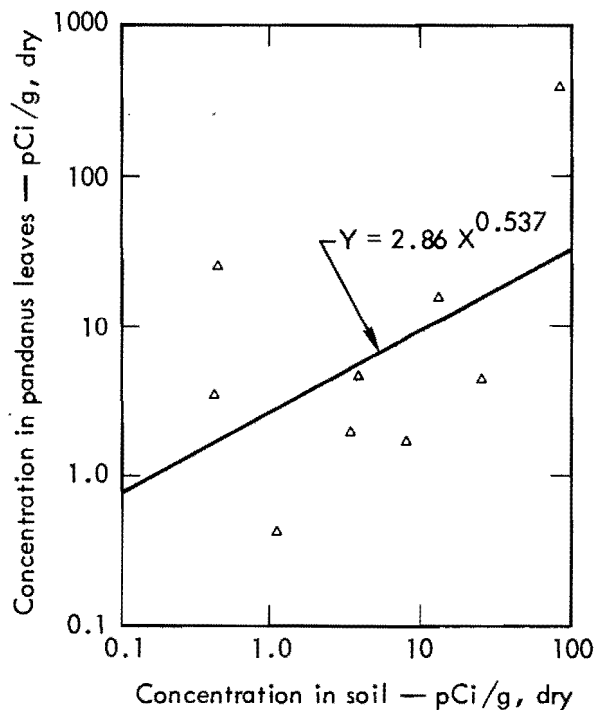


Fig. 136. Statistical correlation between  $^{90}\text{Sr}$  in pandanus leaves and  $^{90}\text{Sr}$  in soil.

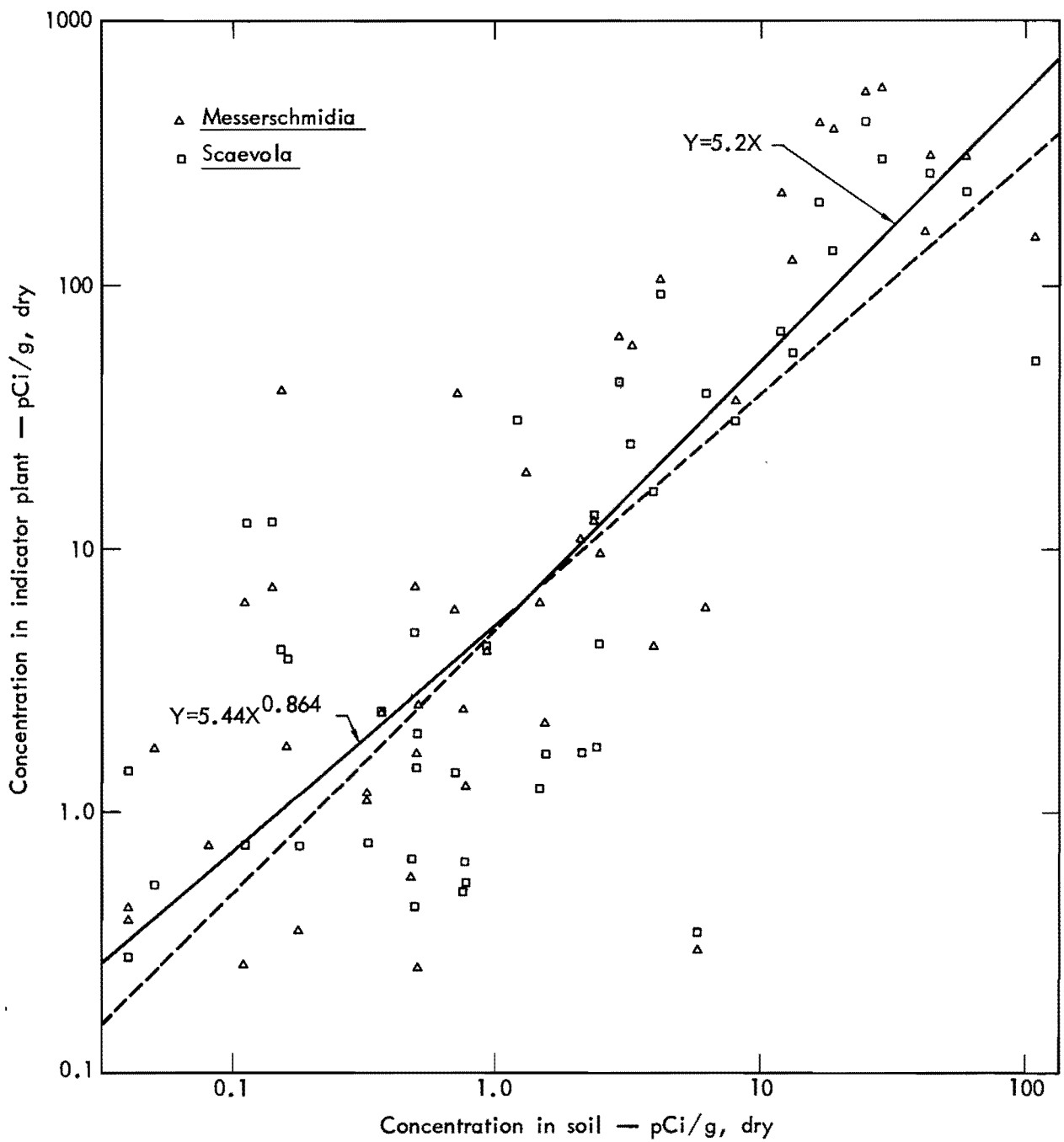


Fig. 137. Statistical correlation between  $^{137}\text{Cs}$  in Messerschmidia and Scaevola and  $^{137}\text{Cs}$  in soil.



Table 173. Statistical correlation between  $^{137}\text{Cs}$  in coconut meat and  $^{137}\text{Cs}$  in indicator plants.

Plant type	Sample size (n)	Correlation coefficient (r)	Level of significance (P)	$\ln Y = A + b \ln X$	
				A	b
<u>Messerschmidia</u>	19	0.80	<0.001	0.060	0.652
<u>Scaevola</u>	19	0.70	<0.001	0.404	0.575
Pooled	38	0.75	<0.001	0.237 <sup>b</sup>	0.612 <sup>a</sup>

<sup>a</sup>An F-test for equality of the regression slopes gives  $F = 0.17$ ,  $P = 0.680$ .

<sup>b</sup>An F-test for equality of the regression intercepts gives  $F = 0.63$ ,  $P = 0.433$ .

and Scaevola may be used for prediction of the concentrations of these nuclides in coconuts growing at the same locations.

Statistical Correlations Between Rat Tissues and Indicator Plants — Rats were the only mammals found on the Atoll. Previous studies by Fall, Medina, and Jackson<sup>3</sup> indicate that although the indigenous rats of Enewetak are omnivorous, plant foods predominated in the diet. The dominant species Messerschmidia

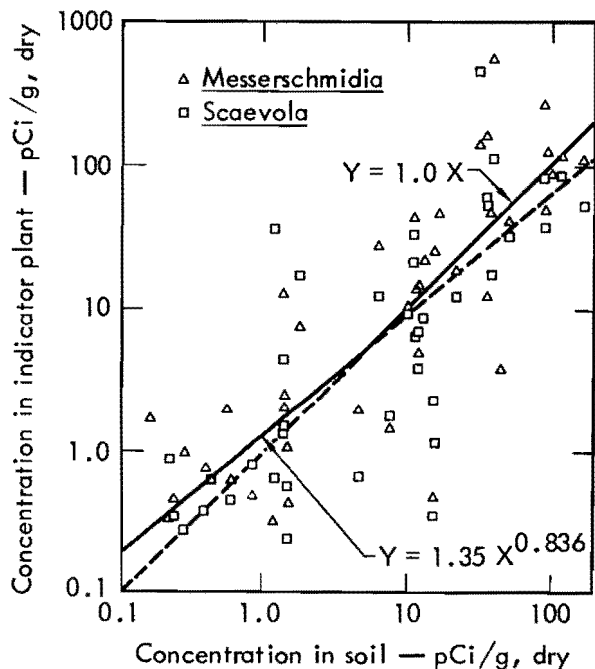


Fig. 138. Statistical correlation between  $^{90}\text{Sr}$  in Messerschmidia and Scaevola and  $^{90}\text{Sr}$  in soil.

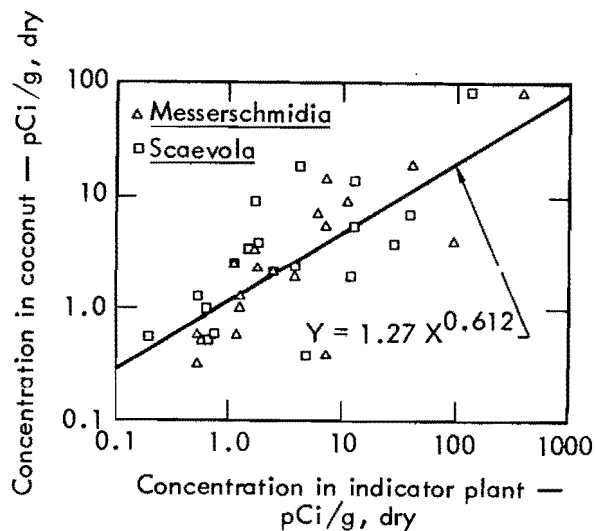


Fig. 139. Statistical correlation between  $^{137}\text{Cs}$  in coconut meat and  $^{137}\text{Cs}$  in Messerschmidia and Scaevola.

Table 174. Statistical correlation between  $^{90}\text{Sr}$  in coconut meat and  $^{90}\text{Sr}$  in indicator plants.

Plant type	Sample size (n)	Correlation coefficient (r)	Level of significance (P)	$\ln Y = A + b \ln X$	
				A	b
<u>Messerschmidia</u>	14	0.39	N. S. <sup>a</sup>	-2.91	0.438
<u>Scaevola</u>	14	0.54	0.05	-2.85	0.548
Pooled	28	0.46	0.02	-2.89 <sup>c</sup>	0.492 <sup>b</sup>

<sup>a</sup>Not significant.

<sup>b</sup>An F-test for equality of the regression slopes gives  $F = 0.08$ ,  $P = 0.779$ .

<sup>c</sup>An F-test for equality of the regression intercepts gives  $F = 0.09$ ,  $P = 0.763$ .

and Scaevola constituted 62% of the diet of the roof rat and 78% of the diet of the Polynesian rat. It is therefore reasonable to regard rats as "model herbivores" in which the concentrations of radionuclides in tissue could be expected to correlate with those in Messerschmidia and Scaevola.

Table 175 summarizes the transfer coefficients of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  to rat muscle. The transfer coefficient is defined as  $\text{pCi/g wet tissue} \div \text{pCi/g dry vegetation}$ . They were calculated from the measured concentrations in rat muscle and in Messerschmidia and Scaevola growing at the same locations where the rats were captured. The water content of rat muscle was assumed to be 73% on the basis of current experience and the literature<sup>4</sup>. The transfer coefficients to rat muscle vary widely. The values for  $^{137}\text{Cs}$  range from 0.1 to 7, and those for  $^{90}\text{Sr}$  range from 0.005 to 1.

Variations of the  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in rat muscle as a function of those in Messerschmidia and Scaevola are presented in Figs. 141 and 142. Linear regression analysis<sup>1</sup> of the log-

transformed data yields the results shown in Tables 176 and 177. Cesium-137 and strontium-90 concentrations in rat muscle correlate significantly with those in Messerschmidia and Scaevola ( $^{137}\text{Cs}$ ,  $P < 0.001$ ,  $^{90}\text{Sr}$ ,  $P < 0.01$ ). Further analysis<sup>2</sup> yields results that justify the conclusion that the individual regression lines have equal slopes and equal intercepts. The resultant pooled regres-

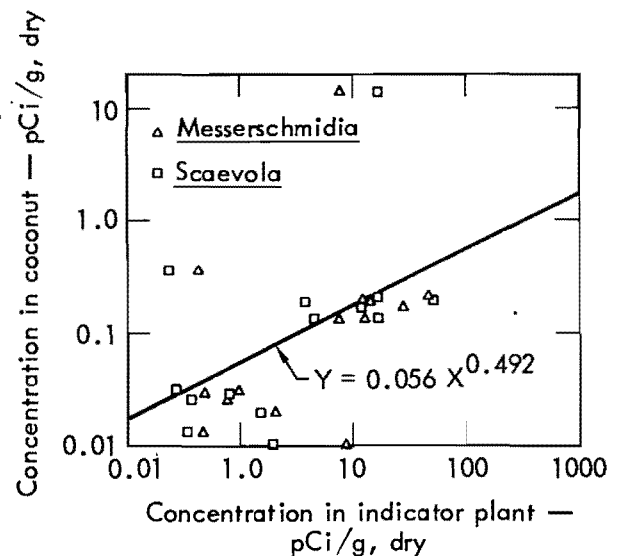


Fig. 140. Statistical correlation between  $^{90}\text{Sr}$  in coconut meat and  $^{90}\text{Sr}$  in Messerschmidia and Scaevola.

Table 175. Relationship between  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in rat muscle and indicator plants.

Plant type	Transfer coefficient, pCi/g wet muscle $\div$ pCi/g dry vegetation							
	Cesium-137				Strontium-90			
	No.	Min	Median	Max	No.	Min	Median	Max
<u>Messerschmidia</u>	16	0.097	0.45	5.68	13	0.0053	0.040	1.28
<u>Scaevola</u>	17	0.11	1.12	6.78	13	0.0048	0.059	1.04
Pooled	33	0.097	0.73	6.78	26	0.0048	0.043	1.28

Table 176. Statistical correlation between  $^{137}\text{Cs}$  in rat muscle and  $^{137}\text{Cs}$  in Messerschmidia and Scaevola.

Plant type	Sample size (n)	Correlation coefficient (r)	Level of significance (P)	$\ln Y = A + b \ln X$	
				A	b
<u>Messerschmidia</u>	16	0.86	<0.001	0.144	0.773
<u>Scaevola</u>	17	0.87	<0.001	0.284	0.801
Pooled	33	0.86	<0.001	0.230 <sup>b</sup>	0.783 <sup>a</sup>

<sup>a</sup>An F-test for equality of the regression slopes gives  $F = 0.03$ ,  $P = 0.869$ .

<sup>b</sup>An F-test for equality of regression intercepts gives  $F = 0.38$ ,  $P = 0.540$ .

Table 177. Statistical correlation between  $^{90}\text{Sr}$  in rat muscle and  $^{90}\text{Sr}$  in Messerschmidia and Scaevola.

Plant type	Sample size (n)	Correlation coefficient (r)	Level of significance (P)	$\ln Y = A + b \ln X$	
				A	b
<u>Messerschmidia</u>	13	0.76	<0.01	-2.10	0.540
<u>Scaevola</u>	13	0.70	<0.01	-2.05	0.557
Pooled	26	0.73	<0.001	-2.07 <sup>b</sup>	0.546 <sup>a</sup>

<sup>a</sup>An F-test for equality of the regression slopes gives  $F = 0.01$ ,  $P = 0.942$ .

<sup>b</sup>An F-test for equality of the regression intercepts gives  $F = 0.03$ ,  $P = 0.856$ .

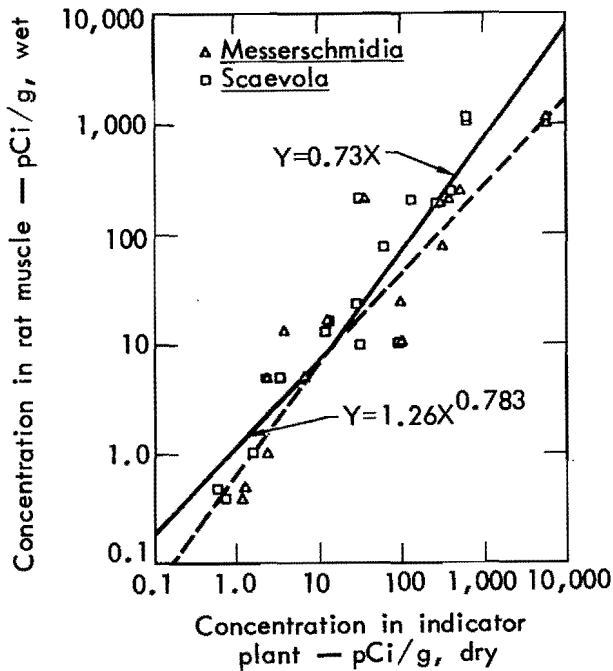


Fig. 141. Statistical correlation between  $^{137}\text{Cs}$  in rat muscle and  $^{137}\text{Cs}$  in Messerschmidia and Scaevola.

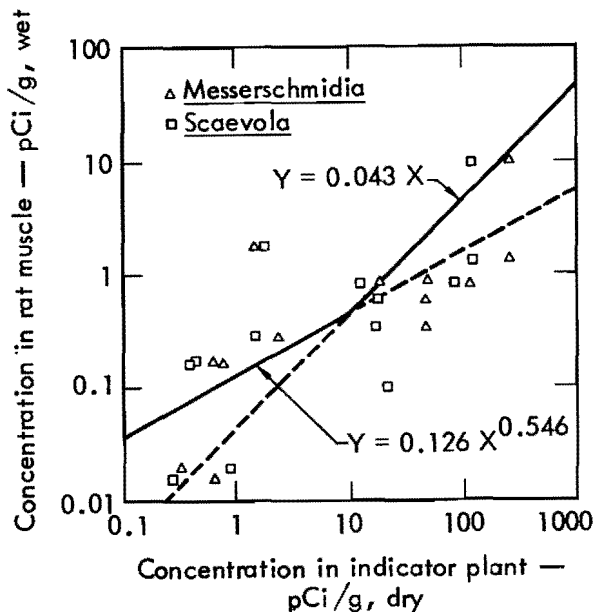


Fig. 142. Statistical correlation between  $^{90}\text{Sr}$  in rat muscle and  $^{90}\text{Sr}$  in Messerschmidia and Scaevola.

sion lines thus can be used to predict  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in rat muscle from those in Messerschmidia or Scaevola.

Since  $^{90}\text{Sr}$  can be expected to concentrate in bone, transfer coefficients of  $^{90}\text{Sr}$  to rat bone were calculated in the same manner. The weight of bone ash was assumed to be 38% of wet weight<sup>5</sup>. The values, shown in Table 178, vary from 0.2 to 4. Variation of the concentrations in bone as a function of those in Messerschmidia and Scaevola are presented in Fig. 143. Results of linear regression analysis are shown in Table 179. There is a highly significant correlation ( $P < 0.001$ ) between the logarithms of the  $^{90}\text{Sr}$  concentrations in rat bone and those in Messerschmidia and Scaevola. Furthermore, the individual regression lines for Messerschmidia and Scaevola can be assumed to have equal slopes and equal intercepts. Thus the pooled regression line can be used to predict  $^{90}\text{Sr}$  concentrations in rat bone from those in Messerschmidia or Scaevola.

#### Prediction of Radionuclide Concentrations in Foods

Coconut — Coconuts were the most extensively sampled of the edible plants; the 16 islands yielded a total of 23 samples of coconut meat. If the mean of the radionuclide concentrations in the samples from an island group were used to represent that island group, assessment of radionuclides in coconut would be as follows: Island group ALICE-IRENE would be based on three samples, JANET would be based on one sample, island group KATE-WILMA plus LEROY would be based on

Table 178. Relationship between  $^{90}\text{Sr}$  concentrations in rat bone and indicator plants.

Plant type	No. of samples	Transfer coefficient, $\text{pCi/g wet bone} \div \text{pCi/g dry vegetation}$		
		Min	Median	Max
<u>Messerschmidia</u>	13	0.20	0.79	2.53
<u>Scaevola</u>	13	0.43	1.22	3.82
Pooled	26	0.20	1.03	3.82

Table 179. Statistical correlation between  $^{90}\text{Sr}$  in rat bone and  $^{90}\text{Sr}$  in Messerschmidia and Scaevola.

Plant type	Sample size (n)	Correlation coefficient (r)	Level of significance (P)	$\ln Y = A + b \ln X$	
				A	b
<u>Messerschmidia</u>	13	0.94	<0.001	0.137	0.852
<u>Scaevola</u>	13	0.94	<0.001	0.331	0.919
Pooled	26	0.93	<0.001	0.256 <sup>b</sup>	0.872 <sup>a</sup>

<sup>a</sup>An F-test for equality of regression slopes gives  $F = 0.23$ ,  $P = 0.635$ .

<sup>b</sup>An F-test for equality of regression intercepts gives  $F = 1.45$ ,  $P = 0.241$ .

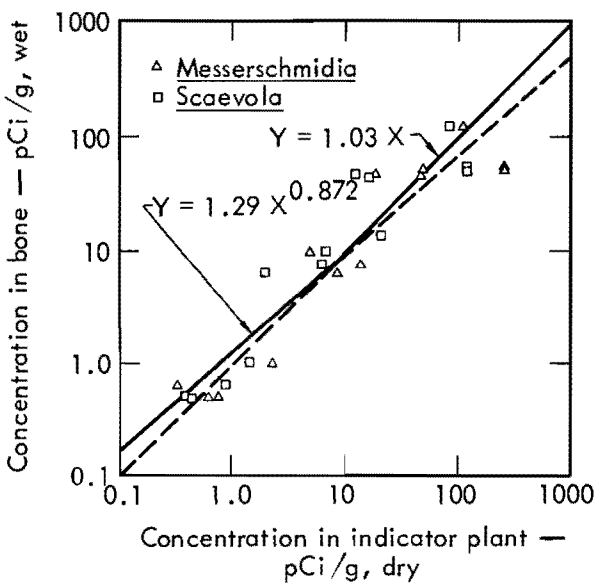


Fig. 143. Statistical correlation between  $^{90}\text{Sr}$  in rat bone and  $^{90}\text{Sr}$  in Messerschmidia and Scaevola.

five samples (from four islands), and island group ALVIN-KEITH would be based on 12 samples (from eight islands). The samples from any island group are relatively small in number, and they would certainly not relate to future harvests, particularly in the case of the northern islands where coconut groves will have to be reestablished. Prediction of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in coconut for all island groups is therefore based on the statistical correlations between coconuts and soil. These take into account each of 22 coconut samples analyzed. Prediction of concentrations of the other radionuclides in coconut is necessarily based on mean values of the concentration in the samples from the island group.

The concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in coconut meat for each island group were predicted from the mean soil concentrations, determined in the following manner: Each of the islands comprising the island group was assigned the median concentration for the 0-15 cm profile as listed in Table 15 and 16 in the chapter on the terrestrial soil and radiation survey. If an island had two listed values (one for dense and one for sparse vegetation), as in the case of BELLE, DAISY, KATE, OLIVE, PEARL, and TILDA, it was assigned the lower of the median concentrations calculated for all the profiles sampled and analyzed. In weighting the mean concentration toward the areas of dense vegetation, we are in essence considering these areas as having more fertile and highly developed soils and hence as soils more suitable for agriculture. The mean for the island group was then computed from the values assigned to each island. Table 180 summarizes the data on mean concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in soil that were used as the starting point for predicting concentrations in coconut and other terrestrial plants.

For the relatively high concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in soil, the concentrations in coconut were predicted using the median value of the experimentally determined soil-to-plant concentration factor (Table 170). Use of a constant rather than varying concentration factor seems not only simple and straightforward, but also readily acceptable as a concept. Use of the median value is consistent with the observed data (Figs. 133 and 134), and when the concentrations in soil are rela-

tively high, it leads to predicted concentrations in coconut that are greater than those derived from the linear regression expression. For the relatively low concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in soil, concentrations in coconut were predicted from the linear regression expressions (Tables 171 and 172).

The above procedure for predicting  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in coconut meat can be summarized as follows:

If  $Y$  = concentration (pCi/g) in dry coconut meat and  $X$  = concentration (pCi/g) in dry soil,

$^{137}\text{Cs}$ :

(1)  $X < 4.7$  pCi/g

$$\ln Y = 0.847 + 0.620 \ln X \quad Y = 2.33X^{0.620}$$

(2)  $X \geq 4.7$  pCi/g

$$Y = 1.3X$$

$^{90}\text{Sr}$ :

(1)  $X < 4.3$  pCi/g

$$\ln Y = -3.01 + 0.482 \ln X \quad Y = 0.049X^{0.482}$$

(2)  $X \geq 4.3$  pCi/g

$$Y = 0.023X$$

These relationships are shown as the solid lines in Figs. 133 and 134.

Coconut Milk — In the absence of definitive data it is reasonable to expect that the distributions of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in meat and milk of coconut would be similar to those of their stable element counterparts potassium and calcium. Thus, the amount of  $^{90}\text{Sr}$  in land plants from Bikini Atoll appeared to depend on the amount of calcium present<sup>4</sup>. Table 181 lists stable potassium and stable calcium concentrations in coconut and other edible and indicator plants. Table 181 indicates that for fresh coconut the potassium concentration is somewhat greater in meat,

Table 180. Mean concentrations of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  in Enewetak soils.

	Concentration in top 15 cm, pCi/g	
	$^{90}\text{Sr}$	$^{137}\text{Cs}$
Island group ALICE-IRENE		
1. ALICE	80	36
2. BELLE (dense median)	123	48
3. CLARA	65	26
4. DAISY (mean)	108	11
5. EDNA	46	4.2
9. IRENE	30	3.2
	Mean	75.3
Island group BELLE		
2. BELLE (dense median)	123	48
Island group JANET		
10. JANET	44	16
Island group KATE-WILMA + LEROY		
11. KATE (mean)	43.5	13.1
12. LUCY	32	11
13. PERCY	13	0.94
14. MARY	29	9.9
15. NANCY	36	12
16. OLIVE ( $^{90}\text{Sr}$ dense median, $^{137}\text{Cs}$ mean)	22	7.65
17. PEARL (mean)	28.2	12.4
18. RUBY	12	1.4
19. SALLY	8.4	3.0
20. TILDA (mean)	19.2	4.2
21. URSULA	6.8	1.7
22. VERA	6.3	2.0
23. WILMA	3.3	1.3
43. LEROY	11	3.2
	Mean	19.3
Island group ALVIN-KEITH		
33. DAVID, 35. ELMER, 37. FRED	0.41	0.21
All others (14 islands)	0.52	0.14
	Weighted mean	0.50
		0.15

Table 181. Stable potassium and stable calcium content of selected edible and indicator plants.

Observation		Concentration <sup>a</sup> , mg/g dry		Reference
Plant type	Source	K	Ca	
Breadfruit	Marshall Is. 1951	-	0.85	19
Breadfruit	Caroline Is. 1951	-	0.70	19
Breadfruit	Panama 1966-67	32	2.2	22
Breadfruit	Colombia 1966-67	26	2.1	22
Breadfruit	Handbook data	15	1.1	6
Coconut meat	Bikini I 1964	-	0.71	4
Coconut meat	Handbook data	5.9	0.26	6
Coconut milk	Handbook data	25 <sup>c</sup>	3.4 <sup>c</sup>	6
Coconut meat	Enewetak 1972-73	7.5(23) <sup>b</sup>	0.24(10)	This study
Pandanus fruit	Rongelap I 1958-63	-	6.1(23)	10
Pandanus leaves	Rongelap I 1958-63	-	13 (66)	10
Pandanus fruit	Eniaetok I, Rongelap 1958-63	-	3.3(9)	10
Pandanus leaves	Eniaetok I, Rongelap 1958-63	-	12 (12)	10
Pandanus fruit	Kabelle I, Rongelap 1958-63	-	9.2(6)	10
Pandanus leaves	Kabelle I, Rongelap 1958-63	-	12 (8)	10
Pandanus fruit	Bikini I 1964	-	17	4
Pandanus leaves	Bikini I 1964	-	17	4
Pandanus fruit	Enewetak 1972-73	16(2) <sup>b</sup>	4.4(1)	This study
Pandanus leaves	Enewetak 1972-73	11(9) <sup>b</sup>	12.6(9)	This study
Tacca whole corm	Rongelap 1958-61 <sup>d</sup>	6.8(3)	6.0(6)	10
Tacca peeled corm	Rongelap 1958-61 <sup>d</sup>	4.9(3)	1.1(3)	10
Tacca peels	Rongelap 1958-61 <sup>d</sup>	19 (3)	5.4(3)	10
Tacca processed	Rongelap 1958-61 <sup>d</sup>	0.14(1)	0.41(2)	10
Tacca whole corm	Bikini 1964	-	5.0	4
Tacca whole corm	Enewetak 1972-73	8.0(1) <sup>b</sup>	9.8(1)	This study
Cassava root	Panama 1966-67	11	1.5	22
Cassava root	Colombia 1966-67	12	1.0	22
Tapioca	Handbook data	0.18	0.10	6

<sup>a</sup>The number shown within parentheses is the number of samples.

<sup>b</sup>The stable K concentration was estimated from the concentrations of <sup>40</sup>K.

<sup>c</sup>The concentrations of stable K and stable Ca in fresh coconut meat are 2.56 mg/g and 0.13 mg/g, respectively. In fresh coconut milk they are 1.47 mg/g and 0.20 mg/g, respectively.<sup>6</sup>

<sup>d</sup>The tacca samples from Rongelap Atoll were collected from the islands of Rongelap, Eniaetok, and Kabelle.



Table 181 (continued).

Observation		Concentration <sup>a</sup> , mg/g dry		Reference
Plant type	Source	K	Ca	
<u>Messerschmidia</u>				
basal leaves	Bikini 1964	-	52	4
<u>Messerschmidia</u>				
terminal leaves	Bikini 1964	-	35	4
<u>Messerschmidia</u>				
leaves	Enewetak and Bikini 1964	9.9(31)	23(31)	24
<u>Messerschmidia</u>				
leaves	Enewetak 1972-73	14(58) <sup>b</sup>	-	This study
<u>Scaevola basal</u>				
leaves	Bikini 1964	-	23	4
<u>Scaevola</u>				
terminal leaves	Bikini 1964	-	19	4
<u>Scaevola leaves</u>	Enewetak 1972-73	16(56) <sup>b</sup>	39(6)	This study

<sup>a</sup>The number shown within parentheses is the number of samples.

<sup>b</sup>The stable K concentration was estimated from the concentrations of <sup>40</sup>K.

<sup>c</sup>The concentrations of stable K and stable Ca in fresh coconut meat are 2.56 mg/g and 0.13 mg/g, respectively. In fresh coconut milk they are 1.47 mg/g and 0.20 mg/g, respectively.<sup>6</sup>

<sup>d</sup>The tacca samples from Rongelap Atoll were collected from the islands of Rongelap, Eniaetok, and Kabelle.

while the calcium concentration is somewhat greater in milk<sup>6</sup>, but the concentrations in meat and milk differ by less than a factor of two.

Table 165 lists the concentrations of the radionuclides measured in milk and meat of coconuts in this survey. The data are too few to allow for statistical analysis, and they show an inconsistent pattern of <sup>137</sup>Cs distribution. Concentrations of <sup>137</sup>Cs are greater in meat in samples from DAISY, JANET, and NANCY, but they are greater in milk in the samples from MARY and DAVID. Strontium-90 concentrations are lower rather than higher in milk in all samples, except possibly those from DAVID. In view of these considera-

tions, it seems reasonable and expedient to assume for purposes of prediction that the concentrations of <sup>137</sup>Cs and <sup>90</sup>Sr in fresh meat and fresh milk are the same. It is interesting to note that the average <sup>137</sup>Cs concentrations in meat and milk from coconuts sampled at Bikini Atoll in 1969 were comparable to within 10-15%<sup>7</sup>. Wet-weight concentrations of radionuclides were calculated from the dry-weight concentrations, assuming 50 and 95% as the water contents of fresh coconut meat and fresh coconut milk. Both of these values are consistent with literature values<sup>4, 6</sup> and with laboratory records.

Pandanus Fruit — Although pandanus was found on 10 islands, samples of fruit could only be obtained from BELLE and KEITH. These fruit samples seem to display soil uptake patterns for  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  that are similar to those displayed by the leaves. Figure 144 shows the variation of the  $^{137}\text{Cs}$  concentrations in fruit and leaves as a function of that in soil, and Fig. 145 shows comparable data for  $^{90}\text{Sr}$ . Fruit and leaves of pandanus seem to display similar soil uptake patterns for  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ , and the concentration factors of fruit are within the range of the concentration factors of leaves (see Table 170).

As Table 182 indicates, data on radionuclide content in fruit or leaves of pandanus from previous radiological surveys

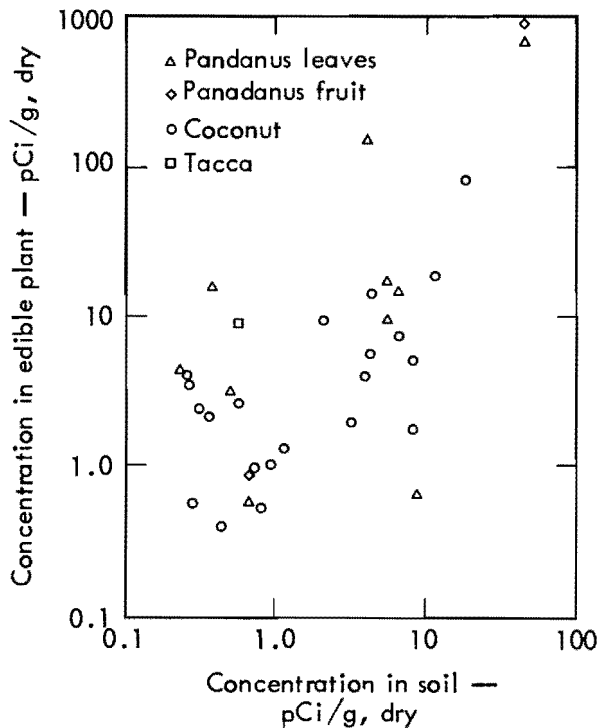


Fig. 144. Correlation of  $^{137}\text{Cs}$  in edible plants with  $^{137}\text{Cs}$  in soil.

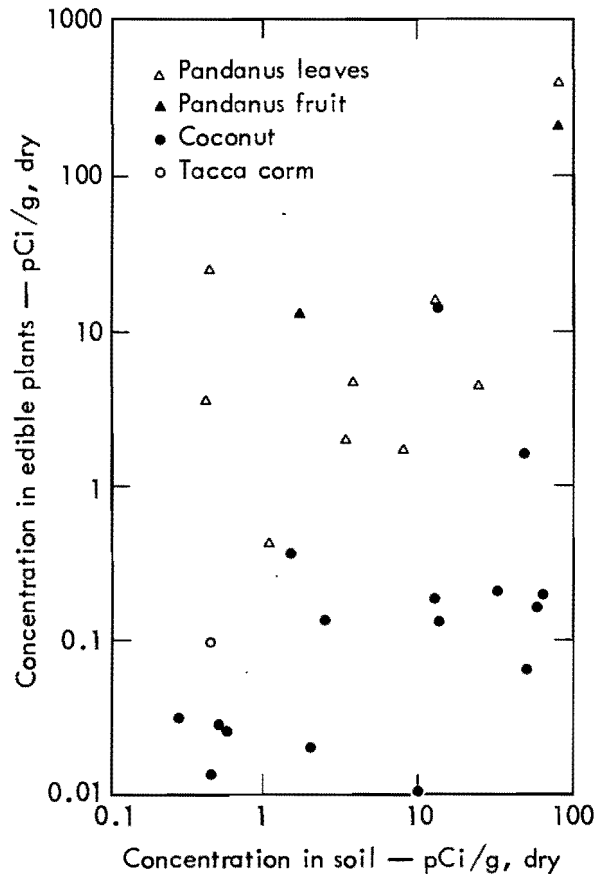


Fig. 145. Correlation of  $^{90}\text{Sr}$  in edible plants with  $^{90}\text{Sr}$  in soil.

of Bikini and Enewetak were limited to just a few samples<sup>4, 7-9</sup>. It was our good fortune to be provided with unpublished data on the radionuclide content in fruit and leaves of pandanus sampled during radiological surveys conducted by the University of Washington on Rongelap Atoll<sup>10</sup>. Table 183 summarizes the available data on concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in fruit and leaves of pandanus from the same site on Rongelap<sup>10</sup> and elsewhere<sup>4</sup>. The two sets of pandanus fruit and leaves from the current survey are included in the table.

Inspection of Table 183 leads to the

Table 182. Average radionuclide content of pandanus and tacca collected on previous surveys at Bikini and Enewetak.

Year	Nuclide	Concentration, pCi/g wet								Reference
		Pandanus				Tacca				
		Fruit		Leaves		Corm		Processed arrowroot <sup>e</sup>		
Bikini	Enewetak	Bikini	Enewetak	Bikini	Enewetak	Bikini	Enewetak			
1964	<sup>60</sup> Co					0.12 <sup>a</sup>				4
	<sup>90</sup> Sr	32 <sup>a, c</sup>		24 <sup>a, c</sup>		0.068				4
	<sup>90</sup> Sr	9300 SU <sup>d</sup>		7200 SU <sup>d</sup>		6900 SU <sup>d</sup>				4, 8
	<sup>106</sup> Ru					1.8 <sup>a</sup>				4
	<sup>137</sup> Cs	3.1 <sup>a</sup>	180 <sup>b</sup>			50 <sup>a</sup>				4
1967	<sup>90</sup> Sr	19 (4-45)				0.17				9
	<sup>137</sup> Cs	52 (14-90)				92 (15-170)				9
1969	<sup>90</sup> Sr	28 <sup>a</sup>						2.4 <sup>a</sup>	0.4 <sup>b</sup>	7
	<sup>137</sup> Cs	130(26-400) <sup>a</sup>						0.6 (0.4-1.1) <sup>a or b</sup>		7
		87 <sup>b</sup>								

<sup>a</sup> Bikini Island.

<sup>b</sup> Enyu Island.

<sup>c</sup> Water content of pandanus and tacca corm is assumed to be 80%.

<sup>d</sup> 1 SU (strontium unit) is equal to 1 pCi <sup>90</sup>Sr/g Ca.

<sup>e</sup> Prepared according to the Marshallese method of preparation by grinding, rinsing three times with salt water and once with fresh water.<sup>7</sup>

Table 183.  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  in fruit and leaves of pandanus.

Date	Location	Concentration, pCi/g dry				Reference
		$^{90}\text{Sr}$		$^{137}\text{Cs}$		
		Fruit	Leaves	Fruit	Leaves	
Aug. 1958	Rongelap Atoll					
	Eniaetok	6.0	25	230	78	10
	Kabelle	6.0	34	309	346	10
Sept. 1959	Rongelap Atoll					
	Rongelap	12.0	14	160	100	10
	Rongelap			152	48	10
	Eniaetok	7.1	19	360	82	10
	Eniaetok	9.0	38	226	105	10
	Kieshiechi	30.0	92	422	97	10
	Mellu	7.1	29	298	50	10
	Gejen	30.0	54	991	111	10
	Aerik	21.0	65	620	496	10
Tufa	5.8	11	126	42	10	
Aug. 1963	Rongelap Atoll					
	Rongelap			170	58	10
	Rongelap	6.6	11	44	21 <sup>a</sup>	10
	Rongelap			140	62 <sup>a</sup>	10
	Eniaetok	15.0	45	260	67	10
	Kabelle			220	170	10
Aug. 1964	Bikini Atoll					
	Bikini	160.0	120			4
Oct. 1972- Feb. 1973	Enewetak Atoll					
	Bogombogo (BELLE)	206.0	391	923	679	This study
	Giriinian (KEITH)			0.86	0.57	This study

<sup>a</sup>Mean of concentrations in terminal and basal leaves.

conclusion that the concentration of  $^{137}\text{Cs}$  in pandanus fruit can be expected to exceed that in leaves, while the concentration of  $^{90}\text{Sr}$  in pandanus leaves can be expected to exceed that in fruit. Thus, if a quantitative relationship can be established between the concentrations in fruit and leaves, it would be possible to predict future concentrations of radionuclides in pandanus fruit using the data obtained from pandanus leaves.

The Wilcoxon matched-pairs, signed-ranks test<sup>11</sup> was used to determine the appropriate conversion factors to be used with the  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  concentrations in pandanus leaves to determine those in fruit. In this nonparametric test, signed differences between concentrations in fruit and leaves are determined, and the differences are ranked according to absolute value. The ranks of like sign are then summed, and the lower sum of the like-signed ranks is compared with an appropriate critical value from a special table. If the observed sum is equal to or less than this critical value for a particular significance level, the null hypothesis may be rejected at that level of significance.

Tables 184 and 185 show the results of Wilcoxon test carried out on the matched pairs of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations listed in Table 183. A series of values was tested to determine the appropriate conversion factors for the two nuclides. Table 184 indicates that if the concentrations of  $^{137}\text{Cs}$  measured in pandanus leaves were increased by any factor from 2 to 3.5, the resulting concentrations would be statistically indistinguishable from those in fruit. A conversion factor of 2.5, which gives essentially equal sums

of minus and plus ranks has been adopted in this evaluation; i. e., the  $^{137}\text{Cs}$  concentration in pandanus fruit is assumed to be 2.5 times that in pandanus leaves. In the case of  $^{90}\text{Sr}$ , Table 185 indicates that if the concentrations measured in pandanus fruit were increased by any factor between 2 and 3, the resulting concentrations would be statistically indistinguishable from those in leaves. A conversion factor of 2.5, which gives essentially equal sums of minus and plus ranks, has been selected. Thus the concentration of  $^{90}\text{Sr}$  in pandanus fruit is assumed to be 40% of that in pandanus leaves.

The concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in pandanus leaves for each island group were predicted from the mean soil concentrations in essentially the same manner described for coconut. The mean concentrations in soil listed in Table 180 were used as the starting point. When the soil concentrations were relatively low, the statistical correlation between pooled pandanus leaves, Messerschmidia, and Scaevola and soil (Tables 171B and 172B) was used for prediction. When the soil concentrations were relatively high, the median of the experimentally determined soil-to-plant concentration factors (Table 170) was used. The median values chosen for the concentration factor in the pooled plants were 5.2 for  $^{137}\text{Cs}$  and 1.0 for  $^{90}\text{Sr}$ . The relationship used for predicting concentrations in pandanus leaves from those in soil are represented as solid curves on the graphs showing Messerschmidia and Scaevola vs soil (Figs. 137 and 138).

The concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in pandanus fruit were subsequently pre-

Table 184. Relationship between  $^{137}\text{Cs}$  concentrations in fruit and leaves of pandanus.

Wilcoxon matched-pairs, signed-ranks test (Ref. 11)<sup>a</sup>

X = pCi/g dry fruit

Y = pCi/g dry leaves

Samples tested	Sum of minus ranks ( $\sum^-$ )	Sum of plus ranks ( $\sum^+$ )	Conclusion about null hypothesis ( $H_0$ )
X - Y	3	168	Reject $H_0$ , $P < 0.005$ ; $X > Y$
X - 1.5 Y	40	131	Reject $H_0$ , $P = 0.025$ ; $X > 1.5 Y$
X - 2 Y	64	107	Not rejected; $X = 2 Y$
X - 2.5 Y	86	85	Not rejected; $X = 2.5 Y$
X - 3 Y	97	56	Not rejected; $X = 3 Y$
X - 3.5 Y	127	44	Not rejected; $X = 3.5 Y$
X - 4 Y	139	32	Reject $H_0$ , $P < 0.01$ ; $X < 4 Y$

<sup>a</sup>This table summarizes the results from the Wilcoxon test using the 18 pairs of data listed in Table 183.

Table 185. Relationship between  $^{90}\text{Sr}$  concentrations in fruit and leaves of pandanus.

Wilcoxon matched-pairs, signed-ranks test (Ref. 11)<sup>a</sup>

X = pCi/g dry fruit

Y = pCi/g dry leaves

Samples tested	Sum of minus ranks ( $\sum^-$ )	Sum of plus ranks ( $\sum^+$ )	Conclusion about null hypothesis ( $H_0$ )
Y - X	11	94	Reject $H_0$ , $P < 0.005$ ; $Y > X$
Y - 1.5 X	17	88	Reject $H_0$ , $P < 0.025$ ; $Y > 1.5 X$
Y - 2 X	36	69	Not rejected; $Y = 2 X$
Y - 2.5 X	53	52	Not rejected; $Y = 2.5 X$
Y - 3 X	60	31	Not rejected; $Y = 3 X$
Y - 3.5 X	89	17	Reject $H_0$ , $P < 0.025$ ; $Y < 3.5 X$

<sup>a</sup>This table summarizes the results from the Wilcoxon test using the 14 pairs of data listed in Table 183.

dicted from those in leaves using respective conversion factors of 2.5 and 0.4. The overall procedure for predicting concentrations in pandanus fruit from those in soil can be summarized as follows: If Y = concentration (pCi/g) in dry pandanus fruit and X = concentration (pCi/g) in dry soil,

$^{137}\text{Cs}$ :

(1)  $X < 1.30$  pCi/g

$$\ln Y = 2.60 + 0.851 \ln X \quad Y = 13.5X^{0.851}$$

(2)  $X \geq 1.30$  pCi/g

$$Y = 13X$$

$^{90}\text{Sr}$ :

(1)  $X < 6.1$  pCi/g

$$\ln Y = -0.617 + 0.836 \ln X \quad Y = 0.539X^{0.836}$$

(2)  $X \geq 6.1$  pCi/g

$$Y = 0.4X$$

Tacca (Arrowroot) — Figure 144 shows graphically the distribution of  $^{137}\text{Cs}$  in edible plants as a function of that in soil. Although only one sample of tacca corm was collected in the current survey, it seems to fall naturally within the overall distribution. The concentration factor of  $^{137}\text{Cs}$  in this sample is 16, which is about a factor of three greater than the median concentration factor in pandanus leaves and ten times greater than the median in coconut (see Table 170). This sample of tacca also seems to be similar to the other edible plants as far as uptake of  $^{90}\text{Sr}$  from soil is concerned (see Fig. 145). The concentration factor of  $^{90}\text{Sr}$  is 0.21, a value intermediate between 0.023, the median concentration factor in coconut meat, and 1.0, the median concentration factor in pandanus leaves (see Table 170). Data on tacca collected in previous radiological surveys

of Bikini and Enewetak are shown in Table 182 and are relatively few<sup>4, 7-9</sup>. Although the data suggest that the  $^{90}\text{Sr}$  concentration in pandanus fruit would exceed that in tacca corm by more than an order of magnitude and that the  $^{137}\text{Cs}$  concentrations in the two plant types would be comparable, it cannot be ascertained that the two plant types were sampled at the same sites. If comparison of the 1967 data on tacca corm from Bikini and the 1969 data on processed arrowroot from Bikini is valid, it can be concluded that most of the  $^{137}\text{Cs}$  content of tacca is lost during processing.

Table 186 shows unpublished data on the concentrations of  $^{137}\text{Cs}$  in tacca and pandanus leaves from the same sites on Rongelap Atoll<sup>10</sup>. The concentrations are greater in pandanus leaves, but they do not exceed those in tacca corm by more than a factor of two. Comparable data on  $^{90}\text{Sr}$  in Table 187 indicate that the  $^{90}\text{Sr}$  concentration in pandanus leaves can be expected to exceed that in tacca corm by a substantial amount. The concentrations in pandanus fruit and tacca would be more comparable; perhaps the concentration in tacca would be somewhat less. If we assume that the stable K concentration provides a measure of the relative uptake of  $^{137}\text{Cs}$ , the stable K data of Table 181 suggest that the uptake of  $^{137}\text{Cs}$  into tacca from soil would not exceed that to pandanus leaves, Messerschmidia, Scaevola, or coconut. Accordingly, on the basis of the stable K data and the Rongelap data, we have assumed that pandanus leaves serve as direct indicators for the uptake of  $^{137}\text{Cs}$  to tacca corms, and that the  $^{137}\text{Cs}$  in tacca can be predicted from that

Table 186. Comparison of  $^{137}\text{Cs}$  in tacca and pandanus from the same sites.<sup>a</sup>

Location	Date	Concentration, pCi/g dry	
		Tacca corms	Pandanus leaves
Rongelap I Pit 1	Mar. 1958	47	110
Eniaetok I Pit 11	Mar. 1958	140	203
Kabelle I Pit 7	Mar. 1958	182	270

<sup>a</sup>These unpublished data from University of Washington radiological survey at Rongelap were provided by Drs. A. H. Seymour and E. E. Held<sup>10</sup>.

in soil using the plant-vs-soil correlation derived for pooled Messerschmidia, Scaevola, and pandanus leaves (Table 171B). Similarly, if the stable calcium content is a measure of the potential  $^{90}\text{Sr}$  uptake, one may conclude that the uptake of  $^{90}\text{Sr}$  to tacca corm and pandanus fruit would be comparable and exceed that to coconut. On the basis of the stable calcium data and the Rongelap data, we have predicted the  $^{90}\text{Sr}$  concentrations in tacca corm from those in soil, assuming that concentration in tacca and pandanus fruit would be the same.

Unpublished data on tacca from the University of Washington radiological surveys on Rongelap<sup>10</sup> have also provided us with information on expected reductions in the  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  dry-weight concentrations from the processing of tacca into arrowroot starch. The  $^{137}\text{Cs}$  concentration would be reduced by a factor of 50 or greater, and the  $^{90}\text{Sr}$  concentration would be reduced by a factor of 20 or greater. Stable potassium and stable calcium experience similar reductions (see Table 181). On this basis the concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  predicted in tacca corm are reduced by factors of 50 and 20 to give the

final concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in dry processed arrowroot starch.

The overall procedure for predicting the concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in arrowroot starch from those in soil can be summarized as follows: If Y = concentration (pCi/g) in dry arrowroot starch and X = concentration (pCi/g) in dry soil,

$^{137}\text{Cs}$ :

(1)  $X < 1.3 \text{ pCi/g}$

$$\ln Y = -2.22 + 0.851 \ln X \quad Y = 0.108X^{0.851}$$

(2)  $X \geq 1.3 \text{ pCi/g}$

$$Y = 0.10X$$

$^{90}\text{Sr}$ :

(1)  $X < 6.1 \text{ pCi/g}$

$$\ln Y = -3.61 + 0.836 \ln X \quad Y = 0.027X^{0.836}$$

(2)  $X \geq 6.1 \text{ pCi/g}$

$$Y = 0.020X$$

Breadfruit — Breadfruit was not obtainable on this survey. The data of Table 181 indicate that stable potassium concentration in breadfruit is relatively high, greater than that in coconut or tacca and comparable to or even greater than that in Messerschmidia, Scaevola, or pandanus fruit. The data of Table 181 also indicate that the stable calcium con-



Table 187. Comparison of  $^{90}\text{Sr}$  in tacca and pandanus from the same sites.<sup>a</sup>

Location		Concentration, pCi/g dry					
		Date	Tacca corms	Date	Pandanus leaves	Date	Pandanus fruit
Rongelap I	Pit 1	Mar. 1958	3.2	Aug. 1958	47		
Eniaetok I	Pit 11	Mar. 1958	3.1	Mar. 1958	42	Mar. 1958	10
				Aug. 1958	41	Sept. 1959	9
		Sept. 1961	6.9	Aug. 1963	45	Aug. 1963	15
Eniaetok I	Pit 10	Sept. 1961	16.7			Sept. 1959	9
Kabelle I	Pit 7	Mar. 1958	4.9	Mar. 1958	36	Mar. 1958	17
				Sept. 1959	26		
		Sept. 1961	20	Sept. 1961	40 <sup>b</sup>		
						Mar. 1963	26
				Aug. 1963	26	Aug. 1963	15

<sup>a</sup>These unpublished data from University of Washington radiological surveys at Rongelap Atoll were provided by Drs. A. H. Seymour and E. E. Held<sup>10</sup>.

<sup>b</sup>Mean of concentrations in terminal and basal leaves.

centration in breadfruit is relatively low; lower concentrations are listed only for coconut. In the absence of additional data, we have assumed that uptake of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  will be proportional to the concentrations of stable potassium and stable calcium. Therefore, for predicting  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in breadfruit, we have assumed that breadfruit and pandanus fruit will experience the same uptake from soil and have simply adopted the same procedure described previously for predicting  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in pandanus fruit from those in soil.

Birds — Birds were captured in numbers on 18 islands distributed over all sections of the Atoll. The mean of the radionuclide concentrations in the samples from each island group were used to represent the island group. Since both muscle and liver are consumed as food, radionuclide concentrations in both muscle and liver are presented in Table 167. The average concentration in edible bird flesh was computed from these data, assuming that the weight of muscle consumed is six times that of liver, a relationship derived from laboratory records.

Bird Eggs — Common noddly or sooty tern eggs were collected on eight islands distributed more or less throughout the Atoll. The mean of the concentrations in the samples from each island group (see Table 168) was used to represent the group.

Coconut Crabs — Coconut crabs were captured on only five of the southern

islands. The means of the concentrations in the four samples from BRUCE, GLENN, JAMES, and KEITH were used to represent the southern island group (Group E, ALVIN-KEITH), and the concentrations in the samples from LEROY was used to represent island group KATE-WILMA and LEROY. Since coconut crabs could not be captured elsewhere on the Atoll, we conclude that only the southern islands would yield coconut crabs in numbers sufficient to contribute substantially to the diet. Both muscle and hepatopancreas are consumed as food. Laboratory records indicate that the dry weights of hepatopancreas (and associated tissues) and muscle are about the same. The concentrations of radionuclides in coconut crab were therefore computed from the concentrations listed in Table 169, assuming equal contributions from hepatopancreas and muscle.

Livestock and Poultry — Although  $^{137}\text{Cs}$  is the radionuclide that would be most effectively transferred to man via meat and poultry, this pathway would still contribute significant quantities of  $^{90}\text{Sr}$  to the diet. Prediction of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in pork and chicken has been based on data obtained from rats. Table 188 summarizes data on the transfer coefficient of  $^{137}\text{Cs}$  in muscle of herbivores that provide meat for human consumption, calculated from environmental data reported for cattle<sup>12</sup>, sheep, and deer<sup>13</sup>. The transfer coefficient is defined as pCi/g wet tissue  $\div$  pCi/g dry feed. Included in Table 188 are the transfer coefficients for rock ptarmigan and willow grouse<sup>14</sup>, two herbivorous game

Table 188. Behavior of  $^{137}\text{Cs}$  in the plant-herbivore-meat pathway.

Location	Observation	No.	Transfer coefficient pCi/kg wet muscle $\div$ pCi/kg dry forage			Reference
			Range		Mean	
			Min	Max		
Fort Collins, Colo.	Dry-lot and pasture-fed cattle	17	0.049	0.57	0.25±0.15 <sup>a</sup>	12
Mendocino County, Calif.	Sheep, age 4 mo	4	0.13 <sup>b</sup>	0.29 <sup>b</sup>	0.19 <sup>b</sup>	13
	Sheep, age 16-17 mo	4	0.10 <sup>b</sup>	0.15 <sup>b</sup>	0.12 <sup>b</sup>	
	Sheep, age 40-41 mo	4	0.23 <sup>b</sup>	0.52 <sup>b</sup>	0.27 <sup>b</sup>	
	Deer (Columbia black-tailed), age 4 mo	4	0.21 <sup>b</sup>	0.36 <sup>b</sup>	0.26 <sup>b</sup>	
	Deer, age 16-17 mo	5	0.17 <sup>b</sup>	0.41 <sup>b</sup>	0.26 <sup>b</sup>	
	Deer, age 40-41 mo	5	0.087 <sup>b</sup>	0.32 <sup>b</sup>	0.17 <sup>b</sup>	
Lapland, Finland	Rock ptarmigan	2 <sup>c</sup>	0.15 <sup>d</sup>	0.24 <sup>d</sup>		14
	Willow grouse	2 <sup>c</sup>	0.29 <sup>d</sup>	0.35 <sup>d</sup>		

<sup>a</sup> Mean value  $\pm \sigma$ .

<sup>b</sup> Transfer coefficients were calculated assuming that dry weight of forage equals dry weight of ruminal contents and that wet weight of muscle equals 3.5 times dry weight of muscle.

<sup>c</sup> Pooled samples each composed of 6-15 specimens.

<sup>d</sup> The concentration in dry crop contents was assumed to be the concentration in dry forage.

birds. Table 189 summarizes transfer coefficients of  $^{137}\text{Cs}$  in rat organs calculated from data on rats and indicator plants reported for previous studies on Enewetak and Bikini by the University of Washington<sup>4</sup> and Bowling Green University<sup>15</sup>. It was assumed that the rats and plants were collected at the same locations. Except for the transfer coefficient of 1.39 reported for Japtan, the concentration factors listed in Table 189 for rats fell within the range of those listed in Table 188 for cattle, sheep, deer, and game birds.

Tracer experiments have demonstrated a similar pattern of deposition of radio-cesium in muscle of livestock and poultry. Hood and Comar<sup>16</sup> noted that the relative concentrations of  $^{137}\text{Cs}$  in various tissues of farm animals 7 days after a single oral dose were quite similar. When normalized to a common body weight, the relative concentrations in muscle of cow, sheep, pig, and hen were 30, 41, 23, and 24, respectively. Although equilibrium between intake and accumulation in organs requires a period of time that varies with species, the equilibrium content in organs following chronic feeding differs very little. The equilibrium content of  $^{137}\text{Cs}$  in muscles of rat, rabbits, dogs, and pigs was found to be 14.5 to 28.5 times the daily dose<sup>17</sup>.

The basic parameters that influence the transfer of radionuclides from vegetation to muscle of herbivores can be conveniently described in terms of a simple model. The radionuclide concentration in muscle can be described by the equation:

$$Q(t) = \frac{f_B I^*}{\lambda_E} (1 - e^{-\lambda_E t}), \quad (1)$$

where

$Q(t)$  = quantity of radionuclide in muscle at time  $t$ , day,

$f_B$  = fraction of ingested nuclide deposited in muscle,

$I^*$  = quantity of radionuclide ingested daily, pCi/day, and

$\lambda_E$  = effective elimination constant, day<sup>-1</sup>.

The quantity of radionuclide in muscle at equilibrium  $Q_{eq}$  is:

$$Q_{eq} = \frac{f_B I^*}{\lambda_E}, \quad (2)$$

since

$$Q_{eq} = m C_B^* \quad \text{and} \quad I^* = J C_P^*, \quad (3a, 3b)$$

where

$m$  = mass of muscle, g,

$C_B^*$  = concentration of radionuclide in muscle, pCi/g,

$J$  = quantity of vegetation ingested daily, pCi/day, and

$C_P^*$  = concentration of radionuclide in vegetation, pCi/g.

One can substitute for  $Q_{eq}$  and  $I^*$  and obtain the following expression for the transfer coefficient

$$\frac{C_B^*}{C_P^*} = \frac{J f_B}{m \lambda_E}. \quad (4)$$

Table 190 presents muscle weight and daily intake of dry feed in livestock and rats. Table 191 presents effective half-lives or accumulation factors of  $^{137}\text{Cs}$  in muscle. The accumulation factor is obtained from chronic-administration experiments and is the ratio of the quantity of radionuclide in an organ to the daily

Table 189. Transfer coefficients of  $^{137}\text{Cs}$  in rat organs<sup>a</sup>.

Date	Location	Rat species	Organ	Plant species	Transfer coefficient	Reference
1964	Enewetak Atoll					
	Engebi (JANET)	Roof rat	Muscle	<u>Messerschmidia</u> and <u>Scaevola</u>	0.28	15
	Engebi (JANET)	Roof rat	All	All	0.12	4
	N. Runit (YVONNE)	Roof rat	Muscle	<u>Messerschmidia</u> and <u>Scaevola</u>	0.58 <sup>c</sup>	15
	Japtan (DAVID)	Polynesian rat	All	All	1.39 <sup>b</sup>	4
	Bikini Atoll					
	Enyu (NAN)	Polynesian rat	All	All	0.32	4
	Bikini (HOW)	Roof and Polynesian rat	All	All	0.29	4
1965	Enewetak Atoll					
	Engebi (JANET)	Roof rat	Muscle	<u>Messerschmidia</u> and <u>Scaevola</u>	0.11	15
	Bijiri (TILDA)	Polynesian rat	Muscle	<u>Messerschmidia</u> and <u>Scaevola</u>	0.46 <sup>c</sup>	15
	Runit (YVONNE)	Roof rat	All	All	0.26	4

<sup>a</sup>Transfer coefficient = pCi/g wet tissue  $\div$  pCi/g dry forage.

<sup>b</sup>Both tissue and plants were low in  $^{137}\text{Cs}$  content.

<sup>c</sup>Messerschmidia and Scaevola differed widely in  $^{137}\text{Cs}$  content.

dose. From Eq. (1) the accumulation factor is

$$AF = Q_{eq}/I^* = f_B/\lambda_E.$$

The effective half-life  $T_E$  is related to the elimination rate  $\lambda_E$  through the relationship  $\lambda_E = \ln 2/T_E$ . Half-lives were generally obtained from experiments involving single administration of  $^{137}\text{Cs}$ .

Table 191 also lists the resultant transfer coefficient to muscle when the data listed in Tables 190 and 191 are

combined according to Eq. (4). The  $f_B$  to muscle has been set equal to 0.5 for the calculation. Table 191 includes whole-body values for half-life and accumulation factor. In using the exponential retention for the whole body to represent muscle, we are following accepted practice.

The transfer coefficients calculated for Table 191 are seen to exceed those of Table 188. This difference is explainable by the difference in character of the two sets of data. Table 188 is representative

Table 190. Muscle weight and daily intake of dry feed in livestock and rats.

Animal	Muscle weight (m), kg	Daily intake of dry feed (J), kg/day	Ratio of daily intake to muscle weight (J/m), day <sup>-1</sup>	References
Rat <sup>a</sup>	0.12	0.017-0.025 <sup>a</sup>	0.18	5, 25
Beef cattle	180	8-15	0.064	26, 27
Dairy cattle	160	10-20	0.094	26, 27
Sheep	24	1.2-2	0.067	26, 27
Swine	85	3.1-4	0.042	26, 27
Chicken <sup>b</sup>	0.7	0.08	0.11	28

<sup>a</sup>The entries for rat assume a total body weight of 260 g. The 25-g/day daily intake is based upon the personal experiences of A. J. Silva in the Bio-Medical Division laboratories at LLL.

<sup>b</sup>The entries for chicken assume that about 50% of the total body weight is muscle and that feeding practice is as described in Ref. 28.

Table 191. Half-lives and accumulation factors of <sup>137</sup>Cs in muscle of livestock and rats.

Animal	Half-life (T <sub>E</sub> ), day	Accumulation factor (AF), day	Transfer coefficient (C <sub>B</sub> <sup>*</sup> /C <sub>P</sub> <sup>*</sup> )	Reference
Rat	13		1.7	29
	8.6 <sup>a</sup>		1.1	30
		8.9 <sup>a</sup>	1.8	25
		16	2.9	17
Dairy cattle	17 <sup>a</sup>		1.2	31
	15 <sup>a,b</sup>		1.0	31
Sheep	12 <sup>a,b</sup>		0.58	31
	17 <sup>a</sup>		0.82	32
Swine	29 <sup>a,b</sup>		0.88	31
	23 <sup>c</sup>		0.70	33
		16	0.67	17
Hen	27 <sup>a</sup>		2.1	33

<sup>a</sup>Whole-body value.

<sup>b</sup>Isotope administered intravenously.

<sup>c</sup>Slow component.

of field data. Since not all of the  $^{137}\text{Cs}$  associated with vegetation is absorbed in the gastrointestinal tract, fractional biological-availability factors are implicit in the data. The data of Table 191, on the other hand, were derived from tracer experiments; in these situations the biological availability of  $^{137}\text{Cs}$  is characteristically near 100%. In Table 191 the transfer coefficients of  $^{137}\text{Cs}$  to muscle are two to three times greater in rats than in swine. Table 175 lists the median and range of the transfer coefficients of  $^{137}\text{Cs}$  in rat muscle calculated for this study, using data from rats and Messerschmidia and Scaevola sampled at the same locations. The median transfer coefficient exceeds by a factor of two or greater the transfer coefficients listed in Table 188 for cattle, sheep, and deer. The considerations enumerated above lead to the conclusion that the transfer coefficient of  $^{137}\text{Cs}$  to pork is half as great as the transfer coefficient to rat muscle.

The transfer coefficients of  $^{137}\text{Cs}$  in Table 188 for rock ptarmigan and willow grouse muscle are comparable to those for muscle of cattle, sheep, and deer. On the other hand, the transfer coefficient calculated for poultry muscle in Table 191 is about equal to that for rat muscle and about two times that for cattle and swine. Surveillance data on  $^{137}\text{Cs}$  in the Chicago diet<sup>18</sup> indicate that the  $^{137}\text{Cs}$  concentrations in poultry were substantially less than those in meat when the fallout rate was relatively high. During the recent periods of relatively low fallout rate,  $^{137}\text{Cs}$  concentrations in poultry and meat have been more or less comparable (see

Table 192). It must be remembered, however, that poultry raised for commerce do not forage but are kept under shelter and given stored feed. We have assumed for present purposes that the transfer coefficients of  $^{137}\text{Cs}$  to rat muscle and poultry muscle are equal.

Strontium accumulates in bone rather than in soft tissues. In repeated oral administration of  $^{90}\text{Sr}$  the accumulation patterns of  $^{90}\text{Sr}$  in skeleton of rats and swine were similar, with accumulation factors intermediate between those of calves and dogs and those of ewes<sup>17</sup>. The maximum accumulation factor varied from 7.2 to 17.5 in the skeleton of rats and from 10.7 to 17.5 in that of pigs<sup>17</sup>. In the establishment of the equilibrium state between intake and elimination in young rats during chronic feeding, the  $^{90}\text{Sr}$  content in the skeleton was 200 times and the concentration 2000 times greater than in muscle. In old animals these relationships were 99 and 665, respectively, and in rats on high calcium diets, 55 and 333<sup>17</sup>. In pigs the concentration in skeleton was 140 times greater than in muscle<sup>17</sup>. In the present study the ratio of the  $^{90}\text{Sr}$  concentration in rat bone (pCi/g wet) and that in rat muscle (pCi/g wet) varied from 3.0 to 150, with a median value of 41 (n = 11).

The quotient of the daily intake of feed and the mass of bone in rat could be expected to exceed that in swine in much the same way that the quotient of the daily intake of feed and the mass of muscle in rat exceeds that in swine (see Table 190). If the accumulation factors to bone in rat and swine are as Ref. 17 indicates, then by Eq. (4) the transfer coefficient from

Table 192.  $^{137}\text{Cs}$  in poultry and meat from Chicago. <sup>a</sup>

Date	Concentration, pCi/kg	
	Poultry	Meat
January 1970	11	28
April	5	12
October	0	14
January 1971	0	24
April	8	25
July	6	33
October	10	19
January 1972	10	12
April	13	18
July	22	20
October	9	19
April 1973	4	10

<sup>a</sup>The data in this table were abstracted from Ref. 18.

indicator plant to bone for  $^{90}\text{Sr}$  would be greater in rats than in pigs by about a factor of four. On the other hand, the data of Ref. 17 also indicate that for the same  $^{90}\text{Sr}$  concentration in bone, the  $^{90}\text{Sr}$  concentration in muscle of pigs could be expected to exceed that in muscle of rats by about the same factor. These relationships thus provide a basis for using the  $^{90}\text{Sr}$  concentrations in rat muscle as a direct indicator for that in pork, and in the absence of data on the behavior of  $^{90}\text{Sr}$  in poultry, as a direct indicator for meat from chicken.

Comparison of Figs. 142 and 143 and Tables 177 and 179 reveals that the correlation between the  $^{90}\text{Sr}$  concentrations in rat bone and indicator plants is stronger than the correlation between rat muscle and indicator plants. Thus the bone ver-

sus plant correlation, together with the bone-to-muscle concentration ratio, could be used to predict  $^{90}\text{Sr}$  concentration in rat muscle from that in Messerschmidia or Scaevola. It was not possible to follow such an approach and develop a simple, straightforward scheme for predicting  $^{90}\text{Sr}$  in rat muscle and obtain results consistent with the observed concentrations in muscle.

The concentrations of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in rat muscle were both predicted from those in Messerschmidia and Scaevola. The median transfer coefficients, which are listed in Table 175, were used with the higher concentrations in the indicator plants, and the statistical correlations between rat muscle and pooled Messerschmidia and Scaevola (see Tables 176 and 177) were used with the lower concen-



trations in the indicator plants. The  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in Messerschmidia and Scaevola initially were predicted from those in soil using the correlations in Tables 171A and 172A or Tables 171B and 172B (also see Figs. 137 and 138) between the concentrations in Messerschmidia and Scaevola and those in soil. The mean concentrations in soil for the islands of interest are listed in Table 180. To simplify the calculations the average concentrations in meat and poultry were computed assuming arbitrarily that pork contributes twice as much meat to the diet as chicken.

The overall procedure for predicting  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in meat and poultry from those in soil can be summarized as follows: If Y = concentration (pCi/g) in fresh meat and poultry and X = concentration (pCi/g) in dry soil,

$^{137}\text{Cs}$ :

(1)  $X < 1.3$  pCi/g

$$\ln Y = 1.15 + 0.666 \ln X \quad Y = 3.15X^{0.666}$$

(2)  $1.3 \text{ pCi/g} \leq X < 2.4 \text{ pCi/g}$

$$\ln Y = 1.12 + 0.783 \ln X \quad Y = 3.05X^{0.783}$$

(3)  $X \geq 2.4$  pCi/g

$$Y = 2.53X$$

$^{90}\text{Sr}$ :

(1)  $X < 6.1$  pCi/g

$$\ln Y = -1.91 + 0.456 \ln X \quad Y = 0.148X^{0.456}$$

(2)  $6.1 \text{ pCi/g} \leq X < 10.7 \text{ pCi/g}$

$$\ln Y = -2.07 + 0.546 \ln X \quad Y = 0.126X^{0.546}$$

(3)  $X > 10.7$  pCi/g

$$Y = 0.043X$$

#### Assessment of the Dosage from Terrestrial Foods

Methodology — The quantity of radio-nuclides ingested via terrestrial foods was computed from the measured and predicted concentrations according

to the expected daily diets listed in Table 139 of the chapter on dietary and living patterns. Except for coconut and arrowroot, the daily intake of the food items listed in this table refers to the grams per day of fresh food. The gram-per-day intakes listed for coconut and arrowroot refer to the dry-weight intake of coconut meat (copra) and processed arrowroot starch. Water content of food items used to compute fresh-weight concentrations from dry-weight concentrations were determined from laboratory experience or estimated from the literature. The water content was assumed to be 50% in fresh coconut meat<sup>4, 6, 19</sup>, 95% in coconut milk<sup>6, 19</sup> and 70% in bread-fruit<sup>6, 19</sup>. Pandanus was initially assumed to be similar to other tropical fruits and have a water content of 80%<sup>6</sup>, which was subsequently confirmed by Ref. 19. The water content was assumed to be 70% in bird muscle and liver on the basis of poultry data<sup>6</sup>; it was assumed to be 75% in eggs<sup>6</sup>. In the case of coconut crabs, the water content was assumed to be 81% in liver<sup>20</sup> and 62% in hepatopancreas<sup>21</sup>.

Evaluation of the potential dose to the returning population has been structured on the basis of basic living patterns (see Table 135) and involves assessment of the contributions of terrestrial food from certain islands or island groups: (A) ALICE-IRENE, (B) BELLE, (C) JANET, (D) KATE-WILMA + LEROY, and (E) ALVIN-KEITH. Table 193 lists the initial concentrations of the radio-nuclides in the terrestrial foods from these islands or island groups. Two reference dates are shown on Table 193. The concentrations based on values in

Table 193. Concentrations of radionuclides in terrestrial foods.

Food item	Concentration, pCi/g dry <sup>a</sup>											
	Jan. 1, 1974						Jan. 1, 1982					
	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu
<b>A. Island group ALICE-IRENE</b>												
Domestic meat				3.08	51.7		← b →					
Pandanus fruit	← Not available →								23.5	221		
Breadfruit	← Not available →								23.5	221		
Wild birds		32.8	0.207	0.040	<0.081	0.0048	← b →					
Bird eggs		13.8	<0.057	0.090	<0.049	0.0015	← b →					
Arrowroot	← Not available →									1.18	1.77	
Coconut meat	← Not available →						0.237	6.64	<0.163	1.35	22.1	0.181
Coconut milk	← Not available →						2.37	66.4	<1.63	13.5	221	1.81
<b>B. Island group BELLE</b>												
Domestic meat				5.04	116		← b →					
Pandanus fruit	← Not available →							0.034	<0.036	38.4	496	<0.24
Breadfruit	← Not available →							0.034	<0.036	38.4	496	
Arrowroot	← Not available →									1.92	3.96	
Coconut meat	← Not available →									2.21	49.6	
Coconut milk	← Not available →									22.1	496	
<b>C. Island group JANET</b>												
Domestic meat				1.80	38.7		← b →					
Pandanus fruit	← Not available →							0.178	<0.031	13.8	165	0.00204
Breadfruit	← Not available →							0.178	<0.031	13.8	165	0.00204
Wild birds		59.9	0.257	0.0076	0.0834	0.0033	← b →					
Bird eggs		34.2	<0.077	0.193	0.114	0.0148	← b →					
Arrowroot	← Not available →									0.687	1.32	
Coconut meat	← Not available →								<0.019	0.790	16.5	
Coconut milk	← Not available →								<0.19	7.90	165	

Table 193 (continued).

Food item	Concentration, pCi/g dry <sup>a</sup>											
	Jan. 1, 1974					Jan. 1, 1982						
	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu
D. Island group KATE-WILMA + LEROY												
Domestic meat				0.79	14.3					b		
Pandanus fruit			Not available				0.0985	<0.344	6.03	61.9	0.00791	
Breadfruit			Not available				0.0985	<0.344	6.03	61.9	0.00791	
Wild birds		54.4	0.406	0.096	0.088	0.0247				b		
Bird eggs		22.5	<0.056	0.0040	<0.050	0.0154				b		
Arrowroot			Not available						0.301	0.495		
Coconut meat			Not available				0.190	2.04	<0.011	0.347	6.19	<0.086
Coconut milk			Not available				1.90	20.4	<0.11	3.47	61.9	<0.86
Coconut crabs	0.480		1.03	1.96	7.59	0.0035				b		
E. Island group ALVIN-KEITH												
Domestic meat				0.103	0.849					b		
Pandanus fruit			Not available				0.034	<0.016	0.236	2.14	0.0039	
Breadfruit			Not available				0.034	<0.016	0.236	2.14	0.0039	
Wild birds		56.6	0.214	0.012	0.085	0.0235				b		
Bird eggs			0.037	0.0036	0.129	0.00065				b		
Arrowroot			Not available						0.012	0.017		
Coconut meat	0.293	<0.229	<0.029	0.034	0.687	<0.0026				b		
Coconut milk	2.97	<2.29	<0.29	0.335	6.87	<0.026				b		
Coconut crabs	0.342		0.498	0.304	1.10	0.0027				b		

<sup>a</sup>Except for domestic meat all the concentrations reported in Table 193 are expressed in pCi/g dry weight. The concentration in domestic meat is expressed in pCi/g fresh weight.

<sup>b</sup>Jan. 1, 1974 data corrected for radioactive decay only to obtain Jan. 1, 1982 values.

foods available at the time of return were corrected for decay and listed under the first possible date of return, January 1, 1974. These concentrations are mostly derived from measurements on birds, bird eggs, and coconut crabs, and they do include the concentrations predicted for coconut and coconut milk from the southern islands (Group E, ALVIN-KEITH). Since swine and poultry can be expected to provide meat within a year or two after return, the concentrations of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  predicted in domestic meat are listed under the date of return. The predicted concentrations in pandanus fruit, breadfruit, arrowroot and, except for the southern islands, coconut and coconut milk were decay corrected and listed under January 1, 1982, or 8 yr after return. Eight years has been assumed as the period required for newly planted crops to mature and yield food. Except for coconut on the southern islands, edible plants will have to be reestablished, and hence their radionuclide concentrations are listed under the later date. Actually, 8 yr is rather short for all but tacca. The concentrations of the radionuclides other than  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  in pandanus fruit and breadfruit were set equal to the mean of the concentration in pandanus leaves (see Table 139). This procedure enabled us to estimate the maximum contribution of these radionuclides to the dose from terrestrial foods.

The integrated dose via ingestion of terrestrial foods was estimated following the procedure described in the chapter on dose estimates for the marine food chain. Equation (6), the expression for the integrated dose, can be written in the form

$$\text{Dose} = I_{\text{O}}^* \times D_{\text{T}}$$

where

$$I_{\text{O}}^* = \text{initial rate of ingestion of a radionuclide, pCi/day}$$

and

$$D_{\text{T}} = \text{the integrated dose from } t = 0 \text{ to } t = T \text{ (day) per unit rate of ingestion of activity rem/pCi/day.}$$

Dosages for each island group integrated over 5, 10, 30, and 70 yr were estimated using rates of ingestion computed from the concentrations of Table 193. It is of interest to consider the two basic diets shown in Table 139 in the chapter on dietary and living patterns, one the expected diet at the time of return, and the other the expected diet 10 yr after return. The 5- and 10-yr integral doses were calculated assuming the diet at the time of return. This diet contains only foods that are available on islands of the group at the time of return, i. e., domestic meat, birds, bird eggs, coconut crabs, and only in the case of the southern islands, coconut meat and coconut milk. The initial rates of ingestion of radionuclides for each island group assuming the diet at the time of return are listed in Table 194. These values were compounded according to the post-return diet described in Table 139 from the concentrations listed in the left side of Table 193 under the date of return, January 1, 1974. The 10-yr integral dose also includes a 2-yr contribution from the edible plants that become available for the first time 8 yr after return. The initial rates of ingestion of these foods were calculated according to the 10-yr post-return diet described in

Table 194. Rate of ingestion of radionuclides from terrestrial foods assuming diet at time of return (Jan. 1, 1974).

Food item	Ingestion rate, pCi/day					
	$^3\text{H}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$
<b>A. Island group ALICE-IRENE</b>						
Pork and chicken				185	3100	
Wild birds		984	6.21	1.21	<2.4	0.143
Bird eggs		69	<0.29	0.45	<0.24	0.0074
Total		1050	6.35	187	3100	0.150
<b>B. Island group BELLF</b>						
Pork and chicken				302	6960	
Total				302	6960	
<b>C. Island group JANET</b>						
Pork and chicken				108	2320	
Wild birds		1800	7.70	0.29	2.5	0.100
Bird eggs		171	<0.39	0.97	0.6	0.074
Total		1970	7.89	109	2320	0.174
<b>D. Island group KATE-WILMA, LEROY</b>						
Pork and chicken				47.4	858	
Wild birds		1800	7.70	0.29	2.50	0.100
Bird eggs		113	<0.28	0.02	<0.25	0.077
Coconut crabs	0.480		1.03	1.96	7.59	0.0035
Total	0.480	1900	8.87	49.7	868	0.180
<b>E. Island group ALVIN-KEITH</b>						
Pork and chicken				6.18	50.9	
Wild birds		1700	6.41	0.37	2.55	0.704
Bird eggs		131	<0.35	0.02	<0.35	0.003
Coconut	29.3	<23	<2.9	3.35	68.7	<0.259
Coconut milk	14.9	<11	<1.42	0.17	3.44	<0.129
Coconut crabs	2.91		4.23	2.58	9.31	0.023
Total	47.1	1850	13.7	12.7	135	0.99

Table 139 from the concentrations listed in the right side of Table 193. The basis of this procedure is described more fully below.

The 30- and 70-yr integral doses were calculated assuming the 10-yr post-return diet. In addition to the foods that are available at the time of return, the 10-yr post-return diet includes pandanus fruit, breadfruit, arrowroot, and for islands other than the southern islands, coconut meat and coconut milk. The initial rates of ingestion for each island group assuming the 10-yr post-return diet are listed in Table 195. These values were compounded according to the 10-yr post-return diet described in Table 139 and are presented in two parts. The rates of ingestion for the foods immediately available were calculated using the concentrations listed on the left side of Table 193, and are presented on the left side of Table 195 under January 1, 1974, the date of return. The rates of ingestion for the foods that are to become available 8 yr after return were calculated using the concentrations on the right side of Table 193. These rates of ingestion are presented on the right side of Table 195 under the 8-yr post-return date, January 1, 1982. In essence, the foods immediately available are assumed to contribute to the diet beginning January 1, 1974, and the edible plants that are yet to be established are assumed to contribute to the diet beginning January 1, 1982.

The values of the dose per unit rate of ingestion  $D_T$  that were used to calculate the 5-, 10-, 30-, and 70-yr doses are listed in Table 196. The doses from  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$ , which can be re-

garded as bone-seekers, were calculated to bone. The dosage from the other nuclides were calculated to the whole body. The dose per unit rate of ingestion  $D_T$  has been calculated assuming that the radionuclide is removed from food and the environment solely by radioactive decay. The origin of  $D_T$  is fully discussed in the chapter on dose estimates for the marine environment. Table 196 can be seen to include 2-, 22-, and 62-yr values of  $D_T$ . These values are used to estimate the 10-, 30-, and 70-yr dosages from ingestion of the foods that do not contribute to the diet until 8 yr after return.

#### Prediction of the Dosage from Terrestrial Foods by Island Group

Estimated Dosage Assuming Diet at Time of Return — Table 197 presents the 5- and 10-yr integral doses calculated assuming the diet at the time of return (see Table 139). These dosage estimates combine the rates of ingestion of Tables 194 and 195 and 2-, 5-, and 10-yr values of the dose per unit rate of ingestion listed in Table 196. The 5- and 10-yr dosages are useful for examining the situation for the first few years following return. The total whole-body dose has been computed as the sum of the whole-body dosages from the non-bone seekers. The total bone dose has been computed as the sum of the total whole-body dose and the bone doses from  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$ .

Terrestrial food from BELLE would contribute the greatest dosages, food from the southern islands ALVIN-KEITH would contribute the least. Strontium-90 accounts for more than 99.9% of the bone

Table 195. Rate of ingestion of radionuclides from terrestrial foods assuming 10-yr post-return diet.

Food item	Ingestion rate, pCi/day											
	January 1, 1974						January 1, 1982					
	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu
A. Island group ALICE-IRENE												
Domestic meat				308	5170							
Pandanus fruit									941	8840		
Breadfruit									807	7570		
Wild birds		197	1.24	0.242	<0.5	0.0286						
Bird eggs		34.5	<0.14	0.226	<0.1	0.0037						
Arrowroot									47	71		
Coconut meat							23.7	664	<16.3	135	2210	18.1
Coconut milk							35.6	<37	<8.5	20	331	<1.7
Total		231	1.31	308	5170	0.0323	59.3	683	12.4	1950	19000	19
B. Island group BELLE												
Domestic meat				504	11600							
Pandanus fruit								1.34	<1.46	1540	19800	<9.5
Breadfruit								1.15	<1.25	1320	17000	<8.1
Arrowroot									77	159		
Coconut meat									221	4960		
Coconut milk									33	743		
Total				504	11600		2.50	1.35	3180	42700		8.8
C. Island group JANET												
Domestic meat				180	3870							
Pandanus fruit								7.12	<1.25	550	6610	0.082
Breadfruit								6.10	<1.07	471	5560	0.071
Wild birds		360	1.54	0.058	0.50	0.020						
Bird eggs		85.5	<0.19	0.482	0.29	0.037						
Arrowroot									28	53		
Coconut meat									<1.85	79	1650	
Coconut milk							<2.54	<2.27	12	248		<1.31
Total		445	1.64	181	3870	0.057	14.5	3.22	1140	14100		0.81

Table 195 (continued).

Food item	Ingestion rate, pCi/day											
	January 1, 1974						January 1, 1982					
	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu
<b>D. Island group KATE-WILMA + LEROY</b>												
Domestic meat				79	1430							
Pandanus fruit							3.94	<13.8	241	2480		0.316
Breadfruit							3.38	<11.8	207	2120		0.271
Wild birds		360	1.54	0.058	0.50	0.020						
Bird eggs		56	<0.14	0.01	<0.12	0.039						
Arrowroot									12	20		
Coconut meat							19.0	204	<1.05	34.7	619	<8.64
Coconut milk							28.5	<6.44	<2.27	5.2	93	<0.38
Coconut crabs	0.480		1.03	1.96	7.59	0.003						
Total	0.480	416	2.59	81	1440	0.062	47.5	215	14.4	500	5330	5.0
<b>E. Island group ALVIN-KEITH</b>												
Domestic meat				10.3	84.9							
Pandanus fruit							1.33	<0.65	9.44	85.4		0.156
Breadfruit							1.14	<0.56	8.09	73.2		0.134
Wild birds		340	1.28	0.073	0.51	0.141						
Bird eggs		65	<0.17	0.009	<0.17	0.002						
Arrowroot			Not available							0.47	0.68	
Coconut meat	29.3	<23	<2.9	3.35	68.7	<0.259						
Coconut milk	44.6	<33	<4.2	0.50	10.3	<0.386						
Coconut crabs	2.91		4.23	2.58	9.3	0.023						
Total	76.8	433	9.17	16.8	174	0.488	2.48	0.60	18.0	159		0.290



Table 196. Integrated dose per unit rate of ingestion to whole body and bone.

Nuclide	Organ	$D_T$ , rem/pCi/day						
		Period of integration						
		2 yr	5 yr	10 yr	22 yr	30 yr	62 yr	70 yr
$^3\text{H}$	Whole body	4.51(-8) <sup>a</sup>	1.05(-7)	1.85(-7)	3.05(-7)	3.51(-7)	4.17(-7)	4.23(-7)
$^{55}\text{Fe}$	Whole body	7.50(-8)	2.35(-7)	3.73(-7)	4.29(-7)	4.32(-7)	4.32(-7)	4.32(-7)
$^{60}\text{Co}$	Whole body	1.27(-5)	2.96(-5)	4.65(-5)	6.09(-5)	6.33(-5)	6.46(-5)	6.46(-5)
$^{90}\text{Sr}$	Bone	2.87(-3)	1.08(-2)	2.39(-2)	4.99(-2)	6.33(-2)	9.70(-2)	1.02(-1)
$^{137}\text{Cs}$	Whole body	3.49(-5)	9.62(-5)	1.89(-4)	3.74(-4)	4.71(-4)	7.22(-4)	7.61(-4)
$^{239,240}\text{Pu}$	Bone	1.51(-6)	9.39(-6)	3.71(-5)	1.75(-4)	3.19(-4)	1.27(-3)	1.59(-3)

<sup>a</sup>The number within parentheses denotes the power of 10. Thus, 4.51(-8) is a contraction of  $4.51 \times 10^{-8}$  rem/pCi/day.

Table 197. Prediction of the dosage from ingestion of terrestrial foods assuming diet at the time of return.

Isotope	5-yr dose, rem		10-yr dose, rem	
	Whole body	Bone	Whole body	Bone
A. Island group ALICE-IRENE				
$^3\text{H}$			2.7(-6)	
$^{55}\text{Fe}$	2.5(-4) <sup>a</sup>		4.4(-4)	
$^{60}\text{Co}$	1.9(-4)		4.5(-4)	
$^{90}\text{Sr}$		2.02		10:1
$^{137}\text{Cs}$	0.298		1.25	
$^{239,240}\text{Pu}$		1.4(-6)		3.4(-5)
Subtotal	0.298	2.02	1.25	10.1
Total 5-yr whole-body dose		0.30 rem	Total 10-yr whole-body dose	1.25 rem
Total 5-yr bone dose		2.32 rem	Total 10-yr bone dose	11.3 rem
B. Island group BELLE				
$^{55}\text{Fe}$			1.9(-7)	
$^{60}\text{Co}$			1.7(-5)	
$^{90}\text{Sr}$		3.26		16.3
$^{137}\text{Cs}$	0.669		2.81	
$^{239,240}\text{Pu}$				1.3(-5)
Subtotal	0.67	3.26	2.81	16.3
Total 5-yr whole-body dose		0.67 rem	Total 10-yr whole-body dose	2.81 rem
Total 5-yr bone dose		3.93 rem	Total 10-yr bone dose	19.2 rem

Table 197 (Continued).

Isotope	5-yr dose, rem		10-yr dose, rem	
	Whole body	Bone	Whole body	Bone
C. Island group JANET				
<sup>55</sup> Fe	4.6(-4)		7.4(-4)	
<sup>60</sup> Co	2.3(-4)		4.1(-4)	
<sup>90</sup> Sr		1.18		5.88
<sup>137</sup> Cs	0.223		0.831	
<sup>239,240</sup> Pu		1.6(-6)		7.6(-6)
Subtotal	0.224	1.18	0.932	5.88
Total 5-yr whole-body dose	0.22 rem		Total 10-yr whole-body dose 0.93 rem	
Total 5-yr bone dose	1.40 rem		Total 10-yr bone dose 6.82 rem	
D. Island group KATE-WILMA + LEROY				
<sup>3</sup> H	5.0(-8)		2.2(-6)	
<sup>55</sup> Fe	4.5(-4)		7.3(-4)	
<sup>60</sup> Co	2.6(-4)		6.0(-4)	
<sup>90</sup> Sr		0.536		2.62
<sup>137</sup> Cs	0.0835		0.350	
<sup>239,240</sup> Pu		1.7(-6)		1.4(-5)
Subtotal	0.0842	0.536	0.351	2.62
Total 5-yr whole-body dose	0.084 rem		Total 10-yr whole-body dose 0.351 rem	
Total 5-yr bone dose	0.620 rem		Total 10-yr bone dose 2.97 rem	

Table 197 (Continued).

Isotope	5-yr dose, rem		10-yr dose, rem	
	Whole body	Bone	Whole body	Bone
E. Island group ALVIN-KEITH				
<sup>3</sup> H	4.9(-6)		8.7(-6)	
<sup>55</sup> Fe	4.4(-4)		6.9(-4)	
<sup>60</sup> Co	4.1(-4)		6.5(-4)	
<sup>90</sup> Sr		0.137		0.355
<sup>137</sup> Cs	0.0130		0.0311	
<sup>239,240</sup> Pu		9.3(-6)	0.0324	3.7(-5)
Subtotal	0.0138	0.137	0.0324	0.303
Total 5-yr whole-body dose	0.014 rem		Total 10-yr whole-body dose	0.032 rem
Total 5-yr bone dose	0.151 rem		Total 10-yr bone dose	0.387 rem

<sup>a</sup>The number within parentheses denotes the power of 10. Thus, 2.5(-4) is a contraction of  $2.5 \times 10^{-4}$ .

dose from the bone-seekers, and  $^{137}\text{Cs}$  accounts for greater than 95% of the total whole-body dose. Table 198 presents the relative contributions of the terrestrial foods to the integral 5- and 10-yr dosages from  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$ . Table 198 indicates that for island group ALVIN-KEITH, domestic meat would contribute about 50% of the 5-yr bone dose from  $^{90}\text{Sr}$ , and coconut and coconut crabs would together contribute about 45%. Edible plants are still absent in the remaining island groups at the time of return, and for these islands meat is estimated to contribute 95% or more of the 5-yr bone dose from  $^{90}\text{Sr}$ . It should be mentioned that meat has not been noted to be an effective agent for the transfer of  $^{90}\text{Sr}$  to man and that prediction of the  $^{90}\text{Sr}$  in meat from that in soil is associated with considerable uncertainty, particularly when the concentration in soil is low.

Assessment of the dosage from ingestion of domestic meat has been made considering only the transfer of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  via muscle. Although liver is consumed in the diet as well as muscle, it has not been considered in the predictive approach for meat. Exclusion of liver from consideration does not affect the  $^{90}\text{Sr}$  bone dose assessment. Although the  $^{90}\text{Sr}$  concentration is more frequently greater in rat liver than in rat muscle, the  $^{90}\text{Sr}$  concentrations in the two organs are statistically indistinguishable by the Wilcoxon matched-pairs signed-rank test<sup>11</sup>. As far as the bone dose from other nuclides is concerned,  $^{239,240}\text{Pu}$  would not be expected to contribute significantly to the bone dose. If the measured concentration of  $^{239,240}\text{Pu}$  in muscle or

liver of rat (see Tables 71 and 72 in the chapter on the terrestrial biota survey) whichever is greater, were used to represent the concentration in meat, the  $^{239,240}\text{Pu}$  in meat would increase the total bone dose by less than 0.1%.

Cesium-137 accounts for 95% or more of the 5-yr whole-body dosages (see Table 197). For the southern islands (ALVIN-KEITH) coconut would contribute about 50% of the total 5-yr whole-body dosage and meat about 40%. For the remaining island groups domestic meat would contribute over 95% of the 5-yr whole-body doses. Coconut crabs would contribute about 1% of the 5-yr whole-body dose for KATE-WILMA + LEROY and about 7% of the 5-yr whole-body dose for ALVIN-KEITH. Since the concentrations of  $^{137}\text{Cs}$  in muscle and liver can be expected to be similar, exclusion of liver from consideration as meat does not substantially influence the prediction of the whole-body dose from meat. The concentrations of  $^{137}\text{Cs}$  in rat muscle are significantly greater than those in rat liver ( $P = 0.02$  by the Wilcoxon matched-pairs signed-rank test), but the conversion factor relating the concentrations in the two tissues differs only slightly from unity (see Tables 71 and 72 in the chapter on the terrestrial biota survey). Both  $^{55}\text{Fe}$  and  $^{60}\text{Co}$  are more concentrated in liver than in muscle. If the measured concentrations of these nuclides in rat liver were used to represent the concentration in meat, the  $^{55}\text{Fe}$  and  $^{60}\text{Co}$  in meat would increase the total whole-body dose only by 0.1% or less.

Table 197 indicates that for the northern island groups, the 10-yr integral doses

Table 198. Relative contributions of terrestrial foods to the integral dose assuming diet at time of return.

Food item	Percentage of total 5-yr		Percentage of total 10-yr	
	<sup>90</sup> Sr dose to bone	<sup>137</sup> Cs dose whole body	<sup>90</sup> Sr dose to bone	<sup>137</sup> Cs dose whole body
A. Island group ALICE-IRENE				
Domestic meat	98.9	100	43.9	46.9
Pandanus fruit			26.8	24.7
Breadfruit			23.1	21.1
Wild birds	0.65	<0.08	0.29	0.04
Bird eggs	0.24	<0.008	0.11	0.004
Arrowroot			1.3	0.20
Coconut meat			3.9	6.2
Coconut milk			0.57	0.93
B. Island group BELLE				
Domestic meat	100	100	44.2	47.1
Pandanus fruit			27.0	24.6
Breadfruit			23.2	21.1
Arrowroot			1.4	0.20
Coconut meat			3.9	6.2
Coconut milk			0.58	0.92
C. Island group JANET				
Domestic meat	99.1	100	43.9	47.0
Pandanus fruit			26.9	24.8
Breadfruit			22.9	20.8
Wild birds	0.27	0.11	0.12	0.05
Bird eggs	0.89	0.03	0.39	0.01
Arrowroot			1.4	0.20
Coconut meat			3.9	6.2
Coconut milk			0.59	0.93
D. Island group KATE-WILMA + LEROY				
Domestic meat	95.4	98.8	43.1	46.3
Pandanus fruit			26.4	24.7
Breadfruit			22.7	21.1
Wild birds	0.58	0.29	0.26	0.14
Bird eggs	0.04	<0.03	0.02	0.01

Table 198 (continued)

Food item	Percentage of total 5-yr		Percentage of total 10-yr	
	<sup>90</sup> Sr dose to bone	<sup>137</sup> Cs dose whole body	<sup>90</sup> Sr dose to bone	<sup>137</sup> Cs dose whole body
D. Island group KATE-WILMA + LEROY (continued)				
Arrowroot			1.3	0.20
Coconut meat			3.8	6.2
Coconut milk			0.57	0.93
Coconut crabs	3.9	0.87	2.4	0.41
E. Island group ALVIN-KEITH				
Domestic meat	48.7	37.7	41.7	30.9
Pandanus fruit			7.6	9.6
Breadfruit			6.5	8.2
Wild birds	2.9	1.9	2.5	1.5
Bird eggs	0.2	<0.26	0.13	0.21
Arrowroot			0.38	0.08
Coconut meat	26.4	50.9	22.6	41.8
Coconut milk	1.4	2.5	1.1	2.1
Coconut crabs	20.3	6.9	17.4	5.6

exceed the 5-yr integral doses by greater than a factor of four. The increase is more than twice the increase in the period of integration. As Table 198 indicates, the pronounced increase in the dosages is primarily due to the 2-yr contribution from pandanus and breadfruit; coconut and arrowroot make smaller contributions to the 10-yr dose. As a consequence, pandanus and breadfruit collectively, and domestic meat each contribute 40-50% of the 10-yr bone dose from <sup>90</sup>Sr and 40-50% of the 10-yr whole-body dose from <sup>137</sup>Cs for the northern island groups. For the

southern islands ALVIN-KEITH, the 10-yr integral dosages are two to three times greater than the 5-yr integral dosages, and pandanus and breadfruit contribute about 15-20% of the 10-yr bone and whole-body dosages from <sup>90</sup>Sr and <sup>137</sup>Cs.

Estimated Dosage Assuming 10-yr Post-Return Diet — Table 199 presents the 30- and 70-yr integral doses calculated assuming the 10-yr post-return diet. These dosages relate primarily to the conditions that will prevail when normal living patterns have become established.

The estimates incorporate the rates of ingestion of Table 195 and the dose factors ( $D_T$ ) of Table 196. The 30- and 70-yr dose factors of Table 196 combine with the rates of ingestion on the left side of Table 195 to yield the estimated 30- and 70-yr doses for the foods available at the time of return. These estimates are listed on the left side of Table 199. The 22- and 62-yr dose factors of Table 196 combine with the rates of ingestion in the right side of Table 195 to yield the estimated 22- and 62-yr doses for the foods that are available beginning 8 yr after return. These estimates are listed on the right side of Table 199. The 22- and 30-yr doses are summed to give the total 30-yr dose, and the 62- and 70-yr doses are summed to give the total 70-yr dose. Total whole-body and total bone dosages are compounded in the same manner as for the 5- and 10-yr integral doses, and the total doses are listed at the bottom of the table.

As in the case of the 5- and 10-yr dosages, the greatest total 30- and 70-yr doses are associated with BELLE and the least with the island group ALVIN-KEITH. Also,  $^{137}\text{Cs}$  accounts for 99% or more of the total whole-body dose and  $^{90}\text{Sr}$  accounts for 99% or more of the total bone dose from bone-seeking nuclides. Table 200 presents the relative contributions of the terrestrial foods to the integral 30- and 70-yr dosages. Except for the southern islands, only a small fraction of the total bone and whole-body dosages is attributable to foods that are available at the time of return. A major fraction of the total dosages, up to 75%, is attributable to pandanus and breadfruit, which

would not begin to enter the diet until several years after return. For the southern islands ALVIN-KEITH, pandanus and breadfruit would contribute about 45% of the total bone dose from  $^{90}\text{Sr}$  and about 45% of the total whole-body dose from  $^{137}\text{Cs}$ .

#### Interpretation of the Dosage Estimates —

Table 201 is a summary which combines the dose predictions of Tables 197 and 199. It indicates that only the average dose rates for the southern island group (ALVIN-KEITH) are less than the 100 mrem/yr normal exposure due to internal and external irradiation from natural sources. From Table 200, it is clear that the dosages from foods obtained on the other island groups could be reduced substantially if the diet were restricted to food items available at the time of return.

Table 202 lists the contributions of each food to the predicted 30-yr dose (shown in Table 199). The table also shows the contributions and the reduced total dosages that could result if steps are taken to modify the diet. The following two examples have been considered: (1) Locally grown pandanus and breadfruit are replaced with pandanus and breadfruit grown on the southern islands, and (2) all foods derived from locally grown plants are replaced with their counterparts grown on the southern islands. Substantial reductions in the total whole-body and bone dosages would be experienced if pandanus and breadfruit are excluded from cultivation on the northern islands and are brought in from the southern islands. Further reductions are possible if the remaining edible plants are also excluded



Table 199. Prediction of the dosage from ingestion of terrestrial foods assuming 10-yr post-return diet.

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem		70-yr dose, rem		Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem		62-yr dose, rem	
		Whole body	Bone	Whole body	Bone		Whole body	Bone	Whole body	Bone
A. Island group										
ALICE-IRENE										
<sup>3</sup> H						59.3	1.8(-5)		2.5(-5)	
<sup>55</sup> Fe	231	1.0(-4) <sup>a</sup>		1.0(-4)		683	0.0003		0.0003	
<sup>60</sup> Co	1.31	8.3(-5)		8.5(-5)		12.4	0.0008		0.0008	
<sup>90</sup> Sr	308		19.5		31.5	1950		97.3		190
<sup>137</sup> Cs	5170	2.44		3.93		19,000	7.11		13.7	
<sup>239,240</sup> Pu	0.0323		1.0(-5)		5.1(-5)	19		0.003		0.024
Subtotal		2.44	19.5	3.93	31.5		7.11	97.3	13.7	190
Total 30-yr whole-body dose		9.55 rem				Total 70-yr whole-body dose		17.7 rem		
Total 30-yr bone dose		126 rem				Total 70-yr bone dose		239 rem		
B. Island group										
BELLE										
<sup>55</sup> Fe						2.50	1.1(-6)		1.1(-6)	
<sup>60</sup> Co						1.35	8.2(-5)		8.7(-5)	
<sup>90</sup> Sr	504		31.9		51.4	3180		159		309
<sup>137</sup> Cs	11,600	5.46		8.83		42,700	16.0		30.8	
<sup>239,240</sup> Pu						8.8		1.5(-3)		1.1(-2)
Subtotal		5.46	31.9	8.83	51.4		16.0	159	30.8	309
Total 30-yr whole-body dose		21.4 rem				Total 70-yr whole-body dose		39.6 rem		
Total 30-yr bone dose		212 rem				Total 70-yr bone dose		400 rem		

Table 199 (continued).

Isotope	Ingestion rate, pCi/day January 1, 1974	<u>30-yr dose, rem</u>		<u>70-yr dose, rem</u>		Ingestion rate, pCi/day January 1, 1984	<u>22-yr dose, rem</u>		<u>62-yr dose, rem</u>	
		Whole body	Bone	Whole body	Bone		Whole body	Bone	Whole body	Bone
C. Island group										
JANET										
<sup>55</sup> Fe	445	1.9(-4)		1.9(-4)		14.5	6.2(-6)		6.2(-6)	
<sup>60</sup> Co	1.64	1.0(-4)		1.1(-4)		3.22	2.0(-4)		2.1(-4)	
<sup>90</sup> Sr	181		11.4		18.4	1140		56.9		111
<sup>137</sup> Cs	3870	1.82		2.95		14,100	5.28		10.2	
<sup>239,240</sup> Pu	0.057		1.8(-5)		9.1(-5)	0.806		1.4(-4)		1.0(-3)
Subtotal		1.82	11.4	2.95	18.4		5.28	56.9	10.2	111
Total 30-yr whole-body dose		7.10 rem				Total 70-yr whole-body dose	13.1 rem			
Total 30-yr bone dose		75.4 rem				Total 70-yr bone dose	142 rem			
D. Island group										
KATE-WILMA + LEROY										
<sup>3</sup> H	0.480	2(-7)		2.0(-7)		47.5	1.5(-5)		2.0(-5)	
<sup>55</sup> Fe	416	1.8(-4)		1.8(-4)		215	9.2(-5)		9.3(-5)	
<sup>60</sup> Co	2.59	1.6(-4)		1.7(-4)		14.4	8.8(-4)		9.3(-4)	
<sup>90</sup> Sr	81.0		5.13		8.26	500		24.9		48.5
<sup>137</sup> Cs	1440	0.677		1.09		5330	1.99		3.85	
<sup>239,240</sup> Pu	0.062		2.0(-5)		9.8(-5)	4.96		8.7(-4)		6.3(-3)
Subtotal		0.677	5.13	1.09	8.26		1.99	24.9	3.85	48.5
Total 30-yr whole-body dose		2.67 rem				Total 70-yr whole-body dose	4.94 rem			
Total 30-yr bone dose		32.7 rem				Total 70-yr bone dose	61.7 rem			

Table 199 (continued).

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem		70-yr dose, rem		Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem		62-yr dose, rem	
		Whole body	Bone	Whole body	Bone		Whole body	Bone	Whole body	Bone
E. Island group										
ALVIN-KEITH										
<sup>3</sup> H	76.8	1.3(-5)		3.3(-5)						
<sup>55</sup> Fe	433	1.9(-4)		1.9(-4)		2.48	1.1(-6)		1.1(-6)	
<sup>60</sup> Co	9.17	5.8(-4)		5.9(-4)		0.60	3.7(-5)		3.9(-5)	
<sup>90</sup> Sr	16.8		1.07		1.72	18.0		0.898		1.75
<sup>137</sup> Cs	174	0.0819		0.132		159	0.0596		0.115	
<sup>239,240</sup> Pu	0.49		1.6(-4)		7.8(-4)	0.290		1.8(-4)		1.3(-3)
Subtotal		0.0826	1.07	0.133	1.72		0.0596	0.898	0.115	1.75
Total 30-yr whole-body dose		0.142 rem				Total 70-yr whole-body dose	0.248 rem			
Total 30-yr bone dose		2.11 rem				Total 70-yr bone dose	3.71 rem			

<sup>a</sup>The number within parentheses denotes the power of 10; thus, 1.0(-4) is a contraction of  $1.0 \times 10^{-4}$ .

Table 200. Relative contributions of terrestrial foods to the integral dose assuming 10-yr post-return diet.

Food item	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body		<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body	
	Commencement date 1/1/74	Commencement date 1/1/82	Commencement date 1/1/74	Commencement date 1/1/82	Commencement date 1/1/74	Commencement date 1/1/82	Commencement date 1/1/74	Commencement date 1/1/82
<b>A. Island group ALICE-IRENE</b>								
Domestic meat	16.7		25.5		14.2		22.3	
Pandanus fruit		40.2		34.7		41.4		36.2
Breadfruit		34.5		29.6		35.5		31.0
Wild birds	0.01		<0.002		0.01		<0.002	
Bird eggs	0.01		<0.0005		0.01		<0.004	
Arrowroot		2.0		0.28		2.1		0.29
Coconut meat		5.8		8.7		5.9		9.1
Coconut milk		<u>0.85</u>		<u>1.3</u>		<u>0.88</u>		<u>1.4</u>
Subtotal	17	83	26	74	14	86	22	78
<b>B. Island group BELLE</b>								
Domestic meat	16.7		25.4		14.3		22.3	
Pandanus fruit		40.2		34.5		41.5		36.1
Breadfruit		34.5		29.6		35.6		31.0
Arrowroot		2.0		0.27		2.1		0.29
Coconut meat		5.8		8.7		6.0		9.0
Coconut milk		<u>0.86</u>		<u>1.3</u>		<u>0.89</u>		<u>1.4</u>
Subtotal	17	83	25	75	14	86	22	78

Table 200 (continued).

Food item	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body		<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body	
	Commencement date 1/1/74	Commencement date 1/1/82	Commencement date 1/1/74	Commencement date 1/1/82	Commencement date 1/1/74	Commencement date 1/1/82	Commencement date 1/1/74	Commencement date 1/1/82
C. Island group JANET								
Domestic meat	16.7		25.7		14.2		22.6	
Pandanus fruit		39.6		34.8		41.2		36.6
Breadfruit		34.4		29.3		35.3		30.7
Wild birds	0.005		0.003		0.005		0.003	
Bird eggs	0.05		0.002		0.04		0.002	
Arrowroot		2.0		0.28		2.1		0.29
Coconut meat		5.8		8.7		5.9		9.1
Coconut milk		<u>0.88</u>		<u>1.3</u>		<u>0.90</u>		<u>1.4</u>
Subtotal	17	83	26	74	14	86	23	77
D. Island group KATE-WILMA + LEROY								
Domestic meat	16.6		25.2		14.2		22.0	
Pandanus fruit		39.8		34.8		41.2		36.2
Breadfruit		34.2		29.7		35.4		30.9
Wild birds	0.01		0.009		0.01		0.008	
Bird eggs	0.002		0.003		0.002		0.002	
Arrowroot		2.0		0.28		2.0		0.29
Coconut meat		5.7		8.7		5.9		9.0
Coconut milk		0.86		1.3		0.89		1.4
Coconut crabs	<u>0.41</u>		<u>0.13</u>		<u>0.35</u>		<u>0.12</u>	
Subtotal	17	83	25	75	15	85	22	78

Table 200 (continued).

Food item	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body		<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body	
	Commencement date		Commencement date		Commencement date		Commencement date	
	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82
E. Island group ALVIN-KEITH								
Domestic meat	33.3		28.3		30.3		26.2	
Pandanus fruit		24.1		22.5		26.5		25.0
Breadfruit		20.6		19.4		22.7		21.4
Wild birds	0.24		0.17		0.22		0.16	
Bird eggs	0.03		0.06		0.03		0.05	
Arrowroot		1.2		0.18		1.3		0.20
Coconut meat	10.8		22.9		9.9		21.2	
Coconut milk	1.6		3.4		1.5		3.2	
Coconut crabs	<u>8.3</u>		<u>3.1</u>		<u>7.6</u>		<u>2.9</u>	
Subtotal	54	46	58	42	50	50	54	46

Table 201. Summary of predicted integral dosages from ingestion of terrestrial foods.

Island group	Integral dose, rem							
	5 yr		10 yr		30 yr		70 yr	
	Whole body	Bone	Whole body	Bone	Whole body	Bone	Whole body	Bone
A. ALICE-IRENE	0.30	2.32	1.25	11.3	9.55	126	17.7	239
B. BELLE	0.67	3.93	2.81	19.2	21.4	212	39.6	400
C. JANET	0.22	1.40	0.93	6.82	7.10	75.4	13.1	142
D. KATE-WILMA + LEROY	0.084	0.62	0.35	2.97	2.67	32.7	4.94	61.7
E. ALVIN-KEITH	0.014	0.15	0.032	0.39	0.14	2.11	0.25	3.71

from cultivation in the north and have to originate in the south. If locally grown edible plants are excluded from the diet, but livestock is permitted to graze freely and provide meat, domestic meat becomes the most significant contributor to the whole-body and bone dosages. Thus further substantial reductions in the dosages for the northern islands would be possible if meat and poultry are also excluded from the diet. The implications of these predicted dosages to the projected living patterns are discussed in the summary section of this chapter.

#### Comparison with Other Locations

Table 203 presents data on  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  concentrations in soil and terrestrial foods from selected locations for which the levels generally can be attributed solely to world-wide fallout. The table provides a means for gaining perspective on the current levels of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  in Enewetak soils and foods, particularly on those from the southern islands.

As Table 203 suggests, the  $^{90}\text{Sr}$  concentrations in soil from the southern

islands of Enewetak are greater than those in soils from Midway, Livermore, and Argonne. The concentrations exceed those from Argonne, which better typifies the United States than Livermore, by about a factor of two. The concentrations of  $^{137}\text{Cs}$  in soils from the southern islands compare well with those from Ujilang and Livermore and are a factor of four lower than those from Brownsville, Nebraska. Thus the  $^{90}\text{Sr}$  in soils from the southern islands is enhanced over the levels that would be expected from world-wide fallout alone, and  $^{137}\text{Cs}$  at present levels in soil is indistinguishable from that attributable to world-wide fallout. The concentrations of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  in Bikini soils far exceed those in soils from the southern islands of Enewetak.

The predicted concentration of  $^{90}\text{Sr}$  in meat and poultry from the southern islands ALVIN-KEITH, is 0.10 pCi/g, a value comparable within a factor of two to the average concentration measured in coconut crabs, to the peak levels measured in meat and whole-grain products from New York, and to the peak levels measured

Table 202. Contributions of terrestrial foods to the predicted 30-yr integral dose.

Food item	Integral 30-yr dose, rem					
	Unmodified diet		Modified diet I <sup>a</sup>		Modified diet II <sup>b</sup>	
	Whole body	Bone	Whole body	Bone	Whole body	Bone
A. Island group ALICE-IRENE						
Domestic meat	2.4	21.9	2.4	21.9	2.4	21.9
Pandanus fruit	3.3	50.3	0.032	0.50	0.032	0.50
Breadfruit	2.8	43.1	0.027	0.43	0.027	0.43
Wild birds	<0.0002	0.015	<0.0002	0.015	<0.0002	0.015
Bird eggs	<0.00005	0.014	<0.00005	0.014	<0.00005	0.014
Arrowroot	0.027	2.4	0.027	2.4	0.0003	0.024
Coconut meat	0.83	7.5	0.83	7.5	0.032	0.24
Coconut milk	<u>0.12</u>	<u>1.1</u>	<u>0.12</u>	<u>1.1</u>	<u>0.005</u>	<u>0.037</u>
Total	9.5	126.	3.4	33.9	2.5	23.2
B. Island group BELLE						
Domestic meat	5.6	37.5	5.6	37.5	5.6	37.5
Pandanus fruit	7.4	84.2	0.032	0.50	0.032	0.50
Breadfruit	6.4	72.3	0.027	0.43	0.027	0.43
Arrowroot	0.060	3.9	0.060	3.9	0.0003	0.024
Coconut meat	1.9	12.9	1.9	12.9	0.032	0.24
Coconut milk	<u>0.28</u>	<u>2.0</u>	<u>0.28</u>	<u>2.0</u>	<u>0.005</u>	<u>0.037</u>
Total	21.4	212.	7.9	57.2	5.7	38.7
C. Island group JANET						
Domestic meat	1.8	13.2	1.8	13.2	1.8	13.2
Pandanus fruit	2.5	29.9	0.032	0.50	0.032	0.50
Breadfruit	2.1	25.6	0.027	0.43	0.027	0.43
Wild birds	0.0002	0.004	0.0002	0.004	0.0002	0.004
Bird eggs	0.0001	0.031	0.0001	0.031	0.0001	0.031
Arrowroot	0.020	1.4	0.020	1.4	0.0003	0.024
Coconut meat	0.62	4.5	0.62	4.5	0.032	0.24
Coconut milk	<u>0.093</u>	<u>0.69</u>	<u>0.093</u>	<u>0.69</u>	<u>0.005</u>	<u>0.037</u>
Total	7.1	75.4	2.6	20.8	1.9	14.8



Table 202 (continued)

Food item	Integral 30-yr dose, rem					
	Unmodified diet		Modified diet I <sup>a</sup>		Modified diet II <sup>b</sup>	
	Whole body	Bone	Whole body	Bone	Whole body	Bone
D. Island group KATE-WILMA + LEROY						
Domestic meat	0.67	5.7	0.67	5.7	0.67	5.7
Pandanus fruit	0.93	12.9	0.032	0.50	0.032	0.50
Breadfruit	0.79	11.1	0.027	0.43	0.027	0.43
Wild birds	0.0002	0.004	0.0002	0.004	0.0002	0.004
Bird eggs	<0.00006	0.0006	<0.00006	0.0006	<0.00006	0.0006
Arrowroot	0.0075	0.60	0.0075	0.60	0.0003	0.024
Coconut meat	0.23	1.9	0.23	1.9	0.032	0.24
Coconut milk	0.035	0.30	0.035	0.30	0.005	0.037
Coconut crabs	<u>0.0036</u>	<u>0.12</u>	<u>0.0036</u>	<u>0.12</u>	<u>0.0036</u>	<u>0.12</u>
Total	2.0	32.7	1.0	9.6	0.77	7.1
E. Island group ALVIN-KEITH						
Domestic meat	0.040	0.69	Same as unmodified diet		Same as unmodified diet	
Pandanus fruit	0.032	0.05				
Breadfruit	0.027	0.43				
Wild birds	0.0002	0.005				
Bird eggs	<0.00008	0.0001				
Arrowroot	0.0003	0.024				
Coconut meat	0.032	0.24				
Coconut milk	0.005	0.037				
Coconut crabs	<u>0.004</u>	<u>0.16</u>				
Total	0.14	2.1				

<sup>a</sup>In modified diet I, pandanus fruit and breadfruit are replaced with pandanus and breadfruit grown on the southern islands.

<sup>b</sup>In modified diet II, all edible plants, i. e., pandanus, breadfruit, tacca, and coconut are replaced with foods grown on the southern islands.

in caribou flesh from Alaska. The levels are comparable to the concentrations measured in birds from Bikini in 1967 and are well below the 19 pCi/g measured in coconut crab from Bikini.

The concentrations of <sup>90</sup>Sr in birds

from ALVIN-KEITH (and from the other islands of the Atoll) are lower by an order of magnitude or more, and the concentrations in bird eggs are lower still. The predicted concentration of <sup>137</sup>Cs in meat and poultry from ALVIN-KEITH is two to

Table 203. Comparison of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  concentrations in soils and terrestrial foods from Enewetak and other locations.

Soil sample	Location	Concentration, pCi/g dry soil		
		$^{90}\text{Sr}$	$^{137}\text{Cs}$	Reference
Soil				
Top 15 cm	Brownsville, Nebr., 1973		0.63(7) <sup>a</sup>	34
Top 15 cm	Argonne, Ill., 1973	0.28 <sup>b</sup>		18
Top 15 cm	Livermore, Calif., 1972	0.09(26) <sup>c,d</sup>	0.16 <sup>c,d</sup>	35
Top 15 cm	ALVIN-KEITH, Enewetak, 1972-1973	0.50	0.15	This study
Top 15 cm	Ujilang Is., Ujilang, 1972-1973		0.18(4)	This study
Top 15 cm	Midway Is., 1972-1973	0.11(8)		This study
Top 15 cm	Bikini Is., Bikini, 1969	12 <sup>f</sup>	40 <sup>b,e</sup>	7
Terrestrial foods sample	Location	Concentration, pCi/g fresh weight		
		$^{90}\text{Sr}$	$^{137}\text{Cs}$	Reference
Animal flesh				
Meat	Chicago, Ill., Nov. 1963		0.27	18
Meat	Chicago, Ill., 1972 (av)		0.017	18
Meat	New York, N. Y., May 1965	0.055 <sup>g</sup>		18
Meat	New York, N. Y., 1972(av)	0.0004 <sup>g</sup>		18
Caribou flesh	Alaska, May 1966	0.077	56	36
Meat and poultry	ALVIN-KEITH, 1974 (prediction)	0.10	0.85	This study
Coconut crab	Bikini, 1967	19	72	9
	ALVIN-KEITH, Enewetak, 1972-1973	0.10	0.38	This study
Poultry	Chicago, Ill., April 1964		0.12	18
Poultry	Chicago, Ill., 1972(av)		0.014	18
Poultry	New York, N. Y., 1972(av)	0.0005		18
Wild birds	Bikini, 1967	0.13	26	9
Wild birds	ALVIN-KEITH, Enewetak, 1972-1973	0.0036	0.026	This study
Eggs	Chicago, Ill., Jan. 1964		0.045	18
	Chicago, Ill., 1972(av)		0.005	18
	New York, N. Y., 1963(av)	0.011		18
Bird eggs	ALVIN-KEITH, Enewetak, 1972-1973	0.0009	0.032	This study

Table 203 (continued)

Terrestrial foods sample	Location	Concentration, pCi/g fresh weight		
		<sup>90</sup> Sr	<sup>137</sup> Cs	Reference
<b>Fruit</b>				
Fresh fruit	Chicago, Ill., Oct. 1962		0.11	18
	Chicago, Ill., 1972(av)		0.006	18
	Chicago, Ill., Jan. 1965	0.020		18
	New York, N. Y., 1968(av)	0.016		18
	New York, N. Y., 1972(av)	0.010		18
Pandanus	Bikini, 1967	19	52	9
Pandanus	Bikini Is., Bikini, 1969	28	130	7
	Enyu Is., Bikini, 1969		87	7
Pandanus	KEITH, Enewetak, 1972- 1973	2.6	0.17	This study
Pandanus	ALVIN-KEITH 1982 (prediction)	0.047	0.43	This study
Breadfruit	ALVIN-KEITH 1982 (prediction)	0.071	0.64	This study
Coconut meat	Bikini, 1967	0.19	110	9
	ALVIN-KEITH, 1972-1973	<0.034	0.65	This study
	ALVIN-KEITH, 1974 (prediction)	0.017	0.34	This study
	Bikini Is., Bikini, 1969	0.31	120	7
	Enyu Is., Bikini, 1969	0.08	21	7
Coconut milk	Bikini Is., Bikini, 1969		130	7
	Enyu Is., Bikini, 1969		23	7
	DAVID, 1972-1973	<0.024	1.2	This study
	ALVIN-KEITH 1974 (prediction)	0.017	0.34	This study
Arrowroot <sup>h</sup>	Bikini Is., Bikini, 1969	2.4	0.6	7
	Enyu Is., Bikini, 1969	0.4	0.7	7
	ALVIN-KEITH, 1982 (prediction)	0.012 <sup>i</sup>	0.018 <sup>i</sup>	This study
<b>Vegetables</b>				
Root vegetables	Chicago, Ill., July 1962		0.089	18
Root vegetables	Chicago, Ill., 1972(av)		0.004	18
Fresh vegetables	New York, N. Y., 1967(av)	0.024		18
	New York, N. Y., 1972(av)	0.014		18

Table 203 (continued)

Terrestrial foods sample	Location	Concentration, pCi/g fresh weight		
		<sup>90</sup> Sr	<sup>137</sup> Cs	Reference
Grains				
Whole-wheat bread	Chicago, Ill., April 1964		0.61	18
	Chicago, Ill., 1972(av)		0.028	18
Whole-grain products	New York, N. Y., Feb. 1964	0.10		18
	New York, N. Y., 1972(av)	0.011		18

<sup>a</sup>The number within parentheses is the number of samples.

<sup>b</sup>The cumulative deposit was assumed to be confined to the top 15 cm. Soil density was assumed to be 1.6 g/cm<sup>3</sup>.

<sup>c</sup>Estimated from concentrations in profiles extending to 25 cm.

<sup>d</sup>Median value.

<sup>e</sup>Estimated by the method of Beck, DeCampo, and Gogolak<sup>37</sup> from the mean exposure rate at proposed village area. The relaxation length in soil was assumed to be 2.5 cm and the entire exposure rate was attributed to <sup>137</sup>Cs<sup>7</sup>.

<sup>f</sup>The <sup>90</sup>Sr concentration was assumed to be 30% of the <sup>137</sup>Cs concentration<sup>7</sup>.

<sup>g</sup>Composite of meat, fish, poultry, shellfish, and eggs.

<sup>h</sup>Processed Marshallese style.

<sup>i</sup>Dry-wt concentration.

three times greater than the concentration measured in coconut crab and the maximum concentration reported for meat from Chicago. On the other hand, the predicted <sup>137</sup>Cs concentrations in domestic meat are 10 to 100 times lower than the concentrations reported in coconut crab and wild birds from Bikini and the maximum concentration in caribou flesh from Alaska. The predicted 0.85 pCi/g concentration of <sup>137</sup>Cs in meat and poultry is comparable to the 0.61 pCi/g measured in whole-wheat bread from Chicago, the maximum measured in the U. S. foods, except for caribou.

The predicted concentrations of <sup>90</sup>Sr and <sup>137</sup>Cs in edible plants from the southern islands are greater than the maximum measured in fruits and vegetables from

the United States. The predicted <sup>90</sup>Sr concentrations are less than the maximum measured in whole grain, and the predicted <sup>137</sup>Cs concentrations are less than or comparable to the maximum measured in whole-wheat bread. The <sup>90</sup>Sr and <sup>137</sup>Cs concentrations measured in pandanus from Bikini are 100 times greater than those predicted in pandanus from VAN-KEITH, and the <sup>137</sup>Cs concentrations measured in coconut from Bikini are 100 times greater than those measured or predicted in coconut from VAN-ALVIN. The concentration of <sup>90</sup>Sr in the pandanus fruit sample from KEITH is inexplicably high. Unfortunately, the aliquot of the pandanus leaves sample taken for <sup>90</sup>Sr analysis was lost during analysis.

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## Summary of Dose Assessment

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The anticipated population doses for six living patterns are determined as the sum of the contributions from four exposure pathways (inhalation, external gamma-rays, marine foods, and terrestrial foods).

Six living patterns were chosen in order to evaluate the range of predicted doses from plausible cases of island habitation. Of the six, two patterns of habitation are most probable (living patterns I and III), while one pattern was chosen to be representative of an upper-limit unmodified environment (living pattern IV). A diet based upon past native habits is included in the dose assessment via the food chains. If an imported diet is adopted by the returning population, the total doses listed in this report are significantly overestimated.

### Dose Assessment

The total 30-yr integral dose predicted for whole body and for bone for the six living patterns is listed in Table 204. This table includes the contributions from each pathway and, for the external dose assessment, is based upon the unmodified conditions for the village island. The largest contribution to the whole body and bone doses comes from the terrestrial food chain; the external dose pathway is the next highest contributor, while the marine food chain and inhalation pathway contribute the least.

The whole-body and bone doses range from 1.0 and 3.8 rem, respectively for

living pattern I (where the village is on Enewetak-Parry, and agriculture is conducted on southern islands), to 11 rem whole body and 80 rem bone for living pattern III (where the village and agriculture are on JANET), to 31 rem whole body and 220 rem bone for living pattern IV (where the village and agriculture are confined to BELLE). The latter living pattern is not one the people have used in the past nor that they have requested upon return; however, it represents a possible extreme exposure situation and is included for comparative purposes.

In general, living on JANET, visiting northern islands, and maintaining agriculture on northern islands (living patterns III, V, and VI) lead to significantly higher doses than if the village and agriculture are located on islands in the southern half of the Atoll (living pattern I). Doses for the same living patterns and conditions have also been calculated for 5, 10, and 70 yr and are shown in Table 205.

Table 206 shows the effect of plowing the village island and graveling the village area, i. e., the "modified" case. For example, for living pattern III where the village is on JANET, the 30 yr integrated external exposure is reduced from 4.0 to 1.7 rem. This comparison indicates that modifying the village island and village area by plowing and graveling does produce a significant reduction in the external exposure dose. The effect on the 5-, 10-, and 70-yr doses from modifying the village island is shown in Table 207.

The most significant contribution via the terrestrial food chain is the dose to



Table 204. The 30-yr integral dose for the six living patterns assuming unmodified conditions.

Living pattern	30-yr integral dose, rem									
	Unmodified conditions									
	Inhalation		External Bone, <sup>a</sup>		Terrestrial <sup>b</sup>		Marine <sup>b</sup>		Total	
	Bone	Lung	Liver	W. B.	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	7(-4)	9(-4)	4(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.029	0.036	0.016	1.6	2.7	33	0.053	0.84	4.4	35
III	0.10	0.13	0.056	4.0	7.1	75	0.053	0.84	11	80
IV	0.47	0.59	0.25	10	21	210	0.053	0.84	31	220
V	0.11	0.13	0.058	2.9	2.7	33	0.053	0.84	5.7	37
VI	0.090	0.11	0.049	4.4	9.6	130	0.053	0.84	14	135

Living pattern	Village island	Agriculture	Visitation
I	Enewetak-Parry	ALVIN-KEITH	Southern Is.
II	Enewetak-Parry	KATE-WILMA + LEROY	Northern Is.
III	JANET	JANET	Northern Is.
IV	BELLE	BELLE	Northern Is.
V	JANET	KATE-WILMA + LEROY	Northern Is.
VI	JANET	ALICE-IRENE	Northern Is.

<sup>a</sup>Taken from the chapter on external dose estimates, Table 22.

<sup>b</sup>Based upon diet 10 yr after return, as described in the dietary and living patterns chapter.

Table 205. The 5-, 10-, 30-, and 70-yr doses for the six living patterns assuming unmodified conditions.

Living pattern	Total integral dose, rem <sup>a</sup> Unmodified conditions							
	5 yr <sup>b</sup>		10 yr <sup>b</sup>		30 yr <sup>c</sup>		70 yr <sup>c</sup>	
	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	0.17	0.58	0.35	1.4	1.0	3.8	2.3	8.5
II	0.48	1.3	1.1	4.3	4.4	35	8.0	68
III	1.2	2.6	2.7	9.2	11	80	20	150
IV	3.4	6.9	7.6	25	31	220	56	420
V	0.81	1.6	1.7	4.9	5.7	37	10	71
VI	1.5	3.8	3.3	14	14	135	25	250

<sup>a</sup>Taken from discussion on external dose estimates, Table 22.

<sup>b</sup>Based upon diet at time of return described in the dietary and living patterns chapter.

<sup>c</sup>Based upon diet 10 yr after return described in the dietary and living patterns chapter.

bone resulting from <sup>90</sup>Sr uptake via pandanus fruit, breadfruit, and coconut. For living pattern III (Table 206) for example, the total bone dose is 75 rem, of which 80% is derived from the estimated intake of breadfruit, pandanus, and coconut. It is important to note, however, that the large contribution to the bone dose via these fruits only occurs when they are grown on northern islands. Pandanus, breadfruit, and coconut grown on the less contaminated southern islands lead to much lower dose commitments.

A comparison of the dose contribution via pandanus, breadfruit, and coconut from the northern and southern half of the Atoll is shown in Table 208; predicted doses via consumption of these food items are higher by a factor of 50 when they are grown in the northern half of the Atoll. Table 209 shows the 30-yr integral dose for the six living patterns for the modified condition and with pandanus,

breadfruit, and coconut grown on the southern islands; the effect of the combination of these preventive measures reduces the dose for living pattern III from 11 to 3.7 rem for the whole body and from 80 to 18 rem for bone (compare Tables 204 and 209). If all agriculture is confined to the southern islands then the whole-body dose is further reduced to 1.9 rem and the bone dose is 4.7 rem (see Table 210 and compare with Table 204).

A comparison of the 30-yr integral dose for living patterns I and III relative to the average United States external background dose over 30 yr is shown in Table 211. In living pattern I for whole-body exposure the integrated 30-yr dose from all pathways is less than that resulting from external U. S. background. The bone dose would be only slightly higher than U. S. background doses. For the modified case for living

Table 206. The 30-yr integral dose for the six living patterns assuming modified conditions.

Living pattern	30-yr integral dose, rem Modified conditions <sup>a</sup>										
	Inhalation			External		Terrestrial <sup>c</sup>		Marine <sup>c</sup>		Total	
	Bone	Lung	Liver	Bone, <sup>b</sup>	W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83		0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	6.6(-3)	1.1		2.7	33	0.053	0.84	3.9	35
III	0.045	0.056	0.024	1.7		7.1	75	0.053	0.84	8.9	78
IV	0.092	0.11	0.050	3.3		21	210	0.053	0.84	24	215
V	0.045	0.056	0.024	1.6		2.7	33	0.053	0.84	4.4	35
VI	0.058	0.072	0.031	3.1		9.6	130	0.053	0.84	13	135

<sup>a</sup>Modified by graveling the village area and by plowing the village island.

<sup>b</sup>Taken from chapter on external dose estimates, Table 22.

<sup>c</sup>Based upon diet 10 yr after return described in the dietary and living patterns chapter.

Table 207. The 5-, 10-, 30-, and 70-yr doses for the six living patterns assuming modified conditions.

Living pattern	Total integral dose, rem Modified conditions <sup>a</sup>							
	5 yr <sup>b</sup>		10 yr <sup>b</sup>		30 yr <sup>c</sup>		70 yr <sup>c</sup>	
	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	0.17	0.58	0.35	1.4	1.0	3.8	2.3	8.5
II	0.48	1.3	1.1	4.3	3.9	35	8.0	68
III	0.60	2.1	1.7	8.2	8.9	78	16	150
IV	1.5	5.0	4.3	22	24	215	46	410
V	0.46	1.3	1.0	4.3	4.4	35	8.0	68
VI	1.1	3.4	2.7	13	13	135	23	250

<sup>a</sup>Taken from discussion on external dose estimates, Table 22.

<sup>b</sup>Based upon diet at time of return described in the dietary and living patterns chapter.

<sup>c</sup>Based upon diet 10 yr after return described in the dietary and living patterns chapter.

Table 208. Bone dose from <sup>90</sup>Sr via pandanus, breadfruit, and coconut.

Location	30-yr integral dose, rem <sup>a</sup> Intake of pandanus, breadfruit, and coconut.
Southern islands	1.2
Northern islands <sup>b</sup>	63

<sup>a</sup>Based upon diet 10 yr after return discussed in dietary and living patterns chapter.

<sup>b</sup>Average of northern island groups I, II, and III.

pattern III, with agriculture conducted on northern islands, the 30-yr integrated dose from all pathways is higher than U. S. background by a factor of three for whole body and by nearly a factor of 26 for bone. However, if for living pattern III the modified case is considered and agriculture is confined to southern islands, then the whole body dose is 1.9 rem, less than U. S. background, and the bone dose is 4.7 rem, which is approximately 1.5 times the U. S. external background dose.

Of the three pathways contributing to whole body-exposure, the marine pathway contributes the least. Tables 204 and 206 indicate the relative importance. As was mentioned in the discussion of the marine pathway dose assessment, the fish from the island group ALICE through IRENE have a higher concentration of <sup>137</sup>Cs and <sup>60</sup>Co than fish from the rest of the Atoll, but the men would not fish exclusively off these islands. However, if such a practice were adopted, the whole-body dose via

Table 209. The 30-yr integral dose for the six living patterns assuming modified conditions and agriculture on the southern islands.

Living pattern	30-yr integral dose, rem									
	Modified conditions <sup>a</sup> and pandanus, breadfruit, coconut, and tacca grown on southern islands									
	Inhalation		External Bone, <sup>b</sup>		Terrestrial <sup>c</sup>		Marine <sup>c</sup>		Total	
	Bone	Lung	Liver	W. B.	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	0.0066	1.1	0.77	7.1	0.053	0.84	1.9	9.1
III	0.045	0.056	0.024	1.7	1.9	15	0.053	0.84	3.7	18
IV	0.092	0.11	0.050	3.3	5.7	39	0.053	0.84	9.1	43
V	0.045	0.056	0.024	1.6	0.77	7.1	0.053	0.84	2.4	9.6
VI	0.058	0.072	0.031	3.1	2.5	23	0.053	0.84	5.7	27

<sup>a</sup>Modified by graveling the village area and by plowing the village island.

<sup>b</sup>Taken from chapter on external dose estimates, Table 22.

<sup>c</sup>Based upon diet 10 yr after return described in dietary and living patterns chapter.

Table 210. The 30-yr integral dose for the six living patterns assuming modified conditions and agriculture on the southern islands.

Living pattern	30-yr integral dose, rem Modified conditions <sup>a</sup> and agriculture on southern islands									
	Inhalation		External Bone, <sup>b</sup>		Terrestrial <sup>c</sup>		Marine <sup>c</sup>		Total	
	Bone	Lung	Liver	W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	0.0066	1.1	0.14	2.1	0.053	0.84	1.3	4.1
III	0.045	0.056	0.024	1.7	0.14	2.1	0.053	0.84	1.9	4.7
IV	0.092	0.11	0.050	3.3	0.14	2.1	0.053	0.84	3.5	6.3
V	0.045	0.056	0.024	1.6	0.14	2.1	0.053	0.84	1.8	4.6
VI	0.058	0.072	0.031	3.1	0.14	2.1	0.053	0.84	3.3	6.1

<sup>a</sup>Modified by graveling the village area and by plowing the village island.

<sup>b</sup>Taken from chapter on external dose estimates, Table 22.

<sup>c</sup>Based upon diet 10 yr after return described in dietary and living patterns chapter.

Table 211. The 30-yr integral dose from all pathways compared to U. S. external background dose.

Location	30-yr integral dose, <sup>a</sup> rem			
	Unmodified case		Modified case	
	Whole body	Bone	Whole body	Bone
Enewetak Atoll Living pattern I	1.0	3.8	1.0	3.8
Enewetak Atoll Living pattern III	11	80	8.9	78
Enewetak Atoll Living pattern III, agriculture confined to southern islands	4.2	7.0	1.9	4.7
U. S. background only <sup>b</sup>	3.0	3.0	3.0	3.0

<sup>a</sup>Sum of all pathways for the Enewetak living patterns (i. e., external, inhalation, marine, and terrestrial).

<sup>b</sup>Based upon background of 100 mrem/yr at sea level.

the marine pathway would increase by nearly a factor of five, while the bone dose would increase by nearly a factor of two. This would still make the whole-body dose contributions via the marine pathway much less significant than the external and the terrestrial pathways.

The major concern via the inhalation pathway is the absorption of plutonium into the lung and subsequently into the liver and bone. The lung, bone, and liver doses for the six living patterns are listed in Table 204 for the unmodified case and in Table 206 for modified conditions. This pathway contributes the least of all pathways to the bone dose. For living pattern I and unmodified conditions, the 30-yr integral dose to the lung is less than 1 mrem. The lung, bone, and liver doses via the inhalation pathway increase if residence, agriculture, and visitation occur primarily on the northern islands. For living pattern III, for example, the lung, bone, and

liver, 30-yr integral doses are 0.13, 0.10, and 0.056 rem, respectively.

For the modified case, shown in Table 206, the northern islands still predominate over the southern islands as potential contributors via the inhalation pathway; however, for living pattern III the 30-yr doses are nearly an order of magnitude lower than in the unmodified case (lung = 0.056 rem, bone = 0.045 rem, and liver = 0.024 rem).

Plutonium isotopes, because of their long half-life, will still be present when the other major isotopes observed at the Atoll have decayed away. Therefore, Tables 212 and 213 are included to show the predicted doses from plutonium to the three major receptor organs (lung, liver and bone) via the three relevant exposure pathways. It is clear, accepting the assumptions made in assessing the pathways, that the potential dose from plutonium is low via all pathways.

## Discussion

It is appropriate to briefly examine the major components of most significance to the radiological dose assessment of the Atoll. They are:

- The significant radionuclides.
- The relative importance of each pathway.
- The ensemble of living patterns.
- Remedial action.

**Significant Radionuclides** — While there are a large number of radionuclides present in the Enewetak environment, four radionuclides ( $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and  $^{239}\text{Pu}$ ) contribute nearly all of the population dose. This is the result of the combination of long half-life, large inventory, and relative importance of the radionuclides in the four pathways.

$^{137}\text{Cs}$  and  $^{60}\text{Co}$  are the major contributions to the external gamma dose, but both also contribute to the total dose via the food chains. The 5-, 10-, 30- and 70-yr doses via all pathways are calculated assuming that disappearance of the nuclides from the Atoll environment is by radioactive decay only. The possibility of the rate of removal being more rapid due to other processes such as penetration of the soil surface with time and runoff into the lagoon and ocean is not accounted for in the dose codes. Thus, to the extent that such time-dependent processes are important in increasing the rate disappearance of radionuclides from the environment, the dose estimates are upper limits.

$^{90}\text{Sr}$  is of major importance in the food chains. In particular, it contributes the major portion of the bone dose via

the terrestrial and marine food chains and is the limiting isotope for the terrestrial food chain and the Atoll. Observations from both soil data and marine data collected during the survey indicate that  $^{90}\text{Sr}$  is turning over more slowly in the Atoll environment than is  $^{137}\text{Cs}$ .

Plutonium is present in substantial amounts in the northern part of the Atoll and in the lagoon. In the southern half of the Atoll the concentration levels are essentially that of world-wide background.  $^{239}\text{Pu}$  is the dominant nuclide, with  $^{238}\text{Pu}$  accounting for 10% of the total plutonium. The major pathway for plutonium is the inhalation pathway for living patterns involving northern islands, while for the southern islands plutonium contributes similarly through all pathways. Over 70 yr, however, the dose contribution from plutonium is very small relative to  $^{90}\text{Sr}$ ,  $^{60}\text{Co}$ , and  $^{137}\text{Cs}$ .

**Relative Importance of Pathways** — The relative ranking of the pathways in their contribution to the total dose for most living patterns is as follows:

- (1) Terrestrial food chain
- (2) External gamma
- (3) Marine food chain
- (4) Inhalation

The terrestrial food chain can potentially contribute far greater doses than the other three pathways.

**The Ensemble of Living Patterns** — Two living patterns (I and II) have been requested by the returning population. For living pattern I (village and agriculture on the southern islands) the 30-yr



Table 212. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table assumes modified conditions.

Plutonium 30-yr integral dose, rem Modified conditions												
Living pattern	Marine			Terrestrial <sup>a</sup>			Inhalation			Total		
	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung
I	0.018	0.047	-	5.0(-5)	1.8(-4)	-	3(-4)	2(-4)	4(-4)	0.018	0.047	4(-4)
II	0.018	0.047	-	1.5(-3)	5.0(-3)	-	0.012	0.0066	0.015	0.032	0.057	0.015
III	0.018	0.047	-	6.9(-3)	5.3(-3)	-	0.045	0.024	0.056	0.070	0.076	0.056
IV	0.018	0.047	-	3.0(-3)	0.010	-	0.092	0.050	0.11	0.11	0.11	0.11
V	0.018	0.047	-	5.0(-5)	1.8(-4)	-	0.045	0.024	0.056	0.063	0.071	0.056
VI	0.018	0.047	-	3.0(-3)	0.010	-	0.058	0.031	0.072	0.079	0.088	0.072

<sup>a</sup>Based upon diet 10 yr after return discussed in chapter on dietary and living patterns.

Table 213. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table assumes unmodified conditions on the village island.

Living pattern	Plutonium 30-yr integral dose, rem Unmodified conditions											
	Marine			Terrestrial <sup>a</sup>			Inhalation			Total		
	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung
I	0.018	0.047	-	5.0(-5)	1.8(-4)	-	7(-4)	4(-4)	9(-4)	0.018	0.048	9(-4)
II	0.018	0.047	-	1.5(-3)	5.0(-3)	-	0.029	0.016	0.036	0.049	0.068	0.036
III	0.018	0.047	-	6.9(-3)	5.3(-3)	-	0.10	0.056	0.13	0.12	0.11	0.13
IV	0.018	0.047	-	3.0(-3)	0.010	-	0.47	0.25	0.59	0.49	0.31	0.59
V	0.018	0.047	-	5.0(-5)	1.8(-4)	-	0.11	0.058	0.13	0.13	0.11	0.13
VI	0.018	0.047	-	3.0(-3)	0.010	-	0.090	0.049	0.11	0.11	0.11	0.11

<sup>a</sup>Based upon diet 10 yr after return discussed in chapter on dietary and living patterns.

integral whole-body and bone doses from all pathways are 1.0 and 3.8 rem respectively, comparable to average United States 30-yr integral external background doses for 3 rem. For living pattern III (village on Engebi and agriculture on northern islands) without any modification, the 30-yr integral whole-body dose is 11 rem and the bone dose 80 rem. Other living patterns involving northern islands and without modification have 30-yr, whole-body doses ranging from 4 to 30 rem and bone doses ranging from 35 to 220 rem.

### Remedial Action

Terrestrial Food Chain—The doses estimated for the various living patterns indicate that careful assessment and design of an agricultural plan must be an integral part of the program plan for returning people to the Atoll. For example, the southern half of the Atoll has sufficient land area to supply pandanus, breadfruit, and coconut for the entire returning population; therefore, even if people were to live on Engebi, the dose commitment could be greatly reduced by confining agriculture to the southern half of the Atoll. This one restriction, especially for pandanus, breadfruit, and coconut would be the single most effective preventive measure for reducing the dose commitment. The combination of modifying the village island and living area and, confining the agriculture to the southern islands, both relatively easy to implement, have a very large impact on reducing the dose (compare Tables 204 and 210).

There are, of course, other options for reducing the dose via the terrestrial pathway. One option would be to dig large area pits on all islands which would be filled with "clean" soil from another source; pandanus, breadfruit, coconut and other plants could then be grown and harvested from these "clean" soil areas throughout the Atoll. The subsequent reduction in dose would lead to doses from <sup>90</sup>Sr equivalent to or less than those predicted for the southern islands. Another option would include removing the surface layer of soil (0-20 cm) from the northern islands and replacing it with uncontaminated topsoil. This approach should also lead to doses equal to or less than those predicted for the southern islands. This form of remedial action would in the process reduce the dose via the inhalation pathway. This alternative, of course, requires the removal and disposition of an enormous amount of soil, and ocean dumping, which would provide the large reservoir needed and minimize the potential man-rem, would probably be the best and easiest method of disposal. This approach is certainly not one of the easier alternatives.

Efforts to maintain a high calcium diet could also be implemented to reduce the uptake of <sup>90</sup>Sr; however, remedial measures to reduce the uptake in the plants or food product would be more effective and desirable as the primary preventive measure.

Of course, the dose commitment would be largely eliminated if no pandanus, breadfruit, or coconut were planted on the Atoll for another 20 to 30 yr and if the diet were to consist of predominantly

imported food. As was discussed in the chapter on dietary and living patterns, imported foods are very likely to form a significant fraction of the diet (possibly 85% or more) and, if so, a plan to control the production of pandanus and breadfruit, or at least the location of production, could essentially reduce dose commitments to levels near U. S. external background.

External Dose — The integral 30 yr external dose is reduced between 30 and 70% for living patterns III, IV; V, and VI as a result of plowing the village island and graveling the village area where people will spend a majority of their time. These procedures are fairly straightforward, relatively easy to implement, and lead to the largest percentage reduction in external dose. An additional reduction in external dose of approximately 16% could be attained if all islands were plowed; however, implementing such a program in order to achieve the additional slight reduction is certainly another order-of-magnitude problem. In any case, any plan to plow all islands would have to receive careful scrutiny to determine the possible effects upon the island and Atoll ecology.

Marine Food Chain — The marine food chain would appear to require no remedial action (see marine food chain chapter ). The marine pathway contribution to the 30-yr integral dose for the modified case and for agriculture on southern islands (Table 210) is less than 4% for whole

unmodified conditions the percentage is far less than these. The concentration of radionuclides in fish muscle is higher in fish around the ALICE-to-IRENE complex, but even if the fishing were confined to these islands, a completely unrealistic fishing pattern, the resulting 30-yr, whole-body and bone doses would still be less significant than the other pathways and less than the 30 yr integral U. S. background dose.

Inhalation Pathway — The dose commitment via the inhalation pathway is due to the presence of plutonium throughout the soil in all of the northern islands. It is not generally localized sufficiently to consider "spot" cleanup. Anything short of removing the top layer of soil and replacing it with uncontaminated soil, or of simply covering existing soil with new soil, or of restricting living on northern islands will have little effect on the dose commitments via the inhalation pathway presented in this chapter. However, it should be noted that the plutonium concentrations on the southern islands are world-wide background levels, and the corresponding dose via the inhalation pathway is less than 1 mrem over 30 yr. This is the same level of exposure one would expect if new soil were brought in to the northern islands. The doses via inhalation on the northern islands is also insignificant relative to other pathways, where remedial action would be far more productive. (See Tables 204 and 206).

Summary of Remedial Action — In summary, the greatest reduction in dose commitment can be realized by developing a carefully designed agricultural plan and limiting the dose via the terrestrial food chains. The next most effective measure would be directed at the external dose commitment by plowing the village island and graveling the village area. Other remedial measures for reducing the dose commitment via the different pathways are possible but reduce the potential dose commitment by far lesser amounts.

YVONNE (Runit) — The island of YVONNE (Runit) is a unique situation among all of the Atoll islands. "Hot spots" of nearly pure plutonium exist throughout the northern part of the island; milligram-size plutonium particles are present and presumably inhalable micron-size particles are also present. The potential health hazard via the inhalation pathway due to the large plutonium inventory is sufficiently great to dictate two basic alternatives for remedial action for this island: (1) make the entire island an exclusion area — off limits to all people, or (2) conduct a cleanup campaign which will eliminate the "hot-spot" plutonium problem and remove whatever amount of soil is

necessary to reduce the soil plutonium concentration to a level comparable to the southern half of the island which has soil concentrations similar to other northern islands. If the latter action were taken, the island could be considered in the overall design for remedial action for the northern islands.

Dose Estimates for Other Assumed Living Patterns — The tables in each section of this chapter describing the dose via a specific pathway (i. e., external, terrestrial, and marine) are presented in a manner in which any combination of living pattern, time distribution, diet, and agricultural pattern can be assumed, and the corresponding dose predicted. We have chosen for dose assessment and presentation in this report the most likely living patterns (I, II, III, V), the most likely distribution of time, the most likely use of islands for agriculture, and the most likely fishing practices. We have also presented two living patterns which represent more extreme possibilities (living patterns IV and VI), although neither has been used in the past nor requested presently by the potential returning population. However, any other desired combination of living pattern and living habits could be assessed from data presented in the report.

## IV. Summary of Findings

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### INTRODUCTION

It has been the purpose of this survey to gain a sufficient understanding of the total radiological environment of Enewetak Atoll to permit judgments as to whether or not all or any part of the Atoll can safely be reinhabited and, if so, what preliminary steps toward cleanup should be taken and what post-rehabilitation constraints must be imposed.

Enewetak Atoll has an extremely broad range of radiological conditions in a small land mass. To gain an understanding of the details of this range of conditions, it has been necessary to obtain and analyze a very large number of samples from all components of the environment. To gain an equivalent understanding of the implications of this range of conditions for rehabilitation of the Enewetak people, it has been necessary to postulate population distributions, life styles, and dietary habits – an endeavor fraught with uncertainties under the best of circumstances, but particularly so for the current, rapidly changing Marshallese culture.

This section is a summary of the data obtained from the Survey, the postulates used, and the population dose assessments derived from data plus postulates. The reader is cautioned against expecting or using a "simple" description of the radiological condition of Enewetak Atoll, because no single value of any component of the radiological condition is applicable to the entire Atoll without being misleading.

### CURRENT RADIOLOGICAL CONDITION OF THE ATOLL

#### External Gamma Radiation Levels

Three independent techniques were used to measure external gamma radiation levels on the Atoll:

- LiF and CaF<sub>2</sub> thermoluminescent dosimeters (TLDs) were exposed for 3½ months on seven of the northern islands.
- A measurement using a Baird-Atomic survey instrument was made at each soil-sampling location on each island.
- An aerial survey with NaI detectors was conducted over the entire surface area of every island.

All three techniques yield results which agree to within about 10%. <sup>60</sup>Co and <sup>137</sup>Cs contribute most of the total external gamma radiation, with the remainder due to small amounts of other gamma emitters such as <sup>125</sup>Sb, <sup>155</sup>Eu, and <sup>241</sup>Am. The amount of <sup>60</sup>Co relative to <sup>137</sup>Cs varies throughout the Atoll, with a range of values from about 0.5 on JANET to greater than 14 on JAMES. Average values for each isotope on each island are given in Table 214. For reference, a map of the Atoll is shown in Fig. 146.

Southern islands (SAM to KEITH) are characterized by low and more or less uniformly distributed gamma-radiation levels over the area of each island. As exposure levels increase, exposure gradients become severe, with beaches

Table 214. Summary of average exposure rates for islands in Enewetak Atoll.

Island	Average exposure rate, $\mu\text{R/hr}$ at 1 m <sup>a</sup>			Range <sup>b</sup>
	<sup>137</sup> Cs	<sup>60</sup> Co	Total $\gamma$ (0-3 MeV)	
ALICE	42	36	81	4-170
BELLE	61	50	115	5-200
CLARA	20	19	42	5-100
DAISY	6.8	14.4	21.3	5-140
EDNA	2.8	2.4	6	5-8
IRENE	14	63	80	3-560
JANET	25	13	40	2-150
KATE	11	7	19	3-22
LUCY	6	7	14	1-20
PERCY	2	2	5	2-11
MARY	5.5	4	10	2-12
NANCY	6	5	12	1-50
OLIVE	6.5	4.5	11	1-15
PEARL	12	45	70	1-400
RUBY	2	12	14	1-42
SALLY	3.5	3	7	3-110
TILDA	4	2	6	2-11
URSULA	3	1.8	5	1-7
VERA	2.8	2	5	1-6
WILMA	1	1	2	1-3
YVONNE	5.6	22.4	33	1-750
SAM	<0.3 (0.20)	<0.6 (0.11)	10.9	0-1
TOM	<0.3 (0.18)	<0.6 (0.13)	<0.9	0-1
URIAH	<0.3 (0.06)	<0.6 (0.43)	<0.9	0-1
VAN	<0.3 (0.08)	<0.6 (0.25)	<0.9	0-1
ALVIN	N. D. (0.06)	<0.6 (0.25)	<0.9	0-1
BRUCE	0.4 (0.22)	0.8 (0.34)	1.2	0-1
CLYDE	<0.3 (0.04)	<0.6 (0.11)	<0.9	0-1
DAVID	N. D. (0.21)	N. D. (0.10)	<0.9	0-5
REX	<0.3 (0.28)	<0.6 (0.25)	<0.9	0-1
ELMER	N. D. (0.19)	N. D. (0.12)	<0.09	0-2
WALT	<0.3 (0.08)	<0.6 (0.10)	<0.9	0-1
FRED	N. D. (0.14)	N. D. (0.12)	<0.9	0-1
GLENN	0.4 (0.33)	<0.6 (0.20)	<0.9	0-1
HENRY	<0.3 (0.14)	<0.6 (0.20)	<0.9	0-1
IRWIN	<0.3 (0.08)	<0.6 (0.46)	<0.9	0-1
JAMES	<0.3 (0.05)	2.8	3.0	0-5
KEITH	<0.3 (0.15)	<0.6 (0.49)	<0.9	0-2
LEROY	2.8	4.8	7.6	3-8

<sup>a</sup>Average dose rates given are derived from aerial survey data. On islands where activity levels are at the lower limit of sensitivity of the aerial survey equipment, dose rates derived from the soil sample data are given in parentheses.

<sup>b</sup>As measured with the Baird-Atomic instrument.

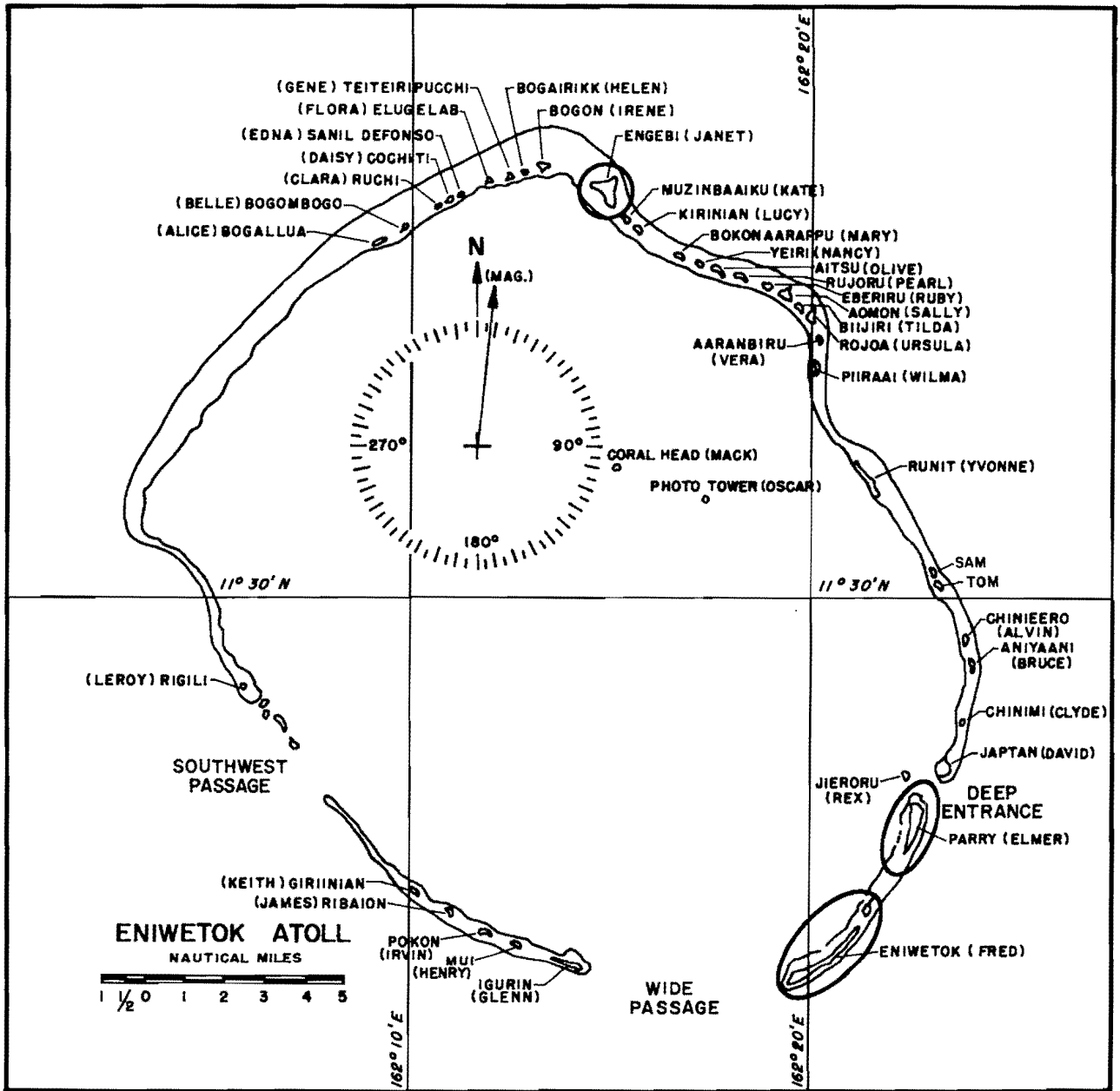


Fig. 146. Islands (those circled) requested as village locations by the Enewetak people.

generally at or very near expected background levels; the highest levels are found in heavy vegetation at island centers or near ground zero sites. "Average" values for islands with relatively high dose levels include a broad range of values for specific areas and should therefore be used with caution.

#### Radioactivity Levels in Enewetak Soil

Approximately 3000 samples of Enewetak soil were analyzed by germanium gamma-spectroscopic (GeLi) and wet-chemistry techniques to determine the distribution of radioactive species on islands in the Atoll. Samples were taken



on every island, but emphasis was given to – and proportionately larger numbers of samples taken on – those islands which were known to have been sites for nuclear testing activity or to have been subjected to large amounts of fallout from such activity.

Two types of soil samples were taken on each island: "surface" and "profile." At "surface" sampling locations, two samples were taken – one a 30-cm<sup>2</sup> × 15-cm-deep core, and the second a composite of two 30-cm<sup>2</sup> × 5-cm-deep cores. At "profile" sampling locations, 100-cm<sup>2</sup> samples were taken from the side wall of a trench dug for the purpose. Nominal depth increments for the profile samples were 0 to 2, 2 to 5, 5 to 10, 10 to 15, 15 to 25, and 25 to 35 cm, and at 10-cm increments to total depth. Total depth for profile samples varied from 35 to 185 cm, depending on the distribution expected from the testing history of the island being sampled.

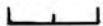
In general, the predominant species found in the soil samples are <sup>90</sup>Sr, <sup>137</sup>Cs, <sup>239</sup>Pu, and <sup>60</sup>Co. <sup>40</sup>K, <sup>55</sup>Fe, <sup>101</sup>Rh, <sup>102m</sup>Rh, <sup>125</sup>Sb, <sup>133</sup>Ba, <sup>134</sup>Cs, <sup>152</sup>Eu, <sup>154</sup>Eu, <sup>155</sup>Eu, <sup>207</sup>Bi, <sup>226</sup>Ra, <sup>235</sup>U, <sup>238</sup>Pu, and <sup>241</sup>Am are also present in some or all of the samples. As was the case for external gamma levels, small amounts of radioactive species on the southern islands (SAM to KEITH) are distributed more or less uniformly over the entire land area. On islands where larger amounts of activity are present, the highest levels of all species are found at the island centers or in proximity to ground-zero sites, usually related in a direct way to the vegetation density in the immediate area. As an example of the

kind of data obtained for each of the predominant isotopes on each of the islands, <sup>90</sup>Sr values for 0-15 cm core samples on JANET are plotted in Fig. 147.

Table 215 presents geometric mean values and ranges for the four predominant radionuclides on islands from ALICE through WILMA. On islands where there are significant differences in activity levels between densely and sparsely vegetated areas, data for both are given. Similar data for groups of southern islands are shown in Table 216.

"Profile" samples showed a wide range of activity distributions as a function of depth on different parts of the Atoll. Examples of the types found are given in Figs. 148-151. Although generalizations in this area are not very meaningful, Fig. 148 shows the profile distribution normally found on the southern islands. Here the activity levels are usually low through the full range of depths sampled. Some sampling locations show concentrations decreasing somewhat from the surface through the first 10 or 20 cm of soil. Figure 149 shows the type of distribution often found inland on islands subjected to fallout but not to construction or other ground-zero earthmoving activities – i. e., a rapid and fairly steady decrease of activity levels from the surface to total depth. Figure 150 shows the distribution found on beaches and exposed areas on these same islands – i. e., uniform or slowly decreasing activity levels from the surface to total depth. Figure 151 shows a distribution pattern found occasionally on islands which have been the sites for tests or have been subjected to construction and earthmoving activities (primarily IRENE, JANET, PEARL,

100 METERS



-630-

Fig. 147. The average  $^{90}\text{Sr}$  activities (pCi/gm) in soil samples collected to a depth of 15 cm.

Table 215. Enewetak soil data, "northern islands" (pCi/g in top 15 cm).

		<sup>90</sup> Sr		<sup>137</sup> Cs		<sup>239</sup> Pu		<sup>60</sup> Co	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
ALICE		80	14-430	36	5.6-141	12	3.9-68	5.9	1.4-33
BELLE	Dense	123	14-670	48	14-170	26	7.2-130	10	3.1-30
	Sparse	44	35-130	8.6	3.3-44	11	5.8-26	4.6	2.4-9.6
CLARA		65	13-310	26	5.6-110	22	3.5-88	6.4	0.91-20
DAISY	Dense	190	100-380	11	3.4-33	41	22-98	11	6.4-26
	Sparse	32	16-120	3.8	0.86-9.0	15	3.8-33	0.85	0.37-7.4
EDNA		46	30-220	4.2	2.7-6.4	18	13-24	0.43	0.33-0.63
IRENE		30	5.9-570	3.2	0.22-41	11	2.4-280	5.4	0.12-520
JANET		44	1.6-630	16	0.57-180	8.5	0.08-170	1.9	0.02-33
KATE	Dense	67	37-200	24	18-37	17	8.6-50	2.7	1.6-5.8
	Sparse	11	1.6-49	4.8	1.8-16	2.3	0.17-14	0.46	0.03-3.5
LUCY		32	10-83	11	2.2-25	7.7	2.4-22	1.5	0.26-3.8
MARY		29	11-140	9.9	5.6-26	8.0	2.0-35	1.5	0.74-4.8
NANCY		36	16-110	12	6.0-28	9.1	2.3-28	1.6	0.56-5.3
PERCY		13	3.6-73	0.94	0.12-17	3.5	1.5-23	0.47	0.08-2.9
OLIVE	Dense	22	4.6-70	8.5	3.5-28	7.7	2.2-30	1.5	0.65-4.1
	Sparse	4.5	2.0-11	0.16	0.07-11	2.8	1.9-4.1	0.11	0.05-0.31
PEARL	Hot spot	62	35-140	19	7.4-55	51	15-530	12	3.6-70
	Remainder	17	3.2-61	7.6	1.2-34	11	0.85-100	4.1	0.49-49
RUBY		12	7.1-63	1.4	0.71-7.2	7.3	3.0-24	0.93	0.29-16
SALLY		8.4	0.87-140	3.0	0.03-30	4.3	0.21-130	0.54	0.05-69
TILDA	Dense	27	17-54	8.4	3.5-20	7.6	1.4-17	1.2	0.61-1.9
	Sparse	8.7	2.2-47	1.0	0.04-5.3	2.5	1.1-34	0.37	0.21-1.7
URSULA		6.8	2.0-19	1.7	0.13-7.8	1.3	0.26-7.3	0.31	0.05-1.7
VERA		6.3	1.1-68	2.0	0.03-12	2.5	0.60-25	0.30	0.02-2.2
WILMA		3.3	0.26-13	1.3	0.31-7.2	1.1	0.1-5.3	0.12	0.01-0.7
Southern YVONNE		1.7	0.09-20	0.40	0.02-3.6	3.2	0.02-50	0.64	0.01-20
Northern Beaches		6.4	1.2-30	0.30	0.03-9.0	2.7	0.34-18	0.13	0.03-1.6

YVONNE - Because of the complex distribution of activities on Northern YVONNE no single mean value for an isotope can be used for the island as a whole without being misleading. Readers should consult the YVONNE discussion in this section and the detailed data in Appendix II for information pertinent to their interests.

SALLY, and YVONNE). In these locations, activity levels below ground level are significantly higher than at the surface. Because of the observed variety of profile distributions, no "average vertical distri-

bution" can be formulated which is applicable to the Atoll as a whole.

The land area which has the most severely nonuniform distribution of radioactive species on the Atoll is that

Table 216. Enewetak soil data, southern islands (pCi/g in top 15 cm).

	<sup>90</sup> Sr		<sup>137</sup> Cs		<sup>239</sup> Pu		<sup>60</sup> Co	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Group A (DAVID, ELMER, FRED)	0.41	0.02-4.8	0.21	0.01-2.1	0.04	0.004-0.31	0.03	0.01-0.15
Group B (All others except LEROY) <sup>a</sup>	0.52	0.03-3.9	0.14	0.004-1.8	0.07	0.004-1.1	0.06	0.007-63
Group C (LEROY)	11	1.6-34	3.2	0.5-10	0.63	0.02-2.0	0.58	0.04-5.0

<sup>a</sup>SAM, TOM, URIAH, VAN, ALVIN, BRUCE, CLYDE, REX, WALT, GLENN, HENRY, IRWIN, JAMES and KEITH.

part of YVONNE which lies north of the tower (Sta. 1310). This area includes the highest external gamma levels found on the Atoll, with levels of 500-750  $\mu$ R/hr found over a five-acre site just south of the CACTUS crater. In addition, pieces of plutonium metal weighing as much as several milligrams are randomly scattered on or near the ground surface over most of the area from CACTUS crater to a line drawn across the island, about 60 m north of the tower. Construction and earthmoving activities during the testing period, for which we have no reliable record, served to redistribute the radioactivity in such a way that it is essentially impossible to get an accurate, detailed, three-dimensional survey of radioactive species present in this area now. Four hundred meters north of the tower, for about 100 m along the ocean-side embankment, for example, there is a visible layer of dark soil roughly 20 cm thick, 10 to 20 cm below the surface, which contains high concentrations of plutonium (3200 pCi/g in one sample).

In an effort to obtain a reasonable estimate of the three-dimensional distribution of radioactive material in this area, 45 profile locations (shown in Fig. 152) were sampled to 150-cm depths. Plutonium data for the profiles along the center of the island, and across the island at the position of the plutonium-bearing layer, are shown in Figs. 153-156. Data from all of the profile samples lead to the following observations:

- There were no large plutonium particles analyzed in any of these samples since the maximum specific activity found was ~800 pCi/g.
- Except for the area in the general vicinity of the exposed plutonium layer, there were few profile sampling locations where plutonium concentrations exceeded 100 pCi/g at any depth. Of the four that did, two had the high concentration in the top 10 cm of soil. Profile sampling locations where plutonium concentrations greater than 100

pCi/g were found at any depth are enclosed in cross-hatched areas in Fig. 152.

Thus it seems likely that soil bearing high concentrations of plutonium – as opposed to pieces of plutonium – is largely limited to a band roughly 350 m wide across the island, centered on the visible plutonium soil layer. Within this band, plutonium concentrations are greatest on the ocean side, less on the lagoon side, and least in the island center – a finding consistent with historical data which indicate that debris was bulldozed away from the shot point toward both shorelines after the event which produced these plutonium particles.

Except for this band across the island, there is no evidence which indicates that plutonium particles on or near the ground surface in the larger area shown in Fig. 152 are also found at any significant depth below the surface. Because of the discrete nature and random distribution of these particles, of course, the only way that their distribution could be further established would be by analysis of very large volumes of soil.

#### Radioactivity Levels in Enewetak Lagoon

Approximately 858 samples taken from the Enewetak lagoon environment were analyzed by germanium gamma-spectroscopic (GeLi) and wet-chemistry techniques to determine the distribution of radioactive species in the lagoon, including 345 sediment and bottom cores, 82 seawater and seawater filters, 21 algae, plankton, or coral, and 410 fish samples. Figure 157 shows the major sampling locations for this marine program.

Analysis of the sediment and core samples indicates the presence of  $^{40}\text{K}$ ,  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ ,  $^{101}\text{Rh}$ ,  $^{102\text{m}}\text{Rh}$ ,  $^{106}\text{Ru}$ ,  $^{127}\text{Sb}$ ,  $^{137}\text{Cs}$ ,  $^{152}\text{Eu}$ ,  $^{154}\text{Eu}$ ,  $^{155}\text{Eu}$ ,  $^{207}\text{Bi}$ ,  $^{235}\text{U}$ ,  $^{238}\text{Pu}$ ,  $^{239,240}\text{Pu}$ , and  $^{241}\text{Am}$  in some, but not necessarily all of the samples. Each nuclide is non-uniformly distributed over the lagoon floor, with the highest levels generally found in the northwest part of the lagoon, 2-3 km southeast of the islands ALICE through IRENE; the next highest levels are found in the area southwest of YVONNE; and the lowest levels are found south of a line extending across the lagoon from the Southwest Passage to TOM. Figure 158, for example, shows the distribution pattern for  $^{90}\text{Sr}$ . Similar figures have been prepared for each of the predominant species found.

Many of the radionuclides found in the marine sediment and core samples were not detected in the water samples, including  $^{102\text{m}}\text{Rh}$ ,  $^{106}\text{Ru}$ ,  $^{125}\text{Sb}$ ,  $^{152}\text{Eu}$ , and  $^{235}\text{U}$ . In only 15 samples from the northern part of the lagoon were  $^{60}\text{Co}$ ,  $^{155}\text{Eu}$ ,  $^{207}\text{Bi}$ , and  $^{241}\text{Am}$  detected.  $^{137}\text{Cs}$  and  $^{239,240}\text{Pu}$  were positively identified in all samples. Table 217 gives the mean surface water concentration of  $^{137}\text{Cs}$  and  $^{239,240}\text{Pu}$  in the four quadrants of the lagoon, in the ocean close to the east side of the lagoon, and for several areas in other parts of the world for comparative purposes.

In the plankton samples, the most abundant isotopes observed were  $^{90}\text{Sr}$  (av 0.86 pCi/g, wet wt) and  $^{207}\text{Bi}$  (0.83 pCi/g), followed in decreasing order of abundance by  $^{60}\text{Co}$  (0.68 pCi/g),  $^{239,240}\text{Pu}$  (0.39 pCi/g),  $^{155}\text{Eu}$  (0.24 pCi/g),  $^{241}\text{Am}$  (0.23 pCi/g), and  $^{137}\text{Cs}$



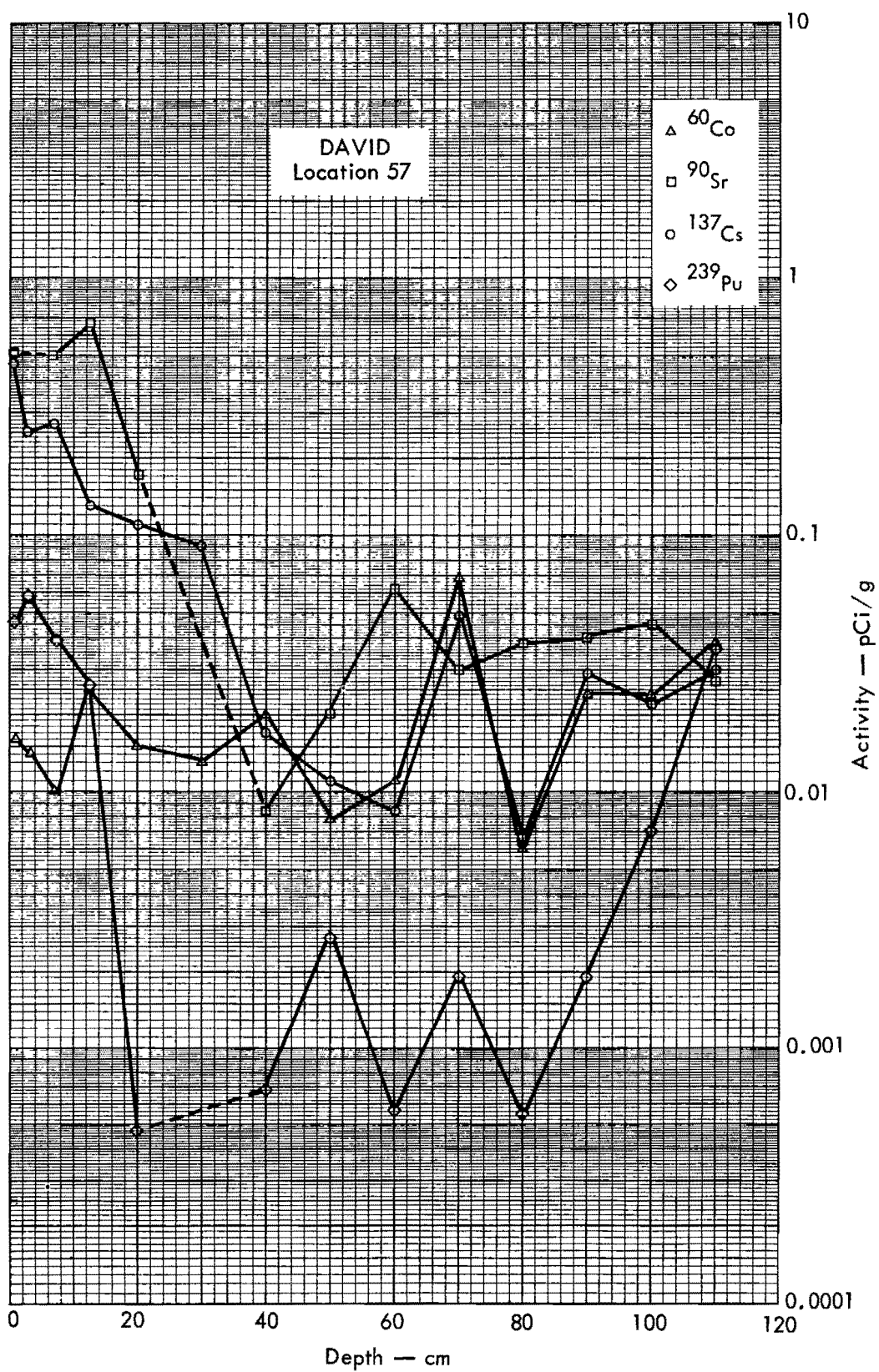


Fig. 148. Activities of selected radionuclides as a function of soil depth.





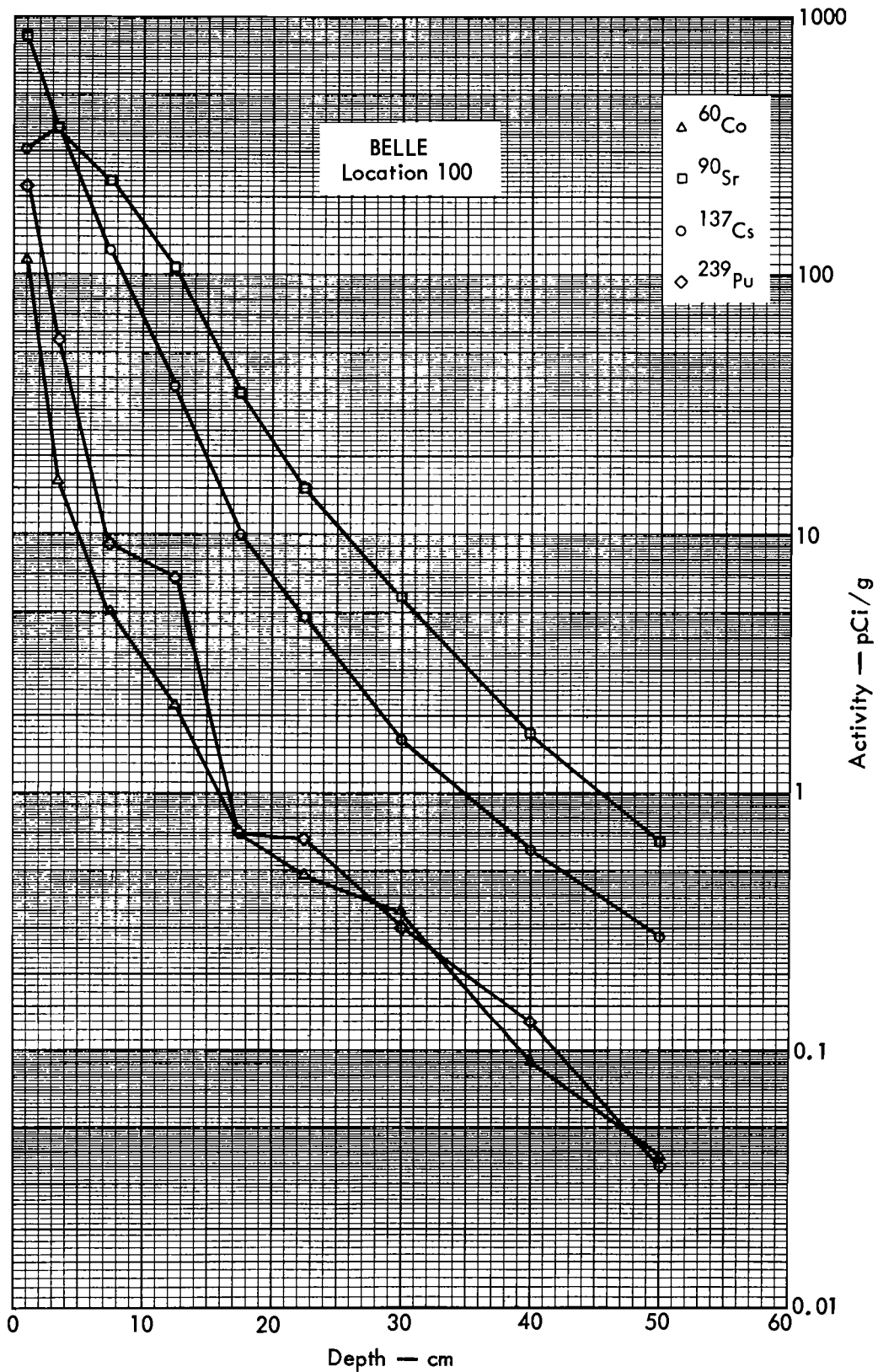


Fig. 149. Activities of selected radionuclides as a function of soil depth.



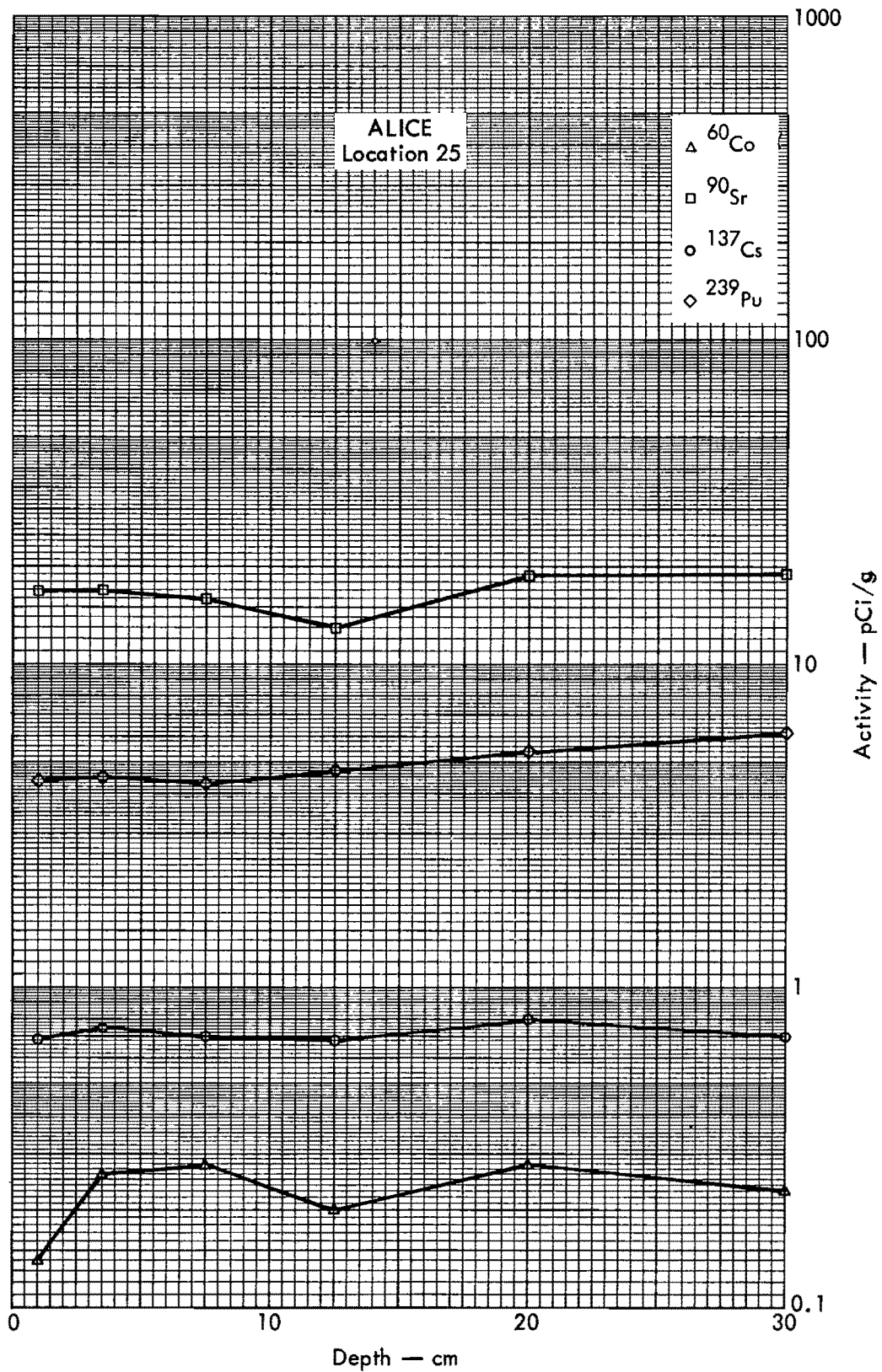


Fig. 150. Activities of selected radionuclides as a function of soil depth.



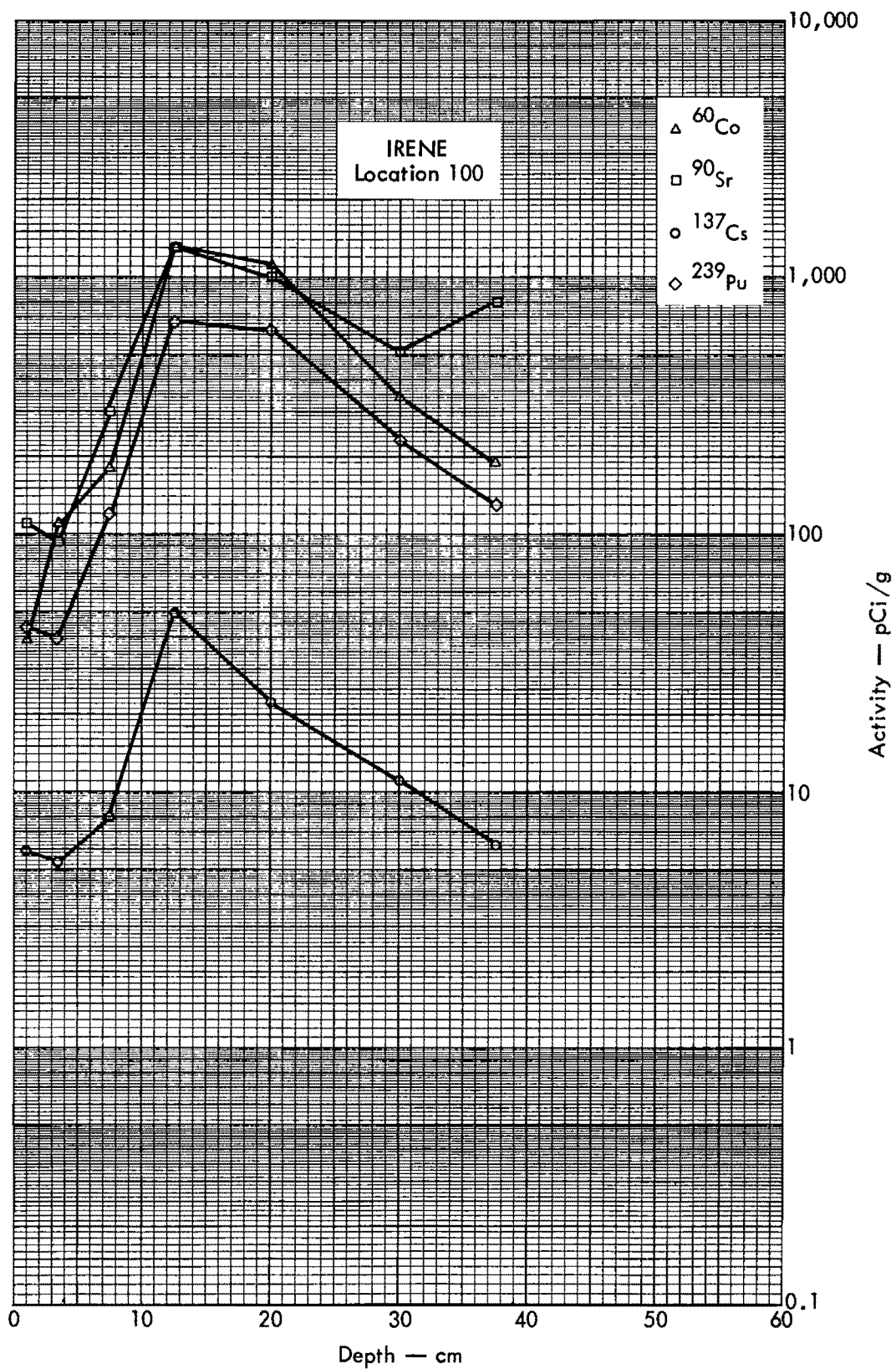


Fig. 151. Activities of selected radionuclides as a function of soil depth.





Fig. 152. Soil-profile locations which were sampled to 150-cm depths, YVONNE.

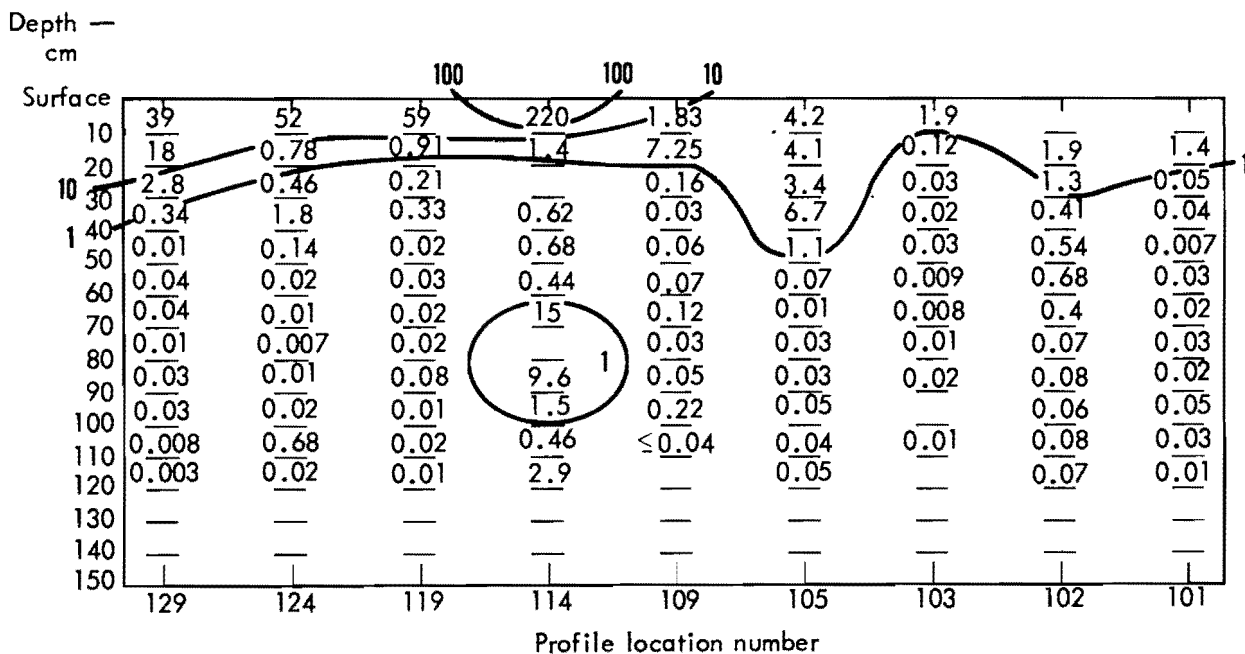


Fig. 153. Plutonium profile data, Locations 101-103, 105, 109, 114, 119, 124, and 129, YVONNE.

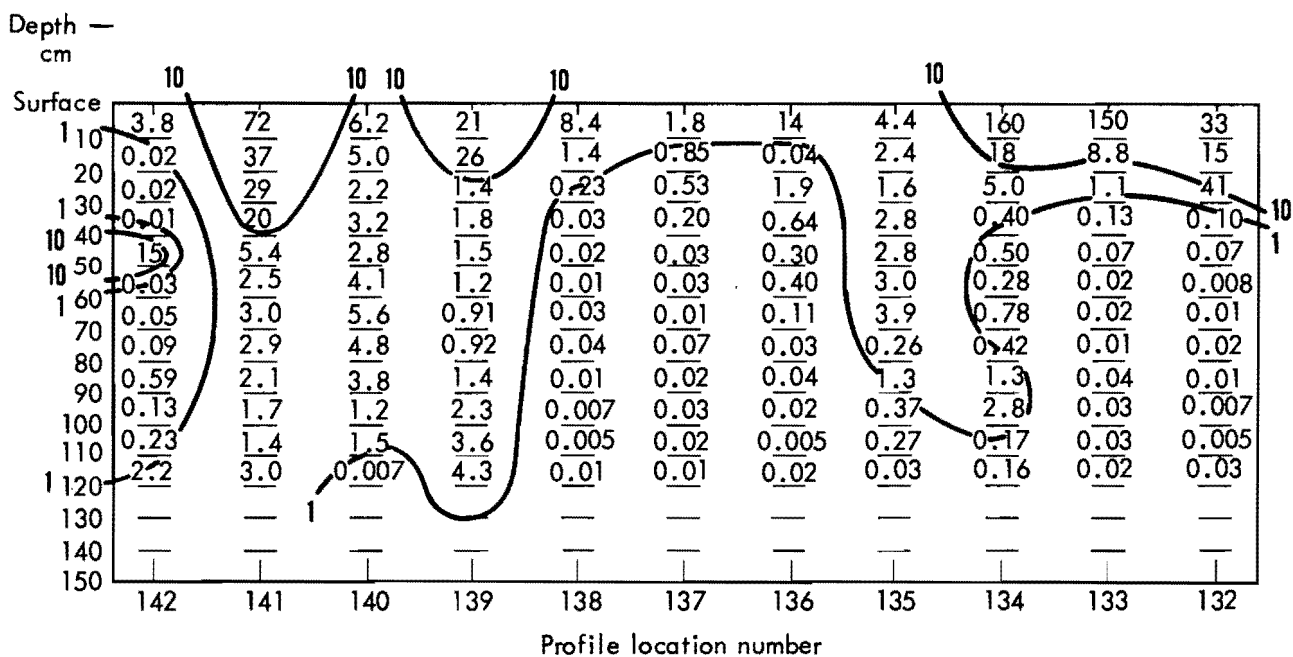


Fig. 154. Plutonium profile data, Locations 132-142, YVONNE.

(0.07 pCi/g). Comparison of these data with similar data obtained in 1964 indicates that, in addition to physical decay,  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  are being lost from the

lagoon with mean residence half-times of 3.3 and 4.1 yr, respectively, while  $^{207}\text{Bi}$  appears to be decreasing at approximately its radioactive decay rate.  $^{90}\text{Sr}$ ,



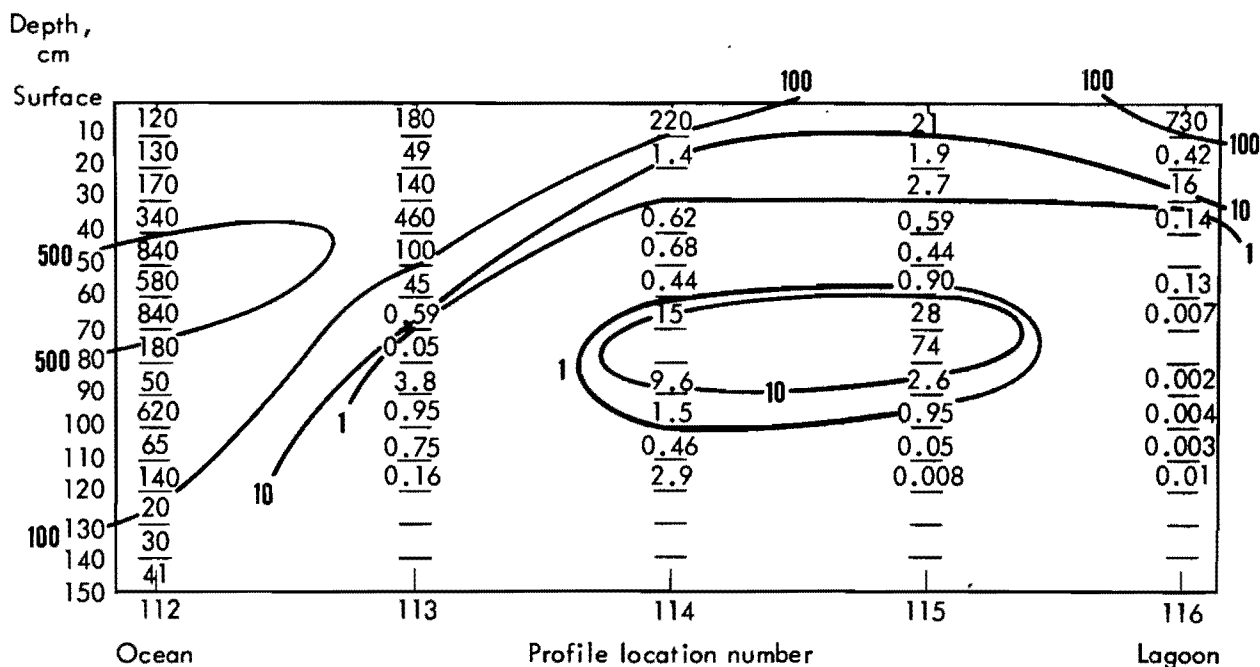


Fig. 155. Plutonium profile data, Locations 112-116, YVONNE.

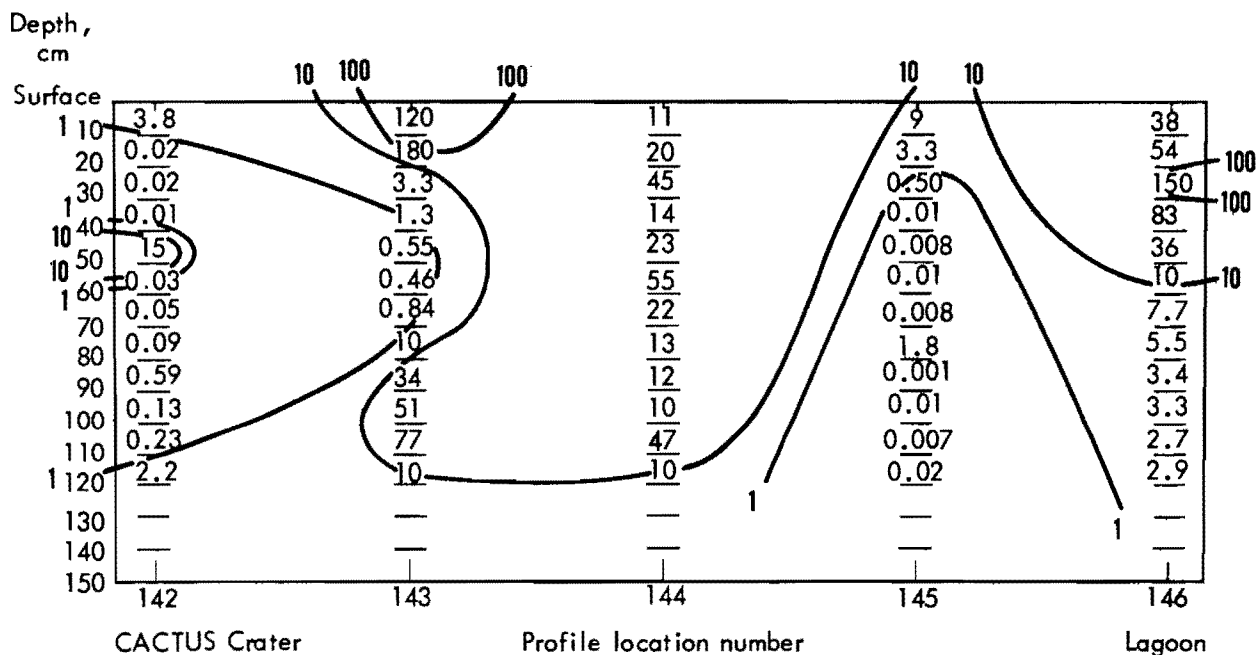


Fig. 156. Plutonium profile data, Locations 142-146, YVONNE.

$^{239,240}\text{Pu}$ ,  $^{155}\text{Eu}$ , and  $^{241}\text{Am}$  were not reported in 1964.

Of the more than 700 species of fish at Enewetak Atoll, the species selected for

this survey were chosen for one or more of the following reasons: (1) They are commonly eaten by the Marshallese; (2) they are relatively abundant at most of the

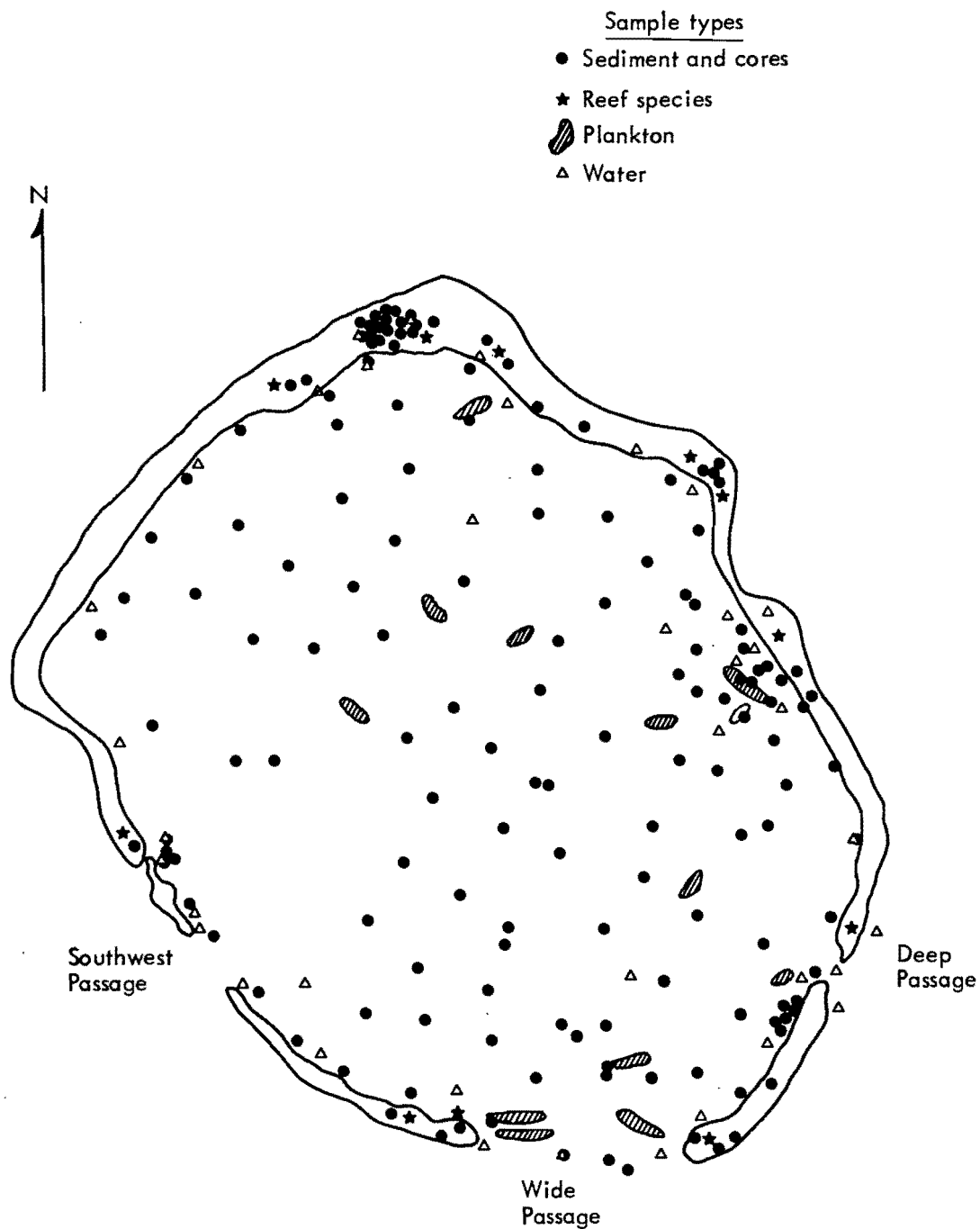


Fig. 157. Enewetak marine program sampling locations.

collection sites; (3) they are representative of a feeding habit; or (4) there is previous relevant radiometric information about the species. The species of reef fishes selected as being representative of feeding habits include the mullet (a plankton and

detritus feeder), convict surgeon (a grazing herbivore), goatfish (a bottom-feeding carnivore), and parrotfish (a coral eater). The tunas, jacks, and dolphins – pelagic fish – and the snappers and groupers – benthic fish – which were also

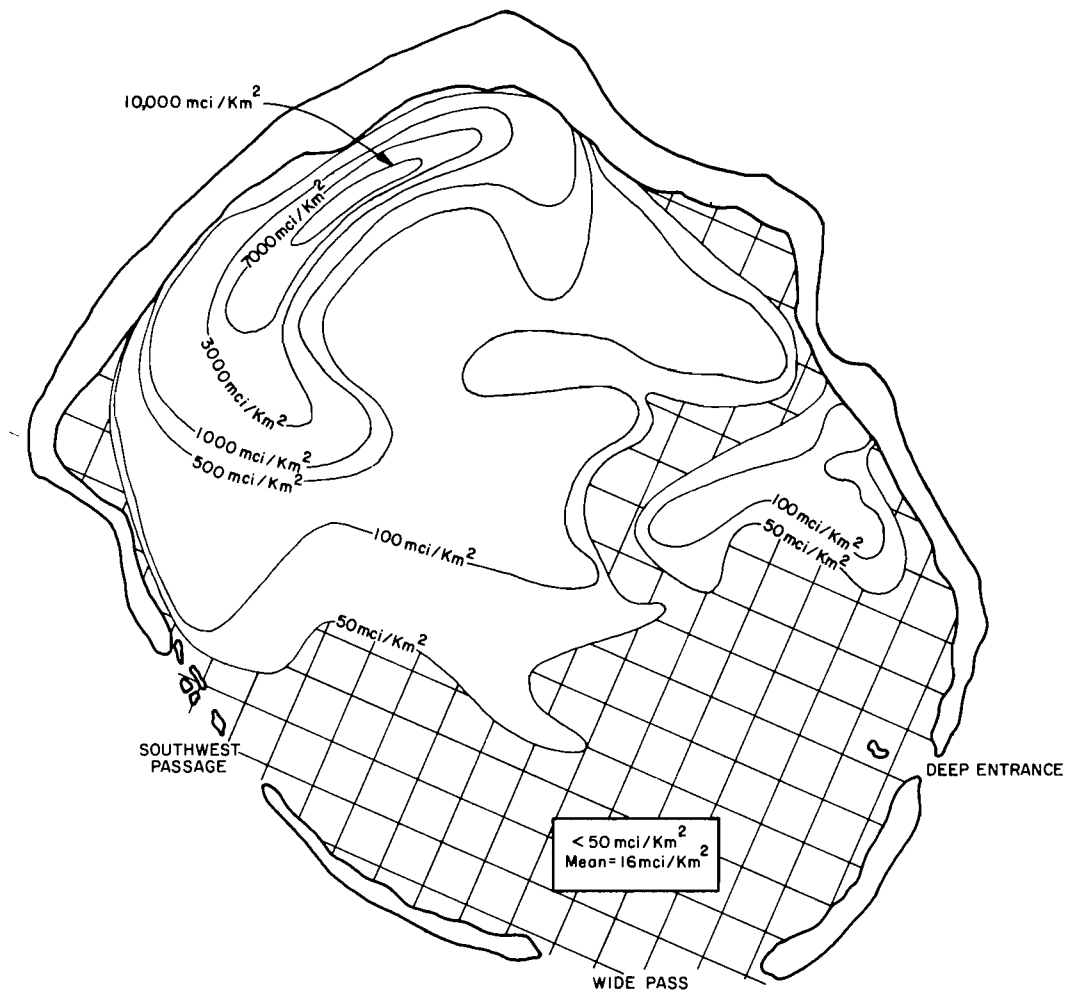


Fig. 158. Activity levels of  $^{90}\text{Sr}$  deposited in the sediments of Enewetak Lagoon.

collected are carnivores of high order in the food chain leading to man.

The number and kind of marine organisms collected at near-shore sites at Enewetak Atoll and at Kwajalein Atoll, where "control" samples were taken, are shown in Table 218. Similar information for the carnivorous fish is given in Table 219.

$^{40}\text{K}$ ,  $^{55}\text{Fe}$ , and  $^{60}\text{Co}$  were the predominant radioactive nuclides found in all fish, although  $^{65}\text{Zn}$ ,  $^{90}\text{Sr}$ ,  $^{101}\text{Rh}$ ,  $^{102m}\text{Rh}$ ,  $^{108m}\text{Ag}$ ,  $^{125}\text{Sb}$ ,  $^{137}\text{Cs}$ ,  $^{152}\text{Eu}$ ,  $^{155}\text{Eu}$ ,  $^{207}\text{Bi}$ ,  $^{239,240}\text{Pu}$ , and  $^{241}\text{Am}$  were also present in some or all samples.

Table 217. Concentration of  $^{137}\text{Cs}$  and  $^{239}\text{Pu}$  in comparative, surface water samples.

Location	Concentration, fCi/liter	
	$^{137}\text{Cs}$	$^{239}\text{Pu}$
Enewetak Lagoon		
SE quadrant	226	9.1
NE quadrant	334	42.6
NW quadrant	579	33.4
SW quadrant	332	21.6
Ocean, east of Enewetak Atoll	89	0.3
Lake Michigan (1971)	88	1.1
Humboldt Bay, Calif. (1973)	300	
14°N 180°W (1972)	143	0.44
12°N 170°E (1972)	170	0.35
Windscale vicinity (1969)	105,000	
Mean surface, Atlantic 0-31°N (1968)		0.7

Table 218. Number of organisms collected at Enewetak Atoll and Kwajalein Atoll near-shore sites, October to December 1972.

Collection site	Organism								Approx total
	Mullet	Goatfish	Convict surgeon	Parrot-fish	Other reef fish	Tridacna	Sea cucumber <sup>a</sup>	Other invertebrates	
Enewetak Atoll									
GLENN-HENRY	~ 25	11	~ 50	2	10	6	4	6 <sup>b</sup>	114
LEROY	~ 50	9	34	3	1	1	0	~ 10 <sup>c</sup>	108
FRED	0	~ 20	~ 50	9	7	3	2		91
DAVID	0	25	~ 50	12	2	4	1		94
BELLE	~ 50	3	30	1	3	10	0		97
IRENE	2	3	12	0	8	0	0		25
JANET	~ 50	3	~ 40	1	0	4	0		98
TILDA-URSULA	~ 35	11	~ 50	2	3	3	3		107
YVONNE	10	~ 15	~ 55	10	3	0	3	9 <sup>d</sup>	105
Kwajalein Atoll									
	-	-	~ 30	1	5	5			41
Approximate Total	~ 220	~ 100	~ 400	41	42	36	13	25	870

<sup>a</sup>The number given is the number of collections from a given site.

<sup>b</sup>Pencil urchins.

<sup>c</sup>Top snails.

<sup>d</sup>Spiny lobster.

Table 219. Number of carnivorous fish collected from the Enewetak and Kwajalein off-shore lagoon sites, October to December 1972.

Collection site	Yellowfin tuna	Organism						Total
		Skipjack	Mackerel	Dolphin	Snapper	Grouper	Ulua	
Enewetak	2	9	3	2	8	8	8	40
Kwajalein	3	1				2		6
Total	5	10	3	2	8	10	8	46

Figures 159-161 show the average concentrations of predominant radionuclides found in convict surgeon samples taken at each of the collection sites around the lagoon. Similar data were obtained from the mullet, goatfish, and parrotfish samples.

Average radionuclide content of light muscle, dark muscle, and liver of skip-

jack collected in Enewetak lagoon are shown in Fig. 162. In general, <sup>55</sup>Fe levels in the large pelagic fish were higher than levels found in other fish types, while other nuclides were present at levels comparable to or lower than those found in the reef fish.

Of the samples collected at Kwajalein, <sup>40</sup>K was present at normal background

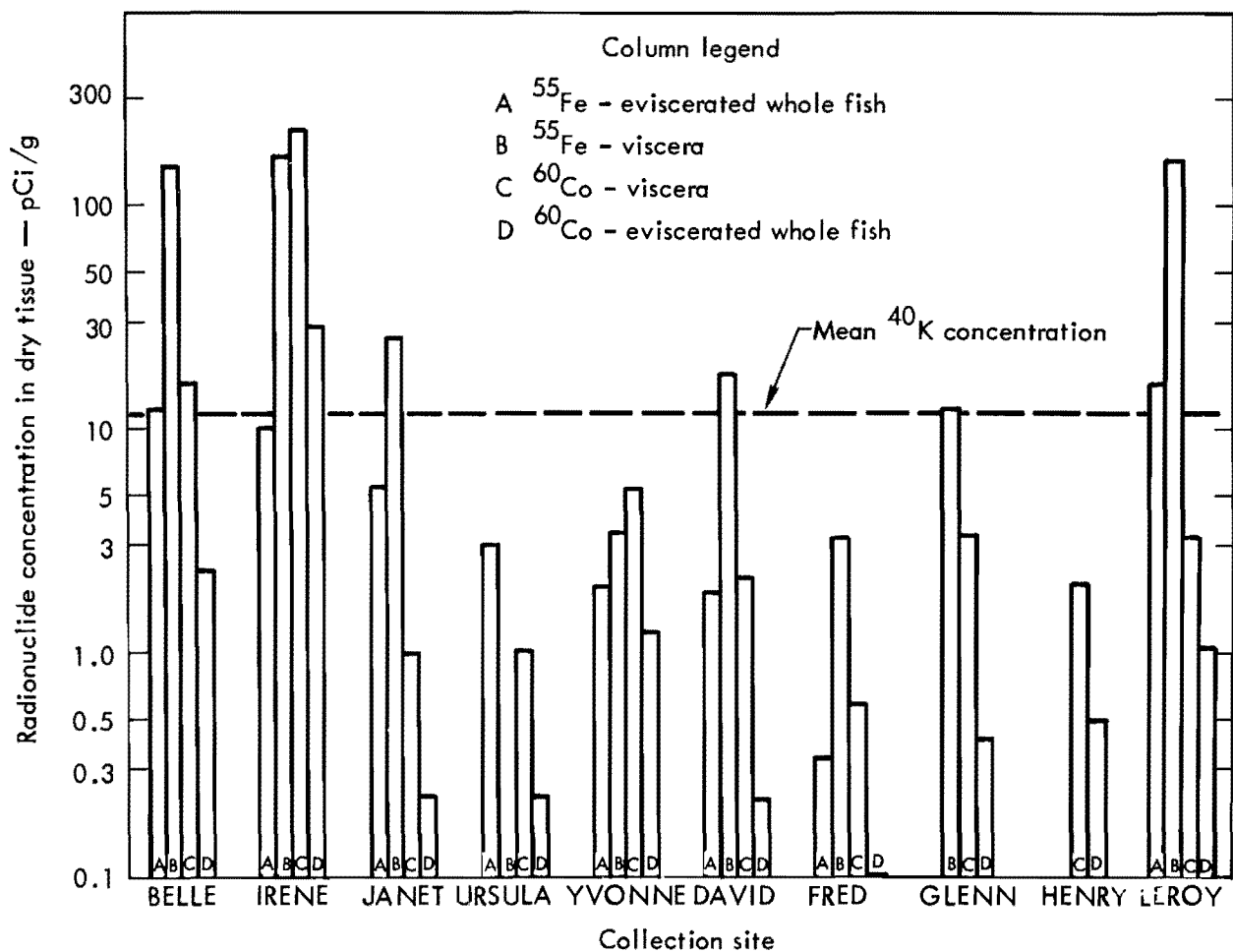


Fig. 159. Average  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ ,  $^{60}\text{Co}$  concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all convict surgeon samples.

Table 220. Comparison of  $^{60}\text{Co}$  and  $^{207}\text{Bi}$  in the viscera of convict surgeon collected in 1964 and 1972.

Island	$^{60}\text{Co}$ in pCi/g, dry			$^{207}\text{Bi}$ in pCi/g, dry		
	1964	1972	Fraction remaining	1964	1972	Fraction remaining
BELLE	120	16	0.13	8.0	2.0	0.25
JANET	8.3	0.96	0.12	1.2	0.2	0.17
GLENN	19	3.3	0.17	2.6	0.7	0.27
LEROY	56	3.4	0.06	5.2	3.1	0.59
YVONNE	64	5.2	0.08	-	-	-
Average			0.11			0.32

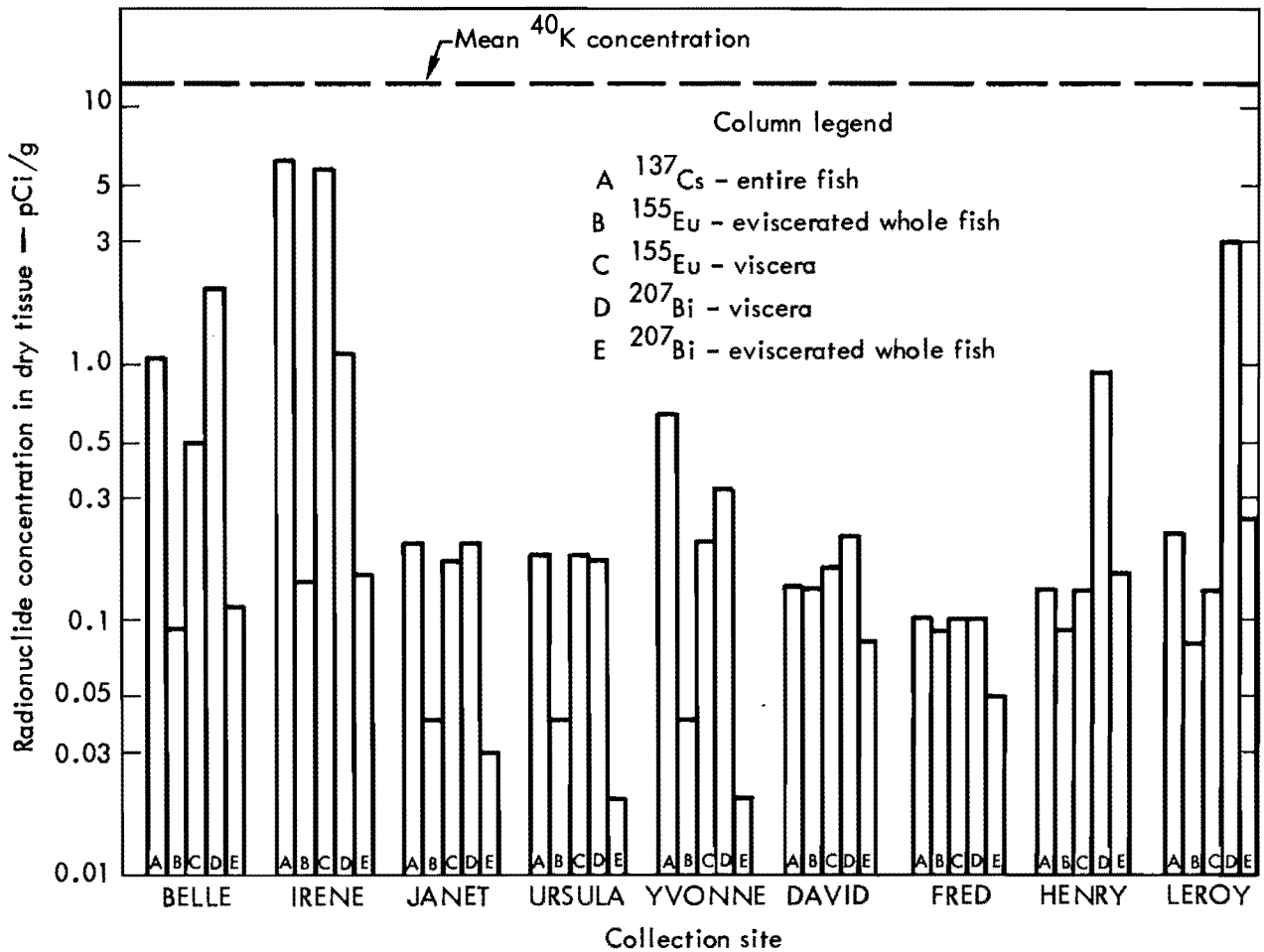


Fig. 160. Average <sup>137</sup>Cs, <sup>155</sup>Eu, and <sup>207</sup>Bi concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The <sup>40</sup>K value is the mean for all convict surgeon samples.

levels (av 15 pCi/g). No <sup>60</sup>Co, <sup>207</sup>Bi, or <sup>155</sup>Eu were observed, but <sup>55</sup>Fe, <sup>137</sup>Cs, <sup>90</sup>Sr, and <sup>239,240</sup>Pu were found in some or all of the samples, usually at levels comparable to the lower values found at Enewetak.

As with the plankton, comparison of data obtained from this survey with similar data from samples taken in 1964 indicates that, for some nuclides at least, there are processes operating to reduce concentrations in the lagoon faster than is expected from radioactive decay alone. Table 220, for example, presents a comparison of

<sup>60</sup>Co and <sup>207</sup>Bi data for the two collection periods. The effective half-life of 2.7 yr for <sup>60</sup>Co (radioactive decay half-life 5.24 yr) and 5.1 yr for <sup>207</sup>Bi (radioactive decay half-life 30 yr) implies an effective half-life in the ecosystem for both isotopes of about 5-6 yr.

Of the marine invertebrates present at Enewetak, tridacna clams, sea cucumbers, spiny lobster, and top snails were collected and analyzed. In the tridacna, <sup>60</sup>Co was the most abundant radioisotope found, and it was present in higher amounts in the kidney than in the viscera,

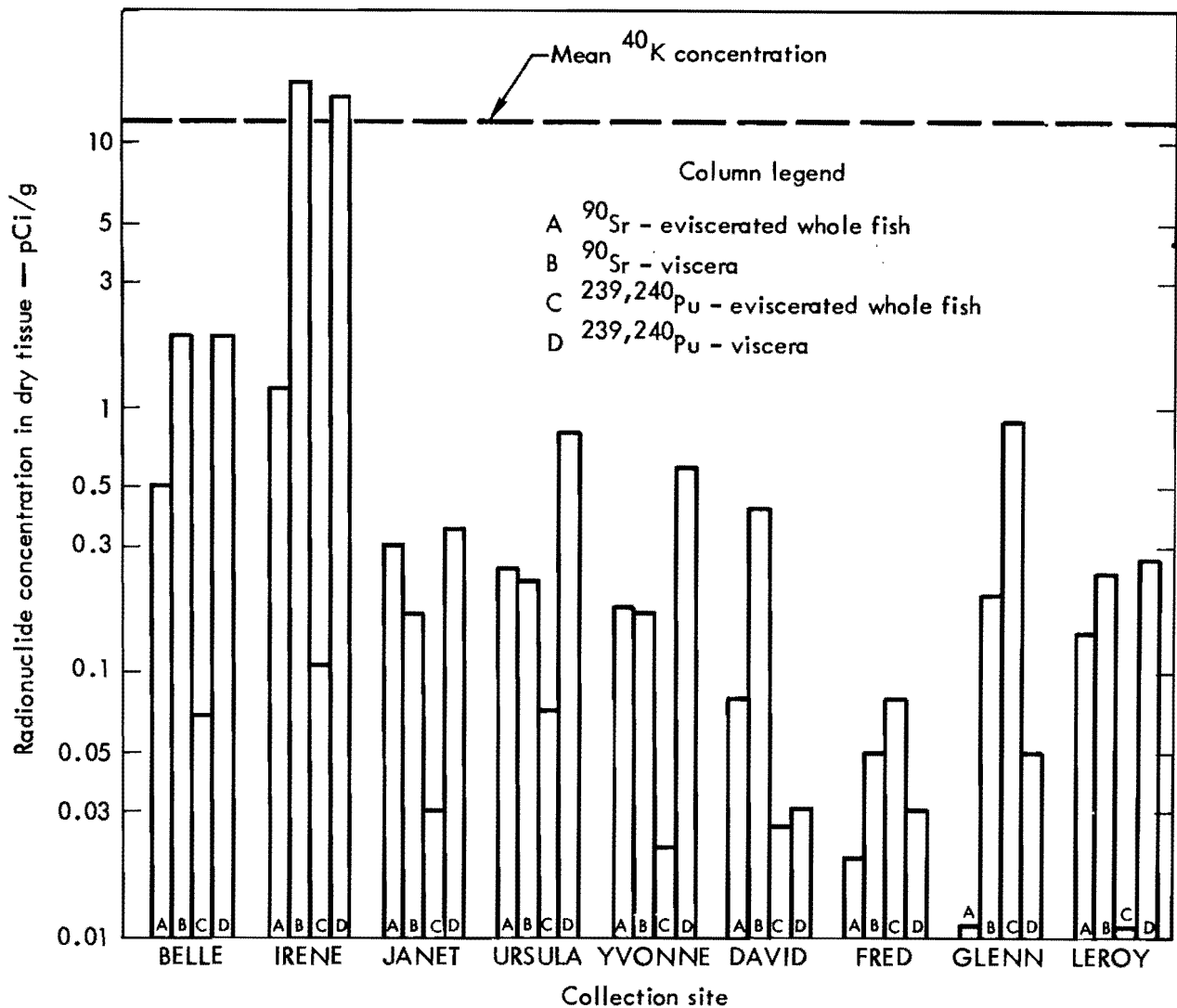


Fig. 161. Average  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  concentration in convict surgeon from Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all convict surgeon samples.

mantle, or muscle. Figures 163-165 present the average radionuclide concentrations of these tissues for the Enewetak locations at which tridacna samples were taken.

Radionuclide distributions for sea cucumbers, spiny lobsters, and top snails were similar to those found for the tridacna, except that high concentrations were not observed in the kidney.

#### Radioactivity Levels in Enewetak Terrestrial Biota

The terrestrial biota survey had as its objective the collection and analysis of all available terrestrial vegetation and animal species which could be used as a basis for estimating population doses through dietary pathways. Not all vegetable and animal components of the Enewetakese diet are currently available

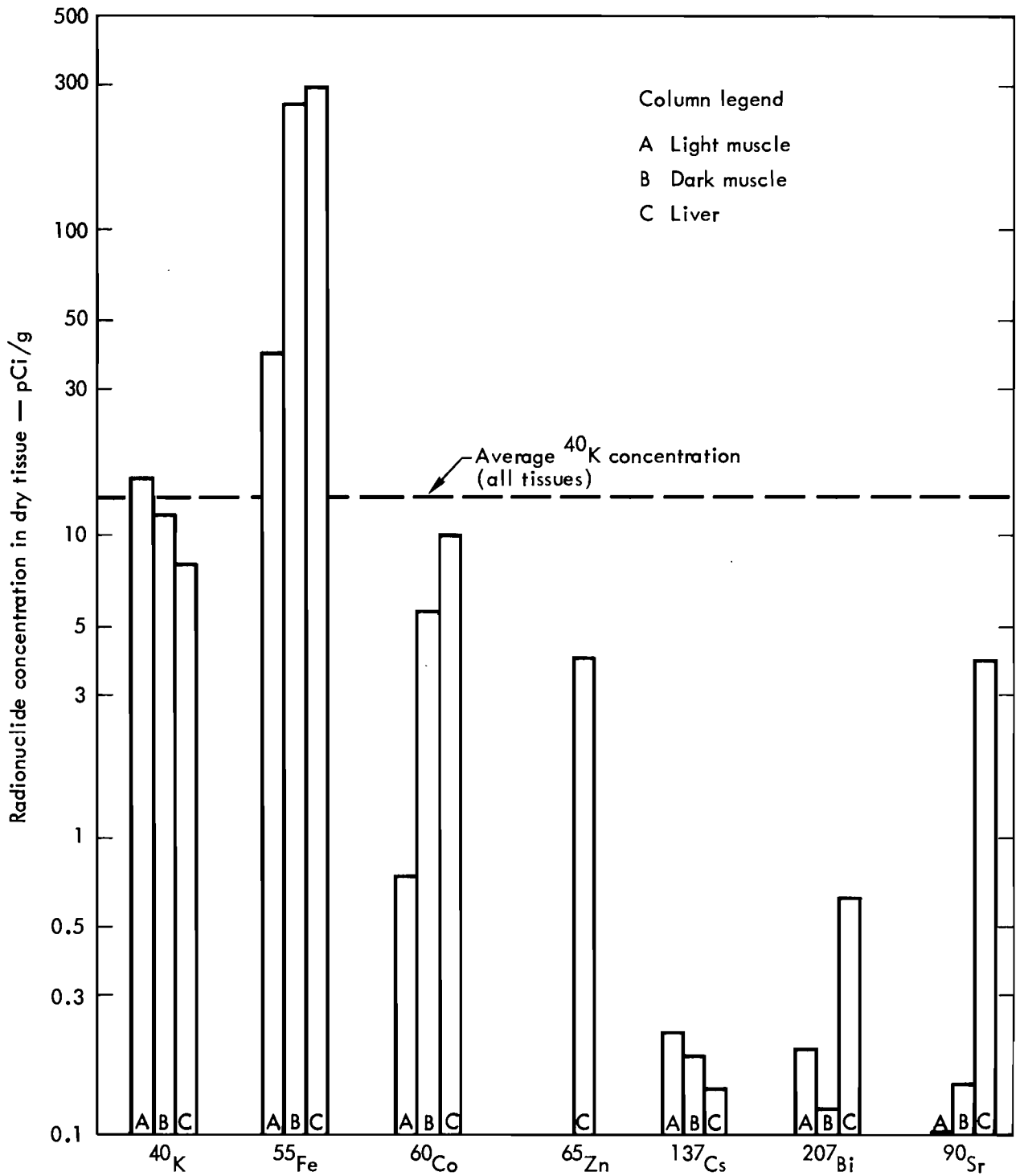


Fig. 162. Average concentration of seven radionuclides in the light muscle (A), dark muscle (B), and liver (C) of three skipjack from Enewetak Atoll, October to December, 1972.



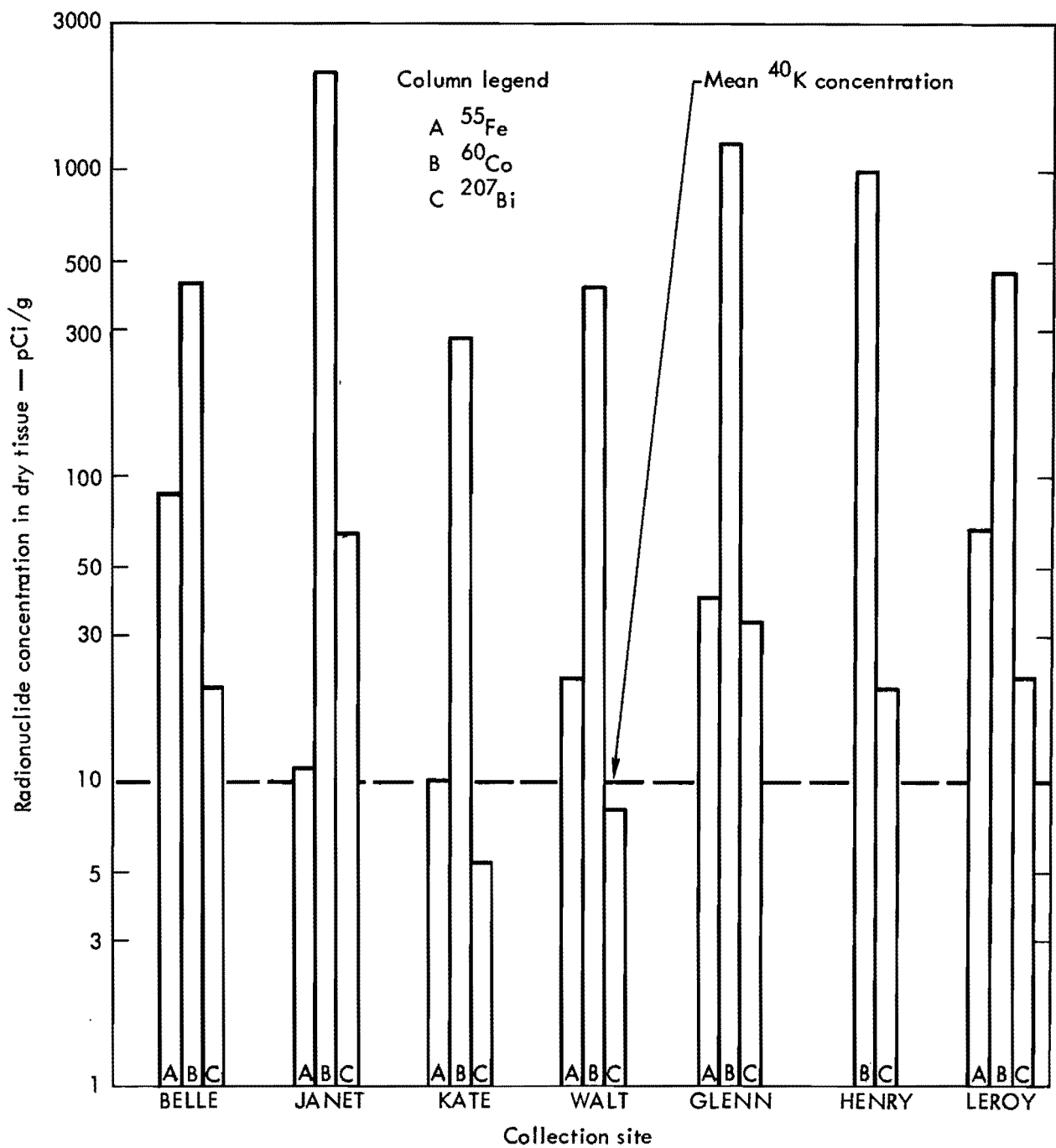


Fig. 163. Average  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ ,  $^{60}\text{Co}$ , and  $^{207}\text{Bi}$  concentration in the kidney of *Tridacna* clams collected at Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean of all *Tridacna* samples.

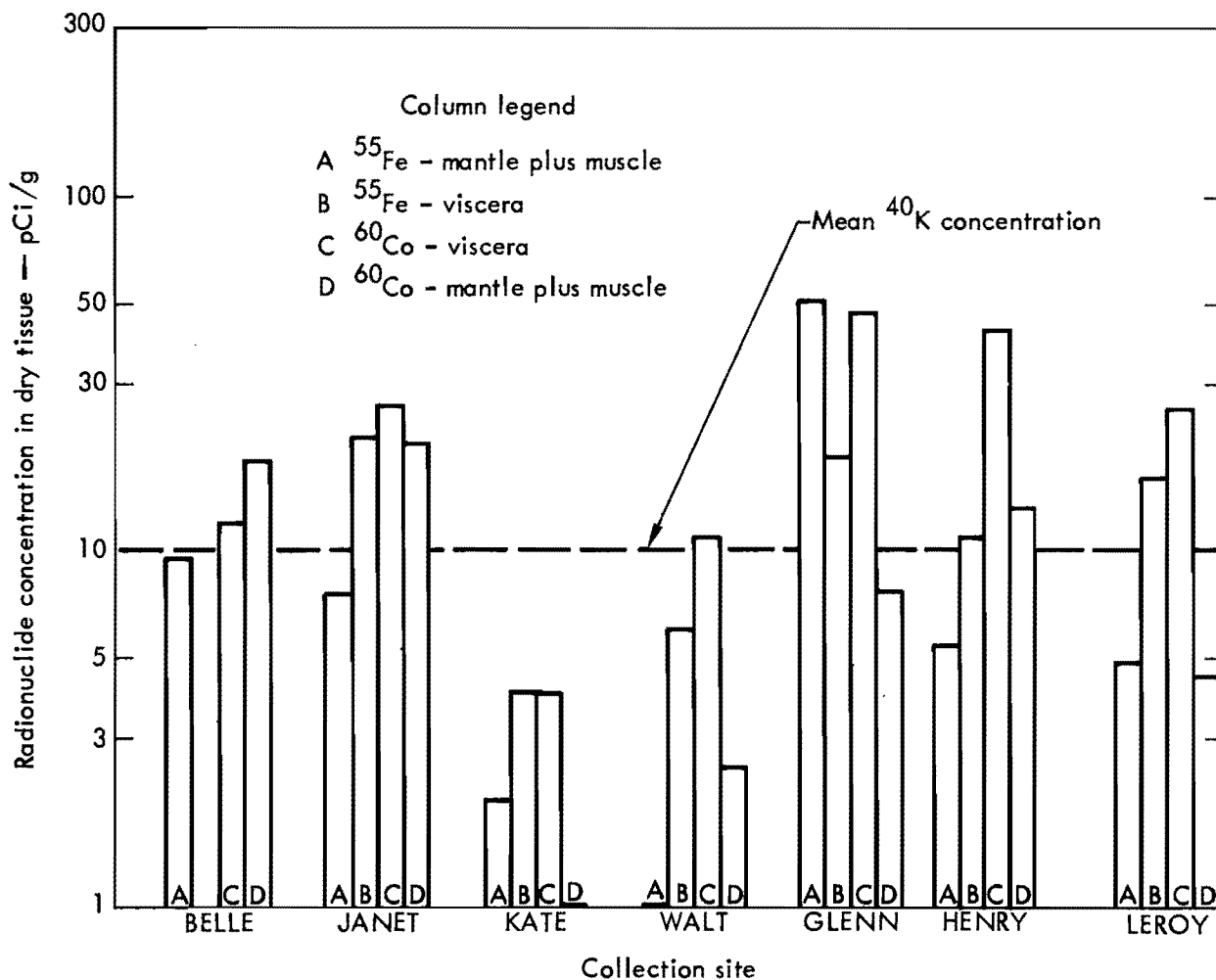


Fig. 164. Average  $^{40}\text{K}$ ,  $^{55}\text{Fe}$ , and  $^{60}\text{Co}$  concentration in the viscera, mantle, and muscle of *Tridacna* clams collected at Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean of all *Tridacna* samples.

on the Atoll; of those that are, not all are available on every island.

A total of 1103 specimens were collected in the field as part of the terrestrial biota survey, distributed as follows:

Soils	42
Plants	208
Birds	116
Eggs	217
Rats	249
Crabs	<u>271</u>
Total	1103

The geographical distribution of specimen collection sites is shown in Fig. 166 and the types of edible sample collected on each island are listed in Table 221.

$^{90}\text{Sr}$  and  $^{137}\text{Cs}$  were observed in essentially all of the plant, rat, and crab samples and in many of the bird and egg samples.  $^{55}\text{Fe}$ ,  $^{60}\text{Co}$ , and  $^{239,240}\text{Pu}$  were observed less frequently, and isotopes such as  $^{207}\text{Bi}$ ,  $^{152}\text{Eu}$ , and  $^{151}\text{Sm}$  were observed occasionally.

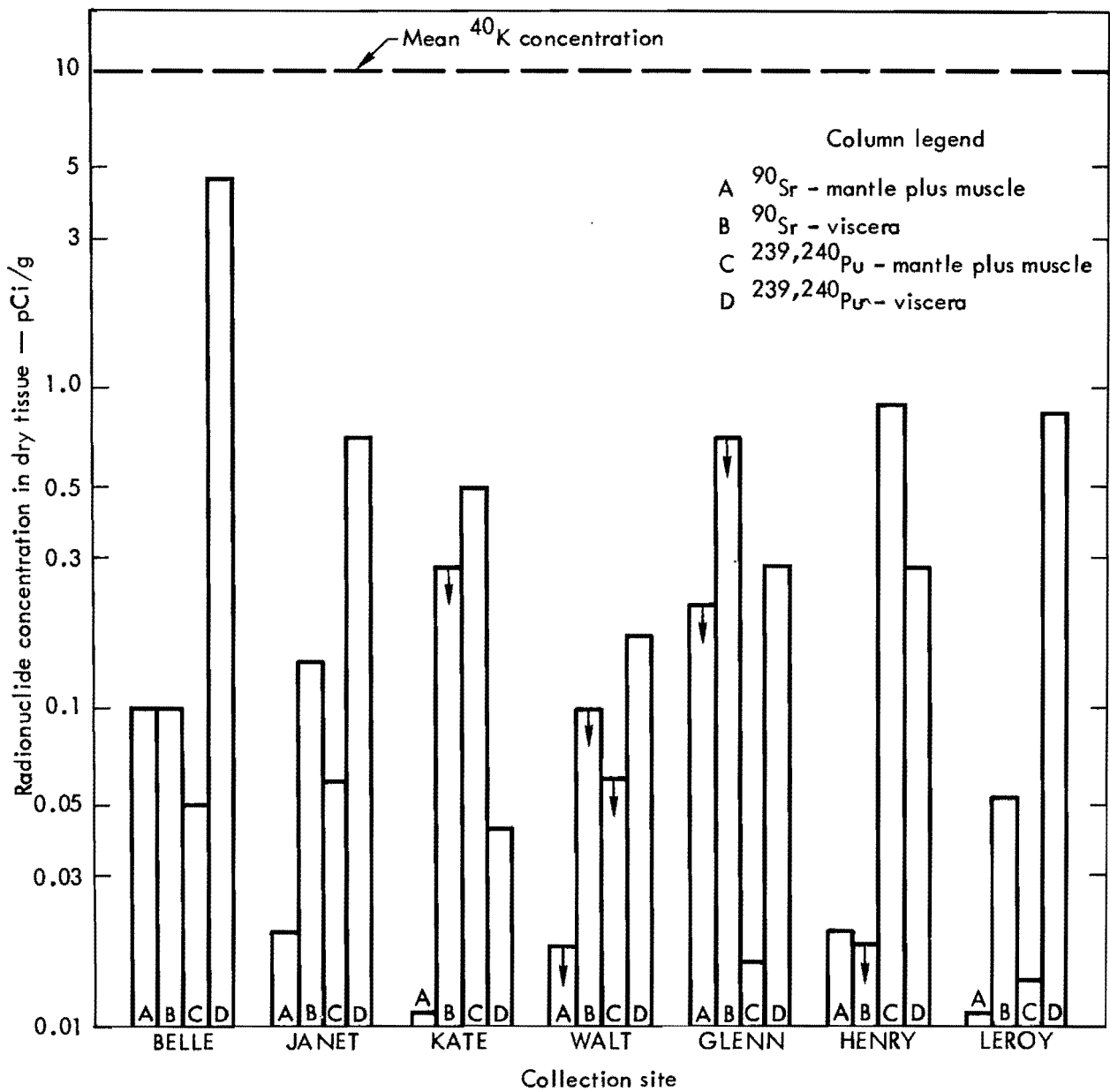


Fig. 165. Average  $^{90}\text{Sr}$  and  $^{239,240}\text{Pu}$  concentration in the viscera, mantle, and muscle of *Tridacna* clams collected at Enewetak Atoll, October to December, 1972. The  $^{40}\text{K}$  value is the mean for all *Tridacna* samples.

Table 221. Terrestrial biota survey. Edible plants and edible animals sampled.

Island No.	Island	Coconut meat	Coconut milk	Pandanus fruit	Pandanus leaves <sup>a</sup>	Tacca corm	Birds	Bird eggs	Coconut crab	Rat <sup>b</sup>
1.	ALICE						x			
2.	BELLE			x	x					
4.	DAISY	x	x							
9.	IRENE	x	x				x	x		
10.	JANET	x	x		x		x	x		x
12.	LUCY						x			
14.	MARY	x	x				x			
15.	NANCY	x	x							
16.	OLIVE						x			
17.	PEARL						x			x
19.	SALLY				x		x	x		x
20.	TILDA				x					
21.	URSULA									x
22.	VERA	x			x					
24.	YVONNE	x					x	x		x
29.	VAN						x			
30.	ALVIN						x			
31.	BRUCE	x					x		x	
32.	CLYDE						x	x		x
33.	DAVID	x	x		x	x	x			x
34.	REX						x	x		
35.	ELMER	x			x					x
37.	FRED	x			x					
38.	GLENN	x							x	x
39.	HENRY	x						x		
40.	IRWIN	x					x	x		
41.	JAMES								x	
42.	KEITH	x		x	x		x		x	
43.	LEROY	x			x		x		x	

<sup>a</sup>Pandanus leaves are not eaten but serve as indicators for pandanus fruit.

<sup>b</sup>Rats are not eaten but serve as indicators for poultry and swine.

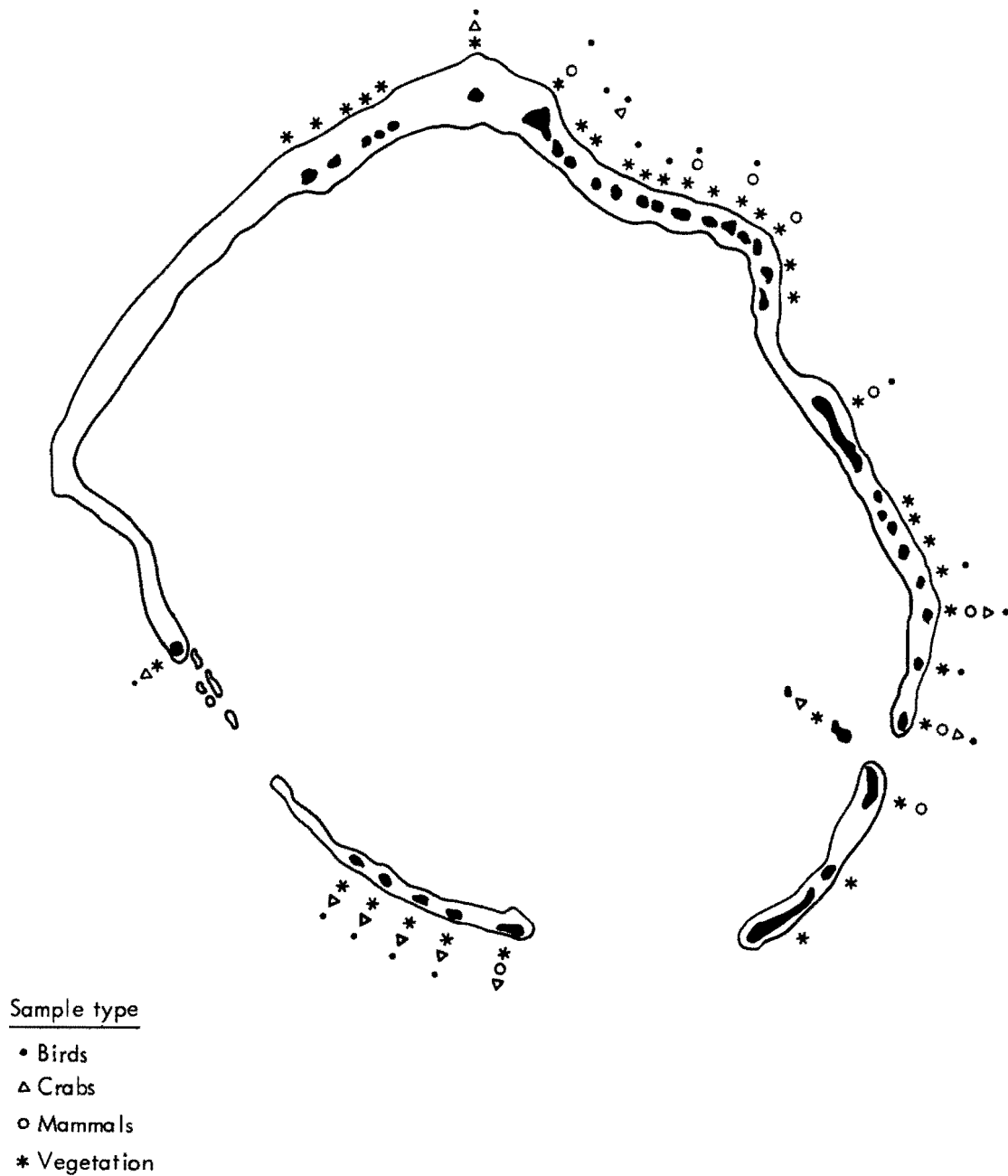


Fig. 166. Terrestrial biota program sampling locations.

For a given sample type, the radio-nuclide content generally corresponded with levels of soil contamination found on the Atoll. Data for  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  in coconut meat versus island sampling location, for example, are plotted in

Fig. 167 and it is apparent that concentrations are significantly higher on the northern islands (islands 1-24) than on those on the southern part of the Atoll.

Since the main vegetation components in the human diet (coconut, pandanus,

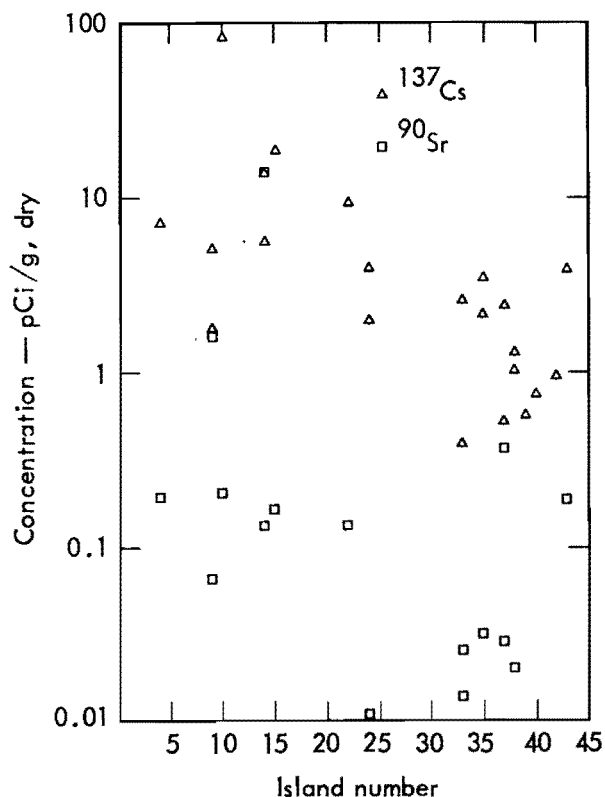


Fig. 167. Concentrations of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  in coconut meat.

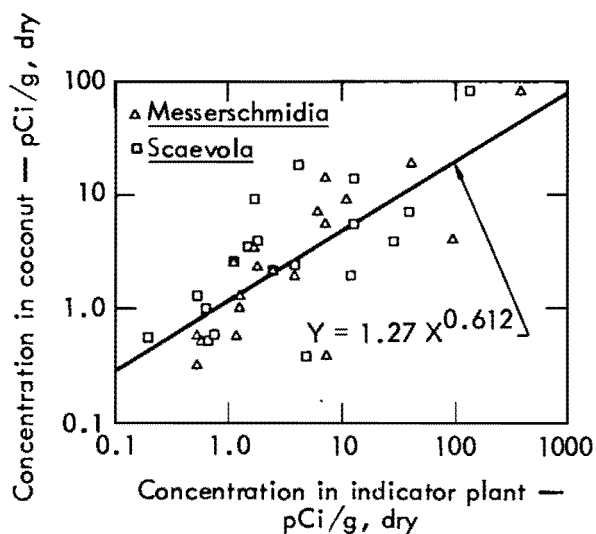


Fig. 168. Statistical correlation between  $^{137}\text{Cs}$  in coconut meat, and  $^{137}\text{Cs}$  in Messerschmidia and Scaevola.

and breadfruit) are not growing now on all of the northern islands, the ubiquitous Messerschmidia and Scaevola were sampled and analyzed extensively with the intent that they be used as "indicator species" for estimating doses from the edible plants should they become available. The correspondence between  $^{137}\text{Cs}$  activity in coconut meat and Messerschmidia and/or Scaevola from the same location is shown in Fig. 168.

To increase accuracy, dose estimates to the human population through the terrestrial vegetation pathway should be based on the geographical distribution of radionuclides. In order to do this, however, a correlation between nuclide content of vegetation and nuclide content of soil must be established. As an example of the correlations that have been developed, data for  $^{137}\text{Cs}$  in Messerschmidia and Scaevola vs  $^{137}\text{Cs}$  in soil are shown in Fig. 169.

Similarly, data obtained from rats — the only mammals now found on the Atoll — were found to correlate with the vegetation radionuclide levels. For example, correlations for  $^{137}\text{Cs}$  in rat muscle vs Messerschmidia/Scaevola are shown in Fig. 170, and for  $^{90}\text{Sr}$  in rat bone vs Messerschmidia/Scaevola are shown in Fig. 171.

Three classes of data obtained from the terrestrial biota survey, therefore, have been used to estimate potential human doses through the terrestrial food pathway:

- Data obtained from the edible organisms where they were available.
- Data obtained from the correlation between edible plants — indicator

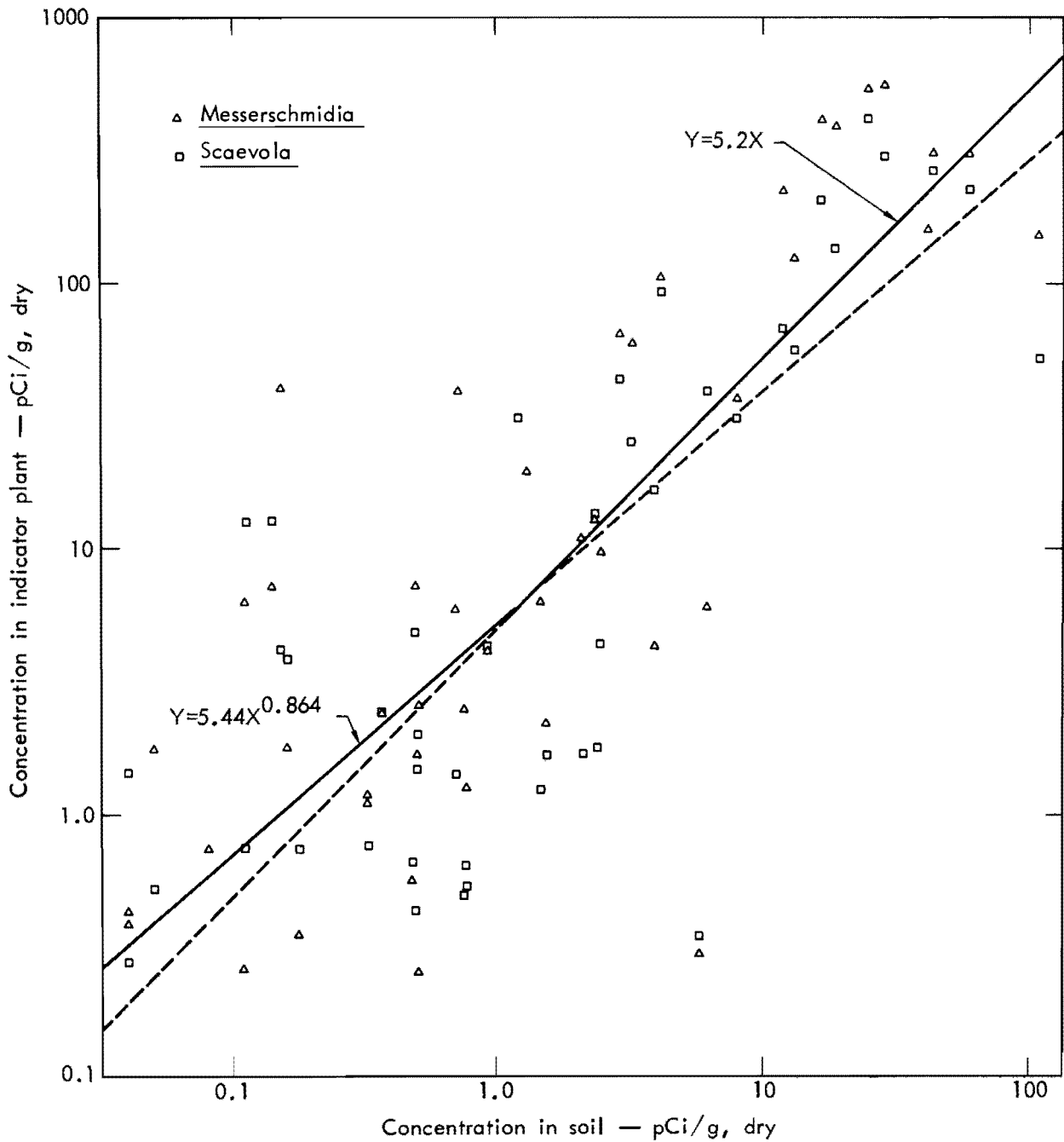


Fig. 169. Statistical correlation between  $^{137}\text{Cs}$  in Messerschmidia and Scaevola and  $^{137}\text{Cs}$  in soil.

plants – soil and applied to the plant component of the diet.

- Data obtained from the correlation between rats – indicator plants – soil and applied to the meat component of the diet.

#### Radioactivity Levels in Enewetak Air

A total of 32 samples of airborne Enewetak particulate debris have been analyzed to determine inhalation exposures likely to be encountered by residents of

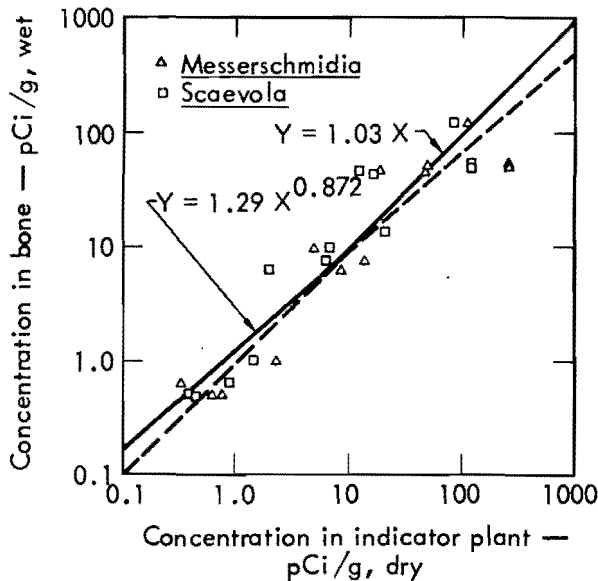


Fig. 170. Statistical correlation between  $^{90}\text{Sr}$  in rat bone and  $^{90}\text{Sr}$  in Messerschmidia and Scaevola.

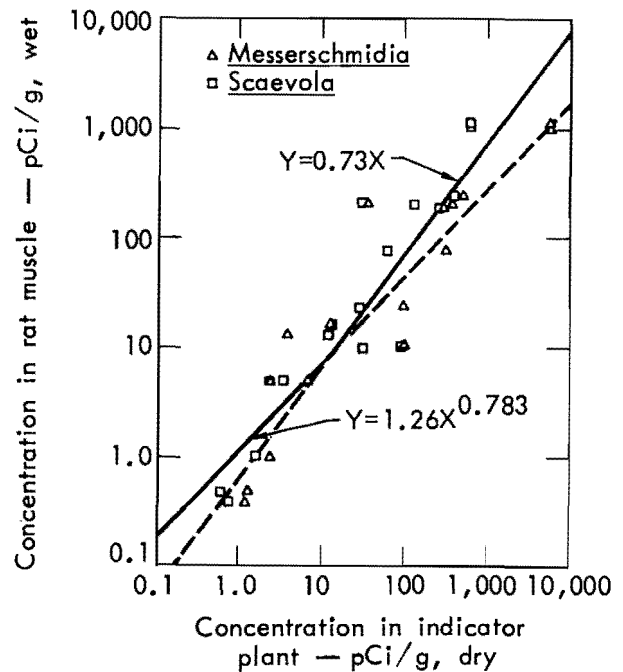


Fig. 171. Statistical correlation between  $^{137}\text{Cs}$  in rat muscle and  $^{137}\text{Cs}$  in Messerschmidia and Scaevola.

the Atoll. Samples were taken using the following three types of equipment:

- Ultra High-Volume Air Sampler (UHVS) – Used to sample large volumes of air in short time intervals. Typical samples were taken at a rate of  $2000 \text{ m}^3/\text{hr}$  for a continuous 24-hr period.
- Low-Volume Air Sampler (VCS) – Used to sample for extended periods. Typical samples were taken at a rate between  $8$  and  $20 \text{ m}^3/\text{hr}$  for a continuous 7-day period.
- Anderson Cascade Impactors (ACI) – Used to obtain data on the particle-size distribution of airborne radioactivity. These samplers operated at a throughput rate of  $34 \text{ m}^3/\text{hr}$ , sampled for 7- to 10-day periods, and separated each sample into the following particle-size ranges:  $0.1\text{-}1.1$ ,  $1.1\text{-}2.0$ ,  $2.0\text{-}3.3$ ,  $3.3\text{-}7.0$ , and  $>7 \mu\text{m}$ .

Air samples were taken on FRED, DAVID, SALLY, JANET, and YVONNE, which are islands that include the full range of airborne activity levels likely to be found on the Atoll.

A number of radionuclides were detected in the surface air, including  $^7\text{Be}$  (53 day),  $^{40}\text{K}$  ( $1.26 \times 10^9$  yr),  $^{54}\text{Mn}$  (303 day),  $^{95}\text{Zr}$  (65 day),  $^{103}\text{Ru}$  (39.6 day),  $^{106}\text{Ru}$  (1.0 yr),  $^{125}\text{Sb}$  (2.7 yr),  $^{137}\text{Cs}$  (30 yr),  $^{144}\text{Ce}$  (285 day),  $^{239}\text{Pu}$  ( $2.4 \times 10^4$  yr),  $^{238}\text{Pu}$  (86 yr), and  $^{241}\text{Am}$  (458 yr).  $^7\text{Be}$  and  $^{40}\text{K}$  are naturally occurring activities.  $^{54}\text{Mn}$ ,  $^{95}\text{Zr}$ ,  $^{103}\text{Ru}$ ,  $^{106}\text{Ru}$ ,  $^{125}\text{Sb}$ , and  $^{144}\text{Ce}$  are intermediate-life activation and fission products found in current worldwide fallout, but present in Enewetak soils in only very reduced quantities due to radioactive decay in the long interval since testing ended. Longer-life  $^{137}\text{Cs}$ ,



Table 222. Comparison of radionuclides in surface air (fCi/m<sup>3</sup>) on Enewetak, Livermore, California, and Balboa, Panama.

Nuclide	YVONNE	Remainder of Enewetak Atoll	Livermore, Calif., 1972	Balboa, Panama, 9°N 79°W, 1972-1973
<sup>7</sup> Be	<49-193	<6-116	90-250	43-143 <sup>c</sup>
<sup>54</sup> Mn	<0.6-2.1	<0.14-4.0	-	-
<sup>95</sup> Zr	<0.4-0.4 <sup>a</sup>	0.03-0.3	0.005-0.4	<0.9-8.5
<sup>103</sup> Ru	<5.5-5.5 <sup>a</sup>	NDET <sup>b</sup>	0.29-3.4	-
<sup>125</sup> Sb	<0.27-0.27 <sup>a</sup>	NDET	0.04-0.23	-
<sup>106</sup> Ru	<0.9-2.6	<0.2-1.6	0.14-2.9	-
<sup>137</sup> Cs	<0.49-0.82	<0.04-2.5	0.63-3.2	0.09-1.7
<sup>144</sup> Ce	<2.5-3.7	<0.22-1.9	0.24-3.1	0.7-11.2
<sup>239, 240</sup> Pu	<0.03-2.6	<0.001-0.025	0.01-0.05	<0.001-0.030
<sup>238</sup> Pu	<0.04-0.13	<0.0028-0.008	0.001-0.005	<0.001-0.003
<sup>241</sup> Am	<0.3-0.30 <sup>a</sup>	NDET	NDET	NDET

<sup>a</sup>Detected only one sample.

<sup>b</sup>Not detected.

<sup>c</sup>Oct. -Dec. 1972 range.

<sup>238</sup>Pu, <sup>239</sup>Pu, and <sup>241</sup>Am in air could be from either local resuspension or from worldwide fallout. A comparison of activity levels at Enewetak with those observed at Livermore, California, and Balboa, Panama is shown in Table 222. It appears that, with the exception of the single sample on which 5.5 fCi/m<sup>3</sup> of <sup>103</sup>Ru was observed, the only airborne radionuclides present at levels consistently higher than those at the other two locations were the Pu-Am species on YVONNE, a result not too surprising, considering the known soil contamination levels on that island.

Of the 32 air samples, four were taken in October 1972 before typhoon Olga struck, and the remainder were

taken between November 28 and December 19, 1972. Wind speeds were almost always greater than 10 knots and often greater than 20 knots at all sampling locations. In addition, frequent light rain showers served to keep the ground surface damp. Table 223 presents climatological data which have been published for Enewetak and Kwajalein. It is apparent that December represents a fairly average month as far as total rainfall and rainfall frequency are concerned, while average windspeeds are higher than those observed most of the year.

#### Radioactive Scrap and Buried Debris

Holmes and Narver, Inc., as part of the engineering survey they conducted

Table 223. Climatological data for Kwajalein and Enewetak.<sup>a</sup>

	Percentage of total time at each wind-speed interval													Av
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		
Wind speed, knots <sup>b</sup>														
0-3	1	1	1	0	1	1	6	10	16	9	3	1	4.2	
4-10	15	12	22	20	27	27	49	60	59	63	42	20	34.7	
11-21	68	80	70	75	69	70	44	29	24	28	53	70	56.7	
22-33	15	7	7	5	3	2	1	1	1	0	2	9	4.4	
>33	1	0	0	0	0	0	0	0	0	0	0	0	0	
Prevailing wind direction and frequency <sup>b</sup>	NE	NE	NE	NE	NE	NE	E/NE	E	NE	NE	NE	NE	--	
	86%	87%	81%	77%	67%	64%	36%	31%	27%	33%	55%	74%	--	
							each							
Precipitation <sup>c</sup>													Yr	Yr. of record
Av. amount, in.	1.02	1.84	1.86	1.28	4.57	3.37	6.45	6.81	6.24	9.09	6.30	2.63	51.46	30
Greatest amount, in.	1.95	10.21	7.33	3.86	8.38	7.03	15.35	14.41	13.17	18.07	17.38	9.18	69.86	13
Least amount, in.	0.12	0.40	0.37	0.49	0.37	1.33	1.36	4.22	1.53	2.60	1.94	0.86	24.42	13
Mean number of days, 0.01 in. or more.	11	10	13	13	16	16	21	21	20	21	21	16	198	10

<sup>a</sup>U. S. Hydrographic Office, Sailing Directions for the Pacific Islands, H. O. Pub. No. 82, Vol. 1, Second Edition (1964), updated to Dec. 5, 1970.

<sup>b</sup>Wind data for Kwaialein.

<sup>c</sup>Precipitation data for Enewetak.

for DNA,<sup>\*</sup> estimated that there were approximately 7200 yd<sup>3</sup> of contaminated metal and concrete present on Enewetak Atoll in December 1972. AEC radiation monitors accompanied the H&N crews in order to identify the radioactive material. Table 224 shows the distribution of this debris on islands where this type of survey was conducted. The amounts of material listed should be taken only as an approximate lower limit, particularly on islands such as PEARL, where very heavy underbrush prevented the survey party from covering all parts of the island. In addition, it is conceivable that radioactive scrap material may be found

on the other northern islands (KATE, LUCY, MARY, NANCY, OLIVE, URSULA, VERA, and WILMA), even though none of them contains ground-zero sites, and neither the aerial radiological survey nor the ground survey parties detected this type of debris.

On the southern islands, there were four locations where radioactive scrap material was found:

- On the north end of ELMER (in the "C" level area of Fig. B.37.1.b in Appendix II) there are several pieces of scrap iron with activity levels above local background.
- In the central part of ELMER (the large "E" level area of Fig. B.39.1.b) a partially shielded <sup>60</sup>Co source was found in a small storage building.

<sup>\*</sup>Engineering Study for a Cleanup Plan, Enewetak Atoll-Marshall Islands, Holmes and Narver, Repts. HN-1348.1 and HN-1348.2 (1973).

Table 224. Contaminated metal and concrete scrap on Enewetak Atoll.

Island	Approximate scrap quantities	Remarks
ALICE	10 yd <sup>3</sup>	Background is up to 170 $\mu$ R/hr. An M-boat wreck on beach reads 8 mR/hr.
BELLE	Small (< 10 yd <sup>3</sup> )	Background up to 250 $\mu$ R/hr.
CLARA	Small (< 10 yd <sup>3</sup> )	Background up to 100 $\mu$ R/hr.
DAISY	Small (< 10 yd <sup>3</sup> )	Background up to 140 $\mu$ R/hr.
EDNA	None	Sandbar
IRENE	Moderate <sup>a</sup>	Up to 1.2 mr/hr.
JANET	568 yd <sup>3</sup>	Activated scrap metal in all sizes can be found in piles or individual pieces scattered over the island at levels up to 8 mr/hr.
PEARL	317 yd <sup>3</sup>	Confined to SGZ area. Levels up to 5 mr/hr.
RUBY	196 yd <sup>3</sup>	
SALLY	2106 yd <sup>3</sup>	Scrap-metal activity levels up to 0.12 mr/hr. Alpha levels on concrete surfaces up to 10 <sup>3</sup> dpm/50 cm <sup>2</sup> .
TILDA	1 yd <sup>3</sup>	
YVONNE	4064 yd <sup>3</sup>	Activity levels up to 60 mr/hr.
Total	7262 yd <sup>3</sup>	

<sup>a</sup>Reference does not identify volume.

- In the south-central part of ELMER (the small "E" level area of Fig. B.39.1.b) there appears to be scrap metal or other radioactive debris on, or just below, the ground surface in heavy underbrush.
- On the north-central shore of GLENN (the "C" area of Fig. B.48.1.b) there is a derelict barge which is contaminated with detectable amounts of <sup>207</sup>Bi.

Because of the extremely low ambient radiation levels on the southern islands and the sensitivity of the aerial survey equipment, we can be reasonably confident that we have found all material above ground with activity levels greater than a few microrentgens per hour. On FRED, for example, the highest radiation level found (the "D" area in Fig. B.46.1.b) proved to be coming from barrels of fly ash stored in a warehouse intended to be

Table 225. Living patterns describing the geographical locations for activities involved in daily living.

	<u>Pattern I</u>	<u>Pattern II</u>
<u>Residence</u>	FRED, ELMER, or DAVID	FRED, ELMER, or DAVID
<u>Agriculture</u>	ALVIN through KEITH	KATE through WILMA + LEROY
<u>Fishing</u>	Entire Atoll	Entire Atoll
	<u>Pattern III</u>	<u>Pattern IV</u>
<u>Residence</u>	JANET	BELLE
<u>Agriculture</u>	JANET	BELLE
<u>Fishing</u>	Entire Atoll	Entire Atoll
	<u>Pattern V</u>	<u>Pattern VI</u>
<u>Residence</u>	JANET	JANET
<u>Agriculture</u>	KATE through WILMA + LEROY	ALICE through IRENE
<u>Fishing</u>	Entire Atoll	Entire Atoll

used for PACE drilling operations. Similarly, the nearby "C" level area proved to be a <sup>60</sup>Co source stored in a lead container in a locked building properly labeled, but of which we were unaware before the survey started.

#### POPULATION DOSE ASSESSMENT

The total radiation dose to the Enewetak people returning to Enewetak Atoll is determined by the sum of the contributions of each of the exposure pathways; i. e.,

$$\begin{aligned}
 \text{Dose} = & D_{\text{inhalation}} + D_{\text{external gamma}} \\
 & + D_{\text{marine food chain}} \\
 & + D_{\text{terrestrial food chain}}
 \end{aligned}$$

The contribution of each pathway to the total dose for an individual depends on living patterns and diet. Six living patterns, shown in Tables 225 and 226, have been selected for the dose assessment on the basis of statements made by the Enewetak people as to how and where they would like to live after they return. Similarly, the diets shown in Table 227 have been selected on the basis of the best current information on the dietary habits of the Enewetak people, the current distribution of edible species on the Atoll, and growth periods before harvest for edible species which will have to be established after return. In addition, these assessments assume that the Enewetak people will continue their current practice of using catchment rain-water for drinking and that underground

Table 226a. Estimated time distribution (in percent) for men, women, children, and infants, with emphasis on residence island. Pattern A.

	Village area	Beaches	Interior	Lagoon	Other islands
Men	50	5	15	10	20
Women	60	10	10	0	20
Children	55	10	15	5	15
Infants	85	5	0	0	10

lens water, where available, will not be a significant part of the diet.

#### $D_{\text{inhalation}}$

$^{239,240}\text{Pu}$  has been found to be the only significant contributor to inhalation doses on Enewetak Atoll. Airborne radioactive species observed during the survey, however, were identified as originating almost entirely from worldwide fallout or cosmic-ray activity. In order to make a conservative estimate of inhalation dosages, it has been assumed that the returning population will be exposed to air with an average dust loading of  $100 \mu\text{g}/\text{m}^3$ , with the same  $^{239,240}\text{Pu}$  content as the local soil, all  $0.4 \mu\text{m}$  in diameter and low in solubility.

Using these assumptions and  $^{239,240}\text{Pu}$  concentrations obtained from the soil

samples, inhalation doses to bone, liver, and lung for each of the six living patterns have been estimated and are shown in Tables 228-230.

The "unmodified" cases represent calculations based on the  $^{239,240}\text{Pu}$  content of the top 2 cm of soil, while the "modified" cases represent calculations based on the average  $^{239,240}\text{Pu}$  content of the top 15 cm of soil. The latter condition would obtain if the soils were plowed or mixed during the replanting operations.

#### $D_{\text{external gamma}}$

Using gamma levels obtained from the aerial survey, estimates of the external gamma dose associated with each of the living patterns have been calculated (Table 231). In this table the "unmodified"

Table 226b. Estimated time distribution (in percent) for men, women, children, and infants with emphasis on additional time spent on nonresidence islands. Pattern B.

	Village area	Beaches	Interior	Lagoon	Other islands
Men	40	5	20	10	25
Women	50	5	15	5	25
Children	50	5	15	10	20
Infants	70	5	5	0	20

Table 227. Postulated diet for the returning adult Enewetak population for time of return and for 10 yr after initial return.

Food item	Diet, g/day	
	At time of return,	10 yr after return
Fish	600	600
Domestic meat	60	100
Pandanus fruit	0	200
Breadfruit	0	150
Wild birds	100	20
Bird eggs	20	10
Arrowroot	0	40
Coconut	100	100
Coconut milk	100	300
Coconut crabs	25	25
Clams	25	25
Garden vegetables	0	0
Imports	200-1000	200-1000
	1030 plus imports	1570 plus imports

Table 228. Cumulative rems to organs from  $^{239,240}\text{Pu}$  via inhalation pathway, bone.

LIVING PATTERN	PCI/G IN SOIL	5 YRS	EXPOSED			
			10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.05	0.0000	0.0000	0.0003	0.0009	0.0018
UNMODIFIED	0.12	0.0000	0.0001	0.0007	0.0022	0.0043
II. MODIFIED	2.00	0.0001	0.0008	0.0122	0.0360	0.0720
UNMODIFIED	4.70	0.0003	0.0020	0.0267	0.0846	0.1692
III. MODIFIED	7.30	0.0004	0.0031	0.0445	0.1314	0.2628
UNMODIFIED	17.00	0.0010	0.0071	0.1037	0.3060	0.6120
IV. MODIFIED	15.00	0.0009	0.0063	0.0915	0.2700	0.5400
UNMODIFIED	77.00	0.0046	0.0323	0.4697	1.3860	2.7720
V. MODIFIED	7.30	0.0004	0.0031	0.0445	0.1314	0.2628
UNMODIFIED	17.60	0.0011	0.0074	0.1074	0.3168	0.6336
VI. MODIFIED	9.50	0.0006	0.0040	0.0579	0.1710	0.3420
UNMODIFIED	14.70	0.0009	0.0062	0.0897	0.2646	0.5292

Table 229. Cumulative rems to organs from <sup>239,240</sup>Pu via inhalation pathway, liver.

LIVING PATTERN	PCI/G IN SOIL	5 YRS	EXPOSED			
			10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.05	0.0000	0.0000	0.0002	0.0005	0.0008
UNMODIFIED	0.12	0.0000	0.0000	0.0004	0.0011	0.0020
II. MODIFIED	2.00	0.0001	0.0005	0.0066	0.0186	0.0340
UNMODIFIED	4.70	0.0002	0.0011	0.0155	0.0437	0.0799
III. MODIFIED	7.30	0.0003	0.0010	0.0241	0.0679	0.1241
UNMODIFIED	17.00	0.0007	0.0041	0.0561	0.1581	0.2890
IV. MODIFIED	15.00	0.0006	0.0036	0.0495	0.1395	0.2550
UNMODIFIED	77.00	0.0031	0.0185	0.2541	0.7161	1.3090
V. MODIFIED	7.30	0.0003	0.0018	0.0241	0.0679	0.1241
UNMODIFIED	17.60	0.0007	0.0042	0.0581	0.1637	0.2992
VI. MODIFIED	9.50	0.0004	0.0023	0.0313	0.0883	0.1515
UNMODIFIED	14.70	0.0006	0.0035	0.0485	0.1367	0.2499

case represents the current conditions; "village graveled" shows the effect of placing a 5-cm gravel layer in the village area; and "\_\_\_\_\_ plowed" indicates the effect of thoroughly mixing the top 30 cm of soil in the specified area.

D marine food chain

Doses via the marine and terrestrial food chains were estimated using the following differential equation to describe the intake and retention by man:

$$\frac{dC_{\text{man}}}{dt} = \frac{I f_{\text{man}} C}{M} - \lambda_{\text{man}} C_{\text{man}} \quad (3)$$

where

$C_{\text{man}}$  = concentration of nuclide in man, pCi/g

I = food intake, g/day,

$f_{\text{man}}$  = fraction of nuclide ingested reaching the organ of reference,

C = concentration of nuclide in food product, pCi/g, (i. e., fish, shellfish, coconut, land crab, etc.),

M = mass of the organ of reference, (g),

and

$\lambda_{\text{man}}$  = effective elimination rate of nuclide from man, (day<sup>-1</sup>).

$$(\lambda_{\text{man}} = \lambda_{\text{biological}} + \lambda_{\text{radioactive}})$$

The concentration C in the food products is calculated assuming that the nuclide

Table 230. Cumulative rems to organs from  $^{239,240}\text{Pu}$  via inhalation pathway, lung.

LIVING PATTERN	PCING IN SOIL	EXPOSED				
		5 YRS	10 YRS	30 YRS	50 YRS	70 YRS
I. MODIFIED	0.05	0.0000	0.0001	0.0004	0.0006	0.0009
UNMODIFIED	0.12	0.0001	0.0003	0.0009	0.0016	0.0022
II. MODIFIED	2.00	0.0017	0.0044	0.0152	0.0260	0.0360
UNMODIFIED	4.70	0.0040	0.0103	0.0357	0.0611	0.0846
III. MODIFIED	7.30	0.0063	0.0161	0.0555	0.0949	0.1314
UNMODIFIED	17.00	0.0146	0.0374	0.1292	0.2210	0.3060
IV. MODIFIED	15.00	0.0129	0.0330	0.1140	0.1950	0.2700
UNMODIFIED	77.00	0.0662	0.1694	0.5852	1.0010	1.3860
V. MODIFIED	7.30	0.0063	0.0161	0.0555	0.0949	0.1314
UNMODIFIED	17.60	0.0151	0.0387	0.1338	0.2288	0.3168
VI. MODIFIED	9.50	0.0082	0.0209	0.0722	0.1235	0.1710
UNMODIFIED	14.70	0.0126	0.0323	0.1117	0.1911	0.2646

disappears only by radioactive decay, i. e., that no other processes are in operation which reduce the nuclide availability in the food chain. Therefore  $C = C_0 e^{-\lambda_r t}$ , where  $C_0$  is the concentration observed at the time of the survey and  $\lambda_r$  is the radioactive decay constant. The concentration in man at any time  $t$  after initial consumption of the food is:

$$C_{\text{man}} = \frac{I f_{\text{man}} C_0}{M(\lambda_{\text{man}} - \lambda_r)} \times \left( e^{-\lambda_r t} - e^{-\lambda_{\text{man}} t} \right), \text{ pCi/g.} \quad (4)$$

The dose at any time  $t$  after initial consumption is

$$\begin{aligned} \text{Dose (rem)} &= KE \int_0^t C_{\text{man}} dt \\ &= KE \int_0^t \frac{I f_{\text{man}} C_0}{M(\lambda_{\text{man}} - \lambda_r)} \\ &\quad \times \left( e^{-\lambda_r t} - e^{-\lambda_{\text{man}} t} \right) dt, \quad (5) \end{aligned}$$

where  $K$  is a conversion constant from pCi/g to rem and equals  $5.1 \times 10^{-5} \frac{\text{disintegrations} \cdot \text{g} \cdot \text{rem}}{\text{pCi} \cdot \text{MeV} \cdot \text{day}}$  and  $E$  is the disintegration energy of the nuclide in MeV, including a factor for relative biological effectiveness (RBE). The final dose is then determined from the integration of the equation, i. e.,



$$\text{Dose} = \frac{KE I f_{\text{man}} C_o}{M(\lambda_{\text{man}} - \lambda_r)} \times \left[ \frac{1 - e^{-\lambda_r t}}{\lambda_r} - \frac{1 - e^{-\lambda_{\text{man}} t}}{\lambda_{\text{man}}} \right], \text{ rem.} \quad (6)$$

Table 232 lists the  $f_{\text{man}}$  (FMAN),  $\lambda_{\text{radioactive}}$  (LR),  $\lambda_{\text{man}}$  (LMAN), and disintegration energy (E) values for all of the isotopes in the dose calculations.

Fish and marine organism data from the survey have been found not to have any

statistically significant differences for dose estimation purposes between samples taken in different parts of the lagoon.

The radionuclide concentration,  $C_o$ , used in the marine food chain dose assessment, therefore, is the average value for all fish from the entire Atoll determined from the survey and is listed in Tables 233 and 234 for each nuclide. The average values for radionuclide concentrations listed in the tables are in pCi per gram dry weight, with data corrected to pCi per gram wet

Table 231. Estimated integral external free-air gamma doses.

Case	Living pattern	Gamma dose, rad			
		Time interval, yr			
		5	10	30	70
I	Village: FRED/ELMER/DAVID Visits to ALVIN-KEITH Time distribution: Table 137				
<u>Unmodified</u>		0.14	0.28	0.83	1.92
II	Village: FRED/ELMER/DAVID Visits to ALICE-WILMA Time distribution: Table 137				
<u>Unmodified</u>		0.38	0.68	1.59	2.97
3. Northern islands plowed		(0.22)	(0.41)	(1.08)	(2.26)
III	Village: JANET No visits to other islands Time distribution: Table 137 with "other islands" time spent in interior of JANET				
<u>Unmodified</u>		0.94	1.71	3.95	6.66
1. Village graveled		(0.82)	(1.49)	(3.48)	(5.96)
2. JANET plowed		(0.36)	(0.68)	(1.70)	(3.24)
IV	Village: BELLE Visits to ALICE-WILMA Time distribution: Table 137				
<u>Unmodified</u>		2.72	4.78	10.06	15.50
1. Village graveled		(1.78)	(3.14)	(6.69)	(10.53)
2. Plus BELLE plowed		(0.83)	(1.47)	(3.26)	(5.47)
3. Plus Northern islands plowed		(0.68)	(1.23)	(2.77)	(4.76)

Table 231 (continued).

V	Village: JANET Visits to KATE-WILMA Time distribution: Table 137				
<u>Unmodified</u>		0.71	1.28	2.94	5.06
1. Village graveled		(0.59)	(1.07)	(2.48)	(4.36)
2. Plus JANET plowed		(0.36)	(0.66)	(1.59)	(3.02)
3. Plus KATE-WILMA plowed		(0.29)	(0.54)	(1.36)	(2.71)
		Gamma dose, rad			
		Time interval, yr			
Case	Living pattern	5	10	30	70
VI	Village: JANET Visits to ALICE-IRENE Time distribution: Table 137				
<u>Unmodified</u>		1.15	2.03	4.39	7.13
1. Village graveled		(1.02)	(1.81)	(3.93)	(6.43)
2. Plus JANET plowed		(0.80)	(1.41)	(3.05)	(5.09)
3. Plus ALICE-IRENE plowed		(0.43)	(0.78)	(1.85)	(3.39)
VIa	Village: JANET Visits to ALICE-WILMA Time distribution: Table 136				
<u>Unmodified</u>		0.76	1.37	3.12	5.33
1. Village graveled		(0.62)	(1.12)	(2.58)	(4.51)
2. Plus JANET plowed		(0.41)	(0.75)	(1.77)	(3.27)
3. Plus Northern islands plowed		(0.30)	(0.56)	(1.40)	(2.76)
VIb	Village: JANET Visits to ALVIN-KEITH Time distribution: Table 136				
<u>Unmodified</u>		0.60	1.10	2.60	4.60
1. Village graveled		(0.48)	(0.88)	(2.14)	(3.90)
2. Plus JANET plowed		(0.25)	(0.48)	(1.26)	(2.56)
Mean population dose (Average of Cases I, II, III, V, and VI)					
<u>Unmodified</u>		0.66	1.20	2.74	4.75
1. Village graveled		(0.59)	(1.07)	(2.46)	(4.33)
2. Plus JANET plowed		(0.41)	(0.74)	(1.75)	(3.25)
3. Plus All Northern islands plowed		(0.29)	(0.54)	(1.36)	(2.70)
Sea level, U.S.A. (80 mrad/yr) Typical					
		0.40	0.80	2.40	5.60

Table 232. The disintegration energy E and the radioactive half-life LR are listed for each radionuclide. The effective biological half-time LMan and the fraction of ingested isotope reaching the organ of reference FMan are listed for three receptor organs, bone, liver, and whole body.

1	BONE MASS= 5.000E+03			LIVER MASS= 1.800E+03		WHOLEBODY MASS= 7.000E+04		
NUCLIDE	E	LR	-LMan-	-FMan-	-LMan-	-FMan-	-LMan-	-FMan-
3 H	6.287E-03	1.549E-04	5.790E-02	9.100E-02	5.790E-02	2.600E-02	5.790E-02	1.000E+00
14 C	6.087E-02	3.314E-07	1.733E-02	2.500E-02	6.930E-02	2.600E-02	6.930E-02	1.000E+00
55FE	6.540E-03	7.032E-04	1.116E-03	1.000E-02	1.954E-03	1.300E-02	1.569E-03	1.000E-01
60CO	8.740E-01	3.609E-04	2.924E-02	2.000E-02	8.191E-03	8.310E-02	8.191E-03	3.000E-01
63NI	1.780E-02	2.064E-05	8.969E-04	1.500E-01	1.407E-03	2.000E-02	1.060E-03	3.000E-01
90SR	5.500E+00	6.781E-05	1.987E-03	3.000E-01	1.156E-01	7.800E-03	1.211E-04	3.000E-01
106RU	1.400E+00	1.899E-03	3.439E-03	3.300E-02	1.180E-02	6.300E-02	7.229E-03	3.000E-01
102RH	1.000E+00	6.544E-04	4.240E-02	1.000E-02	3.873E-02	8.000E-03	6.729E-02	2.000E-01
113CD	1.800E-01	1.356E-04	5.911E-03	9.000E-05	3.601E-03	1.900E-03	1.375E-04	5.900E-02
125SB	3.600E-01	7.032E-04	7.633E-03	3.000E-03	1.894E-02	6.000E-05	1.894E-02	3.000E-02
129 I	7.686E-02	1.187E-10	4.950E-02	7.000E-02	9.900E-02	1.200E-01	5.022E-03	1.000E+00
133BA	3.940E-01	2.637E-04	1.093E-02	3.500E-02	9.745E-04	3.000E-05	1.093E-02	5.000E-02
137CS	5.900E-01	6.329E-05	6.353E-03	9.100E-02	6.363E-03	2.600E-02	7.142E-03	1.000E+00
144CE	3.754E+00	2.432E-03	2.894E-03	3.000E-05	4.797E-03	2.500E-05	3.662E-03	1.000E-04
147PM	2.297E+00	7.032E-04	1.165E-03	3.500E-05	1.760E-03	6.000E-06	1.760E-03	1.000E-04
151SM	1.523E-02	2.110E-05	4.831E-04	3.500E-05	3.727E-03	3.500E-05	1.077E-03	1.000E-04
152EU	6.600E-01	1.531E-04	3.379E-04	3.600E-05	5.610E-03	2.500E-05	3.379E-04	1.000E-04
155EU	1.600E-01	1.055E-03	1.240E-03	3.600E-05	6.511E-03	2.500E-05	1.240E-03	1.000E-04
207BI	1.000E+00	6.329E-05	5.217E-02	3.000E-04	4.626E-02	1.500E-03	1.387E-01	1.000E-02
235 U	4.600E+00	2.662E-12	8.030E-03	5.400E-05	1.899E-06	1.000E-02	8.030E-03	1.000E-04
238PU	4.600E+01	2.134E-05	4.032E-05	1.350E-05	2.323E-05	1.200E-05	3.083E-05	3.000E-05
239PU	5.300E+01	7.794E-08	1.906E-05	1.350E-05	1.977E-06	1.200E-05	9.571E-06	3.000E-05
240PU	5.300E+01	2.809E-07	1.927E-05	1.350E-05	2.180E-06	1.200E-05	9.774E-06	3.000E-05
241AM	5.700E+01	4.145E-06	2.313E-05	4.500E-05	5.161E-05	4.500E-05	2.313E-05	1.000E-04

Table 233. Average concentration, number of samples in the average, standard deviation, and high and low of the range for all fish in the entire Enewetak Atoll.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM		AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
					HIGH	LOW		
01003	MUSCLE	9	3.955E-01	1.517E-01	7.189E-01	1.845E-01	3.955E-01	3.712E-01
19040	MUSCLE	116	1.189E+01	5.277E+00	2.697E+01	2.982E+00	1.189E+01	1.075E+01
26055	MUSCLE	123	1.574E+01	4.108E+01	3.833E+02	1.577E-01	1.566E+01	5.063E+00
27060	MUSCLE	128	2.005E+00	5.377E+00	3.827E+01	4.063E-02	1.958E+00	5.974E-01
38090	MUSCLE	125	1.562E-01	2.460E-01	1.541E+00	1.051E-03	1.177E-01	6.308E-02
44106	MUSCLE	88	8.085E-01	4.558E-01	2.237E+00	3.017E-01	0.	7.058E-01
45102	MUSCLE	128	9.044E-02	6.601E-02	3.729E-01	1.805E-02	0.	7.165E-02
48113	MUSCLE	1	2.635E-01	0.	2.635E-01	2.635E-01	2.635E-01	2.635E-01
51125	MUSCLE	128	2.449E-01	2.581E-01	2.096E+00	7.734E-02	3.910E-02	1.970E-01
55137	MUSCLE	128	3.897E-01	7.940E-01	6.779E+00	2.636E-02	3.493E-01	1.955E-01
56133	MUSCLE	104	1.431E-01	1.205E-01	7.631E-01	2.445E-02	1.598E-02	1.004E-01
58144	MUSCLE	4	2.822E-01	1.269E-02	2.975E-01	2.699E-01	0.	2.820E-01
63152	MUSCLE	128	7.826E-02	5.899E-02	3.415E-01	2.779E-02	0.	6.329E-02
63155	MUSCLE	128	1.107E-01	7.631E-02	5.212E-01	3.097E-02	1.411E-02	9.242E-02
83207	MUSCLE	128	2.409E+00	2.233E+01	2.527E+02	1.965E-02	2.372E+00	1.350E-01
92235	MUSCLE	122	7.932E-02	4.723E-02	2.547E-01	2.271E-02	0.	6.563E-02
94000	MUSCLE	123	2.477E-01	2.003E+00	2.506E+01	4.820E-04	2.444E-01	1.257E-02
94238	MUSCLE	64	1.390E-02	2.175E-02	1.140E-01	1.802E-03	5.241E-03	7.679E-03
95241	MUSCLE	128	1.144E-01	8.462E-02	8.023E-01	2.232E-02	2.771E-03	9.298E-02

\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM  
 \*\*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

Table 234. Radionuclide concentrations in fish (January 1972).

Nuclide	Sample	No. of Samples	Concentration, pCi/g dry weight		
			Average	High	Low
<sup>137</sup> Cs	All fish <sup>a</sup>	128	0.39	6.8	0.026
<sup>60</sup> Co	All fish <sup>a</sup>	128	2.0	38	0.041
<sup>90</sup> Sr	All fish <sup>a</sup>	125	0.16	1.5	0.0010
<sup>90</sup> Sr	Eviscerated whole fish	74	0.21	---	---
<sup>90</sup> Sr	Fish muscle only	51	0.075	---	---

<sup>a</sup>All fish includes eviscerated whole fish and those fish where muscle was separated from bone and only the muscle was analyzed.

weight for use in the dose code by dividing by 3.5, the average wet-to-dry ratio for fish from the Atoll.

Integral doses calculated from the marine survey data are listed in Table 235 for the whole body and bone for 5, 10, 30 and 70 yr. The major contribution to the whole-body dose comes from <sup>137</sup>Cs and <sup>60</sup>Co, while the bone dose comes from <sup>90</sup>Sr, as well as from <sup>137</sup>Cs and <sup>60</sup>Co. The third line of the table gives the summation of the dose to each organ from the three isotopes. The bottom entry in the table lists the dose from all radionuclides listed in the Table 235 footnote.

#### D<sub>1</sub> terrestrial food chain

Evaluation of the potential dose to the returning population via the terrestrial food chain has been structured on the basis of the living patterns in Table 225. The quantity of radionuclides ingested via terrestrial foods was computed from the measured and predicted concentration of activities according to the expected daily diets listed in Table 227. Except for coconut and arrowroot, the daily intake of the food items listed in this table refers

to g/day of fresh food. The g/day intakes listed for coconut and arrowroot refer to the dry weight intake of coconut meat (copra) and processed arrowroot starch. Inferred initial ingestion rates assuming the diet at time of return are shown in Table 236. This diet contains only foods that are available on islands of the group at the time of return, i. e., domestic meat, birds, bird eggs, coconut crabs, and, in the case of the southern islands, coconut meat and coconut milk.

The 30- and 70-yr integral doses were calculated assuming the 10-yr post-return diet. In addition to the foods that are available at the time of return, the 10-yr post-return diet includes pandanus fruit, breadfruit, arrowroot, coconut meat, and coconut milk for all islands. The initial rates of ingestion for each island group assuming the 10-yr post-return diet are listed in Table 237. These values are presented in two parts; the rates of ingestion for the foods immediately available are presented on the left side of Table 237 under January 1, 1974, while the rates of ingestion for the foods that are to become available 8 yr after return

Table 235. Integral dose<sup>a</sup> for 5, 10, 30, and 70 yr from the marine food chain.

Nuclide	Integral dose, rem <sup>b</sup>							
	5 yr		10 yr		30 yr		70 yr	
	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
<sup>137</sup> Cs	0.0061	0.0061	0.012	0.012	0.030	0.030	0.049	0.049
<sup>60</sup> Co	0.0078	0.0078	0.012	0.012	0.017	0.017	0.017	0.017
<sup>90</sup> Sr	---	0.13	---	0.31	---	0.77	--	1.3
Sum	0.014	0.14	0.024	0.33	0.047	0.82	0.066	1.4
All nuclides <sup>c</sup>	0.016	0.14	0.028	0.34	0.053	0.84	0.089	1.6

<sup>a</sup>The dose is based upon the average concentration for fish from the entire Atoll and upon a dietary fish intake of 600 g/day. These doses apply to all six living patterns.

<sup>b</sup>The concentration data were corrected to January 1974, the earliest possible return date to the Atoll; all integral doses are calculated for periods which begin on January 1974.

<sup>c</sup>Isotopes included in the "All nuclides" calculation:

<sup>3</sup> H	<sup>60</sup> Co	<sup>102</sup> Rh	<sup>137</sup> Cs	<sup>152</sup> Eu	<sup>235</sup> U
<sup>14</sup> C	<sup>90</sup> Sr	<sup>113</sup> Cd	<sup>133</sup> Ba	<sup>155</sup> Eu	<sup>238</sup> Pu
<sup>55</sup> Fe	<sup>106</sup> Ru	<sup>125</sup> Sb	<sup>144</sup> Ce	<sup>207</sup> Bi	<sup>239</sup> Pu
					<sup>241</sup> Am

are presented on the right side of Table 237 under the 8-yr post-return date, January 1, 1982. In essence, the foods immediately available are assumed to contribute to the diet beginning January 1, 1974, and the edible plants that are yet to be established are assumed to contribute to the diet beginning January 1, 1982.

Using these data, plus the integrated dose per unit rate of ingestion to whole body and bone shown in Table 238, the integral 5- and 10-yr doses shown in Table 239 have been calculated. The 5- and 10-yr dosages particularly relate to the situation during the initial few years following return.

In computing the bone dose, the whole-body dose from <sup>137</sup>Cs and the other non-bone seekers has been added to the bone dose from <sup>90</sup>Sr and <sup>239,240</sup>Pu. The whole-body dose has been computed as the sum of the whole-body dosages from the non-bone seekers.

Similarly, integral 30- and 70-yr doses have been calculated assuming the 10-yr post-return diet (Table 240).

#### Total Dose

The total 30-yr integral dose predicted for whole body and for bone for the six living patterns are listed in Table 241. This table includes the contributions from each pathway and, for

Table 236. Rate of ingestion of radionuclides from terrestrial foods assuming diet at time of return (Jan. 1, 1974).

Food item	Ingestion rate, pCi/day					
	$^3\text{H}$	$^{55}\text{Fe}$	$^{60}\text{Co}$	$^{90}\text{Sr}$	$^{137}\text{Cs}$	$^{239,240}\text{Pu}$
A. Island group ALICE-IRENE						
Pork and chicken				185	3100	
Wild birds		984	6.21	1.21	<2.4	0.143
Bird eggs		69	<0.29	0.45	<0.24	0.0074
Total		1050	6.35	187	3100	0.150
B. Island group BELLE						
Pork and chicken				302	6960	
Total				302	6960	
C. Island group JANET						
Pork and chicken				108	2320	
Wild birds		1800	7.70	0.29	2.5	0.100
Bird eggs		171	<0.39	0.97	0.6	0.074
Total		1970	7.89	109	2320	0.174
D. Island group KATE-WILMA, LEROY						
Pork and chicken				47.4	858	
Wild birds		1800	7.70	0.29	2.50	0.100
Bird eggs		113	<0.28	0.02	<0.25	0.077
Coconut crabs	0.480		1.03	1.96	7.59	0.0035
Total	0.480	1900	8.87	49.7	868	0.180
E. Island group ALVIN-KEITH						
Pork and chicken				6.18	50.9	
Wild birds		1700	6.41	0.37	2.55	0.704
Bird eggs		131	<0.35	0.02	<0.35	0.003
Coconut	29.3	<23	<2.9	3.35	68.7	<0.259
Coconut milk	14.9	<11	<1.42	0.17	3.44	<0.129
Coconut crabs	2.91		4.23	2.58	9.31	0.023
Total	47.1	1850	13.7	12.7	135	0.99

Table 237. Rate of ingestion of radionuclides from terrestrial foods assuming 10-yr post-return diet.

Food item	Ingestion rate, pCi/day											
	January 1, 1974						January 1, 1982					
	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu
A. Island group ALICE-IRENE												
Domestic meat				308	5170							
Pandanus fruit									941	8840		
Breadfruit									807	7570		
Wild birds		197	1.24	0.242	<0.5	0.0286						
Bird eggs		34.5	<0.14	0.226	<0.1	0.0037						
Arrowroot									47	71		
Coconut meat							23.7	664	<16.3	135	2210	18.1
Coconut milk							35.6	<37	<8.5	20	331	<1.7
Total		231	1.31	308	5170	0.0323	59.3	683	12.4	1950	19000	19
B. Island group BELLE												
Domestic meat				504	11600							
Pandanus fruit								1.34	<1.46	1540	19800	<9.5
Breadfruit								1.15	<1.25	1320	17000	<8.1
Arrowroot									77	159		
Coconut meat									221	4960		
Coconut milk									33	743		
Total				504	11600			2.50	1.35	3180	42700	8.8
C. Island group JANET												
Domestic meat				180	3870							
Pandanus fruit								7.12	<1.25	550	6610	0.082
Breadfruit								6.10	<1.07	471	5560	0.071
Wild birds		360	1.54	0.058	0.50	0.020						
Bird eggs		85.5	<0.19	0.482	0.29	0.037						
Arrowroot									28	53		
Coconut meat									<1.85	79	1650	
Coconut milk								<2.54	<2.27	12	248	<1.31
Total		445	1.64	181	3870	0.057		14.5	3.22	1140	14100	0.81



Table 237 (Continued).

Food item	Ingestion rate, pCi/day											
	January 1, 1974						January 1, 1982					
	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu	<sup>3</sup> H	<sup>55</sup> Fe	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu
D. Island group KATE-WILMA + LEROY												
Domestic meat				79	1430							
Pandanus fruit							3.94	<13.8	241	2480		0.316
Breadfruit							3.38	<11.8	207	2120		0.271
Wild birds		360	1.54	0.058	0.50	0.020						
Bird eggs		56	<0.14	0.01	<0.12	0.039						
Arrowroot									12	20		
Coconut meat							19.0	204	<1.05	34.7	619	<8.64
Coconut milk							28.5	<6.44	<2.27	5.2	93	<0.38
Coconut crabs	0.480		1.03	1.96	7.59	0.003						
Total	0.480	416	2.59	81	1440	0.062	47.5	215	14.4	500	5330	5.0
E. Island group ALVIN-KEITH												
Domestic meat				10.3	84.9							
Pandanus fruit							1.33	<0.65	9.44	85.4		0.156
Breadfruit							1.14	<0.56	8.09	73.2		0.134
Wild birds		340	1.28	0.073	0.51	0.141						
Bird eggs		65	<0.17	0.009	<0.17	0.002						
Arrowroot			Not available							0.47	0.68	
Coconut meat	29.3	<23	<2.9	3.35	68.7	<0.259						
Coconut milk	44.6	<33	<4.2	0.50	10.3	<0.386						
Coconut crabs	2.91		4.23	2.58	9.3	0.023						
Total	76.8	433	9.17	16.8	174	0.488	2.48	0.60	18.0	159		0.290

Table 238. Integrated dose per unit rate of ingestion to whole body and bone.

Nuclide	Organ	$D_T$ , rem/pCi/day						
		Period of integration						
		2 yr	5 yr	10 yr	22 yr	30 yr	62 yr	70 yr
$^3\text{H}$	Whole body	4.51(-8) <sup>a</sup>	1.05(-7)	1.85(-7)	3.05(-7)	3.51(-7)	4.17(-7)	4.23(-7)
$^{55}\text{Fe}$	Whole body	7.50(-8)	2.35(-7)	3.73(-7)	4.29(-7)	4.32(-7)	4.32(-7)	4.32(-7)
$^{60}\text{Co}$	Whole body	1.27(-5)	2.96(-5)	4.65(-5)	6.09(-5)	6.33(-5)	6.46(-5)	6.46(-5)
$^{90}\text{Sr}$	Bone	2.87(-3)	1.08(-2)	2.39(-2)	4.99(-2)	6.33(-2)	9.70(-2)	1.02(-1)
$^{137}\text{Cs}$	Whole body	3.49(-5)	9.62(-5)	1.89(-4)	3.74(-4)	4.71(-4)	7.22(-4)	7.61(-4)
$^{239,240}\text{Pu}$	Bone	1.51(-6)	9.39(-6)	3.71(-5)	1.75(-4)	3.19(-4)	1.27(-3)	1.59(-3)

<sup>a</sup>The number within parentheses denotes the power of 10. Thus, 4.51(-8) is a contraction of  $4.51 \times 10^{-8}$  rem/pCi/day.

Table 239. Prediction of the dosage from ingestion of terrestrial foods assuming diet at the time of return.

Isotope	5-yr dose, rem		10-yr dose, rem	
	Whole body	Bone	Whole body	Bone
A. Island group ALICE-IRENE				
$^3\text{H}$			2.7(-6)	
$^{55}\text{Fe}$	2.5(-4) <sup>a</sup>		4.4(-4)	
$^{60}\text{Co}$	1.9(-4)		4.5(-4)	
$^{90}\text{Sr}$		2.02		10.1
$^{137}\text{Cs}$	0.298		1.25	
$^{239,240}\text{Pu}$		1.4(-6)		3.4(-5)
Subtotal	0.298	2.02	1.25	10.1
Total 5-yr whole-body dose	0.30 rem		Total 10-yr whole-body dose	1.25 rem
Total 5-yr bone dose	2.32 rem		Total 10-yr bone dose	11.3 rem
B. Island group BELLE				
$^{55}\text{Fe}$			1.9(-7)	
$^{60}\text{Co}$			1.7(-5)	
$^{90}\text{Sr}$		3.26		16.3
$^{137}\text{Cs}$	0.669		2.81	
$^{239,240}\text{Pu}$				1.3(-5)
Subtotal	0.67	3.26	2.81	16.3
Total 5-yr whole-body dose	0.67 rem		Total 10-yr whole-body dose	2.81 rem
Total 5-yr bone dose	3.93 rem		Total 10-yr bone dose	19.2 rem

Table 239 (Continued).

Isotope	5-yr dose, rem		10-yr dose, rem	
	Whole body	Bone	Whole body	Bone
C. Island group JANET				
<sup>55</sup> Fe	4.6(-4)		7.4(-4)	
<sup>60</sup> Co	2.3(-4)		4.1(-4)	
<sup>90</sup> Sr		1.18		5.88
<sup>137</sup> Cs	0.223		0.831	
<sup>239,240</sup> Pu		1.6(-6)		7.6(-6)
Subtotal	0.224	1.18	0.932	5.88
Total 5-yr whole-body dose	0.22 rem		Total 10-yr whole-body dose 0.93 rem	
Total 5-yr bone dose	1.40 rem		Total 10-yr bone dose 6.82 rem	
D. Island group KATE-WILMA + LEROY				
<sup>3</sup> H	5.0(-8)		2.2(-6)	
<sup>55</sup> Fe	4.5(-4)		7.3(-4)	
<sup>60</sup> Co	2.6(-4)		6.0(-4)	
<sup>90</sup> Sr		0.536		2.62
<sup>137</sup> Cs	0.0835		0.350	
<sup>239,240</sup> Pu		1.7(-6)		1.4(-5)
Subtotal	0.0842	0.536	0.351	2.62
Total 5-yr whole-body dose	0.084 rem		Total 10-yr whole-body dose 0.351 rem	
Total 5-yr bone dose	0.620 rem		Total 10-yr bone dose 2.97 rem	

Table 239 (Continued)

Isotope	5-yr dose, rem		10-yr dose, rem	
	Whole body	Bone	Whole body	Bone
E. Island group ALVIN-KEITH				
$^3\text{H}$	4.9(-6)		8.7(-6)	
$^{55}\text{Fe}$	4.4(-4)		6.9(-4)	
$^{60}\text{Co}$	4.1(-4)		6.5(-4)	
$^{90}\text{Sr}$		0.137		0.355
$^{137}\text{Cs}$	0.0130		0.0311	
$^{239,240}\text{Pu}$		9.3(-6)	0.0324	3.7(-5)
Subtotal	0.0138	0.137	0.0324	0.303
Total 5-yr whole-body dose	0.014 rem		Total 10-yr whole-body dose	0.032 rem
Total 5-yr bone dose	0.151 rem		Total 10-yr bone dose	0.387 rem

<sup>a</sup>The number within parentheses denotes the power of 10. Thus, 2.5(-4) is a contraction of  $2.5 \times 10^{-4}$ .

Table 240. Prediction of the dosage from ingestion of terrestrial foods assuming 10-yr post-return diet.

Isotope	Ingestion rate, pCi/day January 1, 1974		30-yr dose, rem		70-yr dose, rem		Ingestion rate, pCi/day January 1, 1984		22-yr dose, rem		62-yr dose, rem	
	Whole body	Bone	Whole body	Bone	Whole body	Bone	Whole body	Bone	Whole body	Bone	Whole body	Bone
A. Island group												
ALICE-IRENE												
<sup>3</sup> H							59.3		1.8(-5)		2.5(-5)	
<sup>55</sup> Fe	231		1.0(-4) <sup>a</sup>		1.0(-4)		683		0.0003		0.0003	
<sup>60</sup> Co	1.31		8.3(-5)		8.5(-5)		12.4		0.0008		0.0008	
<sup>90</sup> Sr	308			19.5		31.5	1950			97.3		190
<sup>137</sup> Cs	5170		2.44		3.93		19,000		7.11		13.7	
<sup>239,240</sup> Pu	0.0323			1.0(-5)		5.1(-5)	19			0.003		0.024
Subtotal			2.44	19.5	3.93	31.5			7.11	97.3	13.7	190
Total 30-yr whole-body dose			9.55 rem				Total 70-yr whole-body dose			17.7 rem		
Total 30-yr bone dose			126 rem				Total 70-yr bone dose			239 rem		
B. Island group												
BELLE												
<sup>55</sup> Fe							2.50		1.1(-6)		1.1(-6)	
<sup>60</sup> Co							1.35		8.2(-5)		8.7(-5)	
<sup>90</sup> Sr	504			31.9		51.4	3180			159		309
<sup>137</sup> Cs	11,600		5.46		8.83		42,700		16.0		30.8	
<sup>239,240</sup> Pu							8.8			1.5(-3)		1.1(-2)
Subtotal			5.46	31.9	8.83	51.4			16.0	159	30.8	309
Total 30-yr whole-body dose			21.4 rem				Total 70-yr whole-body dose			39.6 rem		
Total 30-yr bone dose			212 rem				Total 70-yr bone dose			400 rem		

Table 240 (Continued).

Isotope	Ingestion rate, pCi/day January 1, 1974	<u>30-yr dose, rem</u>		<u>70-yr dose, rem</u>		Ingestion rate, pCi/day January 1, 1984	<u>22-yr dose, rem</u>		<u>62-yr dose, rem</u>	
		Whole body	Bone	Whole body	Bone		Whole body	Bone	Whole body	Bone
C. Island group										
JANET										
<sup>55</sup> Fe	445	1.9(-4)		1.9(-4)		14.5	6.2(-6)		6.2(-6)	
<sup>60</sup> Co	1.64	1.0(-4)		1.1(-4)		3.22	2.0(-4)		2.1(-4)	
<sup>90</sup> Sr	181		11.4		18.4	1140		56.9		111
<sup>137</sup> Cs	3870	1.82		2.95		14,100	5.28		10.2	
<sup>239,240</sup> Pu	0.057		1.8(-5)		9.1(-5)	0.806		1.4(-4)		1.0(-3)
Subtotal		1.82	11.4	2.95	18.4		5.28	56.9	10.2	111
Total 30-yr whole-body dose		7.10 rem				Total 70-yr whole-body dose		13.1 rem		
Total 30-yr bone dose		75.4 rem				Total 70-yr bone dose		142 rem		
D. Island group										
KATE-WILMA + LEROY										
<sup>3</sup> H	0.480	2(-7)		2.0(-7)		47.5	1.5(-5)		2.0(-5)	
<sup>55</sup> Fe	416	1.8(-4)		1.8(-4)		215	9.2(-5)		9.3(-5)	
<sup>60</sup> Co	2.59	1.6(-4)		1.7(-4)		14.4	8.8(-4)		9.3(-4)	
<sup>90</sup> Sr	81.0		5.13		8.26	500		24.9		48.5
<sup>137</sup> Cs	1440	0.677		1.09		5330	1.99		3.85	
<sup>239,240</sup> Pu	0.062		2.0(-5)		9.8(-5)	4.96		8.7(-4)		6.3(-3)
Subtotal		0.677	5.13	1.09	8.26		1.99	24.9	3.85	48.5
Total 30-yr whole-body dose		2.67 rem				Total 70-yr whole-body dose		4.94 rem		
Total 30-yr bone dose		32.7 rem				Total 70-yr bone dose		61.7 rem		

Table 240 (Continued).

Isotope	Ingestion rate, pCi/day January 1, 1974	30-yr dose, rem		70-yr dose, rem		Ingestion rate, pCi/day January 1, 1984	22-yr dose, rem		62-yr dose, rem	
		Whole body	Bone	Whole body	Bone		Whole body	Bone	Whole body	Bone
E. Island group										
ALVIN-KEITH										
<sup>3</sup> H	76.8	1.3(-5)		3.3(-5)						
<sup>55</sup> Fe	433	1.9(-4)		1.9(-4)		2.48	1.1(-6)		1.1(-6)	
<sup>60</sup> Co	9.17	5.8(-4)		5.9(-4)		0.60	3.7(-5)		3.9(-5)	
<sup>90</sup> Sr	16.8		1.07		1.72	18.0		0.898		1.75
<sup>137</sup> Cs	174	0.0819		0.132		159	0.0596		0.115	
<sup>239,240</sup> Pu	0.49		1.6(-4)		7.8(-4)	0.290		1.8(-4)		1.3(-3)
Subtotal		0.0826	1.07	0.133	1.72		0.0596	0.898	0.115	1.75
Total 30-yr whole-body dose		0.142 rem				Total 70-yr whole-body dose	0.248 rem			
Total 30-yr bone dose		2.11 rem				Total 70-yr bone dose	3.71 rem			

<sup>a</sup>The number within parentheses denotes the power of 10; thus, 1.0(-4) is a contraction of  $1.0 \times 10^{-4}$ .



Table 241. The 30-yr integral dose for the six living patterns assuming unmodified conditions.

Living pattern	30-yr integral dose, rem									
	Unmodified conditions									
	Inhalation		External Bone, <sup>a</sup>		Terrestrial <sup>b</sup>		Marine <sup>b</sup>		Total	
	Bone	Lung	Liver	W. B.	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	7(-4)	9(-4)	4(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.029	0.036	0.016	1.6	2.7	33	0.053	0.84	4.4	35
III	0.10	0.13	0.056	4.0	7.1	75	0.053	0.84	11	80
IV	0.47	0.59	0.25	10	21	210	0.053	0.84	31	220
V	0.11	0.13	0.058	2.9	2.7	33	0.053	0.84	5.7	37
VI	0.090	0.11	0.049	4.4	9.6	130	0.053	0.84	14	135

Living pattern	Village island	Agriculture	Visitation
I	Enewetak-Parry	ALVIN-KEITH	Southern Is.
II	Enewetak-Parry	KATE-WILMA + LEROY	Northern Is.
III	JANET	JANET	Northern Is.
IV	BELLE	BELLE	Northern Is.
V	JANET	KATE-WILMA + LEROY	Northern Is.
VI	JANET	ALICE-IRENE	Northern Is.

<sup>a</sup>Taken from the chapter on external dose estimates, Table 22.

<sup>b</sup>Based upon diet 10 yr after return, as described in the dietary and living patterns chapter.

the external dose assessment, is based upon the unmodified conditions for the village island. The largest contribution to the whole-body and bone doses comes from the terrestrial food chain, the external dose pathway is the next highest contributor, and the marine food chain and inhalation pathway contribute the least.\* The relative contributions of each diet component to the terrestrial pathway dose is shown in Tables 242 and 243.

In general, living on JANET, visiting northern islands, and maintaining agriculture on northern islands (living patterns III, V, and VI) lead to significantly higher doses than if the village and agriculture are located on islands in the southern half of the Atoll (living pattern I). Doses for these same patterns have been calculated for 5, 10, and 70 yr and are shown in Table 244.

The most significant contribution via the terrestrial food chain is the dose to bone resulting from  $^{90}\text{Sr}$  uptake via

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\* As indicated earlier, these dose calculations assume that the Enewetak people will continue their current practice of using catchment rain water for drinking and that the underground lens water supply will not be a part of their diet. An indication of doses that are to be expected from lens water may be obtained from four water samples taken on JANET in July 1971. These samples, two each from each of two 2.5-m-deep holes about 100 m from the lagoon shore, gave average concentrations of 130 pCi/liter for  $^{90}\text{Sr}$ , and 400 pCi/liter for  $^{137}\text{Cs}$ .  $^{239}\text{Pu}$  concentrations were scattered (<0.03, 21, <0.03, and 17 pCi/liter) but, for our current purpose, we will assume an average value of 20 pCi/liter.

Using these concentrations, and assuming an average daily intake of 100 ml of lens water, the resulting 30-yr doses would be 0.83 rem due to  $^{90}\text{Sr}$ , 0.019 rem due to  $^{137}\text{Cs}$ , and 0.00082 rem due to  $^{239}\text{Pu}$ .

pandanus fruit and breadfruit. For living pattern III, for example, the total terrestrial bone dose is 75 rem, of which 74% is derived from the intake of breadfruit and pandanus. It is important to note, however, that the large contribution to the bone dose via these fruits occurs only when they are grown on northern islands. Pandanus and breadfruit grown on the less contaminated southern islands lead to much lower dose commitments.

Table 245 shows the 30-yr integral dose for the six living patterns for the modified soil condition, i. e., where the village area has 5 cm of gravel and the village island is plowed. Table 246 shows the 5-, 10-, 30-, and 70-yr dose estimates for the same conditions.

Table 247 shows the additional effect on the 30-yr integral dose of limiting growth of pandanus, breadfruit, coconut, and tacca to the southern islands, while Table 248 shows the effect of limiting all terrestrial foods to the southern islands. The effect of the combination of these preventive measures reduces the dose for living pattern III from 11 rem to 1.9 rem for whole body and from 80 to 4.7 rem for bone.

A comparison of the 30-yr integral dose for living patterns I and III relative to the average United States external background dose over 30 yr is shown in Table 249.

Plutonium isotopes, because of their long half-lives, will still be present when the other major isotopes observed at the Atoll have decayed away; therefore, Tables 250 and 251 are included to show the predicted doses from plutonium to the three major receptor organs (lung, liver, and bone) via the three relevant exposure pathways.

The island of YVONNE presents a unique hazard on Enewetak Atoll. Pure plutonium particles are present on or close to the ground surface, randomly scattered in "hot spots" over most of the area from the tower to CACTUS crater. Examination of these "hot spots" has revealed the presence of occasional milligram-size pieces of plutonium metal, as well as smaller pieces which are physically indistinguishable in size from the surrounding coral matrix. Given these current conditions, it must be assumed that pure plutonium particles of respirable size are now also present on the surface or may be present in the future as weathering effects oxidize and break down the larger particles. Lung dose assessments for this area, therefore, must be based on inhalation of pure plutonium particles rather than those having the average plutonium content of the soil.

The potential health hazard via the inhalation pathway is sufficiently great to dictate two basic alternatives for remedial action for this island: (1) Make the entire island an exclusion area – off limits to all people, or (2) conduct a cleanup campaign which will eliminate the "hot-spot" plutonium problem and remove whatever amount of soil is necessary to reduce the soil plutonium concentration to a level comparable to other northern islands. As an indication of the volumes of soil involved, removal of a 10-cm-thick layer of topsoil in the area in which "hot spots" have been detected involves approximately 17,000 m<sup>3</sup> of material. Further removal of soil to reduce the maximum plutonium contamination levels to 50 pCi/g or less involves an additional 25,000 m<sup>3</sup> of material.

Table 242. Relative contributions of terrestrial foods to the integral dose assuming diet at time of return.

Food item	Percentage of total 5-yr		Percentage of total 10-yr	
	<sup>90</sup> Sr dose to bone	<sup>137</sup> Cs dose whole body	<sup>90</sup> Sr dose to bone	<sup>137</sup> Cs dose whole body
A. Island group ALICE-IRENE				
Domestic meat	98.9	100	43.9	46.9
Pandanus fruit			26.8	24.7
Breadfruit			23.1	21.1
Wild birds	0.65	<0.08	0.29	0.04
Bird eggs	0.24	<0.008	0.11	0.004
Arrowroot			1.3	0.20
Coconut meat			3.9	6.2
Coconut milk			0.57	0.93
B. Island group BELLE				
Domestic meat	100	100	44.2	47.1
Pandanus fruit			27.0	24.6
Breadfruit			23.2	21.1
Arrowroot			1.4	0.20
Coconut meat			3.9	6.2
Coconut milk			0.58	0.92

Table 242 (continued)

Food item	Percentage of total 5-yr		Percentage of total 10-yr	
	<sup>90</sup> Sr dose to bone	<sup>137</sup> Cs dose whole body	<sup>90</sup> Sr dose to bone	<sup>137</sup> Cs dose whole body
C. Island group JANET				
Domestic meat	99.1	100	43.9	47.0
Pandanus fruit			26.9	24.8
Breadfruit			22.9	20.8
Wild birds	0.27	0.11	0.12	0.05
Bird eggs	0.89	0.03	0.39	0.01
Arrowroot			1.4	0.20
Coconut meat			3.9	6.2
Coconut milk			0.59	0.93
D. Island group KATE-WILMA + LEROY				
Domestic meat	95.4	98.8	43.1	46.3
Pandanus fruit			26.4	24.7
Breadfruit			22.7	21.1
Wild birds	0.58	0.29	0.26	0.14
Bird eggs	0.04	<0.03	0.02	0.01
Arrowroot			1.3	0.20
Coconut meat			3.8	6.2
Coconut milk			0.57	0.93
Coconut crabs	3.9	0.87	2.4	0.41
E. Island group ALVIN-KEITH				
Domestic meat	48.7	37.7	41.7	30.9
Pandanus fruit			7.6	9.6
Breadfruit			6.5	8.2
Wild birds	2.9	1.9	2.5	1.5
Bird eggs	0.2	<0.26	0.13	0.21
Arrowroot			0.38	0.08
Coconut meat	26.4	50.9	22.6	41.8
Coconut milk	1.4	2.5	1.1	2.1
Coconut crabs	20.3	6.9	17.4	5.6

Table 243. Relative contributions of terrestrial foods to the integral dose assuming 10-yr post-return diet.

Food item	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body		<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body	
	Commencement date 1/1/74	Commencement date 1/1/82	Commencement date 1/1/74	Commencement date 1/1/82	Commencement date 1/1/74	Commencement date 1/1/82	Commencement date 1/1/74	Commencement date 1/1/82
<b>A. Island group ALICE-IRENE</b>								
Domestic meat	16.7		25.5		14.2		22.3	
Pandanus fruit		40.2		34.7		41.4		36.2
Breadfruit		34.5		29.6		35.5		31.0
Wild birds	0.01		<0.002		0.01		<0.002	
Bird eggs	0.01		<0.0005		0.01		<0.004	
Arrowroot		2.0		0.28		2.1		0.29
Coconut meat		5.8		8.7		5.9		9.1
Coconut milk		0.85		1.3		0.88		1.4
Subtotal	17	83	26	74	14	86	22	78
<b>B. Island group BELLE</b>								
Domestic meat	16.7		25.4		14.3		22.3	
Pandanus fruit		40.2		34.5		41.5		36.1
Breadfruit		34.5		29.6		35.6		31.0
Arrowroot		2.0		0.27		2.1		0.29
Coconut meat		5.8		8.7		6.0		9.0
Coconut milk		0.86		1.3		0.89		1.4
Subtotal	17	83	25	75	14	86	22	78

Table 243 (Continued).

Food item	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body		<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body	
	Commencement date		Commencement date		Commencement date		Commencement date	
	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82
<b>C. Island group JANET</b>								
Domestic meat	16.7		25.7		14.2		22.6	
Pandanus fruit		39.6		34.8		41.2		36.6
Breadfruit		34.4		29.3		35.3		30.7
Wild birds	0.005		0.003		0.005		0.003	
Bird eggs	0.05		0.002		0.04		0.002	
Arrowroot		2.0		0.28		2.1		0.29
Coconut meat		5.8		8.7		5.9		9.1
Coconut milk		<u>0.88</u>		<u>1.3</u>		<u>0.90</u>		<u>1.4</u>
Subtotal	17	83	26	74	14	86	23	77
<b>D. Island group KATE-WILMA + LEROY</b>								
Domestic meat	16.6		25.2		14.2		22.0	
Pandanus fruit		39.8		34.8		41.2		36.2
Breadfruit		34.2		29.7		35.4		30.9
Wild birds	0.01		0.009		0.01		0.008	
Bird eggs	0.002		0.003		0.002		0.002	
Arrowroot		2.0		0.28		2.0		0.29
Coconut meat		5.7		8.7		5.9		9.0
Coconut milk		0.86		1.3		0.89		1.4
Coconut crabs	<u>0.41</u>		<u>0.13</u>		<u>0.35</u>		<u>0.12</u>	
Subtotal	17	83	25	75	15	85	22	78

Table 243 (Continued).

Food item	Percentage of total 30-yr dose				Percentage of total 70-yr dose			
	<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body		<sup>90</sup> Sr dose to bone		<sup>137</sup> Cs dose to whole body	
	Commencement date		Commencement date		Commencement date		Commencement date	
	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82	1/1/74	1/1/82
E. Island group ALVIN-KEITH								
Domestic meat	33.3		28.3		30.3		26.2	
Pandanus fruit		24.1		22.5		26.5		25.0
Breadfruit		20.6		19.4		22.7		21.4
Wild birds	0.24		0.17		0.22		0.16	
Bird eggs	0.03		0.06		0.03		0.05	
Arrowroot		1.2		0.18		1.3		0.20
Coconut meat	10.8		22.9		9.9		21.2	
Coconut milk	1.6		3.4		1.5		3.2	
Coconut crabs	8.3		3.1		7.6		2.9	
Subtotal	54	46	58	42	50	50	54	46

Table 244. The 5-, 10-, 30-, and 70-yr doses for the six living patterns assuming unmodified conditions.

Living pattern	Total integral dose, rem Unmodified conditions							
	5 yr		10 yr		30 yr		70 yr	
	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	0.17	0.58	0.35	1.4	1.0	3.8	2.3	8.5
II	0.48	1.3	1.1	4.3	4.4	35	8.0	68
III	1.2	2.6	2.7	9.2	11	80	20	150
IV	3.4	6.9	7.6	25	31	220	56	420
V	0.81	1.6	1.7	4.9	5.7	37	10	71
VI	1.5	3.8	3.3	14	14	135	25	250

Table 245. The 30-yr integral dose for the six living patterns assuming modified conditions.

Living pattern	30-yr integral dose, rem <sup>a</sup> Modified conditions										
	Inhalation			External		Terrestrial		Marine		Total	
	Bone	Lung	Liver	Bone,	W.B.	W.B.	Bone	W.B.	Bone	W.B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83		0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	6.6(-3)	1.1		2.7	33	0.053	0.84	3.9	35
III	0.045	0.056	0.024	1.7		7.1	75	0.053	0.84	8.9	78
IV	0.092	0.11	0.050	3.3		21	210	0.053	0.84	24	215
V	0.045	0.056	0.024	1.6		2.7	33	0.053	0.84	4.4	35
VI	0.058	0.072	0.031	3.1		9.6	130	0.053	0.84	13	135

<sup>a</sup>Modified by graveling the village area and by plowing the village island.



Table 246. The 5-, 10-, 30-, and 70-yr doses for the six living patterns assuming modified conditions.

Living pattern	Total integral dose, rem Modified conditions <sup>a</sup>							
	5 yr		10 yr		30 yr		70 yr	
	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	0.17	0.58	0.35	1.4	1.0	3.8	2.3	8.5
II	0.48	1.3	1.1	4.3	3.9	35	8.0	68
III	0.60	2.1	1.7	8.2	8.9	78	16	150
IV	1.5	5.0	4.3	22	24	215	46	410
V	0.46	1.3	1.0	4.3	4.4	35	8.0	68
VI	1.1	3.4	2.7	13	13	135	23	250

<sup>a</sup>Modified by gravelling the village area and plowing the village island.

Table 247. The 30-yr integral dose for the six living patterns assuming modified conditions and agriculture on the southern islands.

Living pattern	30-yr integral dose, rem Modified conditions <sup>a</sup> and pandanus, breadfruit, coconut, and tacca grown on southern islands									
	Inhalation		External		Terrestrial <sup>c</sup>		Marine		Total	
	Bone	Lung	Liver	Bone, W. B.	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	0.0066	1.1	0.77	7.1	0.053	0.84	1.9	9.1
III	0.045	0.056	0.024	1.7	1.9	15	0.053	0.84	3.7	18
IV	0.092	0.11	0.050	3.3	5.7	39	0.053	0.84	9.1	43
V	0.045	0.056	0.024	1.6	0.77	7.1	0.053	0.84	2.4	9.6
VI	0.058	0.072	0.031	3.1	2.5	23	0.053	0.84	5.7	27

<sup>a</sup>Modified by graveling the village area and by plowing the village island.

Table 248. The 30-yr integral dose for the six living patterns assuming modified conditions and agriculture on the southern islands.

Living pattern	30-yr integral dose, rem Modified conditions <sup>a</sup> and agriculture on southern islands									
	Inhalation		External		Terrestrial		Marine		Total	
	Bone	Lung	Liver	Bone, W. B.	W. B.	Bone	W. B.	Bone	W. B.	Bone
I	3(-4)	4(-4)	2(-4)	0.83	0.14	2.1	0.053	0.84	1.0	3.8
II	0.012	0.015	0.0066	1.1	0.14	2.1	0.053	0.84	1.3	4.1
III	0.045	0.056	0.024	1.7	0.14	2.1	0.053	0.84	1.9	4.7
IV	0.092	0.11	0.050	3.3	0.14	2.1	0.053	0.84	3.5	6.3
V	0.045	0.056	0.024	1.6	0.14	2.1	0.053	0.84	1.8	4.6
VI	0.058	0.072	0.031	3.1	0.14	2.1	0.053	0.84	3.3	6.1

<sup>a</sup>Modified by graveling the village area and by plowing the village island.

Table 249. The 30-yr integral dose from all pathways compared to U. S. external background dose.

Location	30-yr integral dose, <sup>a</sup> rem			
	Unmodified case		Modified case	
	Whole body	Bone	Whole body	Bone
Enewetak Atoll Living pattern I	1.0	3.8	1.0	3.8
Enewetak Atoll Living pattern III	11	80	8.9	78
Enewetak Atoll Living pattern III, agriculture confined to southern islands	4.2	7.0	1.9	4.7
U. S. background only <sup>b</sup>	3.0	3.0	3.0	3.0

<sup>a</sup>Sum of all pathways for the Enewetak living patterns (i. e., external, inhalation, marine, and terrestrial).

<sup>b</sup>Based upon background of 100 mrem/yr at sea level.

Table 250. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table assumes unmodified conditions on the village island.

Plutonium 30-yr integral dose, rem Unmodified conditions												
Living pattern	Marine			Terrestrial			Inhalation			Total		
	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung
I	0.018	0.047	-	5.0(-5)	1.8(-4)	-	7(-4)	4(-4)	9(-4)	0.018	0.048	9(-4)
II	0.018	0.047	-	1.5(-3)	5.0(-3)	-	0.029	0.016	0.036	0.049	0.068	0.036
III	0.018	0.047	-	6.9(-3)	5.3(-3)	-	0.10	0.056	0.13	0.12	0.11	0.13
IV	0.018	0.047	-	3.0(-3)	0.010	-	0.47	0.25	0.59	0.49	0.31	0.59
V	0.018	0.047	-	5.0(-5)	1.8(-4)	-	0.11	0.058	0.13	0.13	0.11	0.13
VI	0.018	0.047	-	3.0(-3)	0.010	-	0.090	0.049	0.11	0.11	0.11	0.11

Table 251. The plutonium 30-yr integral dose to bone, liver, and lung via the three exposure pathways. This table assumes modified conditions.

Plutonium 30-yr integral dose, rem Modified conditions												
Living pattern	Marine			Terrestrial			Inhalation			Total		
	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung	Bone	Liver	Lung
I	0.018	0.047	-	5.0(-5)	1.8(-4)	-	3(-4)	2(-4)	4(-4)	0.018	0.047	4(-4)
II	0.018	0.047	-	1.5(-3)	5.0(-3)	-	0.012	0.0066	0.015	0.032	0.057	0.015
III	0.018	0.047	-	6.9(-3)	5.3(-3)	-	0.045	0.024	0.056	0.070	0.076	0.056
IV	0.018	0.047	-	3.0(-3)	0.010	-	0.092	0.050	0.11	0.11	0.11	0.11
V	0.018	0.047	-	5.0(-5)	1.8(-4)	-	0.045	0.024	0.056	0.063	0.071	0.056
VI	0.018	0.047	-	3.0(-3)	0.010	-	0.058	0.031	0.072	0.079	0.088	0.072

## Appendix I

### Planning and Operations Directive (NVO-121) – 1972 Enewetak Atoll Precleanup Radiological Survey

#### I. BACKGROUND

##### A. History and Purpose

The Enewetak Atoll was extensively used during the 1950's for atmospheric nuclear testing, necessitating displacement of individuals living there. Since the United States Government is prepared to release legally the entire atoll to the trust territory government at the end of 1973, subject to retention of some minor residual rights, rehabilitation of the atoll has been proposed. In anticipation of possible rehabilitation, a preliminary survey of the Enewetak Atoll was conducted by NV during May 1972 to facilitate comprehensive survey planning. This survey established partial information on the extent of radioactive material on the Atoll, but the information was not sufficiently comprehensive to permit careful assessment of the radiological implications of test debris remaining on the atoll or of cleanup costs for material that must be removed before the native population can return. A comprehensive survey is required in order that these assessments may be made. The AEC has accepted responsibility for conducting this survey and has assigned it for Headquarters coordination to DMA and has directed NV to implement the program.

The purpose of this Planning and Operations Directive is to provide guidance and to define responsibilities for the conduct of this survey.

##### B. Political Considerations and Interagency Arrangements

Within the AEC the Assistant General Manager for Military Application is responsible for coordination with the Department of the Interior (including Trust Territories Administration), the Department of Defense, the Environmental Protection Agency, and all other Washington level agencies and officials. There has been established an interagency Washington level coordinating group charged with definition of overall Enewetak Atoll objectives, with one member each from the Department of Interior, Department of Defense, and AEC.

##### C. Objectives of the Survey

Specific objectives of the Enewetak Atoll pre-cleanup radiological survey are as follows:

1. To locate and identify contaminated and activated test debris.
2. To locate and evaluate any significant radiological hazards which may complicate cleanup activities.
3. To identify sources of direct radiation and food chain-to-man paths having radiological implications.

#### D. Survey Plan

The Radiological Survey Plan, which describes the manner in which the technical objectives are to be achieved, is attached as Appendix A.

## II. AUTHORITIES AND RESPONSIBILITIES

Authorization and guidance for the Enewetak Atoll pre-cleanup radiological survey was furnished NV per teletype from AEC Headquarters dated September 13, 1972, attached as Appendix B.

The Division of Military Application will provide overall Washington direction and will coordinate AEC policy relating to the conduct of the survey itself. Standards and requirements for the survey have been defined by the Division of Operational Safety and Biomedical and Environmental Research, and are incorporated in the Survey Plan.

Within the Nevada Operations Office, the Assistant Manager for Operations will be responsible to the Manager for successful accomplishment of the objectives of the Enewetak Atoll radiological survey, laboratory analysis effort and for preparation of the required survey and study reports. He will be supported by a Technical Director who shall have full authority and responsibility for the technical conduct and execution of the survey plan. The Assistant Manager for Operations will be assisted, to the extent required by the Assistant Manager for Engineering and Logistics, and the Director, Pacific Area Support Office, in matters of field support. Within this framework, NV's responsibilities are as follows:

1. To prepare a plan for the conduct of the field survey and for the analysis of samples obtained, utilizing necessary laboratory and contractor support.
2. To select personnel to conduct the field survey.
3. To select laboratories and personnel to accomplish the laboratory analysis work. This task includes the establishment of procedures, standards and methods for the correlation of data between laboratories.
4. To support AEC Headquarters activities required for pathway and dose assessment.
5. To arrange for necessary logistical support.
6. To maintain direct liaison with DNA for field support and to keep AEC Headquarters Divisions cognizant of field activities.
7. Pending further guidance, to address priority considerations in planning for sample analysis and for the biological pathway and dose assessment portions of this task.
8. To develop the appropriate survey reports and submit them to AEC Headquarters.

## III. ORGANIZATION

The organization for the Enewetak Atoll radiological survey program is incorporated in Appendix A.

## IV. SURVEY EXECUTION

The survey will be conducted over a period of about eight weeks starting on or about October 13, 1972.

The field party performing this survey is expected to include representatives of:

1. Division of Operational Safety, (DOS), HQ
2. Office of the Assistant Manager for Operations (AMO), NV
3. National Environmental Research Center (EPA/NERC), Las Vegas, Nev.
4. Laboratory of Radiation Ecology (LRE), University of Washington
5. Lawrence Livermore Laboratory (LLL)
6. Holmes and Narver, Inc. (H&N)
7. Eberline Instrument Corporation (EIC)

The Laboratory effort will continue for some months following the survey and is described in detail in Appendix A.

Initial deployment of equipment and personnel will be via military special air mission from Travis Air Force

Base to Enewetak. Personnel rotation and sample shipments will be handled by normal military and commercial aircraft. A schedule of field survey personnel is attached as Appendix C.

## V. PROGRAM FUNDING

Funds in the amount of \$314,000 have been made available for this survey. Of this, \$100,000 was provided by DOS and \$214,000 by DMA.

Costs will be reported by contractors in category 03-30-01-02 (on-contingent technical support). The Finance Division will record costs as necessary to account for the various funding sources.

Contractors will be provided funding in financial plans in the above category.

LLL internal effort associated with this survey will be costed within LLL program funding.

## APPENDIX A

Enewetak Radiological Survey Plan

29 September 1972

W. E. Nervik, Technical Director

## I. INTRODUCTION

Purpose: AEC Headquarters has accepted responsibility for conducting a comprehensive radiological survey of the Enewetak Atoll. DMA has been given responsibility within Headquarters for the survey and they, in turn, have delegated the responsibility to NVOO.

In the wording of the 13 September 1972 implementing directive from DMA to NVOO:

"It is the overall AEC purpose to gain a sufficient understanding of the total radiological environment of Eniwetok Atoll to permit judgments as to whether all or any part of the atoll can safely be reinhabited

and, if so, what steps toward cleanup should be taken beforehand and what post-rehabilitation constraints must be imposed. It is necessary to thoroughly examine and evaluate radiological conditions on all islands of the atoll and in the local marine environment prior to commencement of cleanup activities in order to obtain sufficient radiological intelligence to develop an appropriate cleanup program.

Specifically, it is necessary:

- 1- To locate and identify contaminated and activated test debris,
- 2- To locate and evaluate any significant radiological hazards which may complicate cleanup activities, and
- 3- To identify sources of direct radiation and food chain-to-man paths having radiological implications.

You are directed to plan, organize, and conduct a radiological field survey to develop sufficient data on the total radiological environment of Eniwetok Atoll to permit the assessments on which the judgments described above can be made. This survey should be accomplished as soon as possible upon completion of the necessary planning and coordination. It should consider the total environment pertinent to rehabilitation including both external radiation dosage and biological food-chain considerations. It is anticipated that technical standards and requirements will be provided by responsible divisions within AEC Headquarters."

Organization: The organization of the field survey, the analytical work, and the interpretive effort associated with the Enewetak Program has largely been determined by the following considerations:

1. At the Headquarters level the Division of Biology and Environmental Research (DBER) will have responsibility for assessing the radiological implications of sources of direct radiation and food-chain-to-man paths. DBER will provide guidance as to the data needed from the field to conduct the assessment.

2. The Division of Operational Safety (DOS) will share responsibility for planning the survey and will provide the coordination of these plans and their extension during the survey with the Assistant General Manager for Environmental Safety (AGMES). DOS will also provide information on the survey to EPA staff at the Washington level upon request. DOS will review and evaluate all data and assessments relevant to the feasibility of various cleanup methods and methods for disposal of hazardous materials, and will make recommendations on requirements, guidelines, and environmental and health protection standards to be employed during cleanup operations.

3. The Enewetak Atoll is currently under the jurisdiction of the Air Force (SAMTEC), and contractor field operations people are on the atoll supporting the PACE experiments. DOD (DNA) has agreed that these people will support the survey program also. The PACE experiments are now standing

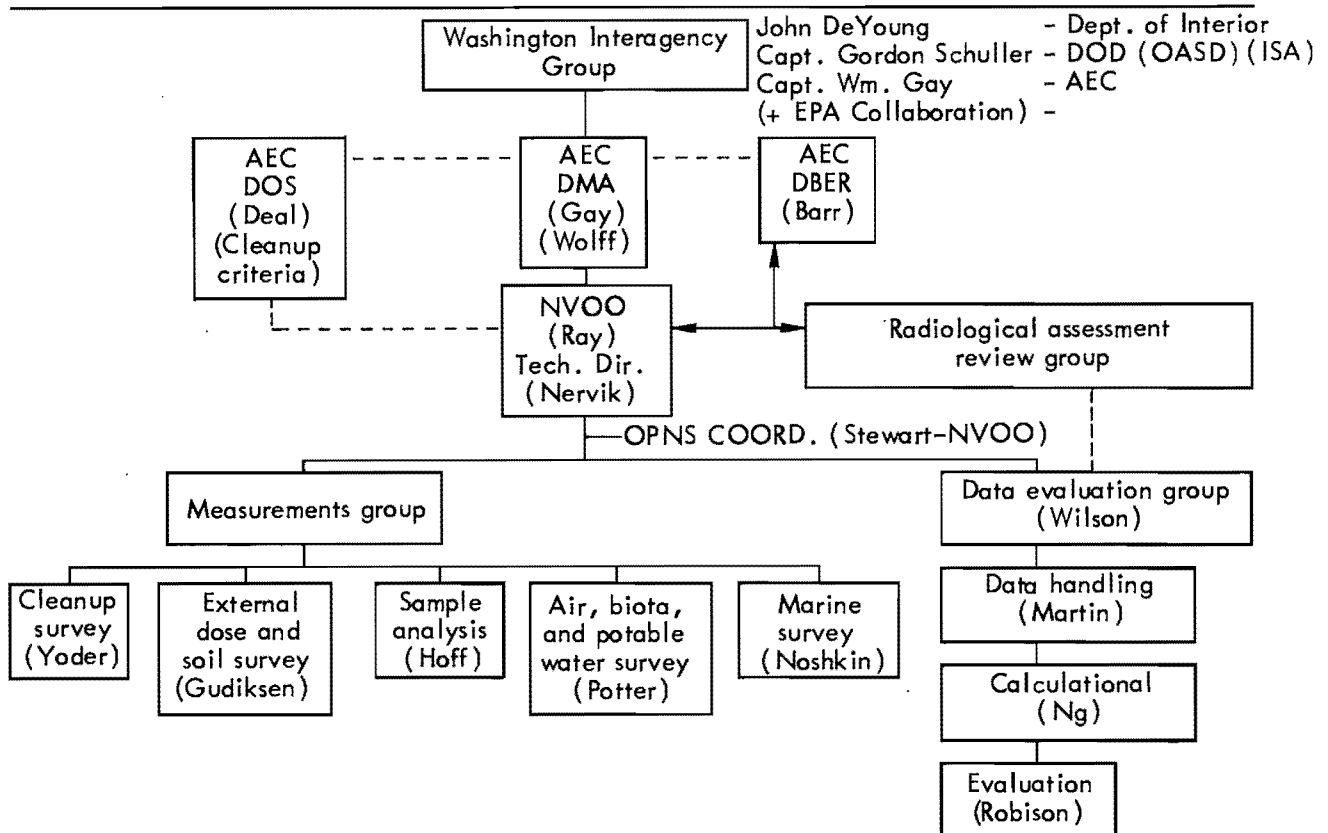


Fig. A.1. Organization of the Enewetak Survey Program.

down, and the PACE people are off the Atoll pending approval of the appropriate environmental statements. In order that we do not put an undue strain on the support capabilities, the radiological survey should be completed before the PACE people return. Their return is now scheduled for January 1, 1973.

4. The Radiological Survey is a fairly large effort superimposed on technical organizations which already have made commitments for their people for FY 73. The number of qualified organizations able and willing to respond is therefore limited.

5. Since no compromise on the quality or comprehensiveness of the survey will be acceptable, participants are being chosen on the basis of their

being able to do the necessary high-quality work in the time frame in which it is needed.

With these considerations in mind, an organizational chart of the Enewetak Survey Program is shown in Fig. A.1. NVOO is the primary organization for implementing the survey, interacting with DMA, DBER, and DOS at the headquarters level. The survey itself, and the interpretive effort associated with it, have been divided into eight categories: the Radiological Assessment Review Group appointed by DBER; Field Operations Coordination at NVOO; measurements involving the Cleanup Survey; External Dose and Soil Survey; Air, Biota, and Potable Water Survey; Marine Survey; and



Sample Analysis; and Data Evaluations. Authors of detailed plans for each of the last six categories are indicated on the chart. It is now expected that the program will involve personnel from the following organizations: NVOO, NERC (EPA), LLL, LASL, MCL, Univ. of Wash., HASL, Eberline Inst. Co., TTPI, Univ. of Hawaii, DOS,

and DBER, plus organizations not yet identified involved in the Radiological Assessment Review Group.

For orientation purposes a map of Enewetak Atoll is shown in Fig. A. 2. Previous surveys in May and July of this year indicate that radiological contamination levels vary from light (1-10  $\mu$ R/hr at 3 ft) for islands on the

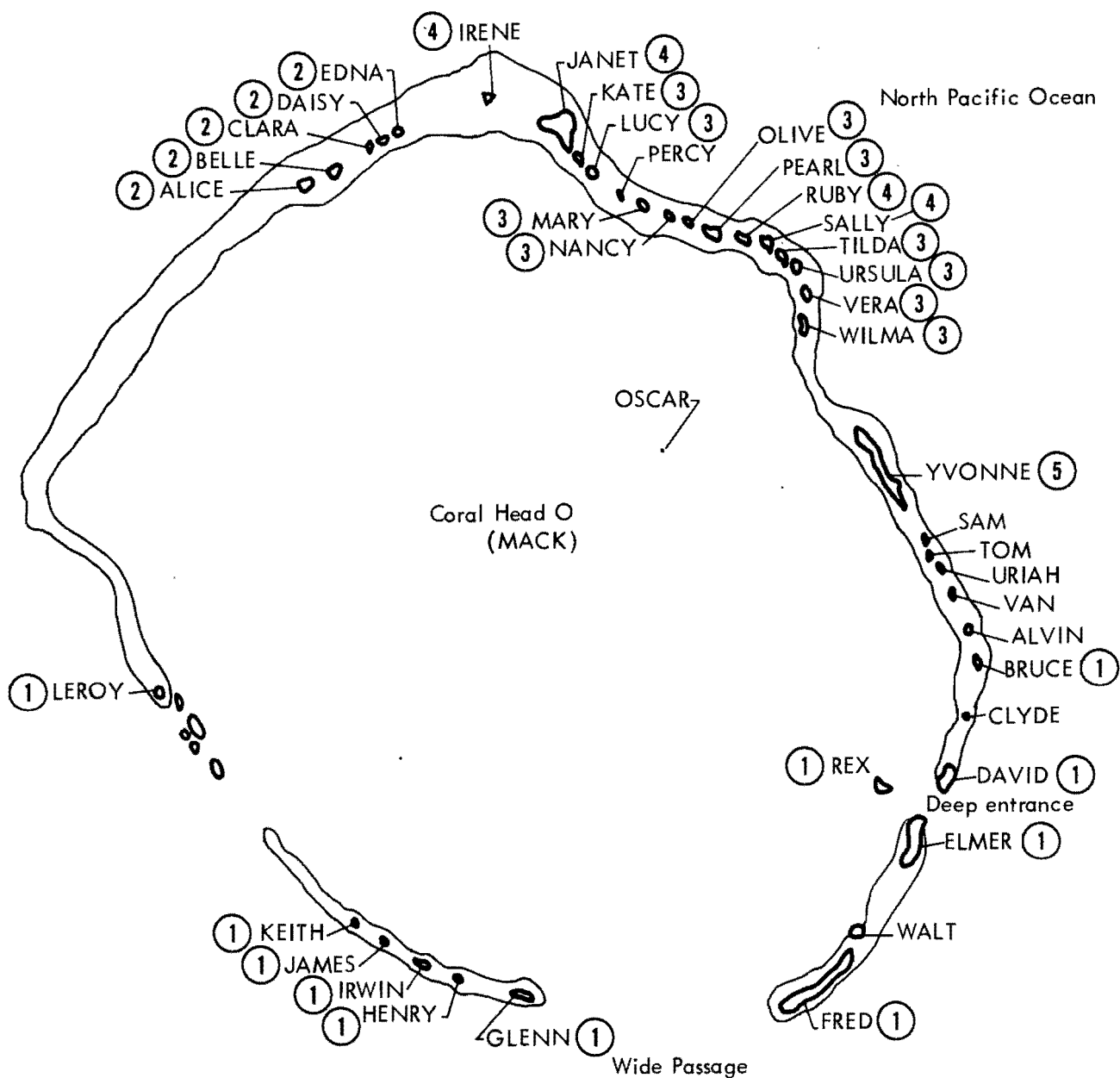


Fig. A. 2. Radiological contamination levels on Enewetak Atoll. Least contaminated, 1; lightly contaminated, 2 (already surveyed); believed lightly contaminated, 3 (not surveyed); moderate contamination, 4; and heavy contamination, 5.

southern half of the Atoll to heavy (>1000  $\mu\text{R/hr}$  at 3 ft) on Runit, with islands on the northern half of the Atoll in intermediate categories. As can be seen from Fig. A. 2, no survey data are available for at least 10 of the islands. Data on radiological levels in the marine environment and in air are particularly scarce. Our intent is to obtain samples and data from the least contaminated islands first, then move to the more highly contaminated islands, and end on Runit. The marine work will run concurrently with the terrestrial survey. This is not, however, meant to imply that the least contaminated land areas have the least contaminated adjacent marine environment. Currents and other processes in the lagoon have probably redistributed the initial inventories of radionuclides to the extent that any attempt to predict relative contamination levels in the marine area near each island is presently impossible.

In this survey, we will design and carry out our field studies in the Atoll with sensitivity to preservation of the natural environment. This means that we will make an effort to utilize the literature, outside experts, and our own experience in order to sample living populations and soils so as not to generate imbalances. Special care will be taken to avoid the addition of persistent toxic material, wastes, and refuse, and to leave the environment of the Atoll in at least as good a condition as when we entered it.

## II. RADIOLOGICAL STATUS AND DOSE EVALUATION

The Data Evaluation Group is an integral part of the program plan for Enewetak, and this Group has been involved since the inception of the study in the development of a measurement and evaluation plan which optimizes the return of information aimed at the objectives. The design of the program has been formulated after considering the following requirements:

1. Program focus. That the program plan be developed in response to a well-defined charter and objectives, as stated and discussed in the first section of this report.
2. Use of existing data. That past studies and data be brought to bear on the measurement and evaluation program design, including survey data from Enewetak and Bikini and the more general literature on radioactivity in food chains in the Atoll. Such data have provided guidance for developing measurement plans which will give comprehensive information for assessing radiological aspects of future habitability and the feasibility of cleanup prior to rehabilitation.
3. Integrated program structure. That information and materials flow through a system of sample collection, identification, analysis, and interpretation which provides for the best utilization of time and resources, minimizes errors and losses, and allows for rapid feedback and long-term access to samples, raw data, and logic

sequences which lead to results and interpretations.

4. Technical resources for evaluation.

That the evaluation of data for radiological assessment be approached in a way which utilizes the very latest understanding of radioactive transport in the environment and of mechanisms and parameters affecting the dose to man. This principle is to be implemented by drawing on resources and capabilities in a number of institutions, including LLL, LASL, HASL, and the University of Washington. In addition, information on projected living patterns of future inhabitants which might influence a radiological assessment will be evaluated with the assistance of experienced individuals. Contact is being made with Dr. John Tobin, an anthropologist very familiar with the living habits of the native population in this matter, and we will also draw on scientific investigators of long experience in the Atoll, such as Drs. Held and Seymour of the University of Washington. Additional key participants and consultants are listed in Table A.1.

5. Communication of results. Finally, that the evaluation, as it proceeds in time, will be in close communication with the Division of Bio-Medical and Environmental Research (DBER) through a review committee headed by Dr. Nathaniel Barr (see Fig. A.1). The advantages to such a communication are twofold:

- a. For maintaining point-in-time cognizance of our activities, methods, and results, which

Table A.1. Major participants in the data Evaluations Group.

Group leader:	D. Wilson (LLL)
Data handling and computations:	W. Martin, W. Phillips (LLL)
Calculations:	Y. Ng (LLL), B. Bennett (HASL), B. Rich (LLL)
Evaluations and applications:	W. Robison (LLL), B. Rich (LLL), C. Richmond (LASL), D. Wilson (LLL)
Consultants:	J. Tobin (TTPI), E. Held (AEC), A. Seymour (U. of Wash.), P. Gustafson (ANL), M. McLaughlin (HASL), P. Conard, M. D. (BNL)

will enable DBER to review the final product more intelligently and more effectively under time constraints, and

- b. For providing guidance during the progress of the survey and to serve as a point of contact for information available across the whole research program in the AEC on environmental radioactivity, including AEC experience in DBER and DOS regarding radiological assessment and rehabilitation on Bikini.

The "Radiological Report on Bikini Atoll," April 1968, by Dr. P. F. Gustafson, then of DBM/AEC and now of ANL, provides an excellent backdrop against which to view the current Enewetak evaluation program. Comparison and contrast of the two situations (Bikini and Enewetak) regarding radiological aspects provide a number

of facts useful in developing a program plan. Most relevant to the Enewetak program is to emphasize the similarity in the environments and the expected lifestyles of the future inhabitants. One could elaborate on second-order differences as they exist or as they are to be expected, but it is most important to point out two major considerations:

1. Regarding the major pathways, evaluation can be based primarily upon the expected similarity which will exist in lifestyle and habits between the returning Bikinians and Enewetakese. The predominant protein source will be from marine fish, but, where possible, coconuts, pandanus, and arrowroot will be cultivated for food. A diet can be constructed on the basis of the Rongalese diet, as was done by Gustafson for Bikinians, and adjusted as indicated by information gained on the specifics of Enewetak Atoll.
2. Serious contrast can be made, however, between Enewetak Atoll and Bikini Atoll as regards the base radiological contamination, which is both larger for Enewetak and compounded by the larger amounts of  $^{239}\text{Pu}$  and other transuranics. Thus, while we cannot yet speak of the relative importance of long-lived fission products, activation products, or alpha radioactive elements, it will be necessary to provide comprehensive assessment of the latter class of radionuclides in order to put these in perspective to the others. This will include assessment of both the inhalation and ingestion pathways.

In brief, the assessment is organized around a pathway-dose two-dimensional matrix. Radionuclide composition of dose transfer media such as foods, air, and water will be coupled with existing models of intake and metabolism to calculate potential dosages, taking into consideration the projected patterns of living of the future inhabitants.

The major pathways under consideration are:

1. External radiation
2. Internal radiation
  - a. Terrestrial foods
  - b. Marine foods
  - c. Water
3. Inhalation, submersion

An understanding of the data base to be generated for these assessments can be obtained in the following sections of this program plan. It is our goal to provide all the data needed to order the relative importance of radionuclides and pathways on the overall picture of radiological assessment for habitability at this time, and to provide data and interpretations which will guide clean-up assessment. These data, however, will not, in all cases, be sufficient to predict potential dosages over the long term. This point is made to emphasize that limitations in the data base may exist which will not allow detailed pathway modeling and projection of infinite future dosages in all cases.

Previous studies at Enewetak provide a basis for developing a list of radionuclide species to be encountered in the measurements program (see

Table A.2. Radionuclides to be expected in the Enewetak environment.

Isotope	$T_{1/2}^{\text{phys}}$ , days	$T_{1/2}^{\text{Eff.}^{\text{a}}}$ , days	Emission	Critical organ <sup>b</sup>	Energy, MeV $\Sigma\text{EF (RBE)}_n$
$^3\text{H}$	$4.5 \times 10^3$	12	$\beta^-$	W. B.	0.0063
$^{14}\text{C}$	$2 \times 10^6$	12	$\beta^-$	Sol. fat	0.054
$^{55}\text{Fe}$	$1.1 \times 10^3$	10	$\epsilon(\text{x ray})$	Submersion W. B.	0.054
		600		Sol. spleen	0.0065
		$3.2 \times 10^3$		Insol. lung	0.0065
$^{60}\text{Co}$	$1.9 \times 10^3$	9.5	$\beta, \gamma$	Insol. GI	0.0065
				Sol. W. B.	1.5
				Sol. GI	0.44
				Insol. lung	0.72
$^{63}\text{Ni}$	$2.9 \times 10^4$	800	$\beta$	Insol. GI	0.44
				Sol. bone	0.11
				Insol. lung	0.021
				Insol. GI	0.021
$^{90}\text{Sr}$	$10^4$	$6.4 \times 10^3$	$\beta$	Sol. bone	1.1
				Insol. lung	1.1
				Insol. GI	1.1
$^{102}\text{Rh}$	$1.06 \times 10^3$	10.4	$\epsilon(\text{x ray})$	W. B.	1.2
$^{102}\text{Rh}$	206	10.4	$\beta^-, \beta^+$	W. B.	0.39
$^{125}\text{Sb}$	876	38	$\beta, \gamma$	Sol. W. B.	0.34
		100		Sol. bone	0.69
				Sol. GI	
		100		Sol. lung	0.23
		100		Insol. lung	0.26
$^{137}\text{Cs}$	$1.1 \times 10^4$	70	$\gamma, \beta$	Sol. W. B.	0.59
		138		Insol. lung	0.41
				Insol. GI	0.34
$^{147}\text{Pm}$	920	570	$\beta$	Sol. bone	0.35
				Sol., insol. GI	0.069
				Insol. lung	0.069
$^{151}\text{Sm}$	$3.7 \times 10^4$	$1.4 \times 10^3$	$\beta$	Sol. bone	0.13
				Sol., insol. GI	0.041
				Insol. lung	0.042
$^{152}\text{Eu}$	$4.7 \times 10^3$	559	$\beta, \gamma$	Sol. GI	0.65
		$1.1 \times 10^3$		Sol. kidney	0.71
				Insol. lung	0.71
$^{154}\text{Eu}$	$5.8 \times 10^3$		$\beta^-, \epsilon, \gamma$	Sol. GI	0.20
		$1.2 \times 10^3$		Sol. kidney	0.25

Table A.2. (Continued).

Isotope	$T_{1/2}^{\text{phys}}$ , days	$T_{1/2}^{\text{Eff.}^{\text{a}}}$ , days	Emission	Critical organ <sup>b</sup>	Energy, MeV $\Sigma \text{EF (RBE)}_n$
		$1.2 \times 10^3$		Sol. bone	0.045
$^{155}\text{Eu}$	621	314	$\beta, \gamma$	Insol. lung	0.86
				Sol. GI	0.075
				Sol. kidney	0.083
				Sol. bone	0.28
$^{207}\text{Bi}$	$2.9 \times 10^3$	5	$\gamma$	Insol. lung	0.095
				Sol. GI	0.24
				Sol. kidney	0.33
$^{235}\text{U}$	$2.6 \times 10^{11}$	100	$\alpha, \beta, \gamma$	Insol. lung	0.45
				Sol. GI	46
				Sol. kidney	46
				Sol. bone	230
$^{238}\text{U}$	$1.7 \times 10^{12}$	100	$\alpha, \gamma$	Insol. lung	46
				Sol. GI	0.43
				Sol. kidney	43
$^{238}\text{Pu}$	$3.3 \times 10^4$	$2.3 \times 10^4$	$\alpha, \gamma$	Insol. lung	43
				Sol. bone	280
$^{239}\text{Pu}$	$8.9 \times 10^6$	$7.2 \times 10^4$	$\alpha, \gamma$	Insol. lung	57
				Sol. bone	270
$^{240}\text{Pu}$	$2.4 \times 10^6$	$7.1 \times 10^4$	$\alpha, \gamma$	Insol. lung	53
				Sol. bone	270
$^{241}\text{Am}$	$1.7 \times 10^5$	$2.3 \times 10^4$	$\alpha, \gamma$	Insol. lung	53
				Sol. kidney	57
				Sol. bone	280
		$5.1 \times 10^4$		Insol. lung	57

<sup>a</sup>Half-life in man following uptake in tissue.

<sup>b</sup>Abbreviations: GI (Gastrointestinal tract); W. B. (Whole body).

Table A.2). This list may not be complete, and the study may turn up other induced activities. Nevertheless, it is most probable that a small number of radionuclide species will lead to the majority of significant dosages as was found for Bikini. In addition to the transuranics, we expect  $^{90}\text{Sr}$ ,  $^{137}\text{Cs}$ ,  $^{60}\text{Co}$ , and perhaps  $^{55}\text{Fe}$  to be

major contributors to dosage, depending on the pathway considered and the circumstances.

Most of this work of assessment will be straightforward and will consist of applying food-chain and dosimetric data well in hand in the literature and available in such sources as ICRP No. 2. However, we recognize the

importance of the results of the measurement program in generating new information on the transport and fate of the heavy elements and also recognize our reliance on other current research and evaluation activities in the areas of heavy-element biological distribution and dosimetry in man.

We plan to work closely with DBER and groups such as the NVOO Applied Ecology Group and the AIBS Advisory Committee on Plutonium, particularly to interpret the significance of plutonium in the context of habitability and cleanup.

### III. EXTERNAL DOSE AND SOIL SURVEY

This soil survey plan is based largely on the draft plan dated 31 August 1972 developed through consultation among the following individuals: Drs. Seymour, Held, Nelson, Welanda, and Schell (Univ. of Wash.), Drs. Eberhart and Gilbert (BNW), Mr. McCraw (DOS), and Mr. Lynch (NVOO).

The survey has been divided into four phases. Phase I is designed to identify any unsuspected radiological problems on the least contaminated islands. Phase II includes islands which have been subjected to fallout to various degrees (minor to somewhat severe) and construction activities which could have modified the distribution of radionuclides. Phase III deals with islands which have been sites for, or very near to, surface ground zeros and/or extensive test activities. Contamination exists in the form of activated metal debris,

radioactive-waste disposal areas, distributed fallout, and localized plutonium contamination. The survey will also include an estimate of the extent of radioactive scrap metal situated on these islands. Finally, Phase IV addresses Runit (YVONNE), the most heavily contaminated island.

The selection process for survey priorities is based upon insult determination of each island from examination of historical records and current radiological data provided by preliminary surveys of Eniwetok Atoll in July 1971, May 1972, and of Runit in July 1972.

#### Field Meter Survey

The survey includes a very detailed examination of the geographical variability of the gamma exposure rate in air on each island due to the gamma rays of greater than 100 keV emitted by radionuclides deposited in the soil. These nuclides are primarily fission and neutron activation products. The Baird-Atomic scintillation instrument, which utilizes a 1 × 1-in. NaI crystal, will be used to make these measurements. Similarly, the flux of gamma rays of energies less than 100 keV due to  $^{239}\text{Pu}$  and  $^{241}\text{Am}$  will be measured by the FIDLER. This instrument consists of a 1/8-in.-thick × 5-in.-diam NaI crystal connected to a rate meter. The geographical variation of these measurements will enable the survey teams to locate the areas contaminated with radioactivity where soil samples may be collected for laboratory analysis to determine the

concentrations of specific radionuclides present.

#### Aerial Radiological Measurements

This method has been used by EG&G, Inc. for several years for rapidly and economically surveying large land areas for radioactive deposition and for the location of lost radioactive sources. The data provided by such a survey will be extremely valuable in guiding the field survey teams in the conduct of their surveys. It will greatly reduce the possibility of the survey teams missing contaminated areas and at the same time increase their efficiency by eliminating their need to extensively survey uncontaminated areas.

The EG&G airborne radiation detection system that we propose to utilize consists of two pods mounted on a helicopter or light aircraft. Each pod contains 20 5 × 2-in. NaI crystals. The signals from these detectors are summed and submitted to a data-acquisition system. The output is monitored by eight single-channel analyzers and a multichannel analyzer for gamma spectral analysis. Also included in the system is an inertial navigation system whose output is recorded simultaneously with the radiation data on magnetic tape.

If the system were mounted on a helicopter traveling at 100 ft/sec, the spatial resolution for  $^{241}\text{Am}$  on the surface is approximately 100 ft when using the single-channel mode of operation. High-energy gamma emitters may be located with a spatial resolution of about 50 ft, based upon the accuracy of

the inertial navigation system. The minimum limits of detection for  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  is about 1  $\mu\text{R/hr}$  and approximately 1  $\mu\text{Ci/m}^2$  for  $^{241}\text{Am}$ . The system may also be flown satisfactorily on small fixed-wing aircraft, but the spatial resolution is directly related to airspeed.

The total weight of the system is 1400 lb and requires three people to operate. It would take approximately 1-3 weeks to complete the survey, depending upon meteorological conditions.

Aerial photographs of the islands may also be taken with a separate EG&G system which incorporates four Hasselblad cameras equipped with 80-mm lenses. High-resolution photographs obtained with this system are a necessity in order to accurately identify locations where soil samples and survey meter readings were obtained, as well as to assist in assessing the amount of cleanup that will be required.

#### Soil-Sampling Program

The soil-sampling program of the survey will be conducted in a manner that will insure statistically meaningful results. Several types of soil samples will be collected for analysis: (1) A sample consisting of two 15-cm-deep cores of 30-cm<sup>2</sup> area each; (2) a surface soil sample collected by a "cookie cutter" of 30-cm<sup>2</sup> area to a depth of 5.0 cm; and (3) a profile collection based upon sidewall sampling in a trench in which complete samples of fixed horizontal area are taken to selected depths. The increments of



depth are chosen according to predicted, suspected, or known radioisotope concentration vs depth relationships and also according to any soil horizons present at the sample location. Nominal depth increments in centimeters will be: 0-2, 2-5, 5-10, 10-15, 15-25, and 25-35 and at 15-cm intervals below 35 cm. If a soil horizon is encountered, the interface lines will be chosen as the increments from the horizon rather than the fixed nominal increments from the surface.

Locations for the collection of soil samples will be chosen on the basis of (1) random selection and (2) ground or aerial survey meter readings. These are described below:

A. Samples collected on the basis of random selection

1. Each island will be divided by a narrow grid, (i.e., approximately 2500 points or 50 × 50-ft grid, whichever is smaller). All areas defined by such a grid will be numbered.
2. If stratification is desired and in order, the strata will be chosen and indicated on the grid network.
3. Individual sample areas will then be chosen within each stratification or grid by selection of the appropriate coordinate number, utilizing random-number tables. The number of samples per island or group has been previously determined through consideration of desired goals and statistical significance.

4. The exact location of the sample collection is to be the center of the area chosen by the random-number technique described in No. 3 above. It is realized that the determination of such a point with any great precision or accuracy in the field is technically impractical in most cases. It is most important, however, that the sample collector make every reasonable effort to locate the position as closely as possible. In particular, the sample should come from within a 10 × 10-ft area defined as the center area of the grid point. Ideally, the sample will come from the exact center of this limited area as just stated. In the field the location will be identified as indicated on the map but will be located probably by pacing or other field direction. The spot so determined by such pacing will be the actual spot at the end of the designated number of paces, and no other. If there is some obstacle to sampling at this specified location (e.g., a concrete pad), then that fact should be recorded in the field and no sample taken.
5. Each sample will be bagged and marked with an appropriate identification code.

B. Samples collected on the basis of survey meter readings.

1. Additional samples will be collected from locations where abnormally high readings were

obtained from either the Baird-Atomic scintillator or the FIDLER.

2. Each sample will be bagged and marked with an appropriate identification code.

#### Field Analysis

A radiation counting laboratory will be established on Enewetak Island. This laboratory will contain a 3 × 3-in. NaI detector and an intrinsic Ge detector, plus associated electronics. These detectors will allow scanning of the samples for gamma-emitting fission and neutron-activation products, as well as for <sup>241</sup>Am. The data obtained by this scanning process should provide information which may influence the collection of additional samples from contaminated areas. This information will also be valuable in determining future analyses to be performed on the samples after their arrival on the continent.

#### Preliminary Soil-Sampling Schedule

As mentioned earlier, the survey will address the least contaminated islands first and proceed to the more heavily contaminated islands.

The following is a more detailed listing of the islands within each of the four phases. Also included is a preliminary estimate of the number and types of soil samples to be collected from each island. The number of 0-5 cm and 0-15 cm samples is arrived at on the basis of one of each for approximately 10<sup>5</sup> ft<sup>2</sup> of surface area and the number of 0-35 cm (profile) samples on the basis of one per 8 × 10<sup>5</sup> ft<sup>2</sup> of area or a minimum of two per island. The other (profile) samples are for special situations, such as decontamination pads or areas in which field activities have disturbed the original soil.

<u>Phase I</u> Island	Approx area, (10 <sup>5</sup> ft <sup>2</sup> )	Number of samples			
		0-5 cm	0-15 cm	0-35 cm (profile)	Other (profile)
GLENN	25	25	25	3	
HENRY	13	13	13	2	
IRWIN	7.5	8	8	2	
JAMES	4.8	5	5	2	
KEITH	11	11	11	2	
LEROY	7	7	7	2	
REX	2	3	3	2	
BRUCE	9	9	9	2	
DAVID	48	48	48		6 (4 ft)
ELMER	80	96	96	4	10 (4 ft)
FRED	140	58	58		7 (4 ft)
Total		283	283	21	23

<u>Phase II</u>		Number of samples			
Island	Approx area, (10 <sup>5</sup> ft <sup>2</sup> )	0-5 cm	0-15 cm	0-35 cm (profile)	Other (profile)
ALICE	10	20	20	2	
BELLE	20	30	30	3	
CLARA	2	8	8	2	
DAISY	1	8	8	1	
EDNA	0.3	5	5	1	
KATE	8	20	20		2 (2 ft)
LUCY	10.5	20	20		3 (2 ft)
MARY	6	20	20	2	
NANCY	9	20	20	3	
OLIVE	14	21	21	3	
PEARL	27	41	41	3	
TILDA	15	30	30	3	
URSULA	12	24	24	3	
VERA	10	20	20	2	
WILMA	7	20	20	—	2 (2 ft)
Total		307	307	28	7

<u>Phase III</u>		Number of samples			
Island	Approx area, (10 <sup>5</sup> ft <sup>2</sup> )	0-5 cm	0-15 cm	0-35 cm (profile)	Other (profile)
IRENE	20	30	30	6	4 (6 ft)
JANET	120	150	150		15 (6 ft)
SALLY	37	40 <sup>a</sup>	40 <sup>a</sup>	10 <sup>a</sup>	6 (6 ft)
Total		220	220	16	

<sup>a</sup>Will be influenced by the extent of PACE activities on this island.

#### Phase IV

The only island included in this phase is YVONNE, which to our knowledge is the most contaminated island in the Atoll. Field surveys will be conducted with the FIDLER and the Baird-Atomic scintillator in order to supplement data obtained during previous surveys. The objective here

will be to obtain survey data on at least as small a grid pattern as is obtained for the other islands. Similarly, a number of soil samples will be collected in selected locations for purposes of evaluating the extent of cleanup required to rehabilitate the island. The extent of which additional data can be obtained by the survey group which

speak to either the radiological hazard on Runit or to the engineering aspects of the cleanup operation is not clear at this time. The kind and amount of such additional data will be determined in the field by the survey team.

#### Thermoluminescent Dosimetry Program

Since the energy response of the Baird-Atomic NaI scintillator is non-linear, the measurements made by this instrument may not be a true measure of the external dose rate produced by the gamma-emitting radionuclides deposited in the soil. To overcome this deficiency we plan to incorporate a thermoluminescent dosimetry (TLD) program which will provide a correlation between the NaI scintillator measurements and the actual dose rate measured by the TLDs.

This program will utilize a combination of LiF and CaF<sub>2</sub>:Dy TLD packets. Approximately 40 packets will be placed at selected locations in such a manner that a broad range of dose rates from 2  $\mu$ R/hr to 200  $\mu$ R/hr will be measured for the correlation study. In order to eliminate exposure during transit time, the dosimeters will be annealed at Enewetak Island just prior to their placement in the field. After having been exposed for one month or more in the field, the TLD packets will be recovered and read out at Enewetak Island.

#### IV. AIR, BIOTA, AND POTABLE WATER SURVEY

The objectives of the terrestrial air, biota, and potable water sampling

program are:

- (a) To collect representative samples of edible plants and animals for radionuclide analysis and subsequent estimation of food-chain transfer of radionuclides to future inhabitants.
- (b) To measure airborne radioactivity for assessment of the inhalation pathway of exposure, particularly for <sup>239</sup>Pu. The air-sampling program will address this exposure route at the numerous "clean islands" and also in the more contaminated areas such as the environment on Runit (YVONNE).
- (c) To correlate the food-chain sampling program with the field gamma measurements and soil-sampling program in order to maximize the information available to quantify rates and mechanisms of transfer of radionuclides from soil to man through food chains. The field survey team will obtain plant samples wherever possible from the soil-sampling sites; the terrestrial food-chain team will obtain some soil samples, where necessary, in the areas where they sample edible plants such as pandanus and arrowroot.

##### 1. Air Sampling

Airborne particulates will be sampled by means of three types of samplers:

- a. Ultra-high volume (UHV) samplers—Two calibrated UHV samplers will be operated at a rate of 1000 cfm. One such

sampler will be operated continuously on Enewetak Island (FRED). The other sampler will be transported from island to island for measurements. Measurements will be made also at selected offshore sites on the LCU. Both samplers will be supported by gross meteorological measurement of wind speed and direction to aid in the interpretation of sources of detected radioactivity.

b. Low-volume (LV) samplers—A large number of calibrated 5-cfm LV samplers will be fielded and operated on a semi-continuous basis. Banks of these samplers will operate continuously on board the Palumbo and the LCU used in marine sampling and transportation. Others will be fielded strategically to investigate radionuclide levels in air downwind from contaminated areas.

c. Anderson cascade impactors—Two 20-cfm, five-stage cascade impactors will be used to obtain long-term samples of air for investigation of the size distribution of airborne radioactive particles.

This combination of air samplers will be utilized to address the question of potential exposure to future inhabitants through inhalation of airborne radioactive particles. The initial plan will provide sufficient data to ascertain whether or not  $^{239}\text{Pu}$  exists in the air at levels in excess of worldwide fallout

background and to define the locations and circumstances of any such elevated levels. These samples will be analyzed on a priority basis so that results can be reviewed by the Data Evaluations Group early in the study. These evaluations will be used to decide on any adjustments in the air-sampling program design and scope which can be proposed to the Technical Director for implementation.

## 2. Biota Sampling

The terrestrial food-chain team will focus their effort on obtaining samples of arrowroot, pandanus, coconut, crabs, birds, and such other plant and animal organisms as may constitute the diet of future inhabitants. The edible vegetation samples will be collected as available and in conjunction with appropriate soil samples. Edible animal species will be collected as available by trapping or shooting.

Inedible plant species to be used as indicators for soil-root-plant pathways will be collected with the soil survey group. At least two or three species that occur on all islands will be used for this purpose in order to obtain comparative data. Samples of these will be collected on the lagoon side, ocean side, and in the central parts of each island at points where soil samples are collected. These will be returned to the Enewetak laboratory for identification and processing.

Rats, which are not considered to be a part of the human food chain, are the only mammals existing on the

islands and may be considered as an indicator species. These will be trapped and specific organs will be analyzed for radioactivity. Collection sites for all specimens will be identified on the radiological survey maps for later correlation.

### 3. Potable Water

The only potable water on the Atoll is derived either from rain water or the distillation plant on Enewetak. Samples of these will be collected for radiochemical analysis, along with sludge samples from the distillation plant. In addition, a marginal lens exists on Engebi which we plan to sample.

### 4. Onsite Laboratory at Enewetak

An onsite laboratory will be established on Enewetak for processing samples obtained by the biota field teams. This will include: forced draft ovens for drying plant material for shipment, dissecting equipment for separating organs from animal species, and counting-equipment screening of specimens before they are returned to LLL. The principal equipment to be used will consist of a pair of 4 X 4-in. NaI detectors and two single-channel analyzers. A few selected samples will also be screened with a Ge(Li) system in order to determine their radionuclide content.

The Data Evaluations Group will be in charge of coordinating collection of data and samples, sample coding preparation, counting and other activities in this onsite laboratory.

## V. ENEWETAK AQUATIC PROGRAM

The mission of the aquatic survey will be to define the contributing radioactivities in the lagoon and reef areas of the Atoll to assess exposure pathways to individuals utilizing the aquatic environment. Sources and levels of activity in the lagoon and reef will be defined using indicator organisms, in situ detectors, sediment, and water analyses. Samples of edible marine vertebrates and invertebrates will be collected and analyzed for specific radionuclides. Many species will be collected from the reef and lagoon areas that were surveyed in 1964. Changes in activities levels noted over the 8-yr period will be assessed. Several methods of assessing the residence time of specific radionuclides in the lagoon environment will be employed.

The types and quantities of samples required will be discussed in the next sections. The entire program, covering both survey and food-chain sampling, will be integrated in order to best use our available sampling facilities.

### Program Implementation

The development of the aquatic program in the Enewetak lagoon was originally designed to take advantage of facilities offered by the research vessel, R. V. Palumbo from the Puerto Rico Nuclear Center. The Palumbo left Puerto Rico on August 20 enroute to San Diego, Hawaii, Kwajalein, Bikini, and Enewetak. The mission of the vessel is in support of a DBER-funded program involving individuals from the University of Washington,

Lawrence Livermore Laboratory, and Puerto Rico Nuclear Center investigating the biogeochemical behavior of the transuranium elements in a labelled marine environment. Due to mechanical failures and other operational problems, the Palumbo has been in the San Diego Naval Shipyard since September 9 undergoing extensive repairs. The vessel left San Diego on September 28. If no further delays are encountered enroute, the Palumbo's present schedule would delay its arrival time in Enewetak by 16 days. The ship will therefore be available in the Enewetak area no earlier than November 18. Although it will be very useful to utilize the Palumbo in the Enewetak lagoon survey we are unable to plan on its availability. In order to conduct a meaningful program early in the survey, additional vessels are being readied for the lagoon work. They include:

(1) LLL Boston Whaler - 17-ft length

Equipped with bottom depth indicator; 65-hp Mercury outboard and 7.5-hp auxilliary motor; davit for over the side work with approximately 500 ft of 3/32-in. steel cable on a hand-operated winch. The vessel will be available for coring, water sampling, dredging, plankton tows, and in situ detection measurements. The ship will be used principally to support near shore and reef work.

(2) An "A" frame is presently under construction to mount on the LCU now enroute to Enewetak. A portable gasoline engine-powered winch containing 1000 ft of 3/32-in. stainless steel hydrographic cable will also be

mounted on the vessel. The LCU will have the capability to conduct all phases of marine sampling and would be used principally to sample the offshore region of the lagoon.

(3) Other ships of opportunity would be used to ferry personnel and gear to reef areas and, when practical, to assist in plankton tows.

If and when the Palumbo arrives in Enewetak, its facilities will be employed to supplement the ongoing program. If, however, the two facilities (Boston Whaler and the LCU) are the only ships available, a complete program addressing all the survey goals could be conducted in 10-12 wk without the Palumbo. This estimate is based on having perfect weather the entire period for 8-10 hr/day, 6-7 days/wk.

A network of buoys will be placed in the lagoon as fixed reference points during the survey. All personnel operating the whaler and sampling from the LCU will be trained and knowledgeable in all sampling techniques. All samples gathered will be properly coded and sample locations plotted on charts. Locations will be determined by using sighting compasses and estimates based on running time and speed from fixed reference points. The whaler will contain all necessary safety equipment and tow a spare six-man raft. The raft will be a means of transport to shallow reef areas.

The aquatic program, independent of the Palumbo, will require five personnel. Two people will operate the whaler and three will sample from the LCU.

The sampling program will proceed from less contaminated areas of the lagoon to the more highly contaminated areas in order to lessen the probability of sample contamination.

Aquatic Survey Goals and Methods

Purpose: To define the activity levels in the lagoon and reef environment in order to assess levels of external exposure and the degree of aerial contamination.

Objective	Method
A. To assess surface exposure over the reef. Only reef covered with less than 3 ft of water will be assayed.	Personnel operating from rafts or on foot utilizing $\beta$ - $\gamma$ survey meters.
B. Immersion dose in offshore beaches.	Analysis of water and sediment samples and <u>in situ</u> detection methods using the Boston Whaler.
C. Definition of activity levels in the lagoon and major outflow areas over the reefs.	
1. Assessment of sediment concentration levels.	Using the Whaler and LCU, sediment cores, grab samples, suspended material, and bottom water will be collected and analyzed. An <u>in situ</u> detector will be used to define relative activity levels of the bottom. A detailed bottom survey using an <u>in situ</u> NaI detector will be conducted off Runit, followed by extensive sediment sampling.
(a) Shore to 10-fathom terrace in lagoon. (b) Terrace to deep basin of lagoon. (c) Deep basin. (d) Craters.	The device used to obtain a bottom sample in any area will depend entirely on the composition of the sediment. The sediment in the lagoon varies from fine sand to coral and algae. The percent of each type of bottom material depends on location, although, in general, a higher percentage of fine material is found closer to shore where a corer may be used. In the deeper area of the lagoon higher percentages of formanifera and nolimeda debris dominate. In these areas dredging and grab sampling will be more successful.
2. Water concentration.	Surface-to-bottom profiles will be obtained by pumping 55-liter water samples. Samples will be obtained from 18 stations in the lagoon and 18 stations over the reef. Both the Whaler and LCU will be utilized. Fifty 5-gal bottom water samples and suspended sediment will be obtained in the Runit area.



3. Additional supplementary data required to assess relative concentration levels in the lagoon.

A variety of indicator organisms will be obtained by dredging the sediment and coral knolls in the lagoon from the LCU and Whaler. Daily plankton collections and invertebrates will complement this effort. Species of algae will be obtained from reef areas for analysis.

#### Miscellaneous activities

The desalination plant will be studied, with emphasis on the fate of the sludge discharged from the plant.

#### Samples to meet survey requirements

##### Water

48 55-liter water samples from the open lagoon and reef.

50 5-gal bottom samples from the Runit area and craters.

##### Sediment

100 core samples, 2- and 3-in. diam

200 grab samples

100 dredge samples

50 suspended sediment samples

50 Runit cores

Detailed vertical profiles of radio-nuclide concentrations in 20 selected cores will be determined. All other samples will be rapidly scanned for relative activity levels and selected samples quantitatively analyzed. Activity levels in vertical sections Runit cores will be determined in about 50 samples.

##### Biota

- (1) 200 plankton samples

If similar areas are sampled, many individual tows will be combined for analysis, especially if the plankton yield is low. All samples will be rapidly scanned in the field and a selected number quantitatively analyzed on the continent.

- (2) Invertebrates, including:

Sponges

Urchins

Sea cucumber

Clams

Coral

Starfish

Langusta

Specimens will be collected from all accessible reef areas. 400-500 individual samples are anticipated and all will be surveyed for relative activity levels. A selected number, probably no more than 200, will be quantitatively analyzed. Included in the latter estimate are all species used in the diet. Some selected shells and coral will be carefully analyzed and correlated with growth rates and concentrations, as indicators of changes in the environment as a function of time.

(3) Gut contents of bottom-feeding fish collected in different areas will be analyzed to assess concentration levels in lagoon areas.

Comparison of the activity levels in each of the above sample types will be used to contour activity levels in the lagoon and reef. Data from many sample types, especially edible organisms, will be used for dose assessment. Field recommendations will be forwarded to the laboratory for guidance in sample preparation and analysis.

#### Food-chain dose assessment requirements

Purpose: To provide samples in order to determine the activity levels in all edible marine species. The data are required to assess dose from aquatic food sources.

There will be close coordination with the radiological assessment team who will generate the information regarding Marshallese diet and define the percentage of each marine trophic level in the diet. This information is necessary to determine the sample size of a species needed, type of species, and post-treatment method of the sample. Assessment of the levels of activity in carnivores, bottom-feeding carnivores, omnivores, herbivores, and all invertebrates will be made. Dietary habits of the Marshallese people will be considered in the treatment of samples. Some species may be consumed whole. The analysis on these defined specimens will be made on the entire fish. For those species where only the flesh or

other organs are consumed, the samples will be dissected and the tissue analyzed. The variability in activity levels in similar species from different areas will be determined. Sampling sites will include those areas visited by the 1964 survey team. Fishing methods will include trawls, gill nets, long lines, traps, rod and reel, and spearing. Although the fishing will be operationally defined, 200 to 300 samples are anticipated for quantitative analysis of all detectable radionuclides.

## VI. RADIOCHEMICAL ANALYSES

Required analytical measurements on samples recovered in the survey of Enewetak Atoll are summarized in this document. The information is presented in tabular form, beginning with a description of various sample types (Table A.3) and estimated quantities to be recovered. In Table A.4 we summarize how samples will be handled, including treatment at Enewetak, form in which the material will be shipped, and necessary initial treatment required before samples are ready for routine analysis.

In Table A.5 we summarize the kinds of analyses expected to be necessary, including a list of nuclides which have been detected in Enewetak samples taken in earlier years. Most of the samples will be GeLi gamma counted as a routine matter. The question as to how many samples will require dissolution and wet chemical analyses can be answered accurately only as the planning and sample recovery progress. We need an assessment

Table A.3. Sample type, quantity.

I. Soil survey program		
A. Soil profiles, 200 × 6 = 1200		
3-in. diam, 0-1, 1-2, 2-3, 3-6, 6-9, 9-12		
115 cc/in., 170 g/in.		
B. Six-in. deep cores       800		
3-in. diam, 0-6-in. two adjacent (2 kg)		
C. Two-in. deep cores       800		
3-in. diam, 0-2-in. 300 g each		
II. Aquatic sampling program		<u>Predicted total</u>
A. Plankton		200
B. Sediment		100 + selected samples
C. Seawater		100
48 (55-liter), 50 (18-liter)		
D. Coral - Selected samples for use as indicator organisms		
E. Invertebrates		
Sea cucumbers	}	
Tridacna		
Spider snail		200
Spiny lobster		
F. Vertebrates		
Edible reef fish and indicator species	}	
Larger lagoon fish (sharks, albacore, tuna, grouper, etc.)		200-300
III. Biota samples		
A. Vegetation - nonedible		300
- edible		50-100
B. Terrestrial animals (including dissected parts)		150
C. Potable water		15
IV. Air samples		
A. High-volume samplers		100
B. Low-volume samplers		80
C. Anderson cascade impactors		80

of the importance of <sup>90</sup>Sr analyses; we expect to infer Pu content from <sup>241</sup>Am measurements in some samples where more precise Pu analytical measurement by wet chemistry is not required. We anticipate that the more

difficult <sup>55</sup>Fe and <sup>63</sup>Ni analysis will be performed only on selected samples, principally from the aquatic food chain.

In Table A.6 we list the laboratories and their capabilities which will be used to perform analytical measurements.

Table A.4. Initial sample processing.

	Treatment at Enewetak	Shipping form	Initial treatment
I. Soils	Package	As recovered	Dry, grind (ball mill), weigh, package, NaI count
II. Aquatic samples			
A. Plankton	Freeze	Frozen	Dry ash.
B. Sediment			
1. Grab samples	Freeze	Frozen	Dry, grind, weigh, analyze.
2. Cores	Freeze	Frozen	Section (volume, wet wt) thaw, dry, grind, weigh analyze.
C. Sea water	Acidify	As water	Analysis
D. Coral	Freeze	Frozen	See soils.
E. Invertebrates	Freeze	Frozen	Weigh, thaw, (dissect?) dry, (dry ash), weight, analyze.
F. Vertebrates	Freeze (filet?)	Frozen	Same as item E.
III. Biota samples			
A. Vegetation	Dry	Dry	Dry, grind, homogenize, analyze.
B. Terrestrial Animals	Freeze	Frozen	Weigh, thaw, (dissect?) dry, (dry ash), weigh, analyze.
C. Potable water	Acidify	As water	Analyze
IV. Air samples	Package	As recovered	Analyze

## VII. CLEANUP ASSESSMENT PLAN

During the field survey of the Islands in the Enewetak Atoll, an attempt will be made to evaluate possible cleanup mechanisms and provide data for future engineering estimates of the decontamination operation. This decontamination assessment is anticipated to take the following form:

1. An estimate of the quantity of activated materials and debris from previous tests will be made. Special attention will be made to record, in a preliminary sense, location, amount, and radiation levels of the debris that should be removed before reoccupation.

2. An attempt will be made to evaluate the feasibility of collecting single particles or "hot spots" by

Table A.5. Kinds of analyses required.

- 
- I. Gamma counting
- A. In general, no dissolution nor chemical separation will be required prior to gamma spectrometry. There could be occasional exceptions to this rule, e.g., sea water will require processing.
- B. It is expected that essentially all samples will be gamma counted. In many cases, this may be the only analysis required.
- C. Nuclides which are expected to be observed and which can be quantitatively measured by gamma spectrometry:  
 $^{40}\text{K}$ ,  $^{60}\text{Co}$ ,  $^{106}\text{Ru}$ ,  $^{137}\text{Cs}$ ,  $^{152,154,155}\text{Eu}$ ,  $^{241}\text{Am}$ ,  $^{125}\text{Sb}$ ,  $^{207}\text{Bi}$ ,  $^{108\text{m}}\text{Ag}$ ,  $^{65}\text{Zn}$ ,  $^{102}\text{Rh}$ , U and Th chain daughters.
- II. Dissolution of sample
- A. Plutonium analyses
1. Alpha counting  $^{238,239+240}\text{Pu}$
  2. Mass spectroscopy  $^{239,240,241,242}\text{Pu}$  where warranted
- B.  $^{90}\text{Sr}$ -beta counting of  $^{90}\text{Y}$  daughter
- C. Other nuclides:  $^{55}\text{Fe}$ ,  $^{63}\text{Ni}$ ,  $^{147}\text{Pm}$ ,  $^{151}\text{Sm}$ ,  $^{14}\text{C}$
- Soft-radiation emitters will require specific chemical separation.
- III. Tritium
- 

Table A.6. Laboratory analytical capability.

Laboratory	Kind of analytical work	Sample rates
LLL	Initial sample preparation, soils	400 samples/month
	Initial sample preparation, biota (including dissolution of all marine samples)	for initial sample preparation of soils
	Complete analytical treatment, sea water	
MCL	Gamma analysis	
	Soil dissolution, chemical analyses for Pu, $^{90}\text{Sr}$	
	Complete analytical treatment, air filters	
UW	$^{55}\text{Fe}$ analysis	Not established
	$^{90}\text{Sr}$ analysis	
Contract analyses	Gamma analysis	
	Soil dissolution, chemical analyses for Pu, $^{90}\text{Sr}$	200-500 samples/month
NERC(EPA)	Chemical analysis for Pu	Not established

---

simple excavation techniques or sieving. Various sized screens will be taken to evaluate the feasibility of separating contaminated debris rather than removal of all contaminated soil and/or coral. The character of the contamination in various areas will be evaluated in terms of the feasibility of removing localized hot spots in preference to whole-scale excavation. An attempt will also be made to locate localized hot areas which will require total excavation.

3. A literature search is presently underway and will be continued to evaluate the applicability of modifying existing techniques, other than whole-scale bulldozing, in decontaminating large contaminated areas.

4. Through evaluation of field survey data, the extent of contaminated areas will be mapped, and contamination profiles folded into the data in order to estimate the total area re-

quiring cleanup.

## VIII. SCHEDULES

A schematic diagram of the schedule for the Enewetak Radiological Survey Program is shown in Fig. A.3.

We now expect that the field survey group will depart for Enewetak on or about October 12, 1972 and that the work on Enewetak will take approximately eight weeks. Samples taken in the field are to be returned to Livermore on weekly scheduled flights. Processing and analysis will begin as soon as the first samples arrive at LLL.

The first data that are expected to be available are those taken in the field (sample types and locations, survey instrument readings, etc.). These should be in reportable form by January 1, at which time a review

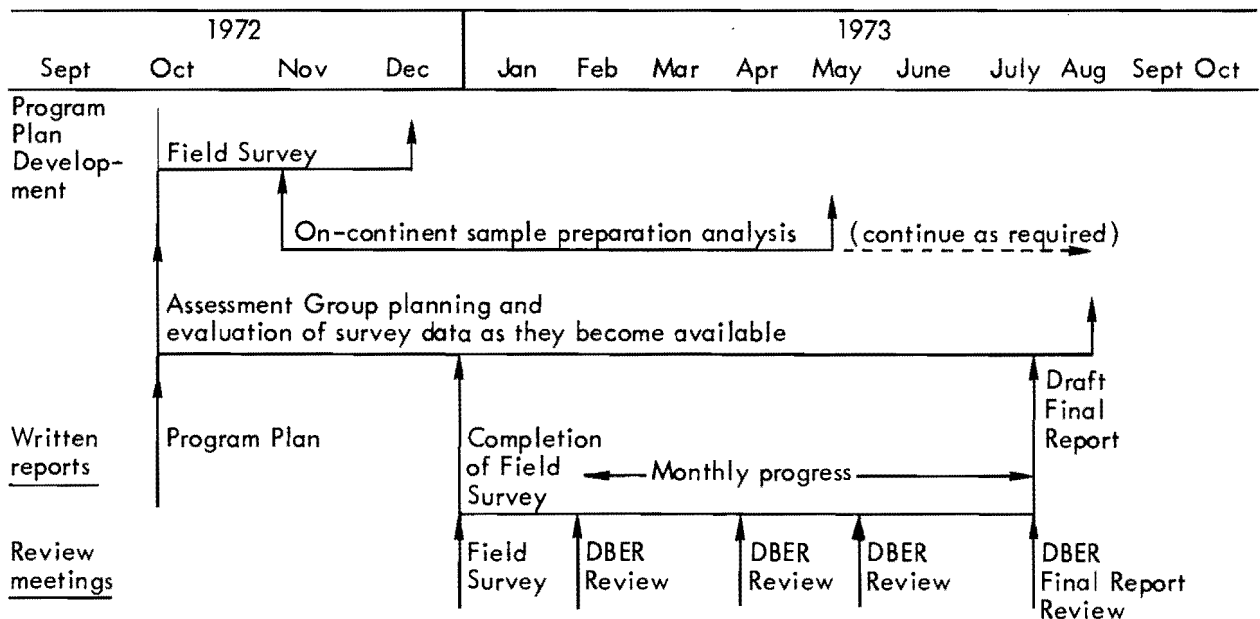


Fig. A.3. Schedule for the Enewetak Radiological Survey Program.

meeting may be scheduled to discuss the status of the program.

Considering all available laboratory capabilities, sample preparation and analysis will certainly take a number of months to complete. Samples will be processed on a priority basis according to the needs of the Radiological Assessment Group, so that the DBER assessment and review can proceed on a continuous schedule

rather than wait for all data to become final. The DBER review schedule shown in Fig. A.3 is a very tentative one. Every attempt will be made to speed up the process, without compromising on quality or completeness, of course, but no one should be under the impression that gathering this much experimental data and interpreting it will be accomplished overnight.

APPENDIX B

R 132155Z SEPT 72

FM USAEC FRANK A CAMM WASHDC

TO: USAEC M E GATES LAS VEGAS NEV

INFO: LT GEN C H DUNN DNA WASHDC

UNCLAS SUBJECT: RADIOLOGICAL SURVEY OF ENIWETOK

PARA. AS A RESULT OF COMMITMENTS MADE BY AMBASSADOR WILLIAMS AND INITIAL AGREEMENTS REACHED DURING AN INTERAGENCY MEETING HELD ON SEPTEMBER 7, 1972, IT IS THE OVERALL AEC PURPOSE TO GAIN A SUFFICIENT UNDERSTANDING OF THE TOTAL RADIOLOGICAL ENVIRONMENT OF ENIWETOK ATOLL TO PERMIT JUDGMENTS AS TO WHETHER ALL OR ANY PART OF THE ATOLL CAN SAFELY BE REINHABITED AND, IF SO, WHAT STEPS TOWARD CLEANUP SHOULD BE TAKEN BEFOREHAND AND WHAT POST-REHABILITATION CONSTRAINTS MUST BE IMPOSED. IT IS NECESSARY TO THOROUGHLY EXAMINE AND EVALUATE RADIOLOGICAL CONDITIONS ON ALL ISLANDS OF THE ATOLL AND IN THE LOCAL MARINE ENVIRONMENT PRIOR TO COMMENCEMENT OF CLEANUP ACTIVITIES IN ORDER TO OBTAIN SUFFICIENT RADIOLOGICAL INTELLIGENCE TO DEVELOP AN APPROPRIATE CLEANUP PROGRAM.

SPECIFICALLY, IT IS NECESSARY:

1. TO LOCATE AND IDENTIFY CONTAMINATED AND ACTIVATED TEST DEBRIS,
2. TO LOCATE AND EVALUATE ANY SIGNIFICANT RADIOLOGICAL HAZARADS WHICH MAY COMPLICATE CLEANUP ACTIVITIES, AND
3. TO IDENTIFY SOURCES OF DIRECT RADIATION AND FOOD CHAIN-TO-MAN PATHS HAVING RADIOLOGICAL IMPLICATIONS.

PARA. YOU ARE DIRECTED TO PLAN, ORGANIZE, AND CONDUCT A RADIOLOGICAL FIELD SURVEY TO DEVELOP SUFFICIENT DATA ON THE TOTAL RADIOLOGICAL ENVIRONMENT OF ENIWETOK ATOLL TO PERMIT THE ASSESSMENTS ON WHICH THE JUDGMENTS DESCRIBED ABOVE CAN BE MADE. THIS SURVEY SHOULD BE ACCOMPLISHED AS SOON AS POSSIBLE UPON COMPLETION OF THE NECESSARY PLANNING AND COORDINATION. IT SHOULD CONSIDER THE TOTAL ENVIRONMENT PERTINENT TO REHABILITATION INCLUDING BOTH EXTERNAL RADIATION DOSAGE AND BIOLOGICAL FOOD-CHAIN CONSIDERATIONS. IT IS ANTICIPATED THAT TECHNICAL STANDARDS AND REQUIREMENTS WILL BE PROVIDED BY RESPONSIBLE DIVISIONS WITHIN AEC HEADQUARTERS. IT IS UNDERSTOOD THAT PLANNING HAS BEEN INITIATED BY DOS AND DBER IN COOPERATION WITH FIELD ORGANIZATIONS AND SUCH PLANNING WILL SERVE AS THE BASIS FOR A COMPREHENSIVE SURVEY PLAN.



PARA. IN IMPLEMENTATING THE ABOVE OBJECTIVE YOU ARE DIRECTED TO:

1. PREPARE A PLAN FOR THE CONDUCT OF RADIOLOGICAL FIELD SURVEY AND ANALYSIS OF SAMPLES OBTAINED UTILIZING NECESSARY LABORATORY AND CONTRACTOR SUPPORT.
2. SELECT PERSONNEL NECESSARY TO CONDUCT THE FIELD SURVEY.
3. SELECT LABORATORIES AND PERSONNEL TO ACCOMPLISH THE NECESSARY LABORATORY WORK FOR ANALYSIS OF SAMPLES. THIS TASK INCLUDES ESTABLISHMENT OF PROCEDURES, STANDARDS, AND METHODS FOR CORRELATION OF DATA BETWEEN LABORATORIES. IN THIS CONTEXT YOU SHOULD PROVIDE FOR REVIEW AND REPORTING OF DATA.
4. SUPPORT PATHWAY AND DOSE ASSESSMENT ACTIONS WHICH WILL COME UNDER OVERALL TECHNICAL DIRECTION OF THE DBER, SUPPORTED BY THE DOS.
5. ARRANGE FOR NECESSARY LOGISTIC SUPPORT.
6. COORDINATE LOGISTIC SUPPORT REQUIREMENTS WITH THOSE OF THE ENGINEERING SURVEY TO BE CONDUCTED CONCURRENTLY BY DNA.
7. DIRECT LIAISON WITH DNA IS AUTHORIZED, AS REQUIRED, KEEPING COGNIZANT AEC HEADQUARTERS DIVISIONS ADVISED.
8. PENDING FURTHER GUIDANCE YOU ARE DIRECTED TO ADDRESS CONSIDERATIONS OF PRIORITY IN PLANNING FOR SAMPLE ANALYSIS AND FOR BIOLOGICAL PATHWAY AND DOSE ASSESSMENT PORTIONS OF THIS TASK. IT IS ANTICIPATED THAT A REVIEW OF THE SURVEY WILL BE CONDUCTED UPON COMPLETION OF THE FIELD EFFORT AND BY THAT TIME MORE DEFINITIVE GUIDANCE WILL BE FORTHCOMING ON PRIORITIES IN THE AREAS OF ANALYSIS AND ASSESSMENT.

PARA. YOU ARE AUTHORIZED TO EXPEND \$150 K IN THE INITIAL PLANNING AND ORGANIZATION OF THIS SURVEY. INITIALLY THE COST OF PERFORMING THIS EFFORT SHOULD BE CHARGED TO THE ON-CONTINENT PROGRAM. FOR YOUR INFORMATION, THE GENERAL MANAGER HAS APPROVED ALTERNATIVE 2 OUTLINED IN THE CONTROLLER'S MEMORANDUM DATED AUGUST 28, 1972, AND WE CURRENTLY WORKING OUT FUNDING ARRANGEMENTS FOR THE ENTIRE SURVEY. YOU WILL BE KEPT ADVISED.

MA:T:WWG:265-1.

APPENDIX C

Tenetative Schedule for Field Survey Personnel:

	SAM									RTN
	<u>10/12</u>	<u>10/18</u>	<u>10/25</u>	<u>11/1</u>	<u>11/8</u>	<u>11/15</u>	<u>11/22</u>	<u>11/29</u>	<u>12/6</u>	<u>FLT</u>
<u>FIELD MANAGER</u>										
Nervik (L)	_____							_____		
Ray (NV)	_____									
McCraw (SEC-DOS)			_____							
Held (AEC-Reg)					_____					
	2	1	1	1	1	1	1	1	1	1
<u>SOIL SURVEY</u>										
Gudiksen (L)	_____							_____		
Rich (L)			_____							
Myers (L)	_____									
Chew (L)					_____					
Lynch (NV)	_____						_____			
Moore (EPA)	_____					_____				
Costa (EPA)	_____									
Martin (EPA)	_____									
Rozell (EPA)	_____									
Vandervoort (EPA)			_____							
Peer (EPA)			_____							
Lambdin (EPA)					_____					
Horton (EPA)					_____					
Phillips (EIC)	_____									
Parker (EIC)	_____									
Price (EIC)	_____									
Young (EIC)	_____									
Sammons (H&N)	_____									
Chambers (H&N)	_____									
	13	13	13	13	12	12	11	9	9	9

SAM  
10/12   10/18   10/25   11/1   11/8   11/15   11/22   11/29   12/6   RTN  
 FLT

MARINE

Noshkin (L)	←————— Palumbo									
Nelson (UW)	—————									
Seymour (UW)	—————									
Eagle (UW)	←————— Palumbo									
Johnson (UW)	—————									
Fowler (L)	—————									
Holladay (L)	—————									
Schell (UW)	←————— Palumbo									
Dawson (L)	—————									
Lusk (UW)	—————									
	6	5	5	5	5	5	5	5	2	1

BIOTA AND AIR

Potter (L)	—————									
Koranda (L)	—————									
McIntyre (L)	—————									
Thompson (L)	—————									
Stuart (L)	—————									
J. Martin (L)	—————									
Clegg (L)	—————									
	4	4	4	7	3	3	3	3		

ELECTRONICS

Newbold (L)	—————									
Bishop (L)	—————									
Breshears (L)	—————									
Jones (L)	—————									
Hoeger (L)	—————									
Cate (L)	—————									
Thrall (EPA)	—————									
Lawson (EPA)	—————									
	5	3	3	3	3	2	2	2		

	SAM									RTN
	<u>10/12</u>	<u>10/18</u>	<u>10/25</u>	<u>11/1</u>	<u>11/8</u>	<u>11/15</u>	<u>11/22</u>	<u>11/29</u>	<u>12/6</u>	<u>FLT</u>

CLEANUP  
TECHNIQUE ASSESSMENT

Yoder (L)	_____						_____			
	1						1	1	1	1

SAMPLE PREPARATION

Phillips (L)	_____									
W. Martin (L)					_____					
Qualheim (L)	_____									
Mendoza (L)				_____						
Wilson (L)							_____			
Schweigher (L)	_____									
Landrum (L)			_____							
Hoff (L)?						_____				
	3	3	3	3	3	3	3	3	3	3

FIELD OPERATIONS

Steward (NV)	_____					_____				
Lease (NV)			_____							
Warren (L)	_____									
Button (L)					_____					
	2	2	3	2	2	2	2	2	2	2

DOCUMENTARY  
PHOTOGRAPHY

Wilson (L) ?				_____						
Tyner (Pan Am)				_____						
				2	2					

EG&G

NaI Detector Survey

Total + EG&G	36	31	32	37	31	29	28	23	17	29
									Average	

## APPENDIX D

### Enewetak Precleanup Survey YVONNE Island Program Radiological Safety Plan

#### I. PURPOSE

The purpose of this plan is:

To provide appropriate procedures for the radiological safety of individuals, equipment and data involved in the sampling program to be conducted on YVONNE Island, Enewetak Atoll;

To minimize or prevent any unnecessary exposure, internal or external, to personnel;

To control radioactive contamination of personnel and equipment; and

To control and prevent radioactive cross-contamination of samples taken from YVONNE Island.

#### II. THE PROBLEM

YVONNE (Runit) Island, lying midway on the windward side of Enewetak Atoll was the site of a number of nuclear test detonations. These nuclear events occurred on the surface, in the air, and on the water near the island, contaminating the immediate vicinity to various extents (see Fig. A.4).

Through literature searches and actual surveys, the present condition of the northern half of the island is determined to be a heterogeneous conglomeration of radioactive contamination from the surface to some considerable depth, mixed and churned into the soil from various construction and earth-moving activities in support of

the test operations. This contamination consists of aged fission products, activated or contaminated scrap metal, and considerable quantities of finely divided plutonium on the surface and buried underground. Evaluation of the extent of this contamination for cleanup considerations, requires a respectable soil sampling program be accomplished. The most important problem faced by the sampling effort is how to safely dig into and remove from this contaminated soil suitable samples for analysis.

A considerable area, from the "Tower Bunker" Hardtack Station 1310, north about 3000 ft contains extensive plutonium contamination, on the surface (levels of around  $2 \times 10^5$  dpm/100 cm<sup>2</sup>), as well as beneath the surface ( $3 \times 10^3$  pCi/g soil at 2-3 ft depth).

Other areas, the Cactus Crater lip, for example, also have plutonium contamination on the surface and at depth. There is also evidence, through reports, notes, etc., that various depressions "craters" were utilized for the burial of contaminated test debris. No specific contamination levels for these burials have been found in the reports.

It is evident that any soil-disturbing activities within the areas indicated above will probably increase the possibility of resuspension of plutonium

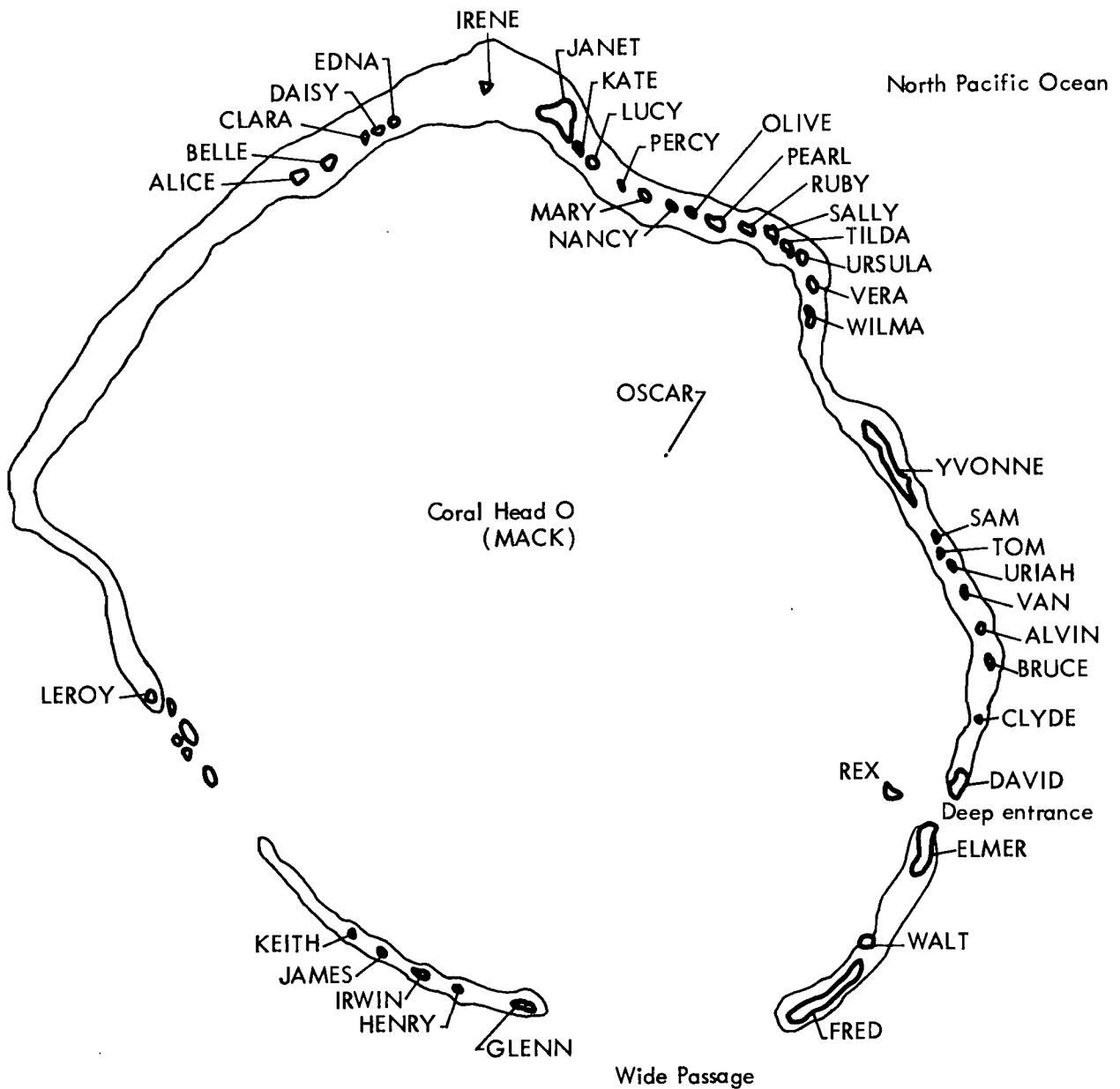


Fig. A. 4. Enewetak Atoll.

particulates, and most certainly, the possibility of contamination of personnel and equipment engaged in the collection of samples. The dryness of the soil, due to the onset of the dry season, and the strong northeasterly tradewinds also increase the resuspension hazard.

### III. ACCESS CONTROLS

The Island of YVONNE is accessible only by boat from Enewetak Island. Landings are made at a personnel pier, located about mid-island. A small concrete ramp exists immediately north of and adjacent to the pier for

the offloading of heavy equipment by barge, LCU, or LCM. Since access to the island is confined to a relatively small area, the actual physical problem of access control is simplified.

For the purpose of this survey, a RADEX area will be established from a point just north of the personnel pier/ramp area, north to the Cactus Crater. Complete rad-safe control will be in effect within this RADEX area. A decontamination pad will be set up for equipment on the lagoon side of this RADEX area, immediately adjacent to the ramp. A personnel decontamination facility and hot line will be established next to the decon pad and will be the sole access route for personnel to the survey area (see Fig. A.5).

The hot line, decon pad, and RADEX area southern boundary will be marked with tape and signs.

No personnel will be allowed into the RADEX area without appropriate rad-safe personnel protective clothing

and respiratory devices, a personnel-monitoring TLD badge, instrumentation, etc., unless deviation is approved by the health physicist in charge, as set forth in the procedures below.

#### IV. MONITORING

Although the principal radiological hazard on YVONNE Island can be attributed to  $^{239}\text{Pu}$ , an alpha emitter, the presence of undetermined amounts of aged fission products and activation products provides a significant amount of beta-gamma emitters to be of additional concern.

It is intended to monitor all personnel, equipment, and areas for surface and airborne radioactive contamination emitting alpha, beta, and gamma radiation.

##### A. Air Monitoring

It is intended to sample for airborne contamination continuously in the immediate downwind area from the

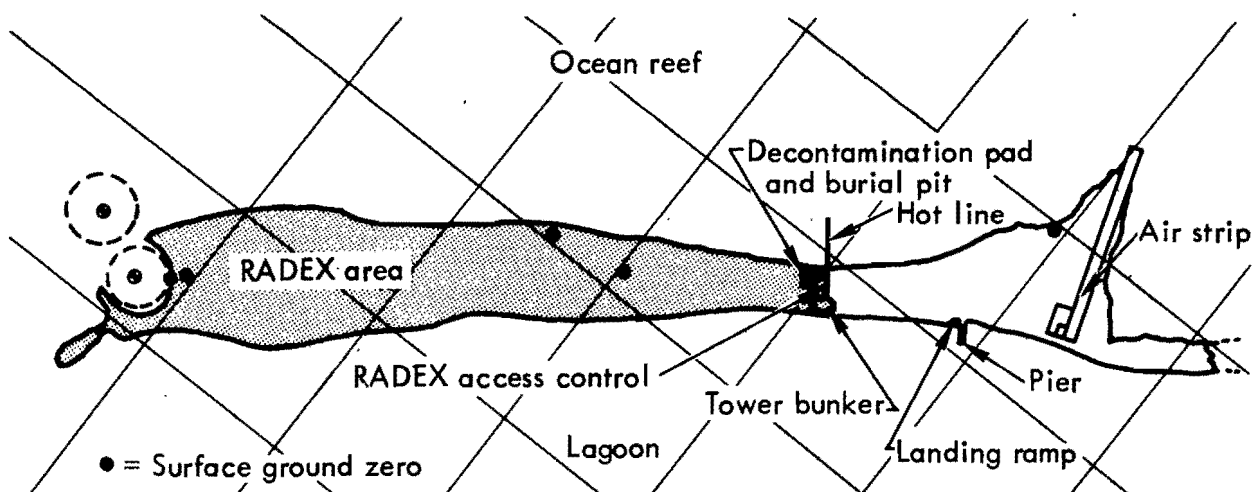


Fig. A. 5. Soil sampling RADEX area, YVONNE.

soil-disturbing activities to detect and evaluate any resuspension of radioactivity. There are presently six Sta-plex high-volume air samplers (22 cfm with a Millipore filter, loaded) in storage on Enewetak. Two 1.5-kW Homelight gasoline-powered portable generators, appropriate transformers, and power cable are also on hand.

Three units will be placed in the downwind area. The other three will remain as backup. Samples will be changed at the end of each workday. Although it is planned to operate the samplers only during working hours, it is possible to allow them complete 24-hr operation if necessary. Additionally, two lapel-type, low-volume air samplers will be brought and will be placed one on the backhoe operator and one on a profile monitor for more realistic evaluation of breathing zone concentrations. Four small, low-volume (3 cfm) portable air samplers will also be available and used where appropriate.

Samples will be counted at Enewetak at the end of the day for gross activity and forwarded to LLL for further analysis. Daily results will be available to the sampling team leaders.

## B. Portable Survey Instruments

Portable survey instrumentation, capable of detection of alpha, beta, and gamma radiations will be utilized.

### 1. Alpha Monitoring

Field alpha emitter detection will be done using an LLL modification of the PAC-1A alpha survey meter. This modification, termed

the "LLL Blue Alphameter," is more sensitive to uniform surface contamination than the previously used PAC-1S, partly due to increased probe area and partly due to decreased probe-to-surface distance. Since the instrument is a proportional air chamber probe, rather than a scintillating surface, it is not light-sensitive when punctured.

Twelve LLL PAC-1A survey instruments with spare probes will be provided. It is also intended to have, as a backup, several PAC-1S survey instruments.

### 2. Gamma Monitoring

The basic instrument utilized by the survey for gamma detection is the low-range Baird-Atomic scintillator. The instrument, calibrated on  $^{137}\text{Cs}$  is very rugged and has given excellent service in the field. It has sufficient range (0-3000  $\mu\text{R}/\text{hr}$ ) to be useful on most of YVONNE. Twelve Baird-Atomic Instruments are available on Enewetak.

### 3. Beta-Gamma Monitoring

For higher gamma exposure rates and for beta-emitter detection capability, the E500B G-M survey instrument will be utilized. Four E500B instruments are available on Enewetak.

### 4. Plutonium-Americium Monitoring

Monitoring for  $^{239}\text{Pu}/^{241}\text{Am}$  will be done with the FIDLER probe. This instrument can also be used to



locate hot spots which may or may not be plutonium or activated scrap metal. Nine FIDLER instruments are available on Enewetak.

### C. Personnel Monitoring

Personnel monitoring for external exposure to beta-gamma radiation will be accomplished utilizing the LLL TLD system. All individuals leaving Enewetak Island, engaged in AEC survey activities are issued an LLL TLD packet. This packet is worn on the upper body in the same manner as a film badge. All personnel landing on YVONNE will be required to wear their TLD packet.

The TLD packets are turned in to the AEC Operations Coordinator prior to leaving Enewetak Atoll. The packets are then forwarded to LLL for reading and evaluation.

A bioassay program to evaluate and document internal contamination and exposure will be conducted. This program is indicated in Part VII.

### D. Swipe Tests

Swipe tests using disks of filter paper will be used to evaluate and detect removable surface contamination on equipment and area surfaces. A routine swipe program is presently in effect on Enewetak Island to detect contamination in Buildings 11 and 15. Equipment used on YVONNE will be swipe-tested and decontaminated, if necessary, prior to its leaving YVONNE.

Swipes may be counted both in the field and at Enewetak. For both alpha and beta-gamma activity, as neces-

sary, portable battery-powered swipe counters are available on Enewetak.

## V. CONTAMINATION CONTROLS

### A. Personnel Contamination Controls

Every effort will be made to prevent radioactive contamination of personnel. Initially, all personnel entering the YVONNE RADEX area or working at the hot line will be suited out in full anti-C clothing consisting of one pair of coveralls, totes, cotton gloves, and cloth hood. All seams will be taped. Those personnel collecting soil samples, displacing soil, or downwind from soil-displacing activities will wear an Acme full-face mask equipped with an Acme OAPR 282 high-efficiency canister. Upon evaluation of the hazards and the effectiveness of contamination controls, the requirement for certain anti-C apparel may be waived by the health physicist in charge of the activity.

All personnel exiting the hot-line area will do so through the hot-line station and will be monitored for alpha and beta-gamma contamination prior to, during, and after removing anti-C gear. Nose swipes will be taken after all anti-C gear is removed. Decontamination capability will be available at the hot line. Smoking and eating will not be permitted in the RADEX area.

All contaminated anti-C gear will be removed and suitably packaged at the hot line. Contaminated waste produced by the survey effort will be collected, bagged, and stored on YVONNE until cleanup activities start, when such material may be disposed of.

## B. Equipment Contamination Controls

All equipment utilized in the RADEX area will be monitored with portable survey instruments and swipe-tested. It will be decontaminated if necessary.

## C. Sample Contamination Controls

Levels of radioactive contamination in soil samples taken from YVONNE Island's northern portion can have considerable amounts of radioisotopes with high  $^{239}\text{Pu}$  levels not uncommon. Therefore, caution must be exercised to prevent not only cross-contamination between individual samples but also contamination of personnel, equipment, and storage areas utilized in the recovery and processing of these samples.

### 1. Sample Collection

Profile samples will be collected from pits dug into the sandy soil of YVONNE Island by backhoe (3- to 4-ft profiles) and by hand (shallow 1- to 2-ft profiles and surface coring). Samples will be carefully removed from the sidewalls of the pits with special sidewall sampling tools in approximately 10-cm increments.

Each individual sample will be bagged at collection in a plastic bag and numbered. The sample will then be bagged twice more in heavy plastic bags to insure no breakage of bags and leakage of material. All samples from a single profile location will again be bagged in a single large plastic bag to keep all contents together for transfer to Enewetak.

To reduce airborne contamination during this windy, dry season, all soil collection areas will be wet down with salt water prior to any soil disturbance activities. If necessary, additional watering may be performed if the soil dries out too much.

### 2. Sample Monitoring

All samples passing over the hot line on YVONNE will be monitored for external alpha contamination. Samples thus found contaminated will be bagged again and marked as having surface contamination on the inner bags. Every effort will be made to prevent contamination by soil samples.

### 3. Segregation and Storage

Soil samples from the northern portion of YVONNE will be segregated from samples taken from other locations and kept in a specially prepared, locked facility. The floors of the special storage area will be covered with a plastic sheet to provide for easy removal of contamination in case of leakage.

### 4. Counting

Selected samples removed from YVONNE may be counted for americium gamma activity. Care will be taken in transfer of these samples from the storage area to the counting room and return. It will not be necessary to open any individual sample bag and thus none are to be opened. Unless from bag breakage, no contamination should result from counting activities.

## 5. Sample Shipping

The samples collected from the northern half of YVONNE Island may very well have specific activities high enough to be classified DOT Type A quantity, Group I shipments. All samples will be shipped to the Mainland (LLL) according to current DOT and USAF regulations. Appropriate shipping containers (DOT-approved paper tigers) will be utilized to accomplish this shipping effort. All labels, monitoring certificates, shipping documents, etc., will conform with all applicable regulations.

## VI. DECONTAMINATION

### A. Personnel Decontamination

A personnel decontamination facility will be provided at the hot line. A salt-water shower and wash stand will be set up. Soap and scrub brushes, etc., will be available. Personnel will be monitored crossing the hot line and will be decontaminated as necessary.

A freshwater shower and washing facilities will be available in the clean area. These facilities, an air-conditioned rest area, and hot lunch facility will be available on the LCU tied to the personnel pier during the survey activity.

### B. Equipment Decontamination

An equipment decontamination pad will be set up adjacent to the concrete landing ramp. A salt-water pump and washdown capability will be provided. All equipment will be monitored as it comes out of the RADEX area through

the decon pad (see Section IX). If contaminated, the equipment will be deconned at the pad. Effluent will flow back into the ground.

## VII. BIOASSAY

Although every effort will be made to prevent personnel contamination, a comprehensive bioassay program will be followed to ascertain any internal contamination and document its absence or presence for the record and as an evaluation of the effectiveness of control measures.

### 1. Nose Swipes

Nose swipes will be taken from all personnel working in the area of airborne contamination immediately after the end of the work period when they remove their anti-C apparel. The swipes will be counted on Enewetak that evening.

### 2. Urine Analysis

A 24-hr collection sample of urine will be submitted by each YVONNE survey participant at the completion of the survey effort. These samples will be forwarded to the U. S. for analysis.

### 3. Fecal Analysis

Fecal samples will be submitted by personnel suspected of having internal plutonium contamination and others as required by the health physicist. These samples will be analyzed by counting with a FIDLER instrument in a fixed geometry on Enewetak Island.

#### 4. Whole-Body Counting

Selected individuals known to be involved in the YVONNE sampling effort have already had baseline whole-body (lung) counts prior to their arrival on Enewetak. These individuals will be whole-body counted again upon the completion of the survey to evaluate any internal deposition acquired due to the survey effort.

### VIII. SAMPLING TEAM COMPOSITION

In order to provide maximum safety and efficiency in the limited time available to the survey, and because of the difficulty of having men work in full anti-C gear, two full teams will be fielded each day, working alternate 2-hr shifts, if possible. These teams will consist of the following capabilities:

1. Backhoe operator
2. Backhoe monitor
3. Sampler, profile (two each)
4. Sampler, shallow profile and surface (two each)
5. Health physicist

Additionally, a single full-time hotline operator and an instrument technician will be required. A total of 16 personnel will be involved in sampling operations on YVONNE.

### IX. CONTAMINATION CRITERIA

For the purpose of this survey, no detectable radioactive contamination, fixed or removable, will be allowed on any personnel or equipment leaving YVONNE Island. "Detectable" means detectable on a portable instrument designed to measure that type of radiation, i.e., GM, PAC, CP, etc.



